Chapter XV
Network Modeling

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ABSTRACT

Network models are some of the earliest and most consistently important data models in GISystems. Network modeling has a strong theoretical basis in the mathematical discipline of graph theory, and methods for describing and measuring networks and proving properties of networks are well-developed. There are a variety of network models in GISystems, which are primarily differentiated by the topological relationships they maintain. Network models can act as the basis for location through the process of linear referencing. Network analyses such as routing and flow modeling have to some extent been implemented, although there are substantial opportunities for additional theoretical advances and diversified application.

INTRODUCTION

Network modeling encompasses a wide range of procedures, techniques, and methods for the examination of phenomena that can be modeled in the form of connected sets of edges and vertices. Such sets are termed networks or graphs, and the mathematical basis for network analysis is known as graph theory. Graph theory contains descriptive measures and indices of networks, as well as methods for proving the properties of networks. Networks have long been recognized as an efficient way to model many types of geographic data, including transportation networks, river networks, and utility networks among many others. Network structures in Geographic Information Systems (GISystems) were among the first to be developed and have persisted with wide use to this day. Most importantly, network models enable the analysis of phenomena that operate on networks. This article reviews the types of networks modeled in geographic applications, describes the graph theoretic bases underlying network models, outlines the implementations of network models in GISystems, and the analysis performed with those models, and describes future challenges in network modeling.

BACKGROUND

The most familiar network models are those used to represent the networks with which much of the population interacts every day: transportation and utility networks. Figure 1 shows three networks (roads, rivers, and railroads) with their typical GISystems representations. For most, the objects that these networks represent are obvious due to a familiarity created by frequent use. Cartographic conventions serve to reinforce the interpretation of the functions of these networks. It is clear that these three networks represent fundamentally different phenomena: roads and railroads are man-made, while river networks are natural. Rivers flow only in one direction while—depending on the network model—roads and railroads can allow flow in both directions. Perhaps most importantly, different types of activities occur on these networks. Pedestrian, bicycle, car, and truck traffic occur only on the road network, and the others are similarly limited in the vehicles that use them.

Similar idiosyncrasies could be noted for many other types of networks that can be modeled in GISystems, including utility networks (electricity, telephone, cable, etc.), other transportation networks (airlines, shipping lanes, transit routes), and even networks based on social connections if there is a geographic component. Although the differences among the variety of networks that can be modeled allow for a great diversity of applications, it is the similarities in their structure that provide a basis for analysis.

GRAPH THEORY FOR NETWORK MODELING

Networks exist as a general class for geoinformatic research based on the concept of topology, and the properties of networks are formalized in the mathematical sub-discipline of graph theory. All networks or graphs (the terms can be used interchangeably), regardless of their application or function, consist of connected sets of edges (a.k.a. arcs or lines) and vertices (a.k.a. nodes or points). The topological properties of graphs are those that are not altered by elastic deformations (such as a stretching or twisting). Therefore, properties such as connectivity and adjacency are topological properties of networks, and they remain constant even if the network is deformed by some process in a GISystem (such as projecting or rubber sheeting). The permanence of these properties allows them to serve as a basis for describing, measuring, and analyzing networks.

Network Descriptions and Measures

In Network Modeling—as in many scientific endeavors—the first concern is to define and describe the basic elements to be analyzed. Simple descriptions of graphs include the number of edges and vertices, the maximum, minimum, or total length of the edges, or the diameter of the graph (the length of the longest minimal cost path between vertices). As a measure of the complexity of a graph, the number of fundamental cycles (cycles that do not contain other cycles) can be computed from the number of edges, vertices,

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