Using spatial analysis in decision making

Techniques for spatial data analysis
Aside - focus

• you should specialise in your reports
  – You should read the guidelines online as to the structure of the report
  – **Key** is to
    1. Have something to say
    2. Find an aspect to work on which interests you
    3. Have enough results to compare and discuss

• **Examples:**
  – Compare all the different “standard” scenarios (standard solution route)
  – Explore the influence of interpolators on results – which parameters do they influence? How and where do the parameters vary?
  – Implement different slope algorithms and compare results for them (you could do this relatively easily using Excel)

• To help you (**NOT ASSESSED**) -> you should prepare a ½ - 1 page summary of what you intend to do for week 10/11 (from 23. March on) – we will comment on it…
Aside - your lab results (labs 1-5)

- Lab 1 – map of Anjeni
- Lab 2 & 3 – soil type map
- Lab 4 – DEMs
  - hillshade IDW, DEM TopoToRaster,
  - hillshade T2R
- Lab 5 – Slope, Slope Length, “LS” (Moore), Watershed
- Note: I and Ryan (TA) have a table with min & max values for the R,K,L,S,C - if you are unsure
Last week

• We looked at hydrological functions
• We saw that different algorithms could be used to derive flow direction and other derivatives – important ideas of converging and diverging flow
• We saw how catchment area and flow accumulation could be derived
• We looked at an example paper discussing the derivation of critical accumulation areas for stream network initiation
• Examined examples of the calculation of compound topographic indices – wetness and stream power index and LS
Outline

• We are going to look at how GIS can be used to help us make **decisions**
• Introduce a range of **multi-criteria evaluation** techniques and look at their use through a very simple example
  - this is closely related to your **bear habitat** (suitability) **analysis** from GEO357 and,
  - lecture on **polygon intersection**
• Examine how these techniques can be used to aid decision making through a **real-world example**...
Learning objectives

You will:

- **know**, and **can illustrate**, the **differences** between **multi-criteria** and **multi-objective approaches** to spatial planning;

- for a given problem, **be able to suggest an MCE approach to finding optimal locations**; and

- will be able to **illustrate** how GIS can be integrated as **a part** of the **spatial decision making process**.
GIS and decision making

- So far we have examined a range of tools in GIS and examined their use in spatial analysis.
- We have considered the use of spatial analysis to:
  - describe data
  - test hypotheses
  - consider site suitability
- Our site suitability examples used overlay and some set of criteria – for instance we tried to select areas suitable for growing rice...
Multi-criteria evaluation

• Our rice example identified areas that *simultaneously* met all specified criteria (through a dominance rule)

• It *did not suggest* which of those areas are most likely to be the best sites for growing rice

*Multi-criteria evaluation (MCE) techniques are required to evaluate the suitability of sites falling within the feasible areas identified using standard GIS overlay procedures.*

Carver, 1991
What is MCE?

• MCE are a suite of techniques used in analysing the trade-offs between choice alternatives with different impacts
• MCE aims to identify the best compromise sites from a set of possible alternatives
• MCE techniques developed in environmental economics and were used aspatially
• They have been adapted for use in GIS to provide a more formal basis for aiding decision making
Basic ideas of MCE

“investigate a number of choice possibilities in the light of multiple criteria and conflicting objectives”

Voogd, 1983, p.21

Criterion: “… a rule to test the desirability of alternative decisions”

Attribute “… properties of elements of a real-world geographical system”

Objective: “… a statement about the desired state of a spatial system”

Malczewski, 1999
So what does this mean?

- MCE uses **criteria** to identify the sites described by their **attributes** which best meet an **objective**

- For example:
  - **Objective**: I need a plot to build a housing estate (and I am a developer)
  - **Criteria**: The houses must be near cinemas, far from main roads and near public transport
  - **Attributes**: The data I will use to describe these criteria at different sites (e.g. distance from road)

- In this case the criterion **clearly conflict** – somewhere **far** from main roads is less likely to be **near** public transport
The following examples all use the same data – we have three possible sites each of which have attributes describing nearness to cinemas and public transport and distance from major roads.

Which site is most suitable?
M1 - Boolean overlay

• **Criteria** – a place is either suitable or not, e.g. must be < 1km from a cinema

• **Solution** is the area which meets all our criteria

• This is a **dominance technique** again – can often leave a very small sub-set of data

• Useful when we have very many sites to screen to do an **initial screening** (get rid of the places that are unfeasible)
Houses must be **less than 2km** from cinema and **more than 300m** from road and **within 200m** of public transport.

Intersection
M2- Weighted linear combination

• **Standardise** the range of all our variables (note that highest value is assumed most suitable)

• **Weight** them according to **perceived importance**

• **Add the layers** and derive a map of nominal suitability

• The location with the **highest score** is the **most suitable**

• Assume that **suitability is linear** with respect to scores and that **variables are independent**

see Malczewski (2000), Eastman et al. (1995)
Layers have values between 0 and 1, 1 is most suitable, 0 least.

Weights are 1 for cinema, 2 for roads and 3 for public transport.

Note, standardising between 0 and 1 has a different effect to standardising between 1 and 2.
M3 - Analytic hierarchy process

- Provides a **more formal basis** for assigning the weights - take values for relative importance between 1 and 9
- 1 means variables have same importance, 9 one variable is absolutely more important than another
- We take the reciprocal if a variable is less important
- Weights are \( 1/(\Sigma\text{column}) \) and sum to 1
- Here, public transport is **absolutely more important** than cinemas

<table>
<thead>
<tr>
<th>Cinema</th>
<th>Road</th>
<th>Public transport</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cinema</td>
<td>1/9</td>
<td>1/2</td>
<td>Cinema 0.083 (i.e. ( 1/(1 + 2 + 9) ))</td>
</tr>
<tr>
<td>Road</td>
<td>2/3</td>
<td>1/3</td>
<td>Roads 0.222</td>
</tr>
<tr>
<td>Public transport</td>
<td>9/3</td>
<td>1/1</td>
<td>Public transport 0.692</td>
</tr>
</tbody>
</table>

We only need to define this side...

see Jones/Eastman for more...
Layers have values between 0 and 1, 1 is most suitable, 0 least.

Weights are as calculated on last slide.

Sum of layers → Ranking
M4 - Ideal point methods

• These methods consider the **distance** of a solution from an ideal solution

• **We identify an ideal solution and then calculate the distance of our alternatives from it using a distance metric**

\[
s_{i+} = \left[ \sum_j w_j^p (v_{ij} - v_{+j})^p \right]^{1/p}
\]

where \( s_{i+} \) is the separation of the \( i \)th alternative from the ideal point

\( w_j^p \) is the weight of attribute \( j \)

\( v_{ij} \) is the standardised value of attribute \( j \) for site \( i \)

\( v_{+j} \) is the ideal value of attribute \( j \)

\( p \) is a power parameter between 1 and \( \infty \)
More on the ideal point method

- The power parameter $p$ determines how we measure distance
  - $p=1$ gives the Manhattan distance, and
  - $p=2$ gives Euclidean distance
    (but note this is distance in criteria space, not real space)
- As $p$ increases the importance of small differences increases
- There are different ways to implement the method – one of these takes the standardised layers and says that the ideal solution is the maximum value\(^1\)
- The best solution is the one that is nearest the ideal in m-dimensions (where m is the number of attributes)

\(^1\)Or vice-versa if the orders are reversed
Standardised values (here 1 is the ideal value)

Distances with weights as in AHP

\[ w_{\text{cinema}} = (0.083)^2 \times (0 - 1)^2 = 0.007 \]

\[ s_{i+} = w^p (v_{ij} - v_{+j})^p \]

\( p=2 \) here

\[ \sqrt{\sum s_{i+}} \]

Ranking
M5 - Concordance methods

• This method attempts to rank sites according to a **pairwise comparison** of alternatives.

• Each criteria is compared for two sites (e.g. are cinemas nearer the house at Site A or B).

• An entry is put in the **concordance matrix** which is equivalent to the **sum of the weights** for the **criteria which are better** for the site (weights *again* from AHP).

• The **final matrix** is used to generate **rankings** (which may be partial – sites can tie).
<table>
<thead>
<tr>
<th></th>
<th>Cinema</th>
<th>Roads</th>
<th>Public transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>1</td>
<td>0.55</td>
<td>0.63</td>
</tr>
<tr>
<td>Site B</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Site C</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Weights</td>
<td>0.083</td>
<td>0.222</td>
<td>0.692</td>
</tr>
</tbody>
</table>

These values are the raw values for the layers.

<table>
<thead>
<tr>
<th></th>
<th>Site A</th>
<th>Site B</th>
<th>Site C</th>
<th>Sum</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site A</td>
<td>-</td>
<td>0.305</td>
<td>0.775</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Site B</td>
<td>0.692</td>
<td>-</td>
<td>0.692</td>
<td>1.384</td>
<td>1</td>
</tr>
<tr>
<td>Site C</td>
<td>0.222</td>
<td>0.305</td>
<td>-</td>
<td>0.527</td>
<td>3</td>
</tr>
</tbody>
</table>

Site A is better than Site B for cinema and roads – so value is 0.083+0.222 = 0.305

Site A is better than Site C for cinema and public transport – so value is 0.083+0.692

Site B is better than Site A for public transport – so value is 0.692
### Summary of results

<table>
<thead>
<tr>
<th>Method</th>
<th>Site A</th>
<th>Site B</th>
<th>Site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Weighted</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>AHP</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Ideal point</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Concordance</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Site rankings, 1 is best…”

You should think about which of these are dominance, contributory and interaction rules.
What about multiple objectives?

• So far we have talked about multiple criteria – we wanted to optimise a site according to a range of criterion

• Often, we also have a range of objectives – so for example a builder might wish to choose the cheapest land, whilst an environmentalist might prefer building to take place on sites which damage the environment least

• These sites may not be the same – so we try to find the best compromise site

• This is multi-objective analysis
Multi-objective analysis

• I will briefly describe a conceptually simple idea here – you can read more in Jones (1997) and Eastman et al. (1995)

• **Multiple Objective Land Allocation** (MOLA) assumes that we have performed multi-criteria analysis already for a number of different objectives and have suitability layers for each objective

• Our task is then to allocate locations according to the differing objectives (which may or may not conflict)
Multiple Objective Land Allocation

- Iterate through all the solution sets and find the **highest ranked sites** in each.
- If a **cell is highly ranked** for only a **single objective**, it can be allocated to that.
- If a cell is highly ranked with respect to several objectives, it is in conflict or meets both objectives.
- We may decide which objective is nearer, and allocate it to that.
- Sites are iteratively allocated until sufficient sites (area) for all the objectives have been found.

N.B: Here we assume objectives A and B are equally important.
Summary

- MCE techniques allow us to categorise and rank a location’s suitability using a range of techniques.
- Here we looked at a range of different MCE techniques including (i) boolean overlay, (ii) weighted linear combination, (iii) analytical hierarchy process, (iv) ideal point method and (v) concordance techniques.
- They can all be applied to raster or vector data – defining the attributes and extracting them is the important thing.
- Different techniques may give different answers.
- MOLA allows us to also consider multiple objectives.
Using GIS for making decisions

• So far we have looked at a set of techniques for ranking based on attributes, criteria and objectives

• These techniques assume some very important things:
  – We know what the question is
  – We know what attributes are related to the question
  – We know how to form rules to compare attributes
  – We know how important different factors are

Computers can’t do these things!!!
Spatial Decision Support Systems (SDSS)

- People make decisions (either rationally or irrationally!)
- SDSS can be thought of as the tools or process that decision makers can use to help them in making decisions through:
  - visualising the problem
  - defining relationships between factors
  - predicting outcomes through modelling
  - evaluating how sensitive decisions are to changes in individual factors (and also to uncertainty)
  - visualising spatial relationships between potential sites

- The following diagram visualises a framework for SDSS
After Malczewski, 1999 p96
What does it all mean!

• The previous diagram is very pretty – but what does it mean?

• It tries to show the steps in the process of SDSS and divides them up into three phases:
  - The **intelligence phase** – here **raw data** are collected, processed and visualised. The decision maker can utilise exploratory spatial analysis techniques to clearly identify the problem
  - The **design phase** – here a set of possible alternatives are identified through use of a range of techniques
  - The **choice phase** – finally we evaluate the alternatives – perhaps one is chosen, or a range are delivered to decision makers
An example

- We are going to explore the flowchart using an example
- It is based on a paper about siting wind farms in Wales – a very controversial topic
- Many complex issues which we will explore
- The question – **where can we put wind farms?**
- Who might care about this question?

Image from: http://www.bwea.org/ukwed/print-map-operational.html
Windfarm map unveiled for Wales

Seven areas across Wales have been chosen by the Welsh Assembly Government for the development of wind farms.

The aim is to increase the amount of energy from renewable sources by 10% over the next five years.

There are around 400 turbines in Wales, and the strategy confirms areas across mid and south Wales for further development, first set out a year ago.

The boundaries were outlined during the consultation process, but are slightly smaller.

Environment Minister Carwyn Jones said he was confident that the planning framework was "appropriate for Wales and will enable us to meet our commitment to deliver four terawatt hours of electricity generated from renewable sources by 2030".

Economic Development Minister Andrew Davies said they would continue to work with local planners, the industry and other key groups "to ensure progress on implementation of our policy and to enable effective planning for renewable energy in all its forms".

The strategy outlines development in the following areas:

- Clocaenog Forest, Denbighshire
- Llwybr Llŷn (the Llyn Forestry Park), Gwynedd
- Rhondda Cynon Taf
- Gwynedd
- Anglesey
- Wrexham

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Welsh Assembly Government

Facilitating Planning For Renewable Energy in Wales: Meeting the Target


http://www.wales.gov.uk/subiplanning/content/tans/tan08/newtan8/arup-review-rpt-e.pdf
COUNCIL BACKS HUGE WIND FARM PLAN

Plans to build the largest onshore wind farm in Europe have been approved by Comhairle nan Eilean Siar (Western Isles Council).

An application by Lewis Wind Power for a 209 turbine wind farm in North Lewis, costing £400m, was passed by 19 votes to eight on Wednesday evening.

It was approved despite more than 4,000 objections.

However, the Scottish Executive must grant planning permission and it could decide to hold a public inquiry.

In addition, the Royal Society for the Protection of Birds (RSPB) has stated that it is willing to take the matter to Europe if necessary.

The council also approved by 22 votes to 7 an application by Beinn Mhor Power for 130 turbines on the Eishken Estate.

The economy of the Western Isles is in trouble. We are on our knees.

Councillor Anne Macdonald

Some councillors accused the authority of ignoring public opinion, but those in favour argued that the social and economic benefits far outweighed the disadvantages.

Local councillor Anne Macdonald said: "The government has given our area a title of outstanding beauty. It is beautiful,
Problem definition

Intelligence phase
GIS

Evaluation criteria

Constraints

Decision matrix

Alternatives

Decision makers preferences

Design phase
MCE

Decision rules

Sensitivity analysis

Choice phase
MCE/GIS

Recommendation

After Malczewski, 1999 p96
Evaluation criteria

• These include:
  - exposure to wind;
  - available area for development;
  - population density;
  - proximity to built-up area;
  - proximity to high voltage power lines;
  - proximity to ports;
  - proximity to major roads;
  - on-site access;
  - prevalence of rare birds;
  - proximity to conservation area;
  - political marginality.

• Are these independent?

• Who might choose these criteria?
Problem definition

Evaluation criteria

Decision matrix

Decision makers preferences

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Sensitivity analysis

Recommendation

Constraints

Alternatives

After Malczewski, 1999 p96
Constraints

• Constraints are the limitations on the values that our evaluation criteria may take

• We apply them by some boolean operation and are left with a number of feasible sites

• Some constraints here are:
  - Must have winds greater than 7ms⁻¹
  - Upland areas, typically above 300m that is flat
  - Sufficient area for at least 25MW
  - “General” absence of nature conservation or historic landscape designations
  - Not allowed in National Parks

• Who do you think defined these constraints?
Intelligence phase

Problem definition

Evaluation criteria

Constraints GIS

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Recommendation

After Malczewski, 1999 p96
Alternatives

• The alternatives are the possible sites that we could site our wind farms on the basis of our constraints

• In this case, seven potential “strategic areas” for development were identified

• Each of these represents a possible strategic site

• Note the fuzzy boundaries
Possible sites
After Malczewski, 1999 p96
Decision matrix

• To identify specific potential sites within these strategic areas a **decision matrix** could be used.

• It can be used to apply our ranking techniques (from the first half of the lecture).

• The matrix normally contains standardised attributes, with each having some range (say 1-100) where 1 is least suitable and 100 is most suitable...

<table>
<thead>
<tr>
<th>A¹</th>
<th>A²</th>
<th>A³</th>
<th>...</th>
<th>Aᴺ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>v_{A₁}</td>
<td>v_{A₂}</td>
<td>v_{A₃}</td>
<td>...</td>
</tr>
<tr>
<td>Site A</td>
<td>v_{B₁}</td>
<td>v_{B₂}</td>
<td>v_{B₃}</td>
<td>...</td>
</tr>
<tr>
<td>Site B</td>
<td>v_{N₁}</td>
<td>v_{N₂}</td>
<td>v_{N₃}</td>
<td>...</td>
</tr>
</tbody>
</table>
Problem definition

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Recommendation

After Malczewski, 1999 p96
Decision maker’s preferences

• Here we apply **weights** to the **different attributes**
• **Different decision makers** might apply different weights to different evaluation criteria
• For instance, **who** do you think might consider the following **important**:
  - exposure to wind;
  - available area for development;
  - proximity to built-up area;
  - proximity to high voltage power lines;
  - proximity to major roads;
  - prevalence of rare birds;
  - political marginality.
• Note that this is a **feedback process** – decision makers may revise weights having seen initial results…
Intelligence phase

- Problem definition
- Evaluation criteria
- Constraints
- Alternatives

Design phase

- Decision matrix
- Decision makers preferences
- Decision rules
- Sensitivity analysis

Choice phase

- MCE/GIS

Recommendation

After Malczewski, 1999 p96
Decision rules

• The **decision rules** are used to **rank** the possible alternatives

• We saw a number of potential decision rules in the first half of the lecture, including:
  – Weighted linear combination
  – Analytical hierarchy process
  – Ideal point method
  – Concordance techniques

• Remember we also have multiple objectives so are likely to use some MOLA techniques…

• These are only a small subset of possible decision rules – we can also use much more complex or simpler rules…
Problem definition

Evaluation criteria

Decision matrix

Constraints

Alternatives

Decision makers preferences

Decision rules

Sensitivity analysis

Recommendation

Intelligence phase
GIS

Design phase
MCE

Choice phase
MCE/GIS

After Malczewski, 1999 p96
Sensitivity analysis

• Sensitivity analysis shows how much a recommendation changes if we change the inputs

• For instance, what happens if
  – we change an evaluation criteria a small amount?
  – the weightings are changed a small amount?
  – we use a different decision rule?
  – data have spatial or attribute errors?

• A solution is robust if the ranking is relatively insensitive to such changes

• Sensitivity analysis helps us understand how our evaluation criteria are related to the problem
Problem definition

Intelligence phase
GIS

Evaluation criteria

Constraints

Alternatives

Decision matrix

Decision rules

Decision makers preferences

Sensitivity analysis

Recommendation

Design phase
MCE

Choice phase
MCE/GIS

After Malczewski, 1999 p96
Recommendation

• Is based on a ranking of alternatives and sensitivity analysis
• May include the best or a group of possible solutions
• We can use GIS to present visualisations of possible solutions
• We should also provide decision makers with information on how the recommendation was reached…
Some final points

• You should think about **who** you would need to make these decisions

• Clearly, just knowing about GIS is not enough

• We need a knowledge of **wind power** too…

• If we have multiple (or competing) objectives it is likely that we need a **range of experts** and **interest groups** involved in the decision making process

• Through using the framework described here and a suitable environment, decision makers can **explore** and **discuss** possible solutions in a way not possible without GIS and MCE…
Summary

• Examined an example of Spatial Decision Support – looking at the problem of siting wind farms in the UK…

• We have looked at a framework for decision making – identifying **three phases** in the process
  - intelligence
  - design
  - choice

• The process was **non-linear** – you should think back to the alternative uses of spatial analysis presented in the first lecture

• The process involves people and not just tools – this is very important
Next week

• We are going to return to uncertainty
• What happens if we calculate the USLE, and every parameter has uncertainty – how do they combine?
• How can we model the influence of uncertainty in elevation on other parameters (e.g. slope, viewsheds, catchment boundaries)?
• How can we represent the idea that semantics are not sharp (e.g. what is a steep slope?)
References

• [http://wales.gov.uk/topics/planning/planningresearch/publishedresearch/arupresearch/?lang=en](http://wales.gov.uk/topics/planning/planningresearch/publishedresearch/arupresearch/?lang=en) (Lots of information about this case study)