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Compiled with assistance from C. Peter Keller, University of Victoria, Canada

EXAM AND DISCUSSION QUESTIONS

- NOTES

This unit begins a three part module introducing concepts and techniques of spatial decision-making. Although it is far from a complete coverage of the topic, it will provide students with a sampling of the kinds of decision-making activities GIS will be required to support.

UNIT 57 - DECISION MAKING USING MULTIPLE CRITERIA

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A. INTRODUCTION

- an introduction to the topic of multiple criteria analysis

- deals with the potential integration of quantitative multiple criteria analysis and GIS

- GIS has the potential to become a very powerful tool to assist in multiple criteria spatial decision making and conflict resolution

- some GIS have already integrated multiple criteria methods with reasonable success (for example TYDAC's SPANS system)
    - it is anticipated that other vendors will integrate multiple criteria methods in the near future

Goals of this unit

- to introduce students to the concept of multiple criteria decision making

- to outline some of the simpler strategies developed to solve multiple criteria problems

- to demonstrate the potential applicability of GIS

B. SPATIAL DECISION MAKING

Examples of spatial decision making

- identify shortest path that connects a specified set of points
    - e.g. for power line route, vehicle scheduling

- identify optimal location of a facility to maximize accessibility
    - e.g. retail store, school, health facility

- identify parcel of land for commercial development which maximizes economic efficiency

General steps involved in traditional approach

1. identify the issue

2. collect the necessary data

3. define the problem rigorously by stating:

- objectives
- assumptions
- constraints

- if there is more than one objective:
    - define the relationship between objectives by quantifying them in commensurate terms, i.e. express each objective in the same units, usually in dollars
        - e.g. wish to minimize both cost of construction and impact on environment
        - must express environmental impact in dollars, e.g. cost of averting impact
    - then collapse the objectives into one objective
        - e.g. minimize sum of construction and environmental costs

4. find appropriate solution procedure

5. solve the problem by finding an optimal solution

Assumptions involved with this type of analysis

- the objectives can be expressed in commensurate terms

- the problem can be collapsed and simplified into a single objective for analysis

- decision makers agree on the relative importance of the commensurable objectives

- however, these assumptions don't necessarily hold, consider the following examples:

Example 1: The fire station location problem

Problem: to locate a new fire station in a city (Schilling, 1976)

Objectives: maximize coverage of population maximize coverage of real estate

- something is "covered" if it is within an established response time of a fire station, e.g. 3 minutes

Conflict: most valued real estate is not necessarily located where most people reside
- most valued real estate in downtown and industrial areas
- people live in the suburbs
- objectives are in spatial conflict

Solution: traditional approach requires that the two objectives be collapsed into one by defining a relationship between the value of real estate and the value of life
- but the two objectives are noncommensurate
- can't place a monetary value on a human life

Example 2: Land suitability assessment

>   Problem: suitability evaluation of a number of sites for commercial development

>   Objectives: maximize economic efficiency minimize environmental impact

>   Conflict: decision makers have to express environmental quality in terms of economic efficiency (monetary values)

>   - different interest groups will value environment differently
>   - no consensus, therefore can't assess environmental quality in monetary terms
>   - objectives are again noncommensurate

General observations

- in the real world, decision making problems rarely collapse into a neat single objective

  diagram

- in this classification of real world spatial decision- making problems, most fall in the bottom right cell
    - real world problems are inherently multiobjective in nature
    - consensus rarely exists concerning the relationships between the various objectives

Conclusion

- more appropriate to identify and maintain the multiple criteria nature of real world problems for analysis and decision making

- decision makers are frequently interested in the trade off relationship between the various criteria
    - this allows them to make the final decisions in a political environment
        - e.g. trading total population covered for total value of real estate covered

>   Example 2: Land suitability assessment

>   Solution: Identify and map the different land uses, land assessments and environmental impacts on separate layers

>   - construct several combinations of overlays based on various priorities
>   - derive suitability surfaces for the different combinations of priorities
>   - let politicians make the ultimate choice

C. MULTIPLE CRITERIA AND GIS

- a GIS is an ideal tool to use to analyze and solve multiple criteria problems
    - GIS databases combine spatial and non-spatial information
    - a GIS generally has ideal data viewing capabilities - it allows for efficient and

effective visual examinations of solutions
- a GIS generally allows users to interactively modify solutions to perform sensitivity analysis
- a GIS, by definition, should also contain spatial query and analytical capabilities such as measurement of area, distance measurement, overlay capability and corridor analysis

D. THE CONCEPT OF NONINFERIORITY

overhead - Noninferiority

- the figure shows the objective space for a two objective problem - the fire station problem
    - two objectives, real estate and population coverage, are represented by the two axes of the graph
    - the shaded area represents the set of all possible feasible locations (subject to constraints of cost, distance etc.)

- P1 represents the solution which optimizes coverage of population alone

- P2 represents the solution which optimizes coverage of real estate

- a site is noninferior if there exists no alternative site where a gain could be obtained in one objective without enforcing a loss in the other
    - P3 represents a feasible solution which is NOT noninferior
    - P3 can move vertically to improve population coverage without changing real estate coverage
        - solutions exist which are better than P3 on one axis (one objective) without necessarily being worse on the other axis

- the dark curved line represents the set of noninferior solutions
    - P4 is an example of a noninferior solution
    - to improve on P4 for one objective requires a loss on the other objective

- the set of noninferior solutions is the set of best compromise solutions or the "trade-off curve" in welfare economics
    - any point on the "trade-off curve" represents a point of Pareto optimality
        - a solution point where no one objective can be improved upon without a sacrifice in another objective

- P4 cannot move vertically to improve population coverage
    - must slide along trade-off curve
    - movement upwards along the curve will imply a change (loss) in the real estate objective
    - P4 therefore is a Pareto optimal or a noninferior solution point

Example 1: Fire station location problem

Solution: Identify the set of all possible sites for the new fire station that represent

noninferior solutions

- for each noninferior solution, examine the trade off between covering more lives relative to more real estate
- make the final and informed decision in the political environment

E. BASIC MULTIPLE CRITERIA SOLUTION TECHNIQUES

- are a number of possible approaches to defining the noninferior solution set

    1. Preference oriented approaches:

    - derive a unique solution by specifying goals or preferences
    - this technique assumes the set of possible solutions is known and small
    - an example is goal programming

    2. Noninferior solution set generating techniques:
    - derive the entire set of noninferior solutions and leave the choice to the decision-maker
    - these techniques are used when a very large number of options exist
        - many of these many not be part of the noninferior set, thus this allows the number of options to be reduced to a limited set
    - an example is the weighting method

F. GOAL PROGRAMMING

- one of the oldest and most well-known multiobjective research methods

- generally utilized where there are a number of competing goals or objectives

    Example 2: Land suitability assessment

    - given a set of parcels of land, identify which best suits a set of development or search criteria
    - the overall aim is to meet all the criteria or goals to the greatest extent possible, to choose the most desirable plan from a set of possible options

Choose criteria and assign weights

overhead - Goal programming example - criteria weights

handout - Goal programming example (2 pages)

- suppose there are 4 sites to be evaluated

- 8 criteria have been identified
    - these likely reflect opinions of different experts, different schools of thought, different objectives
    - e.g. may wish to maximize profit (developer), to minimize cost (engineer) and to

minimize environmental impact (environmentalist)

- weights have been given to each criterion to identify its importance
    - weights must sum to 1
    - e.g. the developer's criteria may have a weight equal to the engineer's and less than the environmentalist's

- each site has been ranked on each of the criteria (see overhead)

Build a concordance matrix

overhead - Goal programming example - Building a concordance matrix

- take each ordered pair of alternatives - e.g. sites A and B, pair AB

- for each criterion, assign the pair to one of three sets:
    - where A beats B (concordance set)
        - e.g. criteria 2 (wt=.1), 4 (.2), 6 (.1), 8 (.1)
    - where B beats A (discordance set)
        - e.g. criteria 1 (wt=.1), 3 (.1), 7 (.1)
    - where A and B tie (tie set)
        - e.g. criteria 5 (wt=.2)

- add up the weights of the cases in each set
    - if A always beats B on all criteria, all 10 cases will be in the concordance set - total weight will be 1

- actual weights for pair AB:
    - concordance set: 0.5
    - discordance set: 0.3
    - tie set: 0.2

- concordance for each pair is determined by summing the weights for criteria assigned to concordance set plus half sum of wts for criteria in tie set
    - for pair AB: 0.5 + 0.1 = 0.6
        - indicates a slight preference for A over B across all criteria

- create a matrix of concordance for each pair

overhead - Goal programming example - Full concordance matrix

    - row is first in pair, column is second

- row total yields index of preferability
    - the larger the index, the more preferred the option

- over all criteria, site D is preferred to site C which is preferred to site A which is preferred to site B

note: an example of this process is provided later in this unit

Summary

- decision maker is asked to specify goals and relative weightings for the different criteria
  - use relative weightings to find most preferred site
  - change weighting to assess sensitivity of solution or to reflect different opinions

G. WEIGHTING METHOD

- used when the set of possible solutions is extremely large

  - identifies or reduces the number of solutions that need to be considered
  - solution of multi-criteria problem is easier if the contents of the noninferior set are known

- this method finds the complete noninferior solution set rather than a single solution
  - final selection is left to decision-makers

- strategy:
  - combine the criteria using a range of different weightings for each criteria - range from 100% on only one criteria to 100% on the other
  - find best solutions for each combination
  - due to the number of combinations that must be evaluated, this is not generally practical for more than 2 criteria

- note the weighting method does not guarantee that all solutions in the noninferior set will be found
  - number found depends on how many combinations of weights are used

H. NORTH BAY BYPASS EXAMPLE

- this section is drawn from B.H. Massam's book Spatial Search which includes many examples of complex spatial decision-making

- a new route is needed for Ontario Highway 11 around the city of North Bay

- this study conducted by Ontario Ministry of Transportation and Communications is similar in methodology to many highway routing studies

- many of these studies use GIS or automated mapping systems to analyze multi-layer databases

- routing studies follow a common strategy:
  - identify factors which are important in evaluating impact of route
  - identify a small number of feasible routes
  - evaluate each route on each of the impact factors
  - reach a decision by combining impact factors on some systematic basis

this study is a particularly good example of the general strategy

Impact factors

- total of 35 criteria
    - grouped into 7 clusters

    overhead - North Bay bypass study - Criteria clusters
    - "Direct Cost" cluster includes construction and property costs
    - "Traffic Service" cluster evaluates effectiveness of route from a traffic engineering viewpoint, includes number of miles with >2% grade

    - "Community Planning" cluster evaluates routes against common planning criteria, including amount of land for potential development which will have improved access as a result of the highway
    - "Neighborhood and Social Impact" cluster includes many factors measuring impact on local communities

Alternative routes

- 9 alternatives identified

- each alternative is a complete route, evaluated as such

- two or more alternatives may share long stretches of common route, differ only in sections

Combination of factors

- factors evaluated by a Technical Advisory Committee
    - all major clusters represented by different members e.g. direct cost cluster represented by engineers, accountants, managers e.g. neighborhood and social impact cluster by representatives of community groups

- each member begins by selecting the cluster most easily understood by him/her
    - reviews supporting text, maps, tables documenting evaluation of routes on factors in selected cluster
    - scores each route on each of the factors in the cluster - scale of 0 to 10, 10 is best score, 0 is worst

- each member moves to a new cluster, scores it, eventually scores all routes on all factors in all clusters

- scores are totaled for each cluster and each route
    - result is a 7 by 9 matrix for each member of the committee
    - big differences depending on background of committee member

- now total over all members to get one 7 by 9 matrix
    - implies that all members get equal weight - so membership of committee is

crucial

Weighting

- how to combine scores from different clusters to get overall evaluation of each route?

  overhead - North Bay bypass study - Weighting schemes

- results in 9 routes, 7 clusters of evaluation factors, 6 weighting schemes

Concordance analysis

- evaluate routes separately for each of the 6 weighting schemes
    - results in a 9x9 concordance matrix for each of the 6 weighting schemes

- gives a matrix of concordances for all pairs of plans

- repeat for each weighting scheme

Results

- routes 2,7,9 consistently best over all weighting schemes, 8 consistently worst

- order of 2,7,9 changes from one scheme to another - 2 is best when cluster 6 is given a high weight

- this provides the decision-makers with a limited set of routes to consider
    - now can proceed with more formal evaluation and public hearings to assess the significance of other factors

REFERENCES

General introduction to multicriteria decision-making:

Cohon, Jared L., 1978. Multiobjective Programming and Planning, Academic Press, Mathematics in Science and Engineering, Vol. 140

Massam, B.H., 1980. Spatial Search. Pergamon, London. Gives many examples of applications of multicriteria methods, in addition to the North Bay study used in this unit.

Rietveld, P. 1980. Multiple Objective Decision Methods and Regional Planning, Studies in Regional Science and Urban Economics; Volume 7, North Holland Publishing Company.

Goal Programming:

Lee, S. M., 1972. Goal Programming for Decision Analysis, Auerbach, Philadelphia. A general introduction to Goal Programming.

The following are examples of applications of Goal Programming:

Barber, G., 1976. "Land-Use Plan Design via Interactive Multi- Objective Programming," Environment and Planning 8:239- 245.

Courtney, J. F., Jr., T.D. Klastorin and T.W. Ruefli, 1972. "A Goal Programming Approach to Urban-Suburban Location Preference," Management Science 18:258-268.

Dane. C.W., N.C. Meador and J.B. White, 1977. "Goal Programming in Land Use Planning," Journal of Forestry 75:325-329.

Weighting Method:

discussed in: Cohon, Jared L., 1978. Multiobjective Programming and Planning, Academic Press, Mathematics in Science and Engineering, Vol. 140.

EXAM AND DISCUSSION QUESTIONS

1. Compare the goal programming and weighting methods in terms of technique, practicality and effectiveness at reaching solutions to difficult problems.

2. Discuss the North Bay study as an exercise in community decision-making. What are its strengths and weaknesses? In what ways did it succeed or fail in involving the community in the decision-making process?

3. How might the methodology of the North Bay study be manipulated or distorted by an unscrupulous agency with a hidden agenda? What can be done to protect against this possibility?

4. One of the advantages of decision-making using GIS is that the effects of changes in criteria can be seen almost immediately, in e.g. search for the best site for an activity. Discuss the impact that this capability might have on the decision-making process. Do you regard this impact as positive or negative?

5. Select a current local planning issue and discuss the decision-making criteria being promoted by various interest groups and individuals.

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UNIT 57 IMAGES
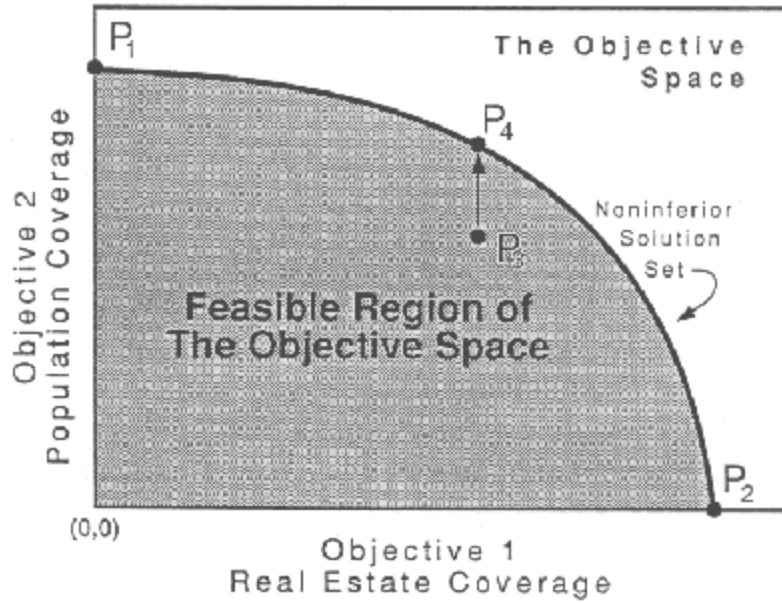
P₁ optimal solution when covering for population

P₂ optimal solution when covering for real estate only

	Alternate Sites				
Criteria	A	B	C	D	Weights
1	4	3	2	1	0.1
2	3	4	1	2	0.1
3	4	3	1	2	0.1
4	1	2	4	3	0.2
5	4	4	2	2	0.2
6	1	4	3	2	0.1
7	4	3	2	1	0.1
8	3	4	2	1	0.1
					1.0

1 = excellent, 4 = poor

Alternate Sites

Criteria	A	B	C	D	Weights
1	4	3	2	1	0.1
2	3	4	1	2	0.1
3	4	3	1	2	0.1
4	1	2	4	3	0.2
5	4	4	2	2	0.2
6	1	4	3	2	0.1
7	4	3	2	1	0.1
8	3	4	2	1	0.1
					1.0

1 = excellent, 4 = poor

Building a Concordance Matrix

Example: Pair AB

Concordance set (A beats B):

Criteria	Weight
2	.1
4	.2
6	.1
8	.1
	.5

Discordance set (B beats A):

Criteria	Weight
1	.1
3	.1
7	.1
	.3

Tie set (A = B):

Criteria	Weight
5	.2
	.2

Concordance for AB

$$0.5 + (0.5 \times 0.2) = 0.6$$

-> slight preference for A over B across all criteria

Full Concordance Matrix for All Pairs

	A	B	C	D	Row
A		0.6	0.3	0.3	1.2
B	0.4		0.2	0.2	0.8
C	0.7	0.8		0.3	1.8
D	0.7	0.8	0.7		2.2

row is first in pair, column is second

Site D > Site C > Site A > Site B

Site D is most preferred and Site B is least preferred

Example: Pair AB

Concordance set (A beats B):

Criteria	Weight
2	.1
4	.2
6	.1
8	.1
	.5

Discordance set (B beats A):

Criteria	Weight
1	.1
3	.1
7	.1
	.3

Tie set (A = B):

Criteria	Weight
5	.2
	.2

Concordance for AB

$$0.5 + (0.5 \times 0.2) = 0.6$$

-> slight preference for A over B
across all criteria

Goal Programming Example
Building a Concordance Matrix

Concordance Matrix

	A	B	C	D	Row
A		0.6	0.3	0.3	1.2
B	0.4		0.2	0.2	0.8
C	0.7	0.8		0.3	1.8
D	0.7	0.8	0.7		2.2

row is first in pair, column is second

Site D > Site C > Site A > Site B
Site D is most preferred and Site B is least preferred