A real-time GIS for the analysis of a traffic system

C. Claramunt, E. Peytchev and A. Bargiela
The Nottingham Trent University
Department of Computing
Nottingham NG1 4BU, United-Kingdom

Abstract.

This paper describes a prototype development of a new system for the integration of real-time traffic data within a GIS. Various functions of traffic monitoring systems are improved in terms of graphic capabilities in particular through the temporal visualisations of traffic conditions within an urban network. Traffic data are integrated and aggregated on a real-time basis. Complementary abstraction levels are used for both the spatial and temporal dimensions. Visualisations and animation tasks are developed using either spatial or thematical views

Introduction

Recent changes in Information Technology have a major effect on the way in which systems are designed and used in many application fields. Geographical Information Systems (GIS) have now been adopted as a successful solution by a wide range of disciplines such as environmental planing, business demographics, property management and urban studies. Large geographical databases are now available, and a new generation of land information systems are developed all around the world with many applications in public administration and industrial companies. Currently one of the most important challenges for GIS is to generate a corporate resource whose full potential will be achieved by making it accessible to a large set of end-users and providing successful solutions for decision makers. The potential of GIS includes the enhancement of local administration, more efficient management of scarce resources and new business opportunities for the nascent geographic information industry. For example a GIS managing both static urban data and dynamic traffic flows information could provide an integrated geographical reference to the management of a traffic system leading to the improvement of the quality of transport systems.

However, current GIS software and interfaces do not provide the set of functions to make this technology compatible with simulation models used for traffic monitoring and management. The integration of GIS and Traffic Management Systems is likely to be a challenging and worthwhile objective for users whose needs are not satisfied by the current static display and analysis functions of GIS. This paper proposes the design and development of an integrated GIS and Traffic Management System. Such a system facilitates the use of geographical data in the context of time-varying information and integrates traffic data as a new component of GIS. This integrated system acts as Decision Support System for the management and control of an urban traffic system. This prototype integrates real-time traffic data provided by a traffic control system with Ordnance Survey geographical data. It implements a geographical database application for the real-time acquisition of data coming from a Traffic Management System. The GIS database integrates historical and current traffic states within appropriate network components. Traffic data are overlaid on urban maps for geographical reference. The application takes advantages of existing software such as the GIS Mapinfo and traffic management system SCOOT. Multiple data views allow the user to examine different aspect of data. Modularity will allow a progressive application and to accept different user-interaction levels from engineers to decision-makers. The system integrates real-time traffic data, cartographic information, aerial photographs and pictorial views. A visual interface proposes some dynamic visualisation capabilities that favour the understanding and management of traffic data. The visual combination of this data provides a richer context for analysing the environmental impacts of traffic systems and for the development of studies related to urban and transport planning.

Through its capabilities for communicating information in an intuitive way geographic information can involve citizens in urban traffic planing for all aspects touching upon their daily lives. Designing and using geographic information applications is a highly skilled activity. An increase in the use of such systems in the context of urban traffic management is likely to enhance the sustainability of cities, which has been identified as a priority challenge for the next century. We will demonstrate how an integrated database design and development of such a GIS can support these objectives. Finally this paper will illustrate how the integration of Traffic and Geographical data can favour the development of Decision Support Systems for government activities involved in the management and planning of modern cities.

The remainder of the paper is organised as follows. Section 2 presents the traffic system and network environment used for the development of our project and Section 3 the principles of the DIME communication system. Section 4 introduces the spatial and temporal aggregations used and Section 5 the visualisation functions developed by OSIRIS. Finally Section 6 draws the conclusions.

Traffic system environment

Traffic systems are typical man-machine systems that include human interactions (i.e., driver-vehicle relationship) and man-machine interactions (i.e., driver-traffic control relationship) [Pursula, 1998]. The development of computing facilities and the increasing complexity of the management of urban traffic have led to the appearance of many traffic monitoring and simulation systems. These systems allow the monitoring and/or simulation of traffic conditions, they are based on different mathematical models from microscopic to macroscopic approaches [SMARTEST, 1997]. In terms of data integration, an important component of a traffic system is the existence of a monitoring system that integrates successive traffic parameters. Within OSIRIS, traffic data are imported from a SCOOT urban traffic control system that optimises the split, cycle and offset times of traffic signals. The SCOOT system, which is largely used by many U.K. cities and also abroad (e.g., Toronto, Beijing, Sao Paulo), provides both unprocessed on-line detector and signal traffic data, plus several derived measures calculated from its traffic model. The traffic data illustration introduced in Figure 1 contains spatial entities that represent the geographical network (e.g. node, road segment, incoming lane) and spatial-temporal entities that describe the entities of the network which are related to incoming traffic data (e.g. lane, traffic unit). The distribution of traffic data between the modules of our application is based on the Distributed memory environment system (DIME) which allows different applications to communicate through local or wide networks while maintaining a shared memory logical view of the data [Argile et al., 1996]. This communication environment is based on a TCP/IP protocol and a client-server architecture. This system has been developed and tested in conjunction with the SCOOT system.

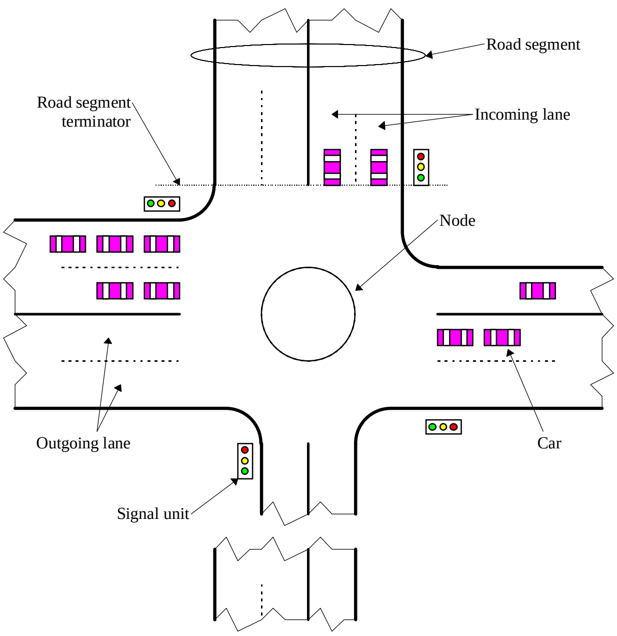


Figure. 1. Traffic network

The SCOOT Traffic Management System retained for the development of this project models a part of the city of Mansfield which is a medium size city in United Kingdom. It represents an appropriate level of complexity and traffic data flows for the objectives of our prototype development. The temporal granularity of incoming traffic data provided by the memory management system is given on a second basis. Such a frequency of communication flow leads to huge volume of traffic data (about 1 million data messages per day). In order to reduce such a volume of data, we decided to aggregate incoming traffic data to half an hour time interval samples. This resolution largely reduces the amount of traffic data generated, and is still relevant for the objectives of an analysis of traffic conditions.

In order to make a distinction between the integration of traffic data and further analysis tasks, our application is separated in two modules: a traffic data pre-processor and a GIS application. The pre-processor calculates averages and maximums of queue lengths, traffic light periods and node saturation, 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 data on either a continuous or discontinuous mode. Aggregated values are sent through a network computing environment to the GIS database. If the GIS application is not connected, the pre-processor temporarily stores calculated data until the next connection. This specialised architecture provides two main advantages: the pre-processor can be implemented on top of an operating system based on a stable and multitasking kernel, and the GIS application is independent of any real-time constraints. Figure 2 illustrates the application data flows.

The formulation of the tasks in the system is in line with the proposition of a supervisory layer of control in a traffic control and management system [Peytchev E., 1999]. In a system with supervisory layer of control the decisions on a short time basis (cycle-by-cycle basis) are taken by the existing operational control real-time systems (SCOOT for the case of this research). The automated decisions on a larger time scale (10 - 30 min. basis) however, are taken by the supervisory layer of control. The pre-processed real-time data can help improve the longer term prediction process within the above mentioned 10-30 min. scale by providing on-line average values on a half-hour basis to the traffic network simulation model. The feedback from the pre-processor to the prediction model, however, is subject of future research. On the other hand, the proposed hierarchical spatial-temporal traffic control [Peytchev E., 1999] is naturally deployed on a distributed computers environment (based on DIME) and the division of the job into two tasks helps the design and the implementation of the system in a distributed environment.

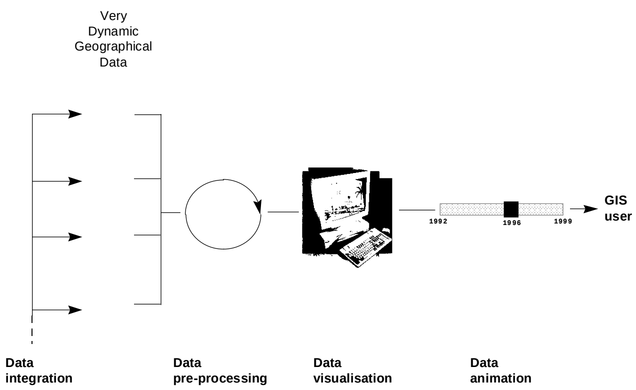


Figure. 2. Application data flows

<u>DIME communication system</u>

The typical DIME environment is presented on Figure 3. Each user application code has an additional component linked to it, which provides the communication interface via DIME API with the shared memory system. The requests for reading/writing data from/to the shared memory (creating or removing areas) are transferred by the DIME library over the network to the memory manager task, where they are being processed and replies are sent back. There are two components of DIME: a) the shared memory manager task which owns the shared area and b) the communication DIME libraries, which are linked to user applications and the memory manager in order to interface to the network.

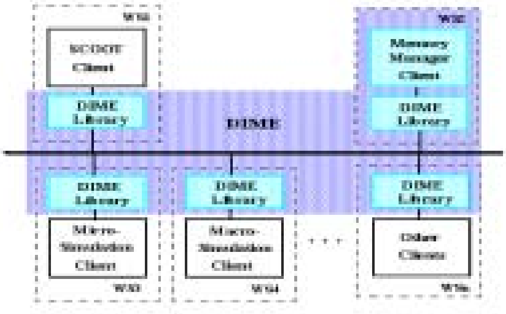


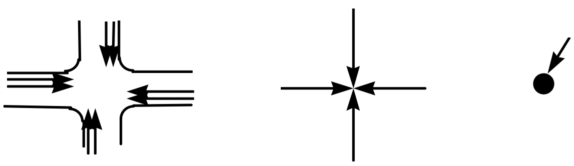
Figure. 3. DIME shared memory system

In a typical traffic control system, there are a number of applications running concurrently and exchanging information within DIME: the operational control real-time system (SCOOT in the case of this study); traffic simulation module (PADSIM); on-line Origin-Destination matrices estimation module (for the case of this research turning movements estimation module described in [Peytchev et al. 1996] and [Peytchev E., 1999]); GIS for real-time traffic information module and other on-line modules like incident detection module etc. The pre-processor task is expected to process up to 115 MBytes of data per day (collected by SCOOT and delivered within DIME).

Traffic database

The database model of OSIRIS integrates traffic and geographical data. Incoming traffic data are based on SCOOT messages. These messages encapsulate data that describe traffic conditions for every lane in the traffic network. They include average or maximum attribute values during red-green periods (e.g. percentage of saturation, percentage of congestion, lengths of queues, current state of the traffic lights). The database design of OSIRIS is based on a previous traffic database design realised using an object oriented-method [Etches et al., 1999]. This model represents the characteristics of traffic flows within an urban system. It integrates the temporal and spatial dimensions of a traffic system using an homogeneous database representation.

The main network entities used for the management of incoming traffic data are as follows: nodes that represent an intersection within the network, road segments that describe a part of the physical network between two nodes and incoming lanes that represent a lane that arrives at a node. These entities allow the representation of traffic flows at three complementary abstraction levels (Figure 4). The representation of a spatio-temporal entity leads to the definition of two relations: a first one that contains geographical data and a second one that describes time-stamped traffic data.



Lane level   Road segment level   Node level

Figure. 4. Network levels

The OSIRIS implementation is realised on top of the MapInfo for Windows GIS, using C++, Delphi (a windows GUI editor and Pascal compiler) and MapBasic programming languages. The geographical component of the database is based on Ordnance Survey Centre Alignment of Roads (OSCAR) data. Such a geographical database provides a comprehensive and accurate representation of the traffic network. The scale of the geographical database is 1:10 000 with an accuracy of one meter. This OSCAR database acts as a support for the development of the real-time traffic database.

Database changes can be categorised in either spatial location changes or thematic attribute changes. In the context of our application, and its time-scale, the geometrical properties of the traffic network are considered as static, traffic conditions are represented by thematic attributes that have a high degree of variation. We argue that the dynamic visualisation of geographical data implies a high level of interaction that supports (1) different temporal abstraction levels that can be interactively defined from an application and user point of view and (2) the combination of different dimensions in the visualisation process in order to analyse patterns in the spatial, temporal and thematic dimensions. Often, passing from one spatial or temporal abstraction level to a lower one provides a fundamental insight to the analysis and understanding of a spatial phenomena. In order to analyse traffic conditions at complementary abstraction levels, several spatial and temporal aggregation mechanisms have been developed. At the spatial level, the aggregation of traffic data is based on three abstraction levels that provide different representations of traffic data flows, from the lower abstraction level to the higher abstraction level, i.e., node, road segment terminator and incoming lane, respectively. Moreover a user-defined abstraction level allows the aggregation of traffic data on pre-selected routes (set of road segment terminators).

At the temporal level, the source temporal granularity provided by DIME (i.e., one second) is aggregated on a half an hour basis by the pre-processor (i.e., averages and maximum of traffic data values). OSIRIS also provides a third aggregation level that allows the definition of user-oriented temporal views. This third aggregation is performed by a re-sampling of the temporal periods. The following figure shows the different stages of these temporal aggregations:

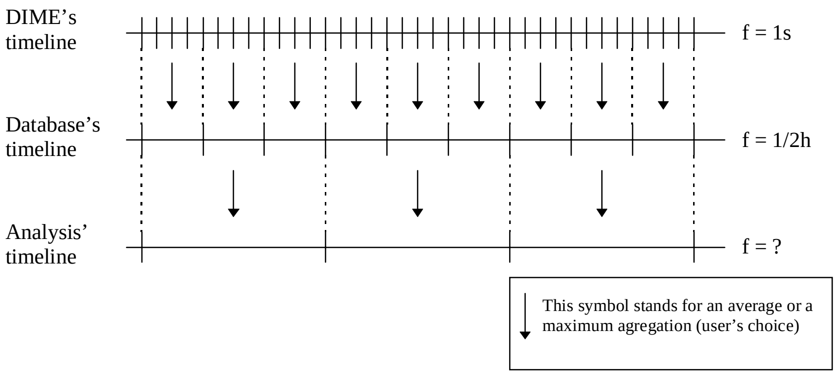


Figure. 5. Temporal aggregation level

At the temporal level, the different temporal granularities of a dynamic GIS can be defined according to user need. Within OSIRIS, the first level of temporal aggregation is provided by the DIME temporal granularity (i.e., one second), the second level is given by the pre-processor aggregation (i.e., half an hour) which is considered as the minimal temporal interval that is of interest for GIS applications. The third user-defined level allows the development of specific temporal analysis according to user needs. Temporal tables are generated by the aggregation of incoming traffic data with respect to specific time intervals and for a selected traffic data attribute.

Traffic data visualisation

The aim of the OSIRIS visualisation tools is to complete the spatial and dynamic view by temporal and statistical charts that provide complementary perspectives. Animations allow users to browse through the temporal traffic states of the selected and aggregated traffic values within a considered period of time. The following examples illustrate the different techniques used in the context of visualisation taks, in other words a multi-dimensional approach of the visualisation of very dynamic data. Such functions enrich the user perception of traffic data through time and act as an exploration tool that can be used to identify traffic patterns in space and time. For example, these visualisations can be used to detect incidents, to identify critical nodes, or for the analysis of traffic patterns within the traffic network. The techniques we retain reflect the dynamic properties of the database generated. The main techniques used are as follows:

- Traffic data values in function of time for a specific collection of network components. These representation are presented using bi-dimensional charts that represent the temporal traffic values for an interval of time.

- Spatial animations of traffic data values in function of time for a specific collection of network components. These animations can also be applied to a user-defined route.
- Chart animations of traffic data values in function of time for a collection of network components and animated distribution charts that represent the distribution of traffic data values for a collection of network components.

Conclusion

The OSIRIS prototype fulfils the objective of an integrated and inter-operable system that supports the real-time integration of traffic data within GIS. Analysis and temporal visualisation functions have been developed, they support a graphical view of traffic conditions using different visual and animated cartographical capabilities. Such facilities extend the potential of the management of traffic systems for both traffic managers and urban planners. The OSIRIS prototype is currently validated with the Nottingham Traffic Control Centre SCOOT system. Further developments include the integration of historical traffic data as a component of an urban GIS, the development of additional functions for simulation purposes and the correlation of traffic and pollution data.

References

Abel, D. J. et al. (1992) Environmental Decision Support System Project: An Exploration of Alternative Architectures for GIS. In *International Journal of GIS*, Taylor and Francis, vol.6, n. 3, pp. 193-204.

Argile A., Peytchev, E., Bargiela, A. and Kosonen, I. (1996) DIME: A Shared Memory Environment for Distributed Simulation, Monitoring and Control of Urban Traffic. In *Proceedings of European Simulation Symposium ESS'96*, Genoa, vol. 1, pp. 152-156.

Bargiela A, and Berry, R. (1999) Enhancing the benefits of UTC through distributed applications, *Traffic Technology International*, Feb./March, pp. 63-66.

Claramunt, C. and Thériault, M. (1995) Managing time in GIS: An Event-oriented Approach. In *Recent Advances in Temporal Databases*, J. Clifford and A. Tuzhilin (eds.) (Berlin: Springer-Verlag), pp. 23-42.

Claramunt, C. and Thériault, M. (1996) Toward Semantics for Modelling Spatio-temporal Processes within GIS. In *Advances in GIS Research I*, M. J. Kraak and M. Molenaar (eds.), Taylor and Francis, pp. 27-43.

Etches, A., Claramunt, C., Bargiela, A. and Kosonen, I. (1999) An Inter-operable TGIS Model for Traffic Systems. *In Innovations in GIS VI*, Gittings, B. (ed.), Taylor & Francis, in press.

Kosonen, I. and Pursula, M. (1995) Object-oriented and Rule-based modelling - Experiences from Traffic Signal Simulation. In *Proceedings of the 6th International Conference on Computing in Civil and Building Engineering*, Berlin, Germany.

Kosonen, I., Bargiela, A. and Claramunt, C. (1998) A Distributed Information System for Traffic Control. In *Proceedings of the Xth European Symposium in Simulation Systems*, Nottingham, A. Bargiela and E. Kerckhoffs (eds.), pp. 355-361.

Langran, G. (1992) *Time in Geographic Information Systems*, London, Taylor & Francis.

Peuquet, D. J. (1994) It's about time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems. *Annals of the Association of the American Geographers*, 84, 3, 441-461.

Peytchev, E., Bargiela, A. and Gessing, R. (1996) A Predictive Macroscopic City Traffic Flows Simulation Model. In *Proceedings of European Simulation Symposium ESS'96*, Genoa, vol. 2, pp. 38-42.

Peytchev E. (1999) *Integrative Framework for Urban Traffic Simulation and Prediction and Confidence Limit Analysis of the Predicted Traffic Flows*, Ph.D. thesis, Department of Computing, The Nottingham Trent University, Nottingham, UK.

Pursula, M. (1998) Simulation of Traffic Systems: An Overview. In *Proceedings of the Xth European Symposium in Simulation Systems*, Nottingham, A. Bargiela and E. Kerckhoffs (eds), pp. 20-24.

SMARTEST (1997) Review of micro-simulation models, Project Deliverable D3, EU Framework 4, DG VII.

Thériault, M., Leroux, D., Vandermissen, N.-H. (1998) Modelling Travel Route and Time within GIS: Its Use for Planning, In *Proceedings of the Xth European Symposium in Simulation Systems*, Nottingham, A. Bargiela and E. Kerckhoffs (eds.), pp. 402-407.