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Unit 58 - Location-Allocation on Networks

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A. INTRODUCTION

Network problems

- a network can be represented digitally by nodes (junctions) and links (connections between nodes)
  - common networks include streets in a city, airline routes, railroads

- a GIS is a convenient way of storing information about a network

- a large number of analytical problems have been developed for networks, e.g.:
    - "shortest path problem" - algorithms to find the shortest route through the network between given origin and destination
    - "traveling salesman problem" - algorithms to find the shortest tour through a given set of destinations, beginning and ending at a given origin
    - "transportation problem" - find the pattern of shipments of goods from a number of factories to a number of outlets which will minimize total shipping cost
    - "traffic assignment problems" - given the numbers of trips to be made between origins and destinations, predict how traffic will allocate itself to a network, i.e. how many vehicles will use each route
    - numerous other problems in vehicle routing and scheduling

- some of these, e.g. shortest path problems, have been incorporated into GIS products, e.g. ARC/INFO's NETWORK, Caliper's TRANSCAD

- others can be used as stand-alone packages in conjunction with a GIS
    - the GIS provides the input, output, display, simple analysis functions
    - the stand-alone package provides the algorithm to solve the particular problem

- this unit examines an example of network problems

Location-allocation problems

- concern the provision of a service to satisfy a spatially dispersed demand

- demand for the service exists at a large number of widely dispersed sites

    - impossible to provide the service everywhere
        - e.g. every household needs a source of groceries, but impossible to provide a grocery store at each household

- for reasons of cost (economies of scale) service must be provided from a few, centralized locations ("sites")
    - sometimes the number of sites is known in advance, e.g. McDonalds wishes to locate 3 restaurants in city x
    - in other cases the optimum number of sites is one aspect of the solution

- two elements to the problem:

    1. Location

        - where to put the central facilities (and possibly how many, how big)

    2. Allocation
        - which subsets of the demand should be served from each site ("trade areas", "service areas")

Objectives

- important components:
    - cost of operating the facilities - includes construction, operating costs - may be independent of locations chosen
    - cost of travel to and from facilities - may be absorbed by the consumer or the provider depending on the context
    - quality of service
        - e.g. important in providing emergency fire service which is dependent on the response time of the fire truck

- different objectives define different versions of the location-allocation problem

Applications

- retailing - locations of stores, restaurants
- emergency facilities - ambulances, fire stations
- schools
- warehouses
- regional offices of government departments
- recreation facilities - public pools

B. EXAMPLE - OIL FIELD BRINE DISPOSAL

- this is an example of both a location-allocation problem and the use of a network model

- concerns waste disposal for the Petrolia, Ontario oil field which has been producing oil since 1850s

- oil extraction from the field generates large quantities of waste fluid
    - waste fluid has been increasing as the field has become depleted
    - waste fluid or "brine" is a salty, smelly fluid
    - brine may be 90%-97% of total volume extracted, only 3%-10% oil

- 14 active producers in the field
    - each producer may operate up to 30 wells
    - each producer operates an oil collection facility to which all liquids from that producer's wells are piped

- oil and brine are separated by each producer at the collection facility using simple gravity separation

- oil is shipped to the refinery by truck

Brine disposal

- brine disposed of by individual producers
    - some of the methods used may lead to violations of provincial pollution standards
    - brine may run onto fields or into surface watercourses

- thus need a better disposal method

- only effective method of disposal is by pumping to a geological formation below the oil producing layer
  - alternative methods are too expensive or impractical, e.g. purification by reverse osmosis, evaporation in holding ponds

Disposal options

- options include: 1. a single, central disposal facility
  - minimum capital cost
  - maximum transport cost 2. requiring each producer to install a facility
  - maximum capital cost
  - zero transport cost 3. some intermediate configuration of shared facilities

The location-allocation problem

- find locations for one or more central facilities and allocate producers to them in order to minimize the total of capital and transport costs

- two alternatives for transport of waste brine to central facilities: pipe and truck
  - assume that both transport routes would follow the same network

C. COSTS

handout - Brine disposal study (2 pages)

overhead - Brine disposal study costs

Pipe cost

- must pay for pipe over its expected lifetime, plus cost of pumping brine through pipe

Truck cost

- must pay for holding tanks for brine, with sufficient capacity to allow for delays in winter, plus cost of loading and unloading truck, and estimated driving time

Disposal well cost

- includes cost of installing disposal well and running pump
  - porosity of formation varies, so there is a risk of failure in a drilled disposal well

- new well - $50-$75,000

- success rate 60-80%

- brine contains dense hydrocarbons - waxes - which will build up over time and block the well

- problem with corrosion of pipes due to high acidity of brine

D. GIS IMPLEMENTATION

- data structure defines
  - network of streets and rights of way - potential routes for trucks/pipes
  - links with attributes of length
  - nodes with attributes of volume produced - nodes include producer sites plus other potential well locations

- GIS database with nodes and links and associated attributes provides:
  - data input functions (editing)
  - data display - graphics, plots
  - storage of geographic data
  - data to be passed to the analysis module

- analysis module interacting with GIS database
  - obtains nodes and links from the GIS
  - performs analysis, reports results directly to the user
  - includes several heuristic methods for solving the optimization problem
  - allows the user access to the display/analysis functions of the GIS

- an analysis module supported in this way by a GIS database provides a primitive spatial decision support system (SDSS) tailored to this specific, advanced form of spatial analysis

  - see Unit 59 for more on spatial decision support systems

E. LOCATION-ALLOCATION ANALYSIS MODULE

overhead - Location-allocation analysis module

1. Finds shortest paths between points on network (could be a GIS function)

2. Defines and modifies model parameters (e.g. components of pipe and truck cost equations)

3. Uses shortest paths and parameters to calculate transport costs by each mode

4. Searches for optimum solution using add, drop and swap heuristics add - start with no facilities, at each step place facilities in location which best improves objective drop - start with facilities at every node, at each step drop the facility which produces least deterioration in the objective swap - try to improve the objective by moving facilities from one node to another

5. Evaluates solutions and displays results

overhead - Brine disposal options costs

Sensitivity analysis

- many parameter values are uncertain
    - e.g. cost of installing pipe, lifetime of pipe and wells

- important to know effect of uncertainty on results
    - e.g. if pipe cost doubles, what will be impact on results?

- in sensitivity analysis, parameter values are changed one at a time to determine its effect on solutions

    overhead - Sensitivity analysis

- in each case, first line gives value assumed for option d, wells at producer locations
    - subsequent lines give effect of changing the parameter
        - e.g. increasing pipe cost leads to greater number of facilities

Problems with link-node models

- some spatial decisions involving networks do not work well with the standard link-node model
    - may need to put a facility or event anywhere on the network not just at intersections

- thus need the ability to identify a location along links

- this may be done by:
    - identifying location by its distance along a link from a node
        - thus network is not a set of links and nodes but an addressing system using link number and distance
    - breaking a link at a given location to form a new node and 2 links
        - e.g. "dynamic segmentation" if the break is temporary

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EXAM AND DISCUSSION QUESTIONS

1. Evaluate the Petrolia study as an example of the application of an objective, scientific

technique. In what ways was the methodology arbitrary? Which parts of it would be most difficult to defend in court, and which parts would be easiest?

2. The Petrolia study was presented as an isolated stage in the decision-making process. Discuss the issues involved in implementing the results of studies like these, and ways in which the models and associated GIS might be involved as the implementation proceeds.

3. What functions would a GIS need to play the role outlined in this unit? What functions would be important in "selling" the solution through the political process, and modifying the solution in response to new concerns?

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