EXPLORING SPACE AND TIME : THE INTERACTION OF TRANSPORTATION AND ENVIRONMENT

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ABSTRACT:

The aim of the study is to explore multi-temporal dimension of interaction between transport, land use and air quality, where the interaction is dynamic and involves changes over spatial and temporal dimensions. This research focus on the extraction of relevant information from geospatial lifelines, which captures object locations in geographic space at regular or irregular temporal intervals. The purpose of this research is to develop conceptual GIS database model that better facilitates the exploration and analysis of spatio-temporal sustainable transportation data sets than conventional -static- GIS database models. The designed model will integrate diverse sets of spatio-temporal data and built-up the dynamic process and relationships. The designed conceptual data model is constituted upon the criteria list. During the establishment of external schema, a progressive approach appropriate to the conceptual data modelling requirements of decision makers was reflected on. Results, possible problems and solution proposals were presented with concluding remarks and future research needs. This paper had described a generic conceptual data model for exploring the interaction between transport, land-use and air quality, where policy integration is highly demanded and can only be achieved by modelling multi-dimensional information, involving time.

1. INTRODUCTION

Transportation is an integral part of our modern society. The movement of people and goods has a tremendous impact on the environment, society and the economy. The transport system delivers its benefits at the cost of many unintended impacts in the domains of the environment, safety, public health, land use and congestion. (Himanen et al., 2004) Transport's environmental impacts are concentrated in urban areas, where the complexity and variety of different components making up the urban environment, and the interactions among them, are the most pronounced in the mega cities. Land use and transportation interaction has been a major research topic for several decades and many theories and models are suggested to study this well-known, complex and dynamic process. Existing models and efforts were based on some prior theories and use mathematical or simulation approaches to study the problem, where little consensus regarding the conclusions can be drawn (Guiliano, 1995) and alternative methods are required. (Shaw and Xin, 2003) There exists an emerged need of improved tools, models and analysis methods for examining the interaction.

The interaction is dynamic and involves changes over spatial and temporal dimensions, where Spatial Information Sciences (SIS) can aid to explore the pattern and understand the relationships. However, current models are generally 2 and/or 2,5 dimensional and temporal dimension is neglected. (Shaw and Xin, 2003; Briggs, 2005) Some other for exploring the interaction between these phenomenas subdivide time into discrete periods. The complexity behind the combination of spatial and temporal modelling and representations is well documented but an efficient solution has yet to emerge (Peuquet, 2001). This research aims to aid to these efforts and focus on the extraction of relevant information from geospatial lifelines, which captures object locations in geographic space at regular or irregular temporal intervals. The purpose of this research is to develop conceptual GIS database model that better facilitates the exploration and analysis of spatio-temporal sustainable transportation data sets than conventional -static- GIS database models. The designed model will integrate diverse sets of spatio-temporal data and built-up the dynamic process and relationships. The remaining sections of the paper are organized as follows. The background issues for temporal-GIS are introduced and current methods for handling spatio-temporal data sets are discussed. At the third section spatio-temporal characteristics of relevant data, being multi-scale and multi-temporal, of the interaction is introduced. Criteria and possible questions to be answered for modelling the interaction are discussed. Results, possible problems and solution proposals were presented with concluding remarks and future research needs.

2. BACKGROUND ISSUES FOR TEMPORAL-GIS

The interaction involves the time element (when), the location element (where), and the attribute element (what), where Sinton (1978) proposes a measurement framework to treat location, time, and attribute as ''fixed'', ''controlled'', and ''measured'' components and developed six scenarios to model.

The conventional GIS with snapshot approach (data for each layer at a given point in time) corresponds to a subset of Sinton's measurement framework, where time is handled as "fixed" component. (Shaw, Xin, 2003) The snap-shot approach does not handle the temporal relationships between GIS feature layers, some overlay analyses must be performed for answering queries related to temporal issues. Sinton's model was reiterated by means of providing examples for "moving objects" (Langran, 1992). The developed space– time composite data model combines the snapshots of a phenomenon (e.g., land use or highway system) at different time points into a single composite GIS layer (Langran and Chrisman, 1988; Langran, 1992). The object is described with its fixed attribute, controlled location, and measured time. The approach would select one object to be tracked, observe one or more locations, and record the time at which the object occupied each observation location. It represents a spatial unit with its unique attribute changes over time. One shortcoming of the approach is that it requires queries on multiple attribute fields to identify the existence of features at multiple time points. This becomes inefficient at large temporal GIS databases.

Another model was proposed, is the event-based spatiotemporal data model (ESTDM) using raster GIS (Peuquet and Duan, 1995). The ESTDM builds an event list with time-stamped entries that record the grid cells experiencing attribute changes from t (i-1) to t and the locations of those grid cells. Although the event list approach is effective of tracking changes between raster GIS data layers, it does not well with vector GIS data that do not share a fixed grid size among the snapshot layers. Although the model constitutes an integrated approach to representing changes, it does not relate events to specific geographical phenomena; while event-oriented models are suitable for temporally stable sequential changes but are not useful for representing sudden changes (eg, earthquakes) and protracted changes (eg, annual rainfall patterns) (Peuquet, 1998). Transport, land use and environment also involves sudden changes, such as traffic congestion, accidents etc.

Worboys (1992, 1994), on the other hand, suggests an object-oriented spatiotemporal data model that consists of multidimensional objects: two-dimensional spatial objects with a third dimension for the event time associated with each object. The basic element in the data model is a spatiotemporal atom that has homogeneous properties in both space and time. Atoms are used to form spatiotemporal objects that represent changes of real world entities. This approach was extended to a spatio-bitemporal model that includes both event time and database time to record the existence of an object in the real world and in a database system, respectively (Worboys, 1998). Hence, the object identity is maintained through time. Yuan (1996, 1999) proposes a three-domain data model that consists of semantic domain, temporal domain, and spatial domain, along with domain links. The semantic domain defines real world entities with unique identifiers throughout the study duration. The temporal domain stores each time instance as a unique object, while the spatial domain is based on the space-time composite data model to derive a set of common spatial features with unique identifiers. Domain links are used to record the links among semantic, temporal, and spatial objects with their unique identifiers.

These models extended the static snapshot spatial data models, however such systems are not suitable for representing, storing and querying continuously moving objects. In a recent study, buffering was used to analyse exposures at about 1.5 million postal code locations, around some 19,000 landfill slides, over 16 years for two different groups of health effects and lag periods – a total of some 10^{11} buffering operations. (Elliot et al., 2001) (Briggs, 2005) The concept of time geography, developed by Hagearstrand's (1970), has been very influential for spatio-temporal modelling. The concept of "lifelines"- passages through space and time- was established. The path is represented in space as a two-dimensional plane (XY), and in time as a third dimension, which is perpendicular to the plane, illustrated in Figure 1. Lifelines can be at any temporal scale, from minutes to an entire life. The lifelines are not entirely free, but are constrained both by our surrounding. This concept of space-time has provided the framework for today's work on spatio-temporal GIS using geometric approaches. Forer (1998) and Miller (1991) used this framework to develop concepts for space-time accessibility.

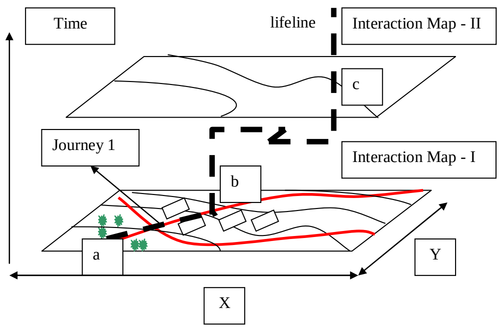

Figure 1 The lifeline concept and the interaction

Forer (1998) described geometric primitives for what he called a time-space aquarium, illustrated in Figure 2. One type of object is a prism that represents a region of space and that can be reached given a starting or ending point in space-time and a maximum velocity. The other type of geometric object is a continuous line tracing variations in position with time. Position of a moving object can be represented as a function f (t) of time, so that changes in object position do not require any explicit change in the database system. With this representation, the database needs to be updated only when the function f (t) changes, for example, when the velocity of an object changes. Recently, there has been some work on extending the capabilities of existing database systems to handle moving-object databases (MOD)(Agarwal et al, 2003).

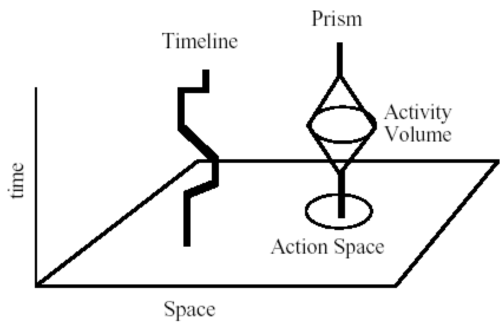

Figure 2 Forer's "space-time aquarium" and basic space-time geometric objects

3. THE MODEL

The goals in the design of this model are two-fold: 1) to efficiently manage and integrate diverse sets of spatio-temporal data so that those data may be queried, and 2) to allow for the explicit representation of dynamic processes, and relationships.

Since transportation is mainly performed on road and highways, 93% in Turkey for example, road information can be selected as example. Modelling road information will cover all other transportation modes. The road information can be categorized into several various groups including; new construction, existing data, traffic data, where geometry is considered as the backbone. Due to simplicity of data maintenance and topology analysis, geometry and topology should be distinct and metadata requirements should be considered. (Demirel, 2004) Data about road and traffic is collected in varying time intervals being; take place (for accidents), hourly, day and night, daily, monthly, seasonal and as built. Additionally, information regarding the transportation improvement projects for multiple years is required. Several factors are influencing emissions from the transportation sector such as being the transportation-mode, number of vehicles, vehicle congestion, length and frequency of vehicle trips and land use designations, where time information regarding these is in wide spectrum. For the interaction and possible queries for detection of trends and patterns additional information is required being land use (existing zone and parcel data, activity locations, land usage classes retrieved from remote sensing images, census data and employment data, demographic data, traffic monitoring (15 minutes), surveys, household activity survey, external stations counts, traffic analysis zones, transit on-board surveys, level of service, traffic count databases, static and dynamic sampling stations for emission parameters.

Information required is multi-scale. For example in air quality studies, while low-level sources such as road traffic tend to be responsible for local variations in pollutant concentrations, these are superimposed upon broader scale variations due to more diffuse emission sources (e.g., from residential activities) and far-travelled pollution. (Briggs, 2005) The relative contributions of these different sources may vary greatly, both from one pollutant to another and from place to place. Carbon monoxide, for example, tends to be derived mainly from local, low-level sources (especially road traffic).

Information is multi-temporal. Changes in urban systems are classified into four being very slow change, slow change, fast change and immediate change. (Wegner and Fürst, 1999) The urban change process developed can be studied at Table 1.

Urban Change Process	Examples
Very slow change	Networks
	Land use
Slow change	Workplaces
	Housing
Fast change	Employment
	Population
Immediate change	Goods transport
	Travel

Table 1 Urban Changes (Wegener and Fürst, 1999)

Pollutants are in motion. As a result, the geographies of exposure vary greatly over time. This can be seen most starkly, perhaps, in the contrasts between night and day. It would therefore seem worthwhile to try to take some account of both time–activity patterns and the temporal patterns of pollution in exposure assessment. The performance of air quality dispersion models are averaging between minutes being 15 minutes to 60 minutes. An overview of the interaction information structure identified is shown in Figure 3.

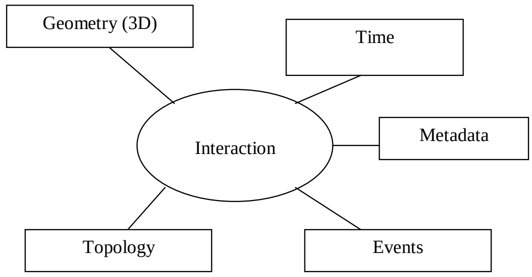

Figure 3 Information Structure

Using the time component as integrator, several questions required for the interaction can be answered such as;

a. What was the air quality within a one-kilometer zone of a highway between years 1990 to 2000?
b. When did major land developments take place within a one-kilometer zone of a new rail transit line after its completion?
c. Where were the vacant land parcels within a one-kilometer zone of ongoing transportation projects in 1996?
d. When did traffic volumes on major streets increase by more than 30% in those traffic analysis zones reaching an employment density of 10,000 per square kilometer?

In order to perform such queries methods should be developed to trace spatial information back through time, to discover spatial clusters in the past and a conceptual data model for large datasets of geospatial lifelines is required. Additionally;

a. Topological, geometric and thematic information should be conceptually independent.
b. Support for multiple topological representations and for various abstraction levels needed be realized.
c. The model designed must include temporal GIS methods for exploring the interaction.
d. Varying temporal and spatial levels are required. (short-term and long-term, 2D and 3D)
e. Different spatial and temporal scales are required.
f. Methods for systematic exploration and visualization are required.
g. Metadata, such as consistency rules and quality must be incorporated.
h. Permanent non-spatial unique feature identifier is required.
i. Quick response to queries is needed.
j. The conceptual data model should be designed independently of consideration of the specific software with which it is going to be implemented.

Haegerstrand's concept of time geography provides a framework for modelling Geospatial Lifelines. The basic element of lifeline data is a space-time observation consisting of a triple <ID, location, time>, where ID is the unique identifier of the object used throughout all recordings of that objects's movement, location is the spatial descriptor, and time is the time stamp, when object is at particular location. Attributes of entities may disappear and later appear. (Hornsby and Egenhofer, 1997). Attributes may also disappear when objects are aggregated (Hornsby and Egenhofer, 1998) Time stamp will refer to when an event occurred in real time, but it is important to store the event time in database (Worboys, 1998), that is, both when the site was polluted and when the pollution became known to company or government official. Recording of geospatial lifelines are discrete, while the phenomena they describe are typically continuous. For this reason, different interpolation methods will be needed depending on the ontological characteristics of the movement.

According to the OGC model, dynamic attributes of an object is the combination of timeStamp, acceleration, bearing, elevation, location and speed, illustrated in Figure 4. In terms of exposure to air pollution, they represent the space–time volume (or prism) within which exposures occur. Information on the location can be used to build a probability surface of where they spend their time between and of the exposures they might thus experience. Similarly, information on the population distribution at specific intervals (home, work), can be used in the sorts of trip-generation models already widely applied in transport planning to predict the time-varying distribution during the intervening periods. Recordings of geospatial lifelines are discrete, while the phenomena they describe are typically continues. For this reason different methods will be needed depending upon movement. Tracking the vehicle might require data recorded at every 5-minute or even 1-minute interval, whereas the recording of peoples workplaces at 6 months would be sufficient.

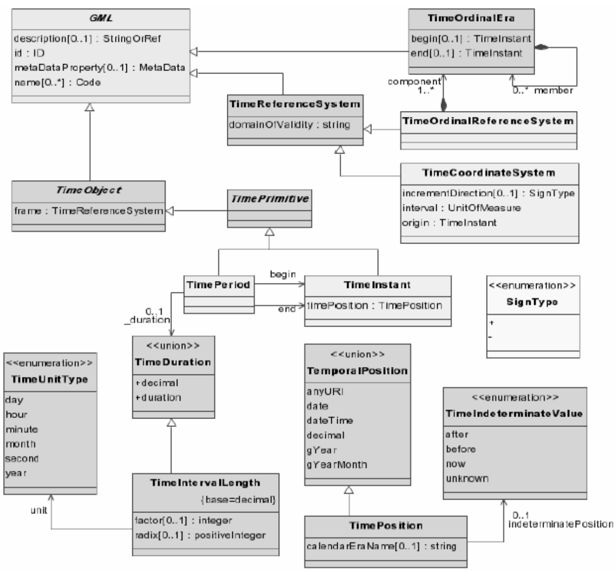

Figure 4. OGC Model

Three dimensional coordinates should be expanded to (x, y, z, t), where movement of a point can be expressed as;

$$x = f_1(t),\ \ y = f_2(t),\ \ z = f_3(t) \tag{1}$$

For moving objects, for example a car moving on the highway, can be expressed by (s,t), where s is the one-dimensional road axis and t is the time. (Gielsdorf, 2007) The relationship between geometry, topology, road events and methods to transform one-dimensional road information to three dimensional road information has been previously examined. (Gielsdorf, 1998, Demirel, 2004) Then, the problem is only a transformation problem of a point cloud having the parameters (X_0, Y_0, Z_0, ω, φ, κ, t). The relation between topology, geometry and movement can be expressed as follows, illustrated in Figure 5;

Link	Movement	Geometry	x(t)	y(t)
1	continous	line	x = const	$y = y_0 + y'{*}t$
2	brake		x = const	$y = y_0 + y'{*}t + y''.t^2$
3	continous		x = const	$y = y_0 + y'{*}t$
4		arc	$x = x_0 + R - \cos((s'{*}t)/R)$	$y = y_0 + R - \sin((s'{*}t)/R)$
5		line	$x = x_0 + x'{*}t$	y = const
6	accelerate		$x = x_0 + x'{*}t + x''.t^2$	y = const
7	continous		$x = x_0 + x'{*}t$	y = const

Figure 5. The relationship between topology, geometry and movement. (Gielsdorf, 2007)

Since it is not possible to generate geometric elements by their parameters without redundancy using the current standard software of GIS and/or modeling standards, redundancies are foreseen. These redundancies can be controlled using user-defined methods and validation rules. Due to these, here can be a performance problem. However, these issues will be less significant in the longer term, with the current speed of spatial technology developments. Furthermore the longer life span of conceptual data models and data compared to software is sufficient for neglecting this issue.

4. CONCLUSION

This paper had described a generic conceptual data model for exploring the interaction between transport, land-use and air quality, where policy integration is highly demanded and can only be achieved by modelling multi-dimensional information, involving time. The model can be developed by means of integration of existing land use and transportation models. A complete set of temporal data will be generated and can be used for the developed conceptual data model. Additionally, temporal databases can grow into very big files, which require innovative approaches to database design and implementation. The proposed model will aid "sustainable development" efforts by developing new models for analysis of spatial and temporal characteristics of transportation. This will in result aid to reason the environmental exposures and their consequences over space and through time.

REFERENCES

Agarwal P.K., Arge, L., Erickson, J., 2003, Indexing Moving Points, Journal of Computer and System Sciences 66, Elsevier Science, USA, pp. 207-243

Briggs, D., 2005, The role of GIS: Coping with space (and time) in air pollution exposure assessment, Journal of toxicology and environmental health, Part A, 68:13, Taylor & Francis Inc., pp.1243-1261

Demirel, H., 2004, A Dynamic Multi-Dimensional Conceptual Data Model Proposal for the Transportation Applications", ISPRS Journal of Photogrammetry and Remote Sensing, 58, pp.301-314

Elliott, P., Briggs, D. J., Morris, S., de Hoogh, C., Hurt, C., Kold Jensen, T., Maitland, I., Richardson, S.,Wakefield, J., and Jarup, L. 2001. Risk of adverse birth outcomes in populations living near landfill sites. B. Med. J. 323:363–368.

Giuliano, G., 1995. Land use impacts of transportation investments: highway and transit. In: Hansen, S. (Ed.), The Geography of Urban Transportation. Guilford Press, New York, pp. 305–341.

Hägerstrand, T. , 1970, 'What about People in Regional Science?' Papers of Regional Science Association, vol. 24, pp. 7-21.

Himanen, V., Lee-Gosselin, M., Perrels, A., 2004, Deliverable 15, Policy research document on desirable future research on the theme of environment, safety, health, land use and congestion, Stella Project, pp 1-37 (retrieved on March 28, 2008 from http://www.stellaproject.org/PartnersOnly/PartnersOnly%20documents/D15versie2.pdf)

Hornsby, K., Egenhofer, M. J., 1997, Qualitative Representation of Change, COSIT 1997, pg. 15-33

Huisman, O. & Forer, P. (1998a), 'Computational agents and urban life spaces: a preliminary realisation of the time-geography of students lifestyles', Proceedings of The 3rd International Conference on GeoComupation, Bristol, UK. p. 18.

Gielsdorf, F., 1998. Datenmodellierung fu¨ r Gleisnetze und Schaffung eines einheitlichen Raumbezugssystems. Deutsche Geodaetische Kommission (German Geodetic Commission) bei der Bayerischen Akademie der Wissenschaften, Munich. DGK Reihe C, No. 491, pp. 21–25

Gielsdorf, F., 2007, Ausgleichungsrechnung und raumbezogene Informationssysteme, Verlag der Bayerischen Akademie der Wissenschaften in Kommission beim Verlag C. H. Beck, ISBN 3 7696 5032 8

Langran, G., Chrisman, N., 1988. A framework for temporal geographic information. Cartographica 25, 1–14.

Langran, G., 1992. Time in Geographic Information Systems. Taylor and Francis, London.

Miller, H. 1991. Modelling accessibility using space-time prism concepts within geographic information systems. Int. J. Geogr. Inf. Syst. 5:287–303.

OGC, 2003, OpenGIS® Interoperability Program Report: Observations and Measurements Version 0.9.2, Open GIS Consortium Inc., OGC 03-022r3, 04.02.2003

Peuquet, D.J., Duan, N., 1995. An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data. International Journal of Geographical Information Systems 9, 7–24.

Peuquet, D., 2001, Making Space for Time: Issues in Space-Time Data Representation, GeoInformatica, Kluwer Academic Publishers. Manufactured in The Netherlands, 5:1, pg. 11-32

Shaw, S. and Xin, X., 2003, Integrated land use and transportation interaction: a temporal GIS exploratory data analysis approach, Journal of Transport Geography 11, Elsevier Ltd., pp. 103-115

Sinton, D.F., 1978. The inherent structure of information as a constraint to analysis: mapped thematic data as a case study. In: Dutton, G. (Ed.), Harvard Papers on Geographic Information Systems, vol. 6. Addison-Wesley, Reading, MA, pp. 1–17.

Wegner, M., Fuerst, F., 1999. Land use transport interaction: state of the art. Deliverable 2a of the project TRANSLAND of the 4th RTD Framework Programme of the European Commission. Institut fur Raumplanung, Univeristat Dortmund.

Worboys, M.F., 1992. A model for spatio-temporal information. Proceedings of the 5th International Symposium on Spatial Data Handling, vol. 2, pp. 602–611.

Worboys, M.F., 1994. Object-oriented approaches to geo-referenced information. International Journal of Geographical Information Systems 8, 385–399.

Worboys, M.F., 1998. A generic model for spatio-bitemporal geographic information. In: Egenhofer, M.J., Golledge, R.G. (Eds.), Spatial and Temporal Reasoning in Geographic Information Systems. Oxford University Press, New York, pp. 25–39.

Yuan, M., 1996. Modeling semantics, temporal, and spatial information in geographic information systems. In: Craglia, M., Couclelis, H. (Eds.), Geographic Information Research: Bridging the Atlantic. Taylor and Francis, London, pp. 334–347.

Yuan, M., 1999. Use of a three-domain representation to enhance GIS support for complex spatiotemporal queries. Transactions in GIS 3, 137–159.