NETWORK ANALYSIS in GIS

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GIS _07_Network Analysis in GIS

LEARNING OBJECTIVES

After studying this unit you should be able to:

- Understand the Concept of Networks and Network Analysis;

- Know the types of Models in Network analysis
- Comprehend Network analysis operation
- Visualise the various applications of Network Analysis

1. Introduction

Network analysis is an operation in GIS which analyses the datasets of geographic network or real world network. Network analysis examine the properties of natural and man-made network in order to understand the behaviour of flows within and around such networks and locational analysis. It focuses on edge-node topology to represent real life networks of information. Its function based on the mathematical sub disciplines of graph theory and topology.

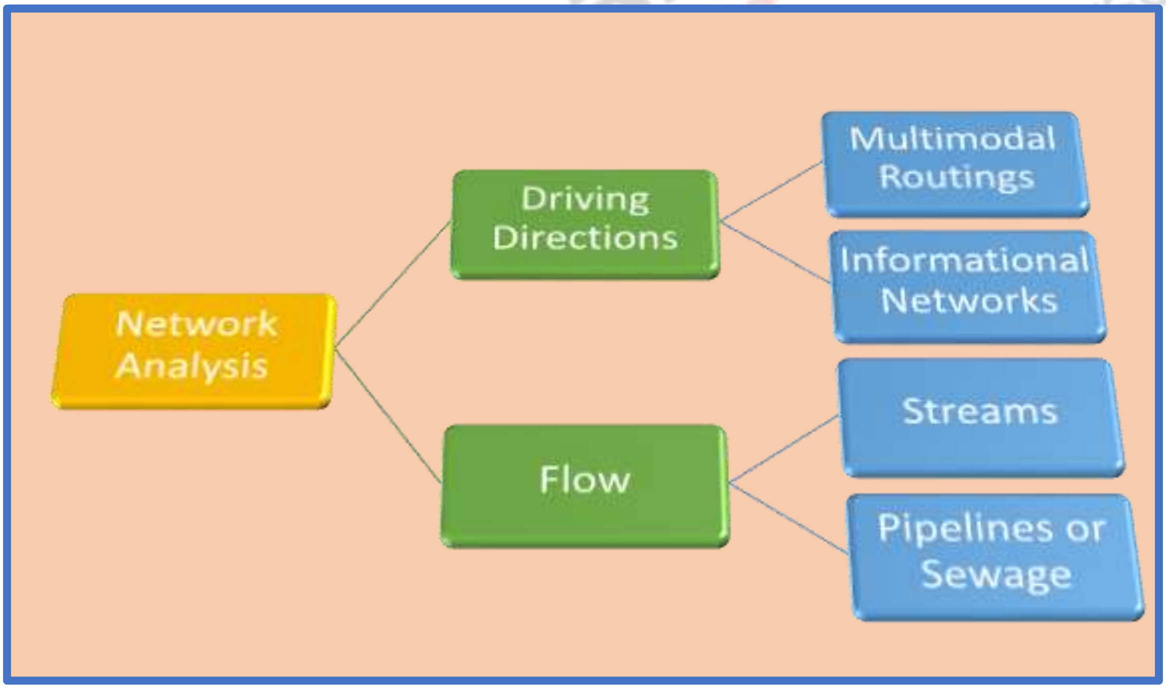

Figure 1: Understanding Network Analysis

2. CONCEPT:

Network analysis is basically set of connected lines. These lines represent railways, streams, roads, waterlines, pipelines, telecommunication lines etc. that normally need to be analyse as a network. It can be direct and indirect or planned and unplanned. Network analyses the movement of people, connectivity and accessibility of railway, roads, pipelines and telecommunications, flow of matter and energy and movement of goods and services. Any type of network is connected by vertices and edges. These network is measured and compared by plotting of graph and linkages of object or feature. Network depends on topological properties i.e. connectivity, adjacency, and incidence.

Types of operation:

- Shortest path analysis
- Best Route
- Closest facility
- Allocation
- location-Allocation
- OD-cost matrix
- Network-partitioning

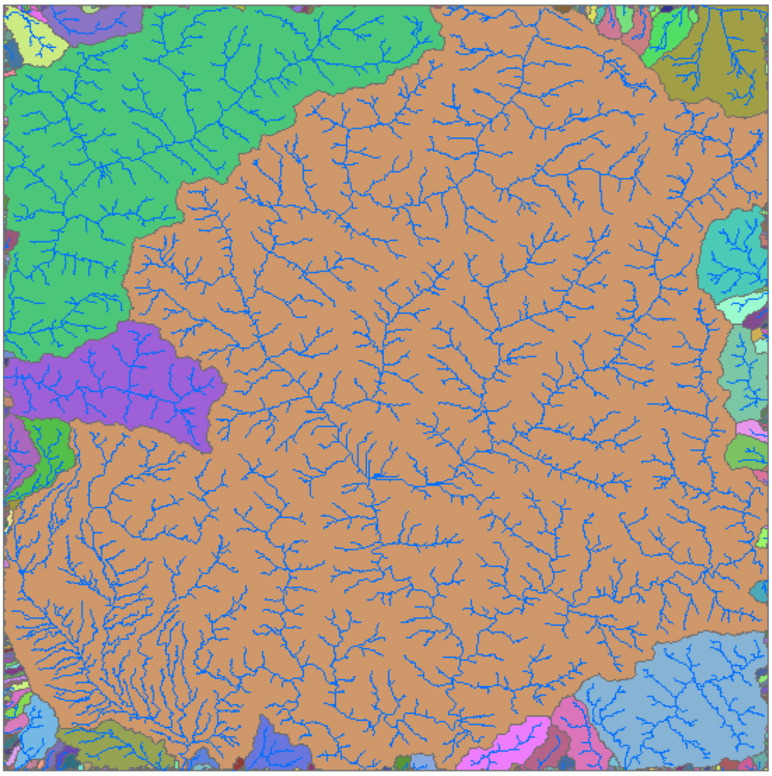

Figure 2: Stream network in Basin

Figure 3: Road connectivity in Delhi University north Campus

3. What is Network?

GIS networks are algorithm of interconnected lines termed as edges and intersections termed as junctions. It work as a path for movement of people, goods and services.

The object navigating the network, follows the edges, and junctions appear when at least two edges intersect. Junctions and edges can have certain attributes affixed to them that increase the cost of traveling in the network, known as impedance. For example, a road network can have speed limits attached to the edges, and a junction can prevent left turns. Networks are either directed (only one direction of travel is allowed within the network) or undirected (in which any direction of travel is allowed).

Network can be “a set of linear features through which resources flow.” “Nodes (the end points of lines) are used as origins and destinations”, and “links (lines) travers from one node to the other”. “Nodes can have properties but in network analysis we are usually more concerned with the characteristics of the links, Laurini and Thompson, 1992”. These include: length, direction, connectivity (lines must connect at least two points), and pattern.

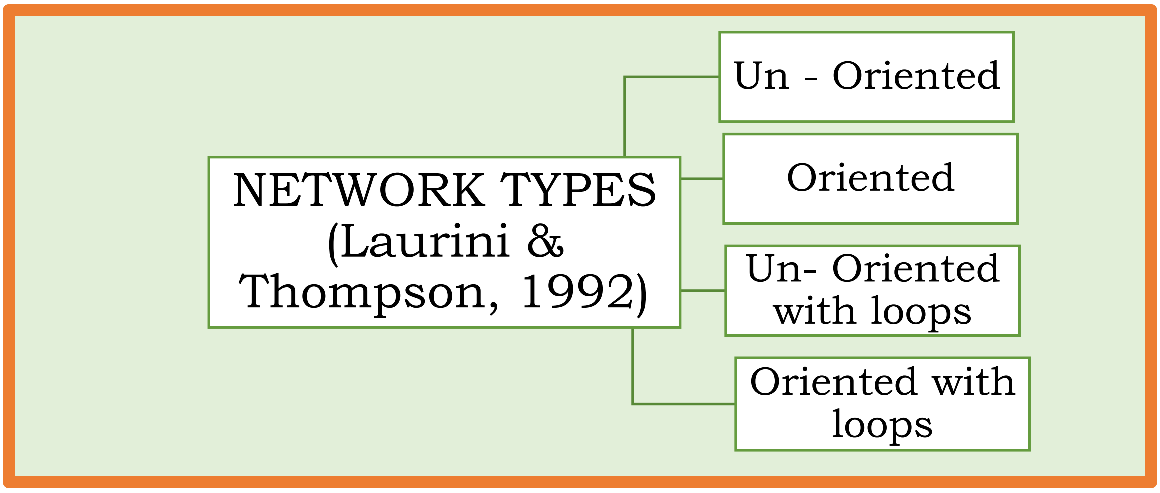

Figure 4: Oriented Network

Rivers flow the direction of downhill, it is the best example of an oriented network. The road connectivity can be either oriented or un-oriented i.e. one way or two way and usually roads contain loops, Trains usually travel in both directions between stations. One track the railway network with smaller lines represented as un-oriented. Somewhere else in the network, lines designated for travel in one direction only for the safety purpose. Two track networks are represented by a pair of oriented links in a network can be either an un-oriented or un-oriented network. The direction of Network or their link can have other properties that represent a cost of moving along that link. For example nodes can have properties that might encourage of discourage travel in that direction.

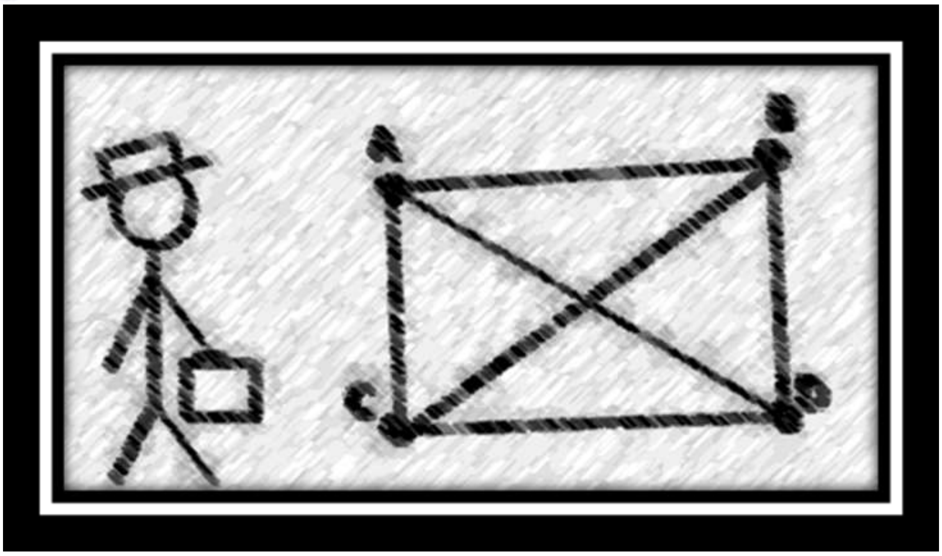

Figure 5: Nodes & Edges

Network Model in GIS

Network model in GIS have the potential to simplify the development of spatial analytical network functions through various type of data model. Many types of data models are transportation network or road network utility network and stream network. These network function helps in planning, development and accessibility.

- **Transportation network or road network**

  It includes roads, railway line, and flight paths. It is generally undirected network because the edge on a network may have a direction assigned to it. The transportation route, the direction, speed, and destination of traversal can be decided by the person. For example person in a car travelling on street. Transportation or road network model play key role in transportation planning, analysis of retail market, measurements of accessibility, allocation of service and more. The understanding of road network patterns provide the idea about the human mobility behaviour.

Figure 6: **Transportation network or road network**

- **Utility network modelling**

  It includes water mains, sewage lines, and electrical circuits. These networks are generally directed. Its path is predetermined. It can be changed, but not by agent.

Figure 7:Utility Network Modelling

- **Stream network**

  It includes flow of stream in catchment, it is directed network because of the natural flow. It this type of modelling is perform for the analysis of drainage based on terrain or digital elevation. It shows the detail information about the connectivity of landscape and land use and land cover pattern. It measures the various attribute related to linear, areal, relief features of stream. Stream network model analyse the geometry (shape, size, drainage density, landforms etc.) it helps in understanding the dynamic behaviour of river flow that reduces the impact of floods and helps in socio-economic condition of human, supply of hydroelectricity energy etc.

Figure 8 : Stream Network

Data requirement

Claussen (1991) has given the description about application of network analysis for positioning and navigation.

Table 1: Requirements for analysing road networks.

System requirements	**Data requirements**
Real time	Accurate
Compact	Up to date
Address conversion function	Topologically correct
Output by visual display or synthetic voice	Attributes
	road conditions • classification • speed restrictions • one way streets • turning restrictions • width and height restrictions • junctions

	• roundabouts • reference landmarks

Network Analysis Operation

Shortest Path

It is a common type of network analysis. It helps in finding the shortest path between two points. In a network of streets, the "shortest" route can is analyse for different variables i.e. distance, time, and monetary cost in terms of purchasing travel tickets or transportation of goods and services. For example an ambulance driver look for the shortest path to his destination for travel the route assign to him or her from point A to point B in the least amount of time, the fair price of purchasing the plane tickets.

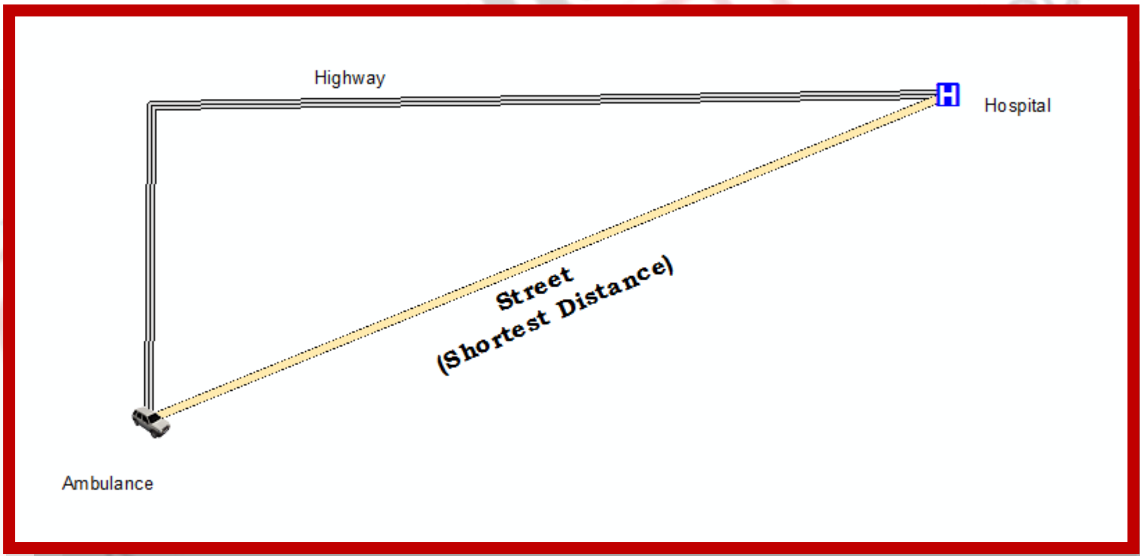

Figure 9: Shortest Path

Travelling Salesman

Sales always travel in order of network of Market. It is most efficient way to reach the market and sales the product. The network path of sales man depends on quickest time in reaching of market, product demand of market and connectedness of market. For example an Amazon agent have to deliver the product in any area. He will follow the path of first route of demanding product and quickest time of network route. UPS uses a traveling salesman algorithm to professionally deliver as many packages as possible to their customers every day.

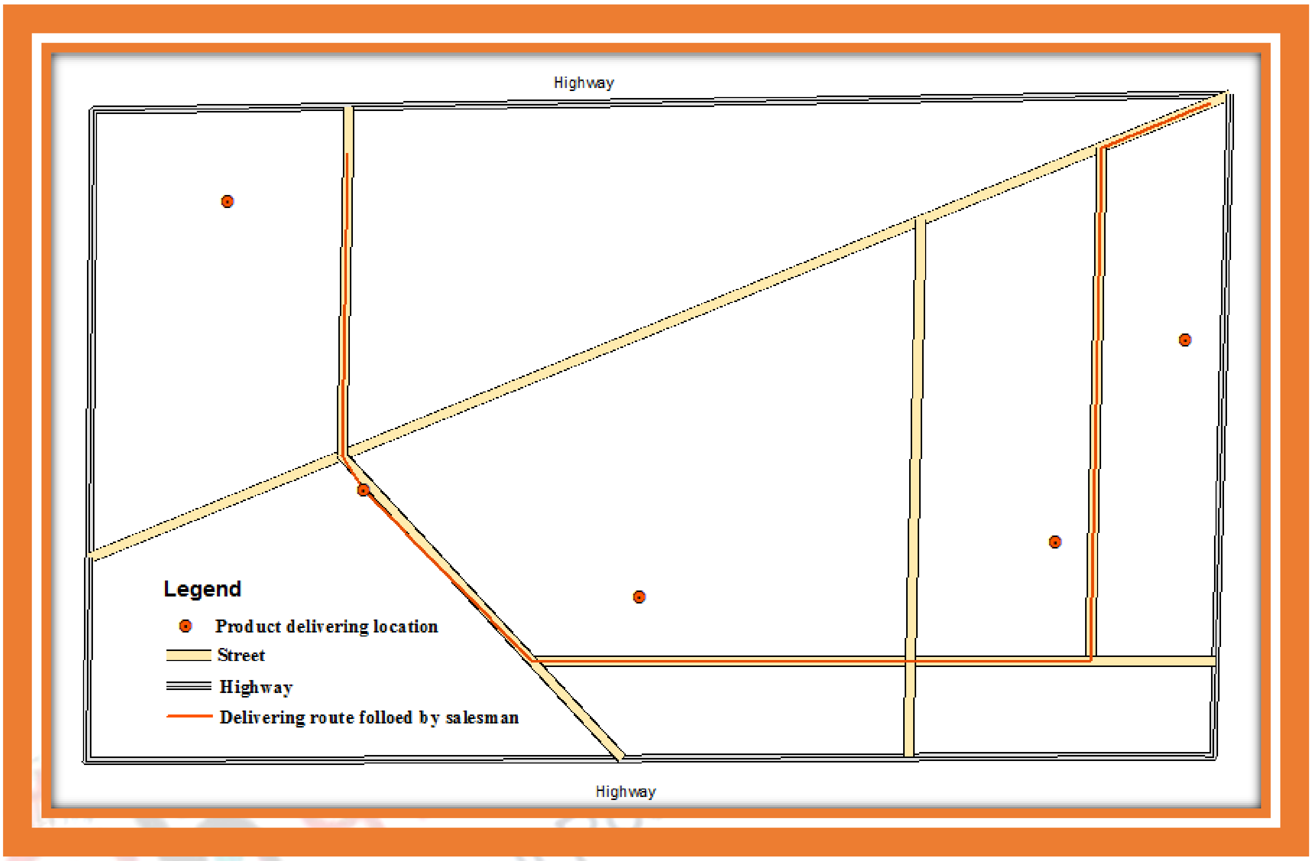

Figure 10: PRODUCT DELIVERING LOCATION

Network Partition

Network partition refers for the subcategorization of network for particular purpose. The size of network region depends on the proximity to specific point in a network. For example coverage area of fire stations are divided in metropolitan region. The network of Indian railway network divided in many zones as per reginal proximity of states.

Transportation Model

Other basic function i.e. buffer, overlay, query already exist in GIS operations are useful in planning Transportation. However, there is many model available for the detail or in depth analysis of network data is available for planning applications like network flow equilibrium models, travel demand models, trip generation and distribution, as well as activity-based models and transportation or land-use interaction models. The usefulness of these model are dependent upon particular use as per demand of transportation influences on land use. There are limited commercial software exists for perform such tasks, nevertheless skilled programmers should be able to design programs to perform these tasks where software is inaccessible or non-existent. GIS is key for the analysis of these type of transportation model.

Network Analysis Workflow

In order for you to perform a network analysis in a GIS program, there are basic steps you need to take. This section walks through the general procedure to do before you solve network analysis network problems:

Organizing the Network Analysis Settings

In any GIS system, like ArcGIS, you need to enable the *Network Analysis* extension. You will also need to display the *Network Analysis* toolbar before you can perform any analysis.

Adding a Dataset to Your GIS Program

Before you are able to perform a network analysis, you need to create a dataset network in which you can perform an analysis. If there is not one available, the original reference source has been modified or has been changed, you will need to build a new one.

Creating the Network Analysis Layer

Layers contain an in-memory classes where inputs, properties, and results can be stored. In the case of performing network analysis, the layer has to be connected to a network dataset. This layer has to be created and added to the dataset before the analysis can be performed. In ArcMap, a network dataset must be added first so that when an analysis layer is created, Network Analyst can bind the analysis layer to the network dataset. The six kinds of network analysis layers in ArcGIS include: route analysis layer, closest facility analysis layer, service area analysis layer, OD cost matrix analysis layer, vehicle routing problem analysis layer, location-allocation analysis layer.

Imputing Network Analysis Features and Records

This step has us add features, or objects, to our dataset input. Network analysis objects are features and records used as input and output during network analysis. These objects can include barriers, routes, facilities, or other man-made structures that will influence the end analysis. When you add these objects, setting the properties for the network analysis layer will further define the function of the input.

Performing the Analysis

After you have finished the other steps of the procedure and created your layer, it is time to perform the network analysis. This can be done by clicking the *Solve* button on the *Network Analysis* toolbar you set up earlier in the process. Your results will then be displayed on the map and double-click the network analysis objects in the *Network Analysis*.

Applications of network analysis

In GIS, networks are used for more than just finding shortest routes. Resource allocation, isochrones construction and many other operations require network data.

Routing: Finding shortest routes is probably the commonest routing problem to occupy GIS users. Finding the shortest route from A to B through a road network is crucial for emergency services, business journeys, or simply planning routes for holiday makers touring a region. In order to carry out such operations it is important to construct an appropriate network. Details of connectivity, one way streets, possible turns and speed limits will be required.

There are a few features that are commonly encountered on road networks which may present problems: for example, streets with different access permissions or turning restrictions. Some of these can be modelled using the type of system described above. The network should also be capable of taking new information and recalculating routes.

Once you have designed and populated your network model then the Dijkstra algorithm can be used to calculate shortest route. If street name or number is held as an attribute for each line then these may be printed out to form a written set of directions. There are some problems for which no efficient algorithms are known and in which heuristics are all we have. The Travelling Salesman Problem (TSP) is one of these. The travelling salesperson has to visit a number of customers then return to base. She/he needs to have details of the shortest tour possible for the sites to be visited. This is the obvious application for 'shortest tour' routines, but there are many others, for instance, giving directions to a Doctor visiting patients in the community. It is possible for a travelling salesperson to traverse the same road twice. The travelling salesperson problem has attracted the attention of Operational Researchers. Using a simple method of calculating the shortest distances between stops, theoretical methods have then worked out all the combinations in which these stops could be visited to find the shortest tour. This sounds simple, but for the computer it is a major task.

If, for example there are 10 patients to visit on a Doctor's round, there are 9 factorial (9!) combinations in which they can be visited. What this means is that the total number of combinations is:

$$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1 = 362\,880$$

That doesn't sound too difficult for a computer, does it? But, try this on your calculator… there should be a 'x!' button somewhere on most scientific calculators. Try 9! to check the answer above. Then increase the number…20! 30!, 40!…see how far you can get. Think about the calculation that lies behind the result. Our calculator gave an error message at 69! For each permutation you have to calculate the shortest route between successive places to visit and sum the results. Finally you can compare the total distances travelled to identify the optimum solution. This complexity explains the interest shown in the TSP by our mathematical friends but we still do not have an efficient algorithm.

So, how do shortest tour options work in GIS? Vincent and Daly (1990) offer two possible solutions:

1. Use fractals. However, this is really at the research end of GIS at present. For those who know something about fractals, the methods involved applying space fitting curves to find which nodes (or stops) are closest together.

2. Cheat! This is how most current solutions work. If you first order the stops, based on their attributes, it is much quicker and less computer intensive to work out the shortest route. As Vincent and Daly (1990) note, however, there is a problem with any of these methods. In the real world the stops which appear closest on the GIS map layer may not be close. There may be a Grand Canyon to cross between the two points! So, once again, the answers you get from your network analysis operations are only as good as the representation of the network which you have put together. Intriguingly, there is a very similar problem to TSP for which algorithms do exist. This is known as the Minimum Spanning Tree (MST) problem. The only difference is that the route only needs to connect to all points using the shortest path – it does not need to return to the start. This has been implemented in GIS.

Resource allocation: Another application of network analysis is resource allocation. The objective is to create service areas around a service centre and, if implemented successfully, allows an organisation to optimise the distribution of the resources based on the capacity of each facility.

For example, centres may be schools with a maximum capacity for children, health centres with a capacity for patients, or warehouses with a capacity for goods. Allocation algorithms use these centres as destinations then model how people or goods will travel through the network to get there. The result is a map that shows the areas served by each service facility e.g. a school or health centre catchment area, or the warehouse’s distribution area. The algorithms usually work by allocating links in the network to the nearest centre, taking into account, of course, the attributes such as one way streets, barriers to movement and so on Applications of such resource allocation operations include siting new schools, revising catchment areas for hospitals, or modelling the effects of closure of a service site. An interesting example of the use of the method in an archaeological application is given in the paper by Zubrow (1990).

Isochrones: Isochrones are lines joining points of equal time (just as isobars join points of equal pressure). Applications of this operation are for finding travel to work zones based on how long people will travel to a centre, or for the establishment of cost surfaces or zones for transportation of goods and services.

For example, a furniture retailer may define zones A, B and C around the retail outlet. If you live in Zone A you can have goods delivered free of charge, if you live in Zone B, you will be charged a nominal fee, and if you live in Zone C you will be charged an exorbitant fee, because they don't want to have to send the delivery vans that far! Alternatively, isochrones could be used to predict the dispersal of a pollutant through a river network from a point source.

GIS will produce a set of isochrones for a centre based on the time it takes to travel along the links in a network. As with the previous operations we discussed, all the attributes, speed limits, capacity and so on, can be incorporated into the operation to obtain realistic results. This will result in the identification of points on the network links which represent the distance travelled in the time given. An interpolation technique could then be used to construct a surface from this set of points and the surface is then reclassified to extract an area that could be reached in that time. An alternative approach would be to identify those points, perhaps representing bus stops or train stations that can be reached within a specified time and then buffer them to show zones within a short walk. This approach was applied by the Pittsburgh Foundation as part of an Access-to-Work Study based on PAT bus route

Scope of network analysis is immense,but there is a gap between the demand and supply for network analysis operations. At present most GIS software have capabilities for calculating shortest routes only . Some may allow calculation of shortest route based on travel times, but most will stick to shortest distance. Whereas, the more sophisticated network models will allow the addition of attributes such as speed limits, turn restrictions and demand to make the operations more realistic. As the market for in-vehicle navigation is growing, the technology is attempting to combine GPS and network analysis technologies with a dedicated set of products and services.

Summary

Network is a set of connected lines and can represent rivers , roads, waterlines , telecommunication lines etc., Networks can be Directed and Undirected / planer and non-planner. In GIS, Networks are widely used for two kinds of modeling : Transportation network and Utility network. In addition, Network analysis analyze the way 'goods' can be transported along these lines (telecommunication lines , road etc). Network analysis can be done in raster or in vector. Different types of operations include:Closest facility; Allocation; location-Allocation; OD-cost matrix and Network-partitioning. Software industry has to facilitate more menus related to network driven operations, especially when the demand is for real time functions dealing with big data.