# Methodology and Examples for Developing Urban GIS's Spatial Analysis Models

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Abstract

The adequate urban spatial analysis and modelling capabilities are missing or are hardly not available in standard commercial GIS software. The consequence is that an urban GIS projectmay not deliver their originally anticipated benefits in a reasonable time frame or within the predefined time schdule.

The main purposeof this paper is to examine the basic issues for developing synthesized as selecting (or designing) a suitable model, mapping the model into a GIS's spatial analysis model and choosing a coupling environment. The section 3 gives four examples of urban GIS's spatial analysis models developed by the author. In the end of this paper, some problems in developing urban GIS's spatial analysis models are briefly discussed.

## 1. Introduction

As an increasing number of urban planning agencies or organizations are becoming proficient in the use of GIS tools for routine types of spatial data storage and retrieval, interests are moving now towards more specified and purposeful applications[Chen, 1992]. However, the adequate urban spatial analysis and modelling capabilities are missing or are hardly not available in standard commercial GIS software. One of the consequences is that an urban GIS project may not deliver their originally anticipated benefits in a reasonable time frame or within the predefined time schdule.

The unsophisticated spatial analysis and modelling capabilities of GIS are resulted from the historial emphasis on cartographic aspects and automation of existing manual map-based operations in the development of GIS. This is reflected in the common representation of GIS data models as a series of thematic overlays register to a common spatial frame of reference [Granger, 1990] and the generic map-based spatial analysis(such as between-layer two-dimentions overlay, with-layer topological operations, i.e, nearest neighbourhood analysis or network analysis and spatial analysis capbilities emphasize the content and structure of a spatial reality (or spatial phenomena). Urban spatial modelling and analysis take into account also the process of the spatial reality or spatial phenomena. For instance, There exist some spatial models which are developed by both researchers and decision makers from different disciplines for describing, explaining and possibly predicting some particular aspect or special process of the spatial reality. Therefore, it is natural to integrate these domain-specific models with GIS's map-based spatial analysis capabilities for developing urban GIS's spatial analysis models.

The main purpose of this paper is to examine the basic issues for developing urban GIS's spatial analysis models. In the following section, a methodology is synthesized as selecting (or designing) a suitable model, mapping the model into a GIS's spatial analysis model and choosing a coupling environment. The section 3 gives four examples of urban GIS's spatial analysis models developed by author. In the end of this paper, some problems in developing urban GIS's spatial analysis models are briefly discussed.

## 2 Methodology for designing urban GIS's spatial analysis models

### 1). Selecting or designing a spatial model

The most essential work for developing urban GIS's spatial analysis capabilities is to select or design a spatial model of the spatial phenomenon or the spatial problem to be analyzed. A spatial model is a set of analytical expressions which describe, explain, and predict some particular aspects or some process of a spatial reality. Its fundamental characteristic is that it is computational. In fact, some of the spatial models emphasize the data spatial struture, while some others emphasize the spatial process of the reality.

There do exist some spatial models which can be used for developing urban GIS's spatial analysis capabilities, such as 'four-steps' traffic volume analysis models, facility location models and the Gauss smoking model. However, spatial models are still laking for some urban spatial phenomenon or the spatial problem to be analyzed. An adequate spatial model should therefore be designed by modeling spatial process, structure and components of the phenomenon or problem.

### 2). Mapping the spatial model into a GIS's spatial analysis model

Generally speaking, the spatial models and GIS are developed from different bases of expertise, each has its own variables and focuses. A spatial model emphasizes the physically-based spatial process (such as mass and energy transfer) and deal with dynamic and continuous phenomena, while GIS manages discrete and static data about spatial stuctures (distribution and spatial relationships) and the relevant continuous phnomenona, while GIS manages discrete and static data about spatial structures (distribution and spatial relationships) and the relevant contents. Therefore, the spatial reality to be analyzed (or modeled) should be mapped or viewed as a set of spatial realities or spatial properties of these entities and their spatial relationships can then be used by spatial models for analysis and modelling.

There are two general approaches to map the spatial reality into spatial objects in GIS. The first one is to classify the spatial reality into spatial objects in terms of points, lines, and polygons, each having its spatial properties or contents as associate attributes. The second is to divide the continous space. In either case, the spatial data contained in GIS is used to define the spatial objects.

On the basis of the above mapping, it is therefore possible to formulate a GIS's spatial analysis model by integrating the analytic capabilities or process modeling functionalities of the spatial model with the spatial data management and map-based analysis capabilities of GIS. The map-based analysis and spatial data may be used in developing model parameters and deriving input data during runs of models[kemp, 1992], and GIS supports the interactive graphic display and efficient data management during the spatial analysis.

3). Choosing a coupling environment

As stated by Nyerges(1992), coupling spatial model with GIS means the software and hardware connection that implements the integration of the analytic funtions (or spatial process modeling) with GIS capabilities. The most coupling occurs through the DBMS of GIS which requires the internal modeling within GIS, i.e, the spatial models are implemented by using GIS provided language or related funtions [Chou and Ding, 1992]. The compatibility of the spatial objects defined above with the data model of GIS determine how easy or difficult it is to couple the two.

## 3. Some examples of urban GIS's spatial analysis models.

### 1). Urban traffic volume analysis model

An urban traffic volume analysis model was developed by coupling the 'four step model' of traffic planning with GIS [Chen, 1992]. The spatial analytic model was used for traffic analysis and simulation, including trip generation, mode choice and trip assignment. As shown in Fig. 1, the spatial entities to be analyzed by the 'four-steps' model (such as traffic zones, road network, and traffic facilities) are mapped into spatial objects in terms of point, line and polygons with the associate attributes in GIS database. GIS is used not only for supporting data storage, display and interactive modeling, but also for deriving parameters or inputs of the model, such as inter-zone distance, node table for traffic zones, shortest distance between two nodes, road segment length, road linear length, road network length, non linear coefficient, and the connectivity matrix between nodes. Some of the intermediate or final analysis results are also sent back to the GIS database. The proposed road network and its relevent parameters are also evaluated and adjusted.

2). Urban construction site analysis model

Another motivation for coupling spatial analytical models with GIS comes from GIS-based site selection of urban construction projects. In order to process construction permit applications, the planning staff needs the basic information (property, planned landuse, building density, infrastructure provision capacity, etc.,) which can be done by mapping the desired project boundaries and overlaying it with other coverage in GIS. In many cases, a suitable construction site should also meet with some other location objectives, such as minimizing the maximum distance between facilities and users (minmax model), maxmizing the coverage of the located facilities(maxcoverage model).
Therefore, the minsum, minmax and maxcoverage models of facility location were coupled with GIS to design an urban GIS's construction site analysis model. As showed in Fig.2, the spatial entities to be analyzed by the facility location models are mapped into spatial objects in GIS, such as the landuse, planned landuse, road network, point facilities, etc. Instead of determing the site location by pure mathematic calculation, a set of GIS's map-based analysis and queries are performed to identify m candidate areas. Then the minmum, minmax and maxcoverage models of facility location may be used to selecting thr most suitable site location from the m candidate areas via analytic analysis.

3). Urban terrain landscape analysis model

While there are many spatial analysis issues which can benefit from the coupling of spatial analytical models in some problem domains or some application areas. Specific spatial analysis models should be formulated by modeling the physically-based spatial process or the human spatial process or the human spatial cognitive process. For instance, the terrain landscape is the perceived figure of physical space. During the process of urban or tourist landscape analysis is a fundamental but very complicated work. In the request of the analysis is a fundamental but very complicated work. In the request of the local urban planners, a terrain landscape analysis model was formulated and programmed by combining domain specific knowledge of landscape planning process with map-based visibility analysis. As showed in Fig.3, the analysis model consists of visual field analysis from single and multiple view point(s), hierarchical visual field analysis, front-view analysis and visual programmed by combining domain specific knowledge of landscape planning process with map-based visibility analysis. As showed in Fig. 3, the analysis model consists of visual field analysis from single and multiple view point(s), hierarchical visual field analysis, front-view analysis and visual corridor analysis from a straight line or a curve line, perspective view from a view point, occluded landscape analysis, simulation of terrain landscape statistics. Since DAM was used as primary spatial data, the analysis model was implemented in the raster GIS environment.

4). Urban flooding analysis model

The spatial process of the submergence flooding in urban area was modelled by combing DTM based analysis and hydrological behavior of flooding[Xiang, 1993]. Since urban flooding is a distributed phenomena over the watershed and the submerged area, an interactive method was proposed for determing the flooding height above the submerged area according to the total quantity of flooding from the breach of the riverbank. The propagation of flooding over the submerged area was simulated with an 'inflation' algorithm and a connected graph was designed for recording the spreading path during the propagation.
maps, but fail to eventually represent much of the evidence available about the distribution of spatial entities and fail to support efficiently spatial analysis and spatial decision making [Lee, 1990]

## 4. Summary

In spite of the efforts devoted to the develop of urban GIS's spatial analysis models, significant problems still exist. One major problem arises from the fact that it is often not possible to define the required precise mathematical spatial models due to an adequate theoretical understanding of the spatial reality. In addition, it is also not easy to verify and validate the spatial model.

Other problems come from the GIS side or from the coupling techniques. Firstly, the so-called 'cartographic data structures' or the discrete 'tessellation 'of current commercial GIS are good at encoding features on maps but fail to eventually represent much of the evidence available about the spatial reality. There is sometimes the mismatch between spatial reality, the forms of discretization used to collect and store data about continuous phenomena and the form in which it must be used in the model. Ideally, the imposition of a spatial grid whose scale is determined by the spatial scale of the processes under study. However, some critical processes operate on many different scales in time and space and there may be scale thresholds at which critical processes change[Kemp, 1992]. In addition, urban spatial analysis may need more complex spatial data models, e.g., a flooding simulation model needs both the vector data of river network and the raster data of terrain elevation. Secondly, spatial analysis in an urban GIS environment would be most effectively constructed when the user is provided with better toolkits for constructing, visualizing and processing databases, for building applications and for accessing one-line expertise(knowledge about data and methodology, etc.) [Dutton, 1991]. Therefore, more flexible application toolkits should be taken into consideration.

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