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The Spatial Dimensions of Multi-Criteria Evaluation – Case Study of a Home Buyer's Spatial Decision Support System

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Abstract. This paper explores the spatial aspects of GIS-based multi-criteria evaluation. We provide a systematic account of geographically defined decision criteria based on three classes of spatial relations: location, proximity, and direction. We also discuss whether the evaluation score of a decision alternative should be directly influenced by neighbouring scores and outline a methodology for distance-based adjustment of evaluation scores. A home buyer case study is employed to demonstrate how spatial criteria can be included in a spatial decision support system and to investigate the effect of geographically adjusting the evaluation scores of decision alternatives. The case study demonstrates how spatial criteria can be presented to decision-makers and their effects be observed in the decision outcome. Further, the spatial adjustment of evaluation scores using the performance of neighbouring properties smoothes the distribution of scores across the study area and allows decision-makers to consider a location's environment.

Keywords: Multi-Criteria Evaluation, Residential Real-Estate Choice, Spatial Decision Support Systems, Spatial Relations.

1 Introduction

When faced with important decisions, humans try to base their decision-making on a rational framework which often includes multiple decision criteria. For example, buying a home is the most important financial decision in life for many families. Home buyers will take more than just the listing price into account, as they will also consider criteria such as property size, number of bedrooms, appearance of the neighbourhood, and proximity to transportation, schools, and recreational areas. A rational approach to decision-making requires rules for the aggregation of these multiple criteria into an evaluation score for each decision alternative.

Multi-criteria evaluation (MCE) was first introduced to the Geographic Information Systems (GIS) discipline about 15 years ago (Janssen and Rietveld 1990, Carver 1991; Malczewski 1999, Thill 1999). Researchers have used the geographic location of decision alternatives for cartographic presentation of evaluation results. But no systematic account of geographically defined decision criteria has been given nor have MCE methods been suggested that explicitly account for spatial variation in

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the method's parameters or in user preferences. In this paper, we focus on these spatial dimensions of MCE methods. We provide a framework for classifying decision criteria that are created based on spatial relations and suggest methods to include them as spatial criteria in GIS-based decision support. We also suggest including spatial aspects in the multi-criteria decision rules to address the question whether the evaluation score of a decision alternative should be influenced by neighbouring locations.

We will first review the literature on GIS-based MCE with respect to the treatment of spatial aspects in the MCE process (section 2). Classes of geographically defined decision criteria are proposed in section 3. Next, we suggest using post-hoc geographic weighting to modify the calculation of evaluation scores with inverse distance-based weights to adjust the suitability of locations to their neighbours' suitability values (section 4). The use of spatial decision criteria and a geographically adjusted decision rule is illustrated in a site selection case study with a multi-criteria decision support system for home buyers (section 5). The concluding section 6 discusses the results and outlines further research questions and potential applications of the proposed methods.

2 Spatial Aspects in GIS-Based Multi-Criteria Evaluation

Over the last 15 years, a number of multi-criteria evaluation methods have been implemented in GIS including Boolean overlay operations for conjunctive (AND) and disjunctive (OR) screening of feasible alternatives (Eastman 1997), weighted linear combination or simple additive weighting (Janssen and Rietveld 1990, Eastman 1997), ideal point methods (Carver 1991, Jankowski 1995, Pereira and Duckstein 1996), concordance analysis (Carver 1991, Joerin et al. 2001), the analytical hierarchy process (Banai 1993, Eastman 1997), and ordered weighted averaging (Jiang and Eastman 2000). In these studies, MCE methods are employed to combine criterion maps (raster model) or feature attributes (vector model) to create evaluation scores for decision alternatives. The spatial references of the criterion values (raster cells, vector features) allow for cartographic display of evaluation results. More recently, an exploratory approach to MCE has been suggested in which interactive maps are used to analyse decision outcomes using the principles of geographic visualization (Jankowski et al. 2001, Rinner and Malczewski 2002, Malczewski and Rinner 2005). No MCE decision rules that include spatial elements have been presented to date.

Specifically spatial aspects discussed in the multi-criteria decision-making literature include geographically distributed decision-makers and decision alternatives, decision objectives relating to geographic objects, and non-uniform weighting across space (van Herwijnen and Rietveld 1999). These authors explain that spatial elements relate to the nature of

(1) decision alternatives,
(2) objectives, and
(3) criterion weights.

(1) Alternatives refer to a choice between various locations. They can be explicitly spatial, implicitly spatial or non-spatial. A decision alternative is explicitly spatial

when it refers to a choice between different locations, implicitly spatial when it has spatial implications on the surrounding region, and it is non-spatial when it has no spatial dimensions. (2) Spatial objectives refer to situations where the objectives relate to geographic objects. Objectives also can be explicitly spatial, implicitly spatial or non-spatial. An objective is explicitly spatial when it relates to how a particular location scores in the evaluation process, implicitly spatial when the level of achievement for an objective is determined by spatial relations, and it is non-spatial when it has no spatial component. (3) Spatial weighting refers to situations where the spatial units are given non-uniform weighting. Feick and Hall (2004) examine the spatial dimensions of multi-criteria weight sensitivity. They test the effect of subjective weighting by decision-makers on the ranking of decision alternatives by mapping the weight sensitivity in order to detect localized variations of decision outcomes.

Decision criteria involved in a specific MCE problem often reflect some of the spatial properties of the decision alternatives, e.g. the slope of terrain in a suitability analysis, or the proximity to existing service facilities in a needs analysis. Rossini (1998) studied the search behaviour of home buyers in Adelaide, Australia and found that locational attributes played a major role in the purchase decision. Over 80 attributes were considered and in addition to price and view as common considerations for most buyers, locational attributes were the number one reason for a purchase. Not only did buyers want a house in a location with particular attributes, such as a beach or hill area, but they also wanted houses that were within a specific distance from their friends or family, city, work and various types of facilities. Zeng and Zhou (2001) develop a real-estate geographic information system (REGIS) to emphasize the significance of spatial factors in residential real-estate decision-making. Their evaluation criteria include attributes relating to the physical environment (slope and aspect, parks and natural reserves, rivers and beaches), amenity and transport (shops and shopping centres, schools and railway stations), pollution and noise (main road pollution and noise, railway noise, aeroplane noise), repayment time (loan, income and transport cost) and potential value increase (price trend). Milla et al. (2005) discuss the role of physical and environmental attributes in a hedonic price model of residential property values. Environmental attributes are defined by the proximity of each location to industrial, educational, and recreational facilities.

Malczewski (1999) proposes a framework for activities in multi-criteria analysis procedures, which includes: defining the decision problem, establishing evaluation criteria and constraints, determining decision alternatives and a decision matrix, applying a decision rule, performing sensitivity analysis, and making a recommendation. Table 1 identifies the spatial aspects of multi-criteria problems that can be differentiated along the activities of the MCE framework. As mentioned before, evaluation criteria and constraints are usually defined spatially in a way that depends on the geographic model. Certain criteria such as “distance to town centre” are explicitly spatial and are usually created using GIS functionality. This paper aims at classifying spatial decision criteria based on spatial relations used to create them. MCE decision rules such as weighted linear combination (or, simple additive weighting) are limited to algebraic combination of numeric attribute values. No MCE methods have been developed that would include explicit spatial processing. In this paper, we also suggest one such method and discuss its possible uses.

Table 1. Spatial aspects of multi-criteria problems that can be differentiated along the activities of the MCE framework; *italic font* indicates aspects that are addressed in this paper

Activity in MCE framework	Spatial aspect in this activity
Evaluation criteria, constraints	Defined as criterion maps (raster model) or feature attributes (vector model) *Use of spatial relations to create decision criteria*
Decision alternatives	Defined as geographic features or cells
Decision matrix	Map-based exploration and spatial analysis of criterion performance
Decision rule	*Inclusion of spatial aspects in the calculation of multi-criteria decision rules*
Sensitivity analysis	Explore spatial patterns of sensitivity
Recommendation	Mapping of evaluation scores or ranks resulting from numerical calculations

3 Decision Criteria Based on Spatial Relations

The spatial relations between geographic objects are key elements of cartographic display and spatial analysis using GIS. Despite their importance, authors have been slow to develop a comprehensive theory of spatial relations, posing major problems for formal geographic modeling (Egenhofer and Mark 1995) and the construction of intelligent GIS (Egenhofer and Franzosa 1991, Robinson 2000). Creating definitions of spatial relations that satisfy real-world examples is difficult due to the many mathematical, cognitive, linguistic and psychological considerations. However, according to Egenhofer and Franzosa (1991) spatial relations can be grouped into three different categories: “topological relations which are invariant under topological transformations of the reference objects, metric relations in terms of distances and directions, and relations concerning the partial and total order of spatial objects as described by propositions such as *in front of, behind, above* and *below*”. Egenhofer and Mark (1995) discuss topology, distance, and direction as elements of their “naïve geography”.

We distinguish three classes of spatial relations applicable to multi-criteria decision-making: the *location* of decision alternatives (derived from topological relations), their *proximity* to desirable or undesirable facilities, and the *direction* relation between certain undesirable facilities and the decision alternatives. The following subsections explain these classes in more detail and explain how spatial relationships in each case can be transformed into standardized, numerical criterion values in order to apply regular MCE methods to them. Examples refer to the residential real-estate case study that follows.

3.1 Location as an Evaluation Criterion

Location refers to topological relations such as “is contained in”. For example, decision alternatives such as houses for sale are conceptualized as points; point-in-polygon analysis would be used to determine the location of an alternative within a

Table 2. Summary of types of explicitly spatial evaluation criteria and types of geographic target objects, by which they are defined

	Relation to, and type of, target object	Example of target object
Location	Located in desirable area	Desirable school district
	Not located in an "avoid" area	Undesirable city neighbourhood
	Located along desirable line feature	River shoreline
Proximity	Located close to desirable public area	Park
	Located close to desirable public point	School
	Located away from undesirable area/point	Industrial area/facility
	Located close to desirable individual (user-specified) location	Place of work, friend's residence
Direction	Not located in an undesirable direction from a point/area	Direction of starting airplanes from an airport

desired or undesired city neighbourhood or school district. Location can be transformed into a Boolean value when standardizing evaluation criteria. A value of "true" represents locations within a desired, or outside an undesired, area, while "false" represents locations outside a desired, or inside an undesired, area.

3.2 Proximity as an Evaluation Criterion

Proximity to desirable facilities, e.g. parks for a home buyer, represents a benefit criterion, while proximity to undesirable facilities, e.g. industrial sites, represents a cost criterion. Proximity values have to be standardized through a common standardization function such as linear scale transformation, which stretches proximity values from 0 to 1. For a benefit criterion, 0 represents the furthest distance in the dataset, while 1 represents the shortest distance. Non-linear transformations are not discussed here, but can provide a useful alternative.

Proximity of decision alternatives to certain other locations can be further subdivided depending on the nature of the other locations. If proximity to a certain type of (public) locations, such as parks or industrial facilities, is considered, the proximity value will be measured as the distance to the closest such facility in the study area. If proximity to specific (individual) locations, such as the place of work or residence of friends, is considered, proximity will be measured as the distance to this specific location.

3.3 Direction as an Evaluation Criterion

Direction between two locations can play a role in decision-making when one location affects another location and this effect depends on direction. For example, houses near an airport may be affected differently by air traffic noise depending on typical start and landing directions. Houses near a slaughter house can be affected by odours depending on the predominant wind direction. Assuming direction as a cost criterion, it can be standardized by giving binary values of 0 to locations within a sector representing the cardinal direction from the origin, and values of 1 to all other locations.

The examples given in Table 2 show that many spatially explicit evaluation criteria can be modeled in different ways. For example, a home buyer could avoid a crime-ridden city neighbourhood by locating outside its boundaries, or by selecting locations with the greatest distance from that neighbourhood.

4 Post-Hoc Spatial Adjustment of Multi-Criteria Evaluation Scores

In this section we further investigate options for the inclusion of spatial dimensions in multi-criteria decision-making by suggesting the adjustment of evaluation scores with a spatially explicit factor. The fundamental observation that suggests adjusting evaluation scores in this way is the influence of nearby alternatives on the assessment of a decision alternative under consideration. In residential real-estate choice, the "potential" of a neighbourhood plays a role in decision-making but is difficult to quantify. However, differences in the aggregate evaluation of houses may indicate whether this potential for future improvement of the neighbourhood is present or not. In the case study described in the following section, the evaluation score for a house is adjusted using the inverse distance-weighted difference between its evaluation score and the scores of the neighbouring houses.

To achieve the distance-weighted adjustment of evaluation scores, we assume that decision alternatives A_i, $1 <= i <= m$ are characterized by decision criteria c_j, $1 <= j <= n$ through criterion values a_{ij}. Those values have been standardized using score-range transformation for benefit criteria resulting in $x_{ij} = (a_{ij} - a_{min,j}) / (a_{max,j} - a_{min,j})$, or for cost criteria resulting in $x_{ij} = (a_{max,j} - a_{ij}) / (a_{max,j} - a_{min,j})$. Criterion importance weights w_j are applied to the standardized values and aggregated resulting in evaluation scores $s_i = \sum_j w_j * x_{ij}$ for each alternative.

Rinner (2004) proposes a distance-based adjustment after completion of this regular MCE process. The evaluation scores are adjusted by distance-based weights of the form $v_{ik} = (1/1+d_{ik})^D$, $1 <= i,k <= m$. The distance weights v_{ik} range from 1 for i=k (the decision alternative itself) and other alternatives nearby, to close to 0 for alternatives that are located furthest away. When two alternatives i, k, are located close together, the weight represents relatively large mutual influence. If two alternatives are located far away from each other, the distance-based weight gets small, thus reducing the mutual influence. D is an exponential factor used to determine the type of decrease of influence with increasing distance, e.g. D = 2 for quadratic decrease. The geographically adjusted final evaluation scores are calculated by applying standardized distance weights to the original evaluation scores, resulting in $s_i' = (\sum_k v_{ik} * s_k) / (\sum_k v_{ik})$.

This method works in a similar way as spatial smoothing (Anselin 1992, Rushton 2003). However, it differs from smoothing in that it takes into account the score of the location at hand. A theoretical justification for modifying evaluation scores can be derived from Slocum et al. (2005, p. 90) who motivate cartographic pattern simplification with the random nature of measured attribute values.

5 Case Study: Residential Real-Estate Choice in Toronto

A residential real-estate case study has been employed to explore the use of spatial relations in decision criteria and demonstrate a method to geographically adjust the evaluation scores for decision alternatives. We created a home buyer's spatial decision support system (SDSS) using ArcGIS 9.0 and Visual Basic for Applications. A sample dataset from the Municipal Property Assessment Corporation contained attributes for 500 houses located in the west end of the City of Toronto, Ontario. For the purpose of this study, we assumed that the last sales price for each house could be substituted for the asking price.

The home buyer's SDSS provides the user with a toolbar to toggle various display layers and start the decision support wizard. The user can select from a list of twelve non-spatial decision criteria and a list of eleven spatial decision criteria.

Table 3. Non-spatial criteria provided in the home buyer's SDSS

Variable	Description	Unit
Asking Price	The selling price of the house	CAN $
Lot Size	The effective lot size of the house property	Square feet
Year Built	The construction year for the house	Year
Size of Living Space	The total area of the living space in the house	Square feet
Bathrooms	The total number of bathrooms in the house	Number
Bedrooms	Number of bedrooms in the house	Number
Basement Characteristics	The total area of the basement or the total area of the basement that is finished. The user can select a finished basement if it is preferred.	Square feet
Heating Type	The heating type for the house (electric, forced air, variety/gas radiator, hot water and other (e.g. – woodstove))	Nominal (EL, FA, GR, HW and OT)
Parking Space	The number of parking spaces for the house	Number
Air Conditioning	Whether or not the house has air conditioning	Boolean (Y or N)
Pool	Whether or not the house has a pool	Boolean (Y or N)
Fireplace	Whether or not the house has a fireplace	Boolean (Y or N)

The non-spatial criteria describe the physical characteristics of each of the houses (Table 3). They include attributes commonly found in most residential real-estate sales listings (e.g. Multiple Listing Service 2006; HomeLife Real Estate Services 2006). Although some of these criteria , such as lot size and size of living space, refer to geometric house characteristics, they can be considered as non-spatial criteria when houses are conceptualized as points. These attributes have been extracted from the original dataset and are included in the attribute table of the geo-coded house locations.

Spatial criteria include examples for the three types of spatial relations identified before: location, proximity, and direction (Table 4). They describe the neighbourhood environment of properties under consideration. The spatial criteria were generated with ArcGIS 9.0 tools and ancillary geospatial layers from DMTI Spatial Inc. and

Statistics Canada. GIS analysis and modeling tools provide the potential to generate many other spatial criteria.

Table 4. Spatial criteria provided in the home buyer's SDSS

Type of Spatial Relation	**Criterion**	**Description**	**Unit**
Location	Neighbourhood	Houses located in specific neighbourhoods.	Boolean
	Waterfront	Houses within a waterfront zone.	Boolean
Proximity	Distance to Public Transit	The straight line distance from a house to the nearest Toronto Transit Commission subway stop.	Metres
	Distance to Highway Exits	The straight line distance from a house to the nearest highway exit.	Metres
	Distance to Schools	The straight line distance from a house to the nearest school.	Metres
	Distance to Hospitals	The straight line distance between a house and the nearest hospital.	Metres
	Distance to Golf Courses	The straight line distance between a house and the nearest golf course.	Metres
	Distance to Parks	The straight line distance between a house and the nearest park.	Metres
	Distance to Downtown	The straight line distance between a house and the boundary of downtown Toronto.	Metres
	Distance from Industrial	The straight line distance between a house and the nearest industrial site.	Metres
Direction	Direction from Airport	Hypothetical flight paths of planes taking off from Pearson Intl. Airport.	Boolean

Two types of location criteria are included in the home buyer's SDSS: neighbourhoods and waterfront zone. Houses in the database are coded with an identifier that corresponds with the neighbourhood in which they are located. A waterfront zone has been defined using a buffer 750 metres from the shore of Lake Ontario. The buffer distance was arbitrarily selected so that an appropriate portion of the houses would be designated as waterfront locations for illustration purposes. A Boolean indicator is used to show which houses are on the waterfront. (The waterfront criterion could also be measured as a proximity criterion and houses could be evaluated based on their actual distance from the shore instead of whether or not they fall within a pre-defined waterfront zone.)

Eight proximity relations are used to provide examples of geographic features a home buyer might wish to be close to or far away from. For each proximity relation, the straight-line distance in metres is measured from a house to the nearest geographic object of a specific type. Distance is measured beforehand and recorded in a column in the property shapefile table to be accessed during run-time.

Two hypothetical flight paths were generated as examples of a direction relation, the third type of spatial criteria included in the home buyer's SDSS. The paths start from a point location representing Toronto's Pearson International Airport and cover

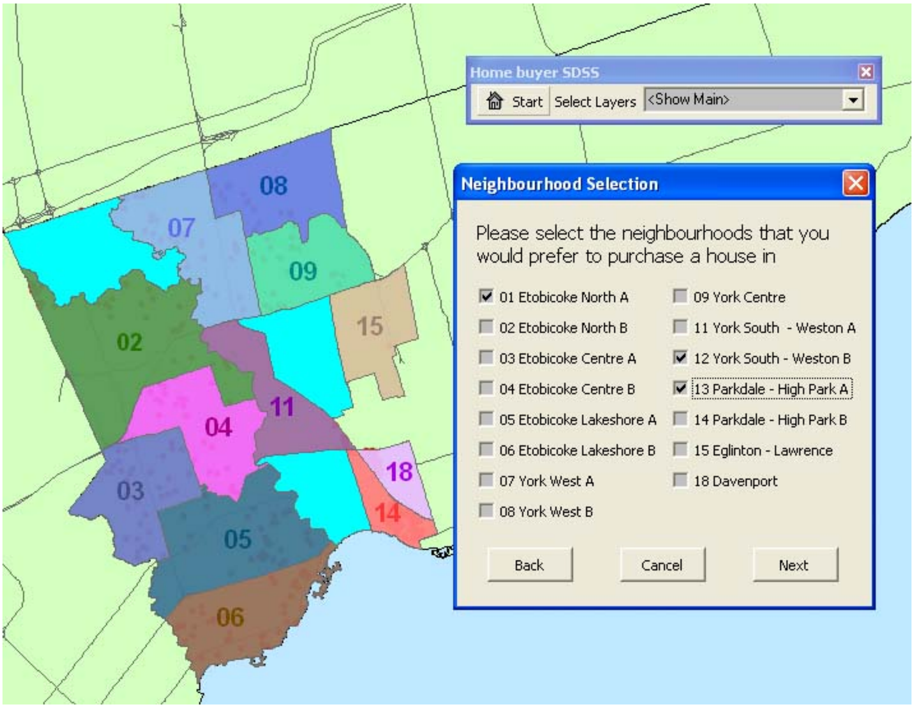

Fig. 1. Neighbourhood criterion selection in the residential real-estate case study

sectors to the northeast and southeast of the airport. Houses lying within each flight path polygon were coded with a Boolean indicator in the property shapefile table.

After the user has finished the selection of non-spatial and spatial criteria, a window opens for each of the spatial criteria. For the neighbourhood criterion, the user can indicate preferred neighbourhoods. They can do this by checking boxes that correspond with each of the neighbourhoods and their selections are displayed on the map (Figure 1). The SDSS then checks the property shapefile table to determine which houses are in the selected neighbourhoods. Houses that are in preferred neighbourhood locations receive a standardized value of 1 for this criterion, while those that are not, receive a value of 0. It is important to note that this criterion does not act as a constraint (or filter) but that it is just one factor in the overall evaluation procedure. If a waterfront location is selected as a criterion, the home buyer's SDSS displays the waterfront zone and highlights waterfront houses on the map (Figure 2). The Boolean values in the property shapefile table are accessed by the SDSS. Each house located within the waterfront boundary receives a standardized value of 1 while those that are not receive a 0.

For each selected proximity criterion, a window is provided for the user to designate whether they would like to maximize or minimize the distance between candidate houses and the target objects corresponding to the criterion. Once the user has indicated the type of criterion (benefit or cost criterion), the pre-calculated distance values are accessed from the property shapefile and the appropriate score range procedure is applied to standardize the values.

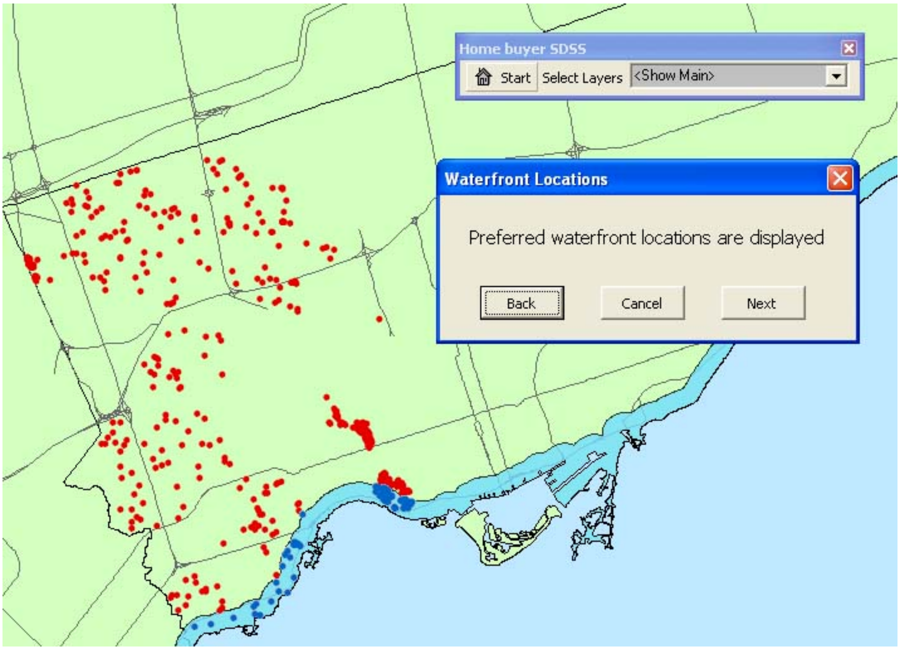

Fig. 2. Waterfront as a location criterion

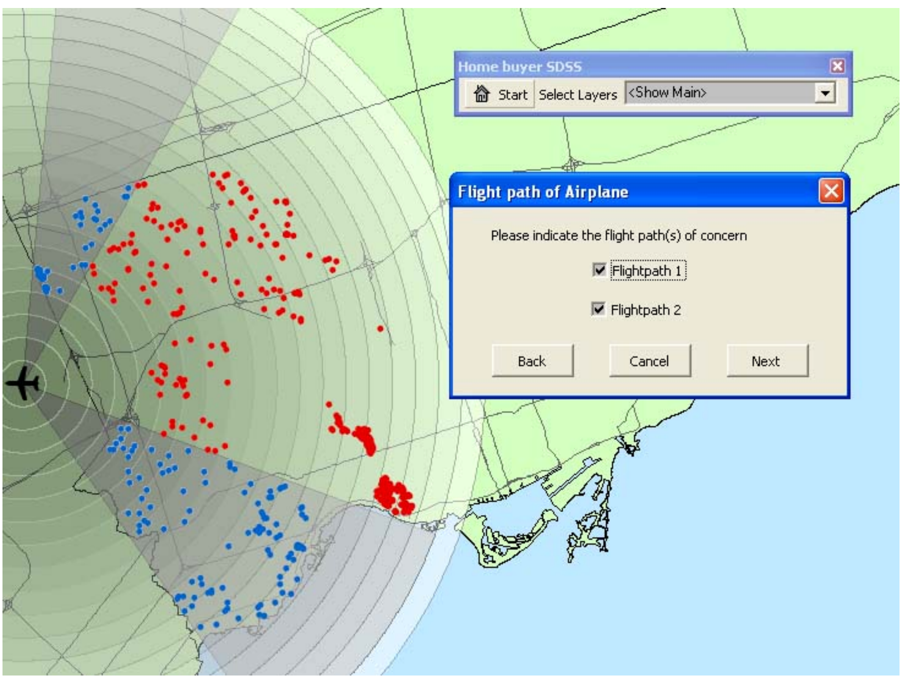

Fig. 3. Example of a direction criterion

If the direction relation is included as a criterion, the hypothetical flight paths are displayed on the map and houses located within these sectors are highlighted (Figure 3). In the home buyer's SDSS the user can decide whether both flight paths are used or just one. For standardization, houses receive a 0 if they lie within a flight path and a 1 if they do not. This is modelled as a cost criterion because houses located within a flight path would be considered less attractive to buyers due to air plane noise.

After criterion selection and parameter settings, the user assigns preference weights to the criteria using sliders. The sliders are initialized to equal weights and a sum of 100. Sliders are dynamically linked so that a change in the value of one will automatically adjust the value of the others to keep their sum constant. Once the weighting is established, the home buyer can choose to calculate a standard evaluation score using the simple additive weighting (SAW) method, or the spatially adjusted method proposed in Section 4. When calculating the geographically adjusted evaluation score, the home buyer's SDSS accesses a table with pre-calculated distance weights. The table contains the straight-line distance in metres measured between each house and all other houses. First the SAW evaluation score is calculated for each house and then the method for spatial adjustment is applied.

The results for the highest scoring houses under the chosen evaluation method are provided in a display window (Figure 4). The house identifier, evaluation score, neighbourhood, and street address are listed in the upper list box. Figure 4 does not show the addresses from the sample dataset for privacy reasons. The user can select a house and it will be highlighted on the map with a blue house symbol, while a detailed description of its attributes will appear in the textbox below the list. The user also has the option of selecting the 'Highlight All Houses' button, which will display the top ten houses on the map.

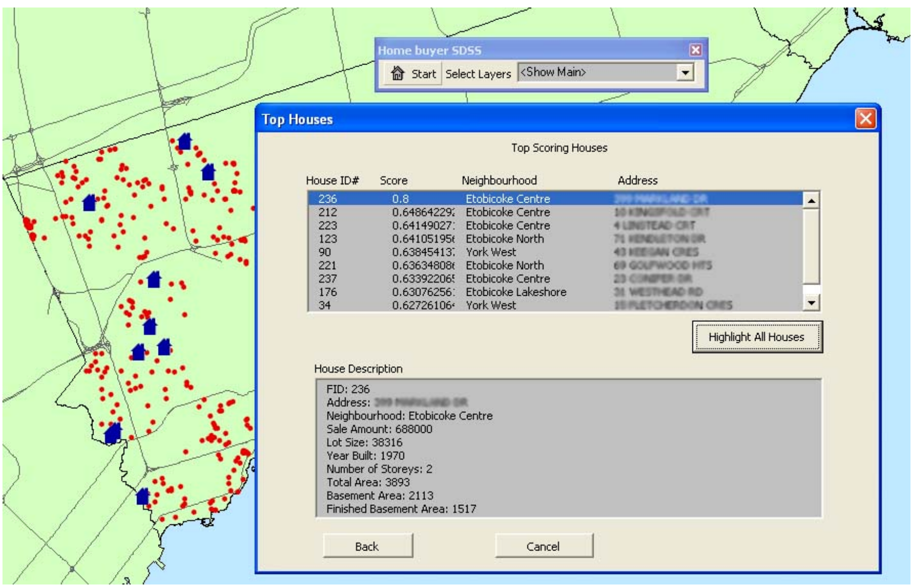

Fig. 4. Display of results in the home buyer's SDSS

The following three scenarios investigate the effectiveness of the implemented MCE methods and explore the influence of spatial relations and geographically weighted adjustment on decision outcomes. The first scenario uses only non-spatial criteria (Table 3) to calculate evaluation scores for each house. The second scenario uses non-spatial and spatial criteria (Tables 3, 4) to generate evaluation scores. It uses the same non-spatial criteria as the first scenario and keeps the weighting proportional to focus on the role spatial relations play in the ranking of decision alternatives through the addition of the spatial criteria. Finally, the third scenario uses spatial adjustment of the evaluation scores from scenarios 1 and 2.

Table 5. Criteria and weights for user scenarios

Criteria	Scenario 1 (non-spatial)	Scenario 2 (mixed)	Scenario 3 (mixed with spatial adjustment)
Asking price	14%	7%	7%
Size of living space	20%	10%	10%
No. of bedrooms	20%	10%	10%
No. of bathrooms	16%	8%	8%
Parking spaces	16%	8%	8%
Air conditioning	14%	7%	7%
Neighbourhood	-	18%	18%
Distance to parks	-	16%	16%
Direction of airport	-	16%	16%

In Scenario 1, houses are assessed by how well they satisfy the hypothetical buyer's non-spatial criteria selection and preference weighting. Houses that rank within the top ten have a low asking price and a high number of bedrooms, bathrooms and parking spaces, as well as air conditioning. The attributes of the houses are the only matter of concern and the home buyer's SDSS determines the best candidates in the study area.

The addition of spatial criteria in Scenario 2 eliminates many of the houses that performed well in the first scenario. This is because their location is not a good one according to the user input. Houses that perform well in Scenario 1 and poorly in Scenario 2 do so because: they are not located in a selected neighbourhood, lie under the flight path of airplanes, are not close to a park, or any combination thereof. Spatial criteria thus add a different layer of suitability measures that go beyond the physical characteristics of individual houses. Through standardization of all criteria, the SDSS balances between satisfying the non-spatial and spatial criteria. Several of the houses that scored well in Scenario 1 reappear in this scenario showing that the user preferences on non-spatial criteria are still being accounted for.

Geographically adjusting the evaluation scores in Scenario 3 affects the ranking of decision alternatives as well. The score for the highest ranking house drops when distance weighting is applied and the range between the scores decreases. This is a result of a spatial smoothing effect as the total variation between scores becomes smaller. Further, the relative ranking of the top ten houses shows significant change, with the ranking of some high scoring houses from Scenario 1 and 2 being altered in Scenario 3. Houses that experience an increase in their ranking do so because they are within close proximity to neighbours that also satisfy user criteria and preference weighting well. Conversely, houses that fare poorly after their scores are geographically adjusted suffer from the influence of neighbouring houses that did not score well in the evaluation procedure for Scenario 2. In areas with a high density of houses the effect is often cumulative, with the change in one house being the result of all of the neighbours. In low density areas, the geographically weighted score for a house can be affected by only a few houses that have a strong influence due to close proximity, significant difference in score from the house in question, or both. The results demonstrate that geographic adjustment can be effectively used within MCE.

6 Conclusions and Outlook

In this paper, we study the influence of spatial factors at two stages in MCE: geographically explicit decision criteria and geographically adjusted evaluation scores. Building on previous work that used spatial decision criteria, we propose a classification of criteria based on the spatial relations they represent. In a case study, we give examples for all three classes based on location, proximity, and direction relations. Further, we suggest exploring spatial aspects of multi-criteria decision rules. As an example, we propose to adjust final evaluation scores based on neighbouring scores. A distance-based weighting of neighbouring scores was introduced and implemented in the case study of a home buyer's SDSS. Through this proof-of-concept we could demonstrate how spatial criteria can be presented to decision-makers and their effects be observed in the decision outcome. Further, the spatial adjustment of evaluation scores using those of neighbouring properties smoothes the distribution of scores across the study area and allows decision-makers to consider the performance of adjacent properties.

With the increasing popularity of map-based decision support tools explicit handling of spatial aspects of decision problems will likely become of larger interest to the Geographic Information Science community and to GIS and SDSS developers. With respect to spatially explicit decision criteria, more variants of the suggested classes could be explored. For example, decision-makers may want to avoid adjacency to desired facilities in keeping a minimum distance to schools or mall parking lots. Visibility should also be included in the criterion generating process as an additional spatial relation. In terms of distance-weighted adjustment, more research is needed into the interaction with possible spatial association among criterion values. Both proposed methods would benefit from taking into account non-linear scaling of distance-based criteria and adjustment factors. For many criteria, distance should be measured in street distance or travel time rather than straight-line distance. For spatial adjustment, distance could be replaced by another neighbourhood concept and the consequences be studied.

With reference to the case study implementation, the SDSS should be made flexible enough to take any map layer as a criterion. Further, we did not yet include individually defined reference locations for proximity criteria (e.g. work location, friend's residence) which are different for each decision-maker. These are likely to be among the most useful features of a home buyer's SDSS. In order to confirm this hypothesis and examine the utility of the spatially explicit decision support system, we plan to conduct expert interviews with real-estate agents and focus groups with actual home buyers.

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