Geog 464 Learning Objective Outline

LOO 10 Multi-criteria Data Analysis Techniques

10.1 What is the reason behind transforming raw criterion data values into standardized criterion scores?
RUGIS Chapter 7 Section 7.1

Many of the equations that underlie operations for multiple criteria evaluation (MCE) are not available in commercial GIS with the exception of weighted summation-based overlay. That operation is available in ArcGIS, IDRISI, and CommonGIS. We provide a description of the operations that are most valuable to incorporating MCE into GIS as is done in several experimental GIS packages. These same equations can be implemented in a scripting language such as Python to extend ArcGIS.

MCE involves data transformations resulting in a summary score, also called a final appraisal score. The idea of computing a final appraisal score is to provide one measure used as the basis for rank-ordering decision alternatives from best to worst.

Today we examine three types of data transformations common to MCE approaches, and their interpretations using sensitivity analysis:
- standardization of data to a common scale,
- transformation of decision maker preferences into numeric weights, and
- aggregation of standardized data with numeric weights into a common measure using a summary score.

Sensitivity analysis deals with exploring potential changes in criteria, weights, and/or options (alternatives) available, and/or errors and interpreting the changes as they influence the final appraisal score.

Data Standardization in MCE
In MCE, the attributes of decision alternatives have known preference order, that is “what is preferred as compared to what”. This order is used for evaluating the alternatives.

preference order:
high data value is better - a high data value is deemed to be better than a medium data value, which in turn is considered still better than the low data value.
Low data value is better - a low data value is deemed to be better than medium, and medium data value is better than high data value.

Attributes with known preference order are called *evaluation criteria* or simply “criteria”.
Criteria can be expressed on various measurement scales. This creates a problem of dealing with the proverbial “apples and oranges measurement scale comparison” when evaluating decision alternatives.

For example, evaluating alternative wastewater building sites on such diverse criteria like soil permeability (a number between 0 and 1), land cover class (alpha code), and distance to the nearest paved road (in feet or meters) can be a challenge when we consider the different ways that criteria can be measured. The transformation of evaluation criteria to a common scale is also called *criterion standardization*.

Standardization approach:
- Maximum is used when higher data values are deemed more preferred; hence we take the reference from the maximum data value.
- Minimum is used when the lower data values are deemed more preferred.

For example:
When maximum is best – number of households served by new wastewater facility is a high number
When minimum is best – total daily load of contaminant added to the river is low number

A *linear equation approach* is used when proportionality is important and when the standardized scores are positive. Proportionality preserves comparability of data values between the raw data range and the standardized range, i.e, double or triple a data value means the same thing in both ranges.

A *non-linear equation* approach is used when some of the raw data values are negative or when the ends of the ranges must be 0 and 1 for interpretability. For each criterion the worst standardized score is always equal to 0, and the best always equals 1. This is also true for negative raw criterion values. Unfortunately, this procedure does not produce standardized data values proportional to raw data.

10.2 What is the significance of decision maker preferences; and what is the major conceptual difference between ranking, rating, and pairwise comparison? *RUGIS* Chapter 7 Section 7.2

The next most important step in MCE approach deals with decision maker (DM) (or stakeholder or decision analyst) preferences in regard to criteria. Criteria might be of differing importance due to policies, established hierarchies, cause-effect relationships and (often) subjective preferences. Preferences are expressions of personal, organizational, and/or societal values. For example, what is more preferred "more jobs or cleaner environment". This "value" is the same idea presented using the "value structure" perspective.

DM's preferences are expressed in terms of weights. *Weight* is a numeric amount assigned to an evaluation criterion indicating its importance relative to other criteria in the decision situation. Weights are usually normalized so that their sum for all criteria considered in a decision situation equals 1; that is all weights sum to 1 (or 100).

How do we select weights?
The larger the difference in a range of normalized data values, the more important the weight. Consider an aquatic habitat restoration problem where the restoration cost ranges from $1 million to $8 million for different restoration sites, and consider the effectiveness of effort for restoring original habitat ranges from 85% to 100%. One deems the cost as the more important criterion than the restoration effectiveness because the range of possible cost improvement from $1 million to $8 million is much greater (i.e., 8 times or 800%) than the range restoration effectiveness from 85% to 100% (i.e., 15%).

Three common procedures for transforming DM preferences into weights are:
1) *ranking*, 2) *rating*, and 3) *pairwise comparison*.

1) Ranking
The ranking approach to deriving criteria weights is the simplest. In practice, however, the number of criteria limits the practicality of using ranking. The larger the number of criteria the more difficult it is to arrive at a reliable ranking. One limit for the number of criteria, derived from psychometrics, is 7+-2. This means that on average, people are capable of discriminating at most 9 importance levels that can be assigned ranks. This limitation can be overcome by using hierarchical ranking schemes. Another limitation of ranking is the lack of its theoretical foundations.

2) Rating
Rating is easy to understand by using the analogy of distributing a fixed amount of points, on the priority basis, across a set of objectives represented by evaluation criteria. For example, let us say you have 100 points to distribute across 10 categories. You have to distribute all the points. You can give 100 points to one category, leaving the other 9 with none. Or, you can give most points to a few categories, or spread it evenly. If you spread it evenly, it is similar to not using a weighting technique at all, because all categories are equally weighted. However, rating, similarly to ranking, lacks theoretical foundations and its practicality is limited to a small number of criteria. The approach may be misused if the DM does not pay attention to the definition of criteria and ranges of criterion values.

A good approach is start with the "least important" criterion, and assign it a weight of 10 points. Then, take the next most important criterion and assign it a weight in relation to the least important – say 15 points. Do this until all 100 points are distributed. If you run out of points then, reweight the least important to 5 points, and adjust all other weights accordingly until you get to 100 points.

3) Pairwise Comparison
Pairwise comparison, in contrast to ranking and rating, has a solid theoretical foundation based on ratio-scale judgments about pairs of criteria. The advantage of this technique is that information can be used from handbooks, regression output, or decision makers/experts can be asked to rank-order individual factors. One can actually compute a doubling of weights, and be able to interpret what it means. The disadvantage of pairwise comparison is a large number of judgments that must be made when the number of criteria. The more the criteria, the increase in judgments is exponential.

10.3 What are advantages and disadvantages of using weighted linear combination and ideal point decision rules for establishing option priorities? *RUGIS* Chapter 7. Section 7.3

A decision rule is a procedure for ordering alternatives from most to least desirable. The use of a decision rule may facilitate:
a) selection of the most desirable alternative,
b) sorting of alternatives into classes arranged into a priority order,
c) ranking of alternatives from best to worst.

In MCE approach the overall appraisal score is the value of a method that aggregates the outcomes of a decision alternative over all evaluation criteria with the DM's preferences. This is why in the MCE context the decision rules are also called aggregation methods is ChoiceExplorer.

Two of the most popular decision rules (i.e., aggregation functions) are *Weighted Linear Combination (WLC)* and *Ideal Point*.

Weighted Linear Combination Decision Rule
The WLC decision rule has been widely used for its simplicity. The assumption for using WLC decision rule is that evaluation criteria are preferentially independent (the importance attached to one criterion is independent from the importance attached to other criteria).

To compute:
Multiply the criterion standardized score by the weight for that criterion for each alternative.
Sum the result for each criterion.
Sum across all criteria.
The result is the final appraisal score for each alternative (option).
The final scores can then be ordered (ranked).

Weighted Summation has been implemented in GIS packages such ArcGIS, IDRISI, SPANS, and CommonGIS, and of course GeoChoicePerspective. The decision rule can be operationalized in any GIS software with overlay capabilities. The WLC was implemented in ArcGIS as the Weighted Overlay tool and it can be found in the Overlay toolset belonging to Spatial Analyst toolbox.

Ideal Point Decision Rule
The ideal point decision rule calculates the final appraisal score for each decision alternative based on the combination of separation from the Ideal Point and separation from the Nadir. The *Ideal Point* represents a hypothetical alternative consisting of the most preferred data values for the evaluation criteria. The *Nadir* represents a hypothetical alternative consisting of the least desirable data values for the evaluation criteria. For example, each facility location is described by a set of criteria data values. Each parcel where a facility could be

located is measured as some distant from the river. The Ideal Point for the river distance criterion would be the location deemed the best in the dataset – did you choose the farthest or closest to the river? The Nadir for the distance criterion would be the one deemed "worst". Thus, the *Ideal Point* (alternative) is a hypothetical alternative composed of all the "best measured criteria data values" in the overall dataset. The Nadir is the hypothetical alternative composed of all the worst "measured criteria data values" across the dataset. The best and worst (that is, all) data values are of course established by the normalized scores of the criteria.

The alternative that is closest to the ideal point and at the same time furthest from the Nadir is the best alternative under this decision rule. The ideal point decision rule is an attractive approach to decision problems in which the independence among the criteria is difficult to test. The Ideal Point decision rule was implemented in GeoChoicePerspectives in the MCE component called ChoiceExplorer, and a group decision process component called ChoicePerspectives. This rule was also implemented in CommonGIS (Andrienko et al., 2003).

10.4 What is sensitivity analysis and how would we use it to clarify option priorities?
RUGIS Chapter 7. Section 7.4
Despite the best efforts to provide a complete set of relevant evaluation criteria, compute accurate criteria values, and elicit true preferences of the decision makers, the data and assumptions of any MCE analysis are subject to change and/or error. *Sensitivity analysis* is the investigation of potential changes in criteria, weights, and/or options available, and/or errors with interpretation of those changes.

Sensitivity of criteria
Evaluation criteria may be dropped or added to change the description of a decision problem, e.g. what if cost was not part of a decision problem for siting the Green County wastewater plant. The simplest form of sensitivity analysis for criteria is to observe the effects of deleting or adding criteria on the ranking of options. One can also use a more systematic approach by deleting one criterion at a time and checking the effect of deletion on the ranking. By repeating this step for each criterion one can identify the "weak" criteria that have little effect on the overall ranking. Such criteria can be potentially eliminated without altering the solution, thereby simplifying the decision problem considerations.

Sensitivity of weights
Priorities, often expressed by numeric weights in MCE techniques, may shift as a result of changing information, political situation, persuasion, or simply decision maker views. One purpose of performing sensitivity analysis is to *check how stable the ranking of options is to changes in criterion weights*. If small changes in criterion weights have no influence on the ranking of options one may have more confidence in the stability of one's ranking. If, on the other hand, small changes in weights change the ranking, one may want to reexamine one's preferences or simply accept the fact that the small change in preferences may shift the order of options. One way to get a quick understanding of the influence of criterion weight on the ranking scores within GeoChoicePerspectives is to use the "perform sensitivity analysis" on the tool pull-down and give a criterion a full weight of "100" (and push others to "0"), and see what happens to the appraisal scores for decision alternatives. A "0" weight essentially removes the criterion from consideration, much like sensitivity for criteria.

Sensitivity of options (alternatives)
One can change the set of decision options and observe changes in option ranking, while adding or deleting an option. Often, two decision options score close to each other. One can then investigate changes needed in a given criterion weight or in criteria scores in order to bring two options to a tie. If the changes are small then this is useful information for making a choice between the top-scoring option and the runner-up option. Such changes can be made in GeoChoicePerspectives through use of the "select options" on the tool pull-down.