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MULTI-CRITERIA DECISION ANALYSIS FOR LOCATION BASED SERVICES

Martin Raubal[1] and Claus Rinner[2]
[1]Institute for Geoinformatics, University of Münster, Robert-Koch-Str. 26-28, 48149 Münster, Germany, raubal@uni-muenster.de, tel: +49-251-8339769, fax: +49-251-8339763
[2]Department of Geography, University of Toronto, 100 Saint George Street, Toronto ON M5S 3G3, Canada, rinner@geog.utoronto.ca, tel: +1-416-9786047, fax: +1-416-9463886

Abstract

Location based services assist people in their decision-making during the performance of tasks in space and time. Current services support simple spatial queries, such as finding the shortest path between two locations or the nearest restaurant from the current location of the user. Three major limitations of present location based services are their insufficiencies in considering individual user preferences, time constraints, and possible subtasks. This paper focuses on the problem of personalization by demonstrating an approach that represents user preferences in a qualitative way and uses them as input for multi-criteria decision analysis. This underlines our key point that location based services should act as personal spatial (and temporal) decision support services for their users. A traveler scenario is used as a case study.

INTRODUCTION

Location based services (LBS) assist people in their decision-making during the performance of tasks in space and time. Location based navigation services support simple spatial queries, such as “shortest route from here to there” and “nearest restaurant from here” where “here” stands for the location of the user. Three major limitations of current LBS were identified, namely their insufficiencies in considering individual user preferences, time constraints, and possible subtasks (Raubal, Miller et al. forthcoming 2004). This paper tackles the first limitation by demonstrating an approach that gathers user preferences in a qualitative way and uses them as input for multi-criteria decision analysis. Such analysis allows for taking several decision-relevant attributes into consideration during the decision-making process. The user can define their relative importance by assigning weights. The weighted attribute values are then combined based on a decision rule, leading to evaluation scores for each decision alternative. In this way, users are supported by the LBS to make a rational decision based on multiple criteria, thus going beyond query-based facility selection (Rinner 2003). For proof of concept, a traveler scenario is implemented and tested with profiles of different user groups.

The next section describes our case study including data acquisition and representation. The section on modeling introduces decision rules in general and the steps of performing multi-criteria decision analysis based on the weighted linear combination rule in particular. This process includes the selection of criteria by the user, qualitative standardization of these criteria, and the definition of weights for the criteria. The next section demonstrates the prototype implementation and presents the results of the case study. The final section draws conclusions and outlines directions for future work.

CASE STUDY

A traveler is in a foreign city and decides to extend her stay. It is late in the evening and she needs to find a hotel. With current LBS it is possible to locate all hotels close to the traveler's position, e.g., those within 500m. But the traveler wants the hotel to best fit her preferences, such as a reasonable price for the room, a private bath, and a late check-out time. All of these criteria are subjective and therefore assigned different importance by different travelers. The following modeling framework demonstrates how this task can be solved by a location based service that integrates user preferences in a qualitative way and uses them as input for multi-criteria decision analysis.

In this case study we use a data set for the city of Münster, Germany. The base map consists of the street network. Hotels were digitized as points according to their location on an analog city map. The hotel feature class consists of the attributes *Name*, *Address*, *Price*, *Private bath*, and *Check-out time*. All values for these attributes except the last one were taken from the City of Münster Hotel Guide (Stadt Münster 2003). *Price* is the average price for a single room and *Private bath* is a Boolean value. Check-out times were gathered by calling hotel receptions. All data management was done in ESRI® ArcMap™.

MODELING

The first part of the task—finding all hotels located close to the traveler—is solved by selecting *hotels within 500m of current location*. This selection uses a decision rule that is *non-compensatory*. Non-compensatory operators do not allow for a tradeoff between good and poor criteria values (Jankowski 1995). In other words, the distance from the current position is a "hard" selection criterion. This type of criterion is typically applied in present LBS.

Solving the second part of the task requires the integration of *compensatory decision rules*, which allow users to control the trade-off between good and poor characteristics of alternative locations. Compensatory rules require standardization of criterion values. Values are then aggregated to a single score per alternative according to the rule. The user typically selects the highest scoring alternative.

GIS-based decision support systems in general allow testing different standardization and aggregation procedures to explore differences in the results. Decision rules that have been implemented in GIS include weighted linear combination, analytic hierarchy process, ideal point, concordance, and ordered weighted averaging methods (Malczewski 1999).

In this paper we will aggregate multiple criteria into a single evaluation score for each decision alternative (hotel) according to the *weighted linear combination (WLC) rule* (also called weighted average or simple additive weighting). We suggest an interactive approach, which lets the user (1) select decision criteria, (2) express her preferred criteria values on a qualitative scale, and (3) define the importance of each criterion.

Selection of decision criteria

In a vector-based GIS context, attributes of geographic features may serve as decision criteria while in a raster-based system, different raster datasets would represent decision criteria (Longley, Goodchild et al. 2001). In a location problem such as the hotel selection, the decision alternatives would typically be modeled as features. Thus we will offer users the selection of attributes of hotel features to base their decision on.

A second concern regarding decision criteria relates to the levels of measurement (Chrisman 1997) that can be handled in a multi-criteria analysis. We will allow users to work with numerical, ordinal, as well as nominal criteria. However, the WLC decision rule requires commensurate, numerical criteria so that all selected criteria have to be transformed to a common, numerical scale as described in the following paragraph.

Standardization of criteria on a qualitative scale

Standardization of criteria is required to allow for trade-off between criteria in the calculation of the final evaluation score. In order to improve the system's usability we work with a simple "Good – Fair – Poor" qualitative scale. According to the rank-order rule, the qualitative values can be transformed to numerical values of 3, 2, and 1, respectively, for further processing. Table 1 shows an example of standardized criteria values for a business traveler.

Table 1: Example of standardized criteria values for a business traveler.

Criterion	Original values	Standardized values
Hotel price	80-120€	Good
	50-80€	Fair
	>120€	Poor
Private bath	Yes	Good
	No	Poor
Check-out time	>10:00	Good
	<10:00	Poor

This approach can be described as a value/utility function (Russell and Norvig 1995) in which the user transforms ranges of attribute values to a single utility score according to her preferences. In our simplified approach, the value/utility function allows for a transformation of attribute intervals (e.g., price ranges) or attribute categories (e.g., no private bath) into utility scores. Another common method of deriving commensurate decision criteria is linear scale transformation, which is limited to numerical attribute data.

Importance weights for criteria

The WLC decision rule allows the user to specify a set of weights representing the relative importance of criteria according to the user's preferences. The weight of a criterion defines its impact on the compensatory aggregation. For example, if price is considered twice as important as having a private bath, then a high price cannot be fully compensated by the benefit of a private bath. By default, criterion weights are set to $1/n$ to represent n equally important criteria. Mathematically, the score of alternative i is calculated as $s_i = \Sigma w_j x_{ij}$, where w_j is the weight of criterion j, and x_{ij} is the standardized attribute value of alternative i for criterion j (Malczewski 1999).

IMPLEMENTATION

A prototype of the personalized LBS was implemented using ESRI® ArcPad™ and the data set for the city of Münster, Germany, described above. The traveler scenario is tested by analyzing various user types—a business traveler, a tourist, and a low-budget tourist—with different preferences and at different locations. In the following we will use the profile of the business traveler (see also Table 1) to demonstrate the implementation. Figure 1 illustrates the filtering of hotels within 500m of the user's position (a) and the selection of criteria (b). Figure 2 shows the standardization of criteria (a) and the definition of relative importance weights (b).

Figure 1 a, b: ArcPad™ desktop emulation showing the filtering of nearby hotels marked in red (a) and the selection of criteria (b) by the user.

This prototype was implemented as an ArcPad "Applet" using the ArcPad Studio development environment. The applet adds a custom toolbar to ArcPad's user interface. The tool represented by a pin icon allows the user to specify her current position on the city street map. In the future, the position should be gathered from a connected GPS receiver although the option of relocating the position marker may still be offered.

As soon as a position is determined, all hotels within a 500m buffer around this position are selected and highlighted. The buffer distance should be made modifiable by the user through an additional user interface widget. Clicking on the hotel choice tool opens a custom form for the remaining user input. Events in the form are handled through VBScript subroutines. The form consists of three tabs ("pages" in ArcPad terminology) corresponding to the three steps identified above.

The "Criteria" tab presents a list of all attributes of the hotel features. The selection of attributes to be used as criteria will move them to the bottom list, which controls further settings on the following tabs.

The "Standardization" tab suggests a way of defining attribute ranges for poor, fair, and good levels for each criterion. The setting requires the user to select the criterion, then iteratively select the three standardization levels, and define the range in terms of minimum and maximum value for each level. The range definition is facilitated by offering the list of all attribute values for the selected hotels.

Figure 2: ArcPad™ desktop emulation showing the standardization of criteria (a) and the definition of relative importance weights (b) by the user.

The "Weights" tab allows the user to specify the relative importance of criteria on a percent range, with weights adding up to a total of 100%. Changing the weight for one criterion using the corresponding slider will proportionally adapt the weights for the other criteria to preserve the total value. Currently, the applet is limited to a maximum of six criteria due to the space limitations for positioning the slider widgets.

Clicking the "OK" button for the custom form triggers a subroutine, which reads all user input from the form and performs the WLC evaluation method. The resulting final scores are stored as a new field in the hotels feature attribute table. This field is used for labeling the hotel markers on the map so that the user can find the best-ranked hotel. In the final map only those hotels within the buffer zone are marked, whose scores fall within the top three overall scores. Figure 3 shows the result of the multi-criteria decision analysis for the business traveler profile: One hotel from the initial selection has the maximum score of 3.00. The scores of the other hotels in the buffer zone amount to 2.48 and 1.74 (not marked because not within the top three overall scores) respectively. These alternatives are therefore less preferable according to this user's preferences. This is due to lower scores for the attributes *Price* and *Private bath*. Note that for the business traveler higher weights were put on the attributes *Private bath* and *Check-out time* (37% each) because the hotel price is paid by her company (if within a predefined range) and therefore not so important for the traveler.

The tests for the tourist and low-budget tourist types yielded plausible results too. The tourist's weights were set equally and the service suggested three reasonably priced hotels (with scores of 2.31 each). The hotel proposed to the business traveler was not considered here because it is too expensive with regard to the tourist's preferences. For the low-budget tourist a high weight (58%) was set for the *Price* criterion with a low-valued preferred price range. As a result, the service suggested a hotel without a private bath but at a low price. This hotel was previously disregarded for both the business traveler and the tourist. The complete test profiles and results can be found at http://ifgi.uni-muenster.de/~raubal/Publications/RefConferences/Raubal&Rinner_TestProfiles.pdf.

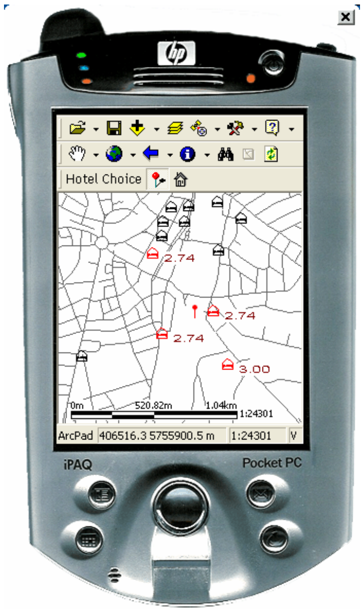

Figure 3: ArcPad™ desktop emulation showing the result of the WLC evaluation method.

In future versions of this tool, an actual ranking of hotels could be derived from evaluation scores, and an appropriate cartographic visualization be chosen for the ranks, e.g., proportional symbol mapping (Slocum 1999). Our initial tests demonstrate the importance of user preferences in location based decision services.

CONCLUSIONS AND FUTURE WORK

This paper makes a case for location based services, which are capable of supporting *personal spatial decision-making* by taking into account individual users' subjective preferences. The suggested approach lets the user choose qualitative utility scores for selected criteria and weight their relative importance. The test case of a hotel finder service demonstrates that different users can be offered specific choices through personalization of LBS.

In the context of location dependency, service development requires personalization of user interfaces, which can highly benefit from the shown approach. For example, standardizations that have been used before (e.g., acceptable hotel price ranges) and the last used criterion weights for each type of location choice (hotel, restaurant) should be stored.

Future work needs to investigate the usability and usefulness of such services by conducting human subject tests addressing both the user interface design and the suggested decision support method. Standardizing criterion values on a qualitative scale might be problematic because it is not fully compatible with a numerical evaluation method. This problem could be addressed by either using numerical standardization (limited to numerical attributes), or using a qualitative aggregation rule.

Another issue concerns the architecture of the proposed service. Our implementation is fully client-based although LBS typically require server access to keep underlying data (e.g., the hotel attributes) up-to-date. We hypothesize however that the decision analysis functionality can be performed on the client as long as the processing is kept as simple as the WLC method used in this applet.

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