Research Article

Spatial group choice: a SDSS tool for collaborative spatial decision-making

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Abstract. Current trends in modern organizations towards flatter structures and the involvement of many stakeholder groups in solving spatial decision problems have created a need for information technology capable of supporting collaborative spatial decision-making. Such information technology has developed in recent years for the computerized support of group decision-making aimed at solving business problems, e.g., market strategies, corporate planning, product development, and others. Similar information technology to support group decision-making aimed at solving spatial decision problems, e.g., site selection, choice of environmental and economic strategies, and urban/regional development, are now beginning to appear in the research literature. GIS, often designed for spatial decision support, have lacked a capability to collate interests and interactions to support collaborative spatial decision-making. As a step towards addressing this void, we present a spatial decision support system for groups (SDSS-G) called Spatial Group Choice. A spatial problem focusing on prioritizing habitat site development is used as a backdrop to present the design and development issues. We discuss the technical and social-oriented design guidelines adopted for the development of Spatial Group Choice using a framework that characterizes meetings in terms of spatial-temporal dimensionality. We then describe the design and implementation of Spatial Group Choice, including a ‘tour’ of the software, using a habitat restoration decision problem. We conclude with issues unresolved and prospects for future development.

1. Introduction

Current trends in modern organizations towards flatter structures and the involvement of many stakeholder groups in solving decision problems have created a need for information technology capable of supporting collaborative decision-making. Such information technology has developed in recent years for the computerized support of group decision-making aimed at solving business problems, e.g., market strategies, corporate planning, product development, and others. Group decision support solutions are now part of the commercial product offerings developed on the premise that workgroups will dominate the emerging organizational structures of the near future (Orsborne et al. 1990, Coleman and Khanna, 1995).

Similar information technology to support group decision-making aimed at solving spatial decision problems, e.g., land use/resource development negotiations, site selection, choice of environmental and economic strategies, and urban/regional
development, is now being discussed in geography and planning literature (Armstrong 1993, Faber et al. 1995, Nyerges 1995, Shiffer 1992, 1995, NCGIA 1995). This surge of interest in collaborative spatial decision-making (CSDM) has been spurred not only by the trend in business organizations but foremost by the realization that effective solutions to spatial problems require collaboration and consensus building. Many spatial problems are labelled as ‘wicked’ or difficult (Rittel and Webber 1973) because they contain intangibles that cannot be easily quantified and modelled, their structure is only partially known or burdened by uncertainties, and potential solutions often become NIMBY (Not In My Back Yard) controversies (Couclelis and Monmonier 1995). These problems require the participation and collaboration of people representing diverse areas of competence, political agendas, and social interests. As a consequence, solutions to pervasive spatial problems often must be generated by diverse groups (Golay and Nyerges 1995).

People participate in ‘groupwork’, hence decision-making, in at least three different ways—collaborative, coordinated and cooperative. ‘Collaborative’ or its noun counterpart ‘collaboration’ in the phrase CSDM, is taken to mean a committed effort on the part of two or more people to devise a new understanding or solution for a spatial decision task. A collaborative effort is one whereby the participants in a group agree to work on the same task (or subtask), and can be differentiated from cooperative and coordinated efforts (Roschelle and Teasley 1995). A cooperative effort is one where participants agree to work on different tasks and share results, and a coordinated effort is one whereby participants agree to sequence the results of their cooperative effort. The distinguishing issue is whether participants are working together on the same task (problem). It should be understood that coordinated efforts are indeed cooperative, and collaborative efforts, are indeed coordinated. By working in a collaborative fashion, the participants create synergy, and each comes away with a synergistic sense of how to undertake decision-making.

The need for computerized decision support results from the importance of group decision-making and problem solving carried out predominantly during meetings, and from common problems associated with a meeting such as: overemphasis on social-emotional rather than task activities, failure to adequately define a problem before rushing to judgment, pressure constricting creativity felt by subordinates in the presence of bosses, and the feeling of disconnection/alienation from the meeting (Nunamaker et al. 1993). A number of other problems hampering the effectiveness of meetings is given by Mosvick and Nelson (1987) and include (after Lewis 1994): getting off the subject, too lengthy, inconclusive, disorganized, no goals or agenda, individuals dominate discussion, not effective for making decisions, rambling, redundant, or digressive discussion. Despite these negative effects, the attractiveness of a group approach to decision-making comes in general from the fact that individual contributions are increased by a synergistic effect resulting from meeting dynamics. Sage (1991) identifies several human decision-making abilities that information technology might augment in meetings, such as (1) help decision-makers formulate, frame, or assess decision situations by identifying the salient features of the environment, recognizing needs, identifying appropriate objectives by which to measure the successful resolution of an issue; (2) provide support in enhancing the abilities of decision-makers to obtain and analyse possible impacts of alternative courses of action, and (3) enhance the ability of decision-makers to interpret impacts in terms of objectives, leading to an evaluation of alternatives and selection of a preferred alternative option. Consequently, a final outcome of a computer-supported decision
meeting can be more than a simple sum of individual contributions. The attractiveness of a computer-supported group approach to spatial decision-making comes from a possibility of engaging diverse participants as competent stakeholders through computer-mediated communication, problem exploration, and negotiation support.

Geographical information systems (GIS), often designed and extended as spatial decision support systems (SDSS) (Densham 1991), have lacked a capability to collate interests and interactions to support collaborative spatial decision-making (CSDM), e.g., in the context of face-to-face meetings. Existing GIS and SDSS do not have tools to support interactions among group members such as shared graphics, group modelling, and group consensus building tools. As a step toward addressing this void, we present a SDSS for groups (SDSS-G) called Spatial Group Choice. The basic intent of Spatial Group Choice is to help the group members: (1) explore and understand the problem, (2) articulate and share decision criteria and criteria preferences, (3) evaluate the solution alternatives, and (4) negotiate the consensus solution. These group decision support functions operationalize the concept of Principled Negotiations (Raiffa 1982) stressing the importance of negotiations focused on objective interests rather than on particular positions such as being for or against a particular alternative.

In order to set the context for the presentation of Spatial Group Choice we discuss in § 2 a spatial choice task involving habitat restoration site selection as a collaborative spatial decision-making problem. We present the system design considerations in § 3 and the implementation of Spatial Choice in § 4. System capabilities are presented in § 5 using the restoration choice problem. We conclude with unresolved issues and prospects for future development.

2. The need for group-based site selection in restoration planning as an example of CSDM

Although the practice of restoration planning and decision-making is still in its infancy, the application of concepts and methods from restoration ecology is in high demand due to nationwide environmental degradation (Cairns 1993). In the United States, much of the practice has been spurred on by one or more of the twenty-three federal laws and mandates which call for restoration of various environments—most of these laws and mandates passed in the last ten years (see Berger 1991 for a review). One of the fundamental issues in restoration ecology is selecting the best sites to develop among many, since human and capital resources are commonly in short supply.

Although locational conflict pervades the habitat site selection process, and debate continues as to a best approach, experience with generic measures for locational selection criteria have been developing with some success. Westman (1991) in general, and Shreffler and Thom (1993) for north-west estuaries, describe some of the more fundamental criteria of concern in most restoration projects, including: size of the site, borders of the site to surrounding habitat, habitat mosaic, edge-to-ratio permeability of species movement (can species move through), distance to the nearest dispersal source of a problem, and mix of neighboring habitat types. Although most of the practice in restoration has been with revegetation of land-based projects (e.g., Moreno and Heyerdahl 1992), there is a growing concern to deal with habitat restoration in estuarine environments, mostly due to Federal Superfund cleanups and other state and local toxic cleanup efforts (Shreffler and Thom 1993).
2.1. A task analysis of a habitat site selection process in the Duwamish Waterway area

The Duwamish River and its engineered section called the Duwamish Waterway is a tributary which connects the Green River to Elliott Bay in the Puget Sound Region of Washington State. The Duwamish Waterway area has been changed dramatically by urban and industrial development over the last 150 years, and particularly since the early 1900s. In conjunction with the enormous regional growth in Puget Sound during this time, the Duwamish Waterway area has become a centre for industrial and manufacturing operations which have played, and continue to play, a vital role in the regional economy. However, this economic development has come with an environmental cost to the Bay and the estuarine environments. In addition to water and sediment pollution from anthropogenic sources associated with development along the river and around the region, the habitats for fish (e.g., salmon), other aquatic life, birds, and mammals have been significantly degraded or destroyed over the years. For example, some habitat modification activities have taken the form of river channeling/straightening, dredging and filling, construction of urban infrastructure, and shoreline and stream stabilization.

In March 1990, the National Oceanic and Atmospheric Administration (NOAA), acting as a natural resource trustee under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), filed a lawsuit (United States of America versus City of Seattle and Municipality of Metropolitan Seattle). To avoid a costly and time-consuming legal process, the parties worked out a settlement agreement which included a combined (City of Seattle and the King County Department of Metropolitan Services) maximum funding of $24 million for environmental clean-up and restoration/development of which sediment remediation is estimated at $12 million, habitat development is estimated at $10 million, and pollution source-control projects are estimated at $2 million between 1992 and 1997. Thus, the Elliott Bay/Duwamish Restoration Program was created (King County Department of Metropolitan Services 1994). The habitat component of this project includes the selection of a few suitable sites along the Duwamish Waterway for funding of habitat development activities.

The programme is an interesting real world CSDM setting from which to model a research effort because a number of different parties with various positions and interests are involved. In addition to NOAA, the City of Seattle, and King County Department of Metropolitan Services, the consent decree has also provided the ability to direct the programme to the U.S. Fish and Wildlife Service, the Washington State Department of Ecology, the Muckleshoot Indian Tribe, and the Suquamish Tribe. This intergovernmental ‘Panel of Managers’ called the NOAA Restoration Panel must work with other interested governments and agencies, technical specialists, and the private sector, and the public, to ensure that the programme goals are achieved.

Furthermore, locally this region is also very interesting because the Duwamish Corridor has been the focus of a major public-private partnership (with a diverse membership) which is helping to establish plans to reverse troubling economic trends and to create or sustain economic growth opportunities in the years ahead in this important region. The partnership, called the Duwamish Coalition, is committed to job creation and economic development while protecting local neighborhoods and the environment (i.e., ‘win-win’ solutions). These activities provide an even richer database and context for the decision-making tasks which face the people, governments, and industries of the region.
Guided by literature in group decision-making (McGrath 1984, Gray 1989) and habitat restoration (Cairns 1993, Shreffler and Thom 1993, Westman 1991), the second author undertook a task analysis of a decision process concerning habitat sites in the Elliott Bay/Duwamish River Corridor (NOAA 1993). He interviewed several members of the Habitat Technical Working Group responsible for recommending alternatives to the NOAA Restoration Panel. The task analysis established that GIS was used at the beginning of the study to identify feasible alternatives from all of land parcels surrounding the Waterway. However, GIS was not found to be flexible enough to handle the task of decision-making, primarily because it did not support multi-criteria decision models, and the normal flow of group decision-making. In addition, collaboration in the decision process was found to be consensus in nature, but constrained by organizational agendas and lack of trust that sometimes make it a contentious undertaking. The latter is due to vested interests within and among organizations. The public participation meetings always had a dozen map displays to help orient both panel members and audience, but all but one was hand drafted. Limited manual-based representations most likely limit the communication and decision process both in small groups and large groups.

The lack of use of GIS in the decision-making process indicated to us that our research on spatial decision support tools for groups was coming in a timely fashion. We concluded that we could use the results of the task analysis as a basis for the development of a task model for habitat restoration decision-making, which in turn would help us design software as decision aid tools for the decision process.

2.2. A task model for habitat site selection

It has been found that decision process is influenced not only by the decision context, e.g., as described above in terms of habitat restoration, but also by the nature of the decision aid tools and the synergy between the decision aid tools and decision strategy adopted by the decision-maker (Todd and Benbasat 1994). When considering the potential influences of the decision context on decision aid tools, and the reverse influence of tools on process, it is convenient to express these potential influences in terms of a task model (Nyerges 1993). A task model for group-based habitat site selection brings together many variables, in addition, to those for decision process and decision aids (figure 1). The adaptive structuration theory (AST) of DeSanctis and Poole (1994) has been adopted in this research to provide a theoretical basis for the task model. AST was developed as a theory of how small-groups interact while using advanced information technology tools. GIS and its offspring, SDSS-G, are assumed to be such advanced technology tools.

Each of the boxes in figure 1 represent an emphasis in regards to input, process, and outcomes in habitat decision-making. The connections between the boxes imply a fundamental influence between the topics listed within the boxes, whereby each variable within a box has some relation to variables in connected boxes. Such simplicity provides an easy way to discover variables for hypothesis creation, as well as hypothesis testing. It is recognized that the input, process, and outcome labelling are but simplifications of a complex and dynamic process. However, these three categories provide a convenient means of organizing the description below.

In regards to input, in box 1 it is possible to enumerate the types of decision aid capabilities that are provided to a group. Later sections of this paper treat this in some detail, because it is the focus of the paper. However, a brief example is the availability of different map types that depict attributes of habitat sites. In box 2,
the concern is with the institutional connections of the group to its respective organizations, e.g., procedural rules such as agendas for meetings. These are usually agreed upon in advance of using the technology. In box 3, the concern is with the character of the group. Examples include knowledge of the subject matter as well as computer use, in addition to how members are inclined to treat each other due to pre-existing relations between certain members in the group.

In regards to process, the concern of box 4 is with decision-making as social interaction through human-computer-human interaction. The concern comes in two forms, one of introducing (called appropriating) decision aids (from box 1) into the decision process, and a second with an evolving decision process itself. Synthesizing the task analysis from the previous section into a sequence of activities that can be supported with incremental advances in existing tools, the following six steps act as a normative description of the habitat decision process (Nyerges and Jankowski 1993, Jankowski and Ewart 1995):

1. Developing a list of objectives as part of problem scoping.
2. Developing a list of feasible alternatives as problem definition.
3. Specifying criteria useful for measuring the degree to which the objectives are met by alternatives as part of problem structuring.
4. Enumerating preference levels for criteria as a core of the spatial choice process.
5. Integrating the achievements of alternatives on criteria with criterion preferences into one overall measure of alternative performance as aggregation.
6. Negotiating the selection of the best alternatives as part of a political process.

It is within the context of these six steps that we wish to explore the impacts of SDSS-G information technology tools on the dynamics of a decision process.

Coinciding with that process, in box 5, the use of decision aids act as emerging structures to enhance or suppress decision-making activity. For example, maps may get used in ways such that new types of information presentations are added back
into the decision process. These new maps are considered emergent structures, that might get reused if deemed useful, or eliminated if deemed confusing. What maps are actually created depends to some extent on the direction of individual and group interests.

In regards to decision-making outcomes, in box 6 the concern is with the type of decision that results from a specific process, and is dependent on all other influences. The decision solution is a list of prioritized habitat alternatives via consensus. In box 7 the concern is with long-lasting change in social structures that result from either single or multiple decision processes. Such social structures include new or broken social relations among the participants. In some cases these relations could be cooperative agreements to work more closely together in future endeavours, or the reverse.

In the context of locational conflict situations for NIMBY situations, Coucelis and Monmonier (1995) point out certain technical needs of groups involved with problem structuring that are different from needs in decision-making. Consequently, they suggest that SDSS tools as described in the literature (Densham 1991), are not sufficient for locational conflict resolution, and suggest a new type of system called spatial understanding support systems (SUSS). We tend to agree that SDSS tools need to evolve, and the type of tools being designed here can in fact apply to some problem structuring situations they describe. Whether a new name such as SUSS is needed is not as significant as the need to recognize that problem structuring must be addressed as part of the decision aid tools for habitat restoration problems. It is fair to say that even the software tools described in the next section may not be totally satisfactory for all locational conflict problems, given the multitude of issues involving group-based site selection. However, given the nature of the design discussed in the next section, the proposed software tools clearly address the locational problem structuring need.

3. Design considerations for spatial decision support system for groups

The intent of a SDSS covers many of the same basic features in a GIS, but the features are more specialized than GIS. These specialized features are intended to support alternative generation, modelling, evaluation, and cartographic display functions within a general problem domain (Densham and Rushton 1988, Densham and Goodchild 1994). SDSS, developed originally with a single decision-maker in mind, have been extended recently to group decision-making. Meeting participants can collaborate on design and construction of various geographical alternatives, sharing interactive mapping tools over a local area network (Faber et al. 1995). The concurrent use of SDSS tools can be supported by knowledge-based techniques and intelligent software agents (Jones et al. 1997). The evaluation of collaboratively designed alternatives can be carried out with multi-criteria evaluation techniques enhanced by voting tools (Malczewski 1996). The evaluation results can be visualized on special-purpose maps capable of geographically representing consensus solutions (Armstrong and Densham 1995).

Just like the lineage of SDSS can be traced to decision support systems (DSS), there is a similarity between SDSS-G and group support systems (GSS) aimed at solving business problems. A GSS is defined by Jessup and Valacich (1993) as ‘... computer-based information systems used to support intellectual collaborative work’. Lewis (1994) places GSS in the larger context of computer-supported cooperative work (CSCW) as a type of groupware software. The organization of any groupware
software, also including SDSS-G, can be classified according to dimensions of location and time (DeSanctis and Gallupe 1987, Greif and Sarin 1987). Four different arrangements are possible ranging from: (1) the same location and time (collaborative work using a conferencing room with a local area computer network), through (2) the same location and different time (collaborative work using leave behind word processing supported by a local, or wide area computer network), (3) different locations and same time (collaborative work using interactive desktop audio and video, supported by a wide area network, a dedicated wide band-width telephone line, or a satellite link), to (4) different locations and different times (collaborative work using e-mail, wide area network, and network-resident multimedia tools). The design for SDSS-G discussed in this paper focuses on the first organizational arrangement: the same location and time.

3.1. Design requirements for a SDSS-G used in a meeting room environment

The main purpose of designing a SDSS-G prototype named Spatial Group Choice was to develop a software for a series of experiments with groups in a face-to-face meeting environment. In these experiments the groups would be using Spatial Group Choice to solve a real world problem of habitat development site selection described in § 2. During the design the SDSS-G design guidelines, outlined in the previous section, were used for the specification of the system’s scope, functionality, and interface. Based on the characteristics of the site selection decision task and decision-makers (group members range from experts to novices in using spatial decision support tools) the following design requirements were specified:

(i) The system should offer decisional guidance to users in the form of a problem solving agenda, listing five major steps used in a decision choice problem: (1) problem exploration, (2) criteria selection, (3) criteria prioritization, (4) alternative evaluation, and (5) consensus negotiations.

(ii) The system should not be restrictive, allowing the users to select tools and procedures in any order.

(iii) The system should be comprehensive within the realm of a discrete spatial choice problem, and thus offer a number of decision space exploration tools and evaluation techniques.

(iv) The interface should be both process-oriented and data-oriented allowing an equally easy access to task-solving techniques as well as maps and data visualization tools.

(v) The system should be capable of supporting facilitated meetings and hence, allow for the information exchange to proceed among group members, and between group members and the facilitator.

(vi) The group members should have access to all functional controls except the consensus results accessible only by the facilitator, and these controls are to be displayed on a public screen for group’s viewing and further consideration.

(vii) The system functionality should include extensive multiple criteria evaluation capabilities, sensitivity analysis, specialized maps to support the enumeration of preferences and comparison of alternative performance, voting, and consensus building tools.

3.2. Design guidelines

With the above requirements in mind, we set out to establish design guidelines for development of the software. The design of SDSS-G can be guided by the same
three characteristics as specified for a GSS: holistic attributes, interface, and functionality (Silver 1991, DeSanctis 1993). Holistic attributes represented by restrictiveness, comprehensiveness, and decisional guidance describe the range of intended uses and interactions between SDSS-G and the group. Restrictiveness describes the level of structure embedded in the software and imposed on the decision-making process. More restrictive SDSS-G requires the group to follow the pre-specified sequence of steps while less restrictive SDSS-G leaves the group more freedom to customize the use of software to match its specific decision-making process. Comprehensiveness expresses the richness of functions offered by the system. A more comprehensive SDSS-G will be suitable for a larger number of tasks but it may also require the guidance of facilitator and/or chauffeur (a person who runs the technical details of operating the system). Decisional guidance is the degree to which the SDSS-G directs the users to invoke the system operations. It ranges from a total lack of guidance where the users pick and choose the SDSS-G’s options as they see fit, to a wizard-driven SDSS-G providing suggestions on the next possible step.

Interface can be characterized in terms of representations used by group members when interacting with the software, information exchange among group members, and the location of function controls. Representations can be process-oriented and data-oriented. The process-oriented interface emphasizes selections that offer tools and techniques used in problem-solving, e.g., GIS operations, agenda writer, weighting, scoring, and voting procedures. The data-oriented interface can present spatial and attribute data in the form of interactive maps, drawings, images, graphs, and attribute data tables. The information exchange can include communication between individual members (one-to-one), the facilitator and group members (one-to-many) and vice-versa (many-to-one). The object of exchange may be restricted only to task-related information, but it may also include the expressions of group emotions, moods, and social dynamics. The location of function controls relates to availability of controls. The function controls can be available equally to every group member and the meeting facilitator, or they can be restricted depending on the intended mode of SDSS-G operation. If the system is intended to be used without the facilitator, the full allocation of controls to every group member is a reasonable solution. If the system requires facilitation and technical assistance, the functional controls may be allocated among group members, facilitator, and chauffeur respectively.

Functionality of SDSS-G can be specified at two levels: basic and advanced. At the basic level a SDSS-G should be capable of performing fundamental functions such as idea generation via mapping and text processing tools, idea organization via editing tools, evaluation of alternatives by scoring, representation of preferences by weights, voting tools, and shared display. Additionally, at the basic functionality level, SDSS-G should provide individual and shared map displays that support the visualization of alternative locations, background information, and spatial distributions of attributes associated with alternatives. The shared maps may reflect a group’s position on preferences and ranking of choice options. At an advanced level a SDSS-G should provide all the functions of the basic level plus specialized modelling tools for location/allocation, multiple criteria evaluation, and spatial data visualization including specialized maps to support the enumeration of preferences, comparison of alternative performance, and sensitivity analysis.

To establish a framework for development, we employed the design guidelines in a mock-up of the human-computer interface. The design of human-computer interface
was carried out using a lo-fi (low fidelity) prototyping strategy (Rettig 1994). In accordance with the lo-fi strategy, we prepared the paper mockup of the system interface comprised of windows, menus, and selections and engaged the future users in simulated system's use sessions. These sessions were videotaped and provided us with much needed feedback on system's functionality and user-friendliness. The advantage of lo-fi prototyping over a hi-fi (high fidelity) approach is that one is able very quickly, during the same test session, to implement a user's comments and ideas with basic office supplies such as paper, scissors, and pens. The lo-fi approach worked well in our case enabling us quickly to converge on a satisfactory system design.

4. System implementation

4.1. System architecture and development languages

The prototype design was translated into hardware and software requirements for system architecture and programming environment. Considering the type of decision-making task at hand, decision-makers, and decision environment (computer-supported meeting room), we decided that the hardware requirements included a network of PCs, large public screen, and an LCD panel with a high intensity overhead projector connected to the facilitator's computer. The software requirements included operating system, network software, multicriteria evaluation software for decision modelling and voting, and interactive map visualization software. The design architecture for Spatial Group Choice is presented in figure 2. The system is comprised of two modules—a multi-criteria evaluation software we call Group Choice, with a submodule for multi-criteria decision-making (we call MCDM) and a voting submodule (we call Consensus), and a module for spatial visualization, customized from ArcView 2. Consequently, the integrated software of Group Choice

![Spatial Group Choice](image)

Figure 2. Design architecture for Spatial Group Choice.
 Spatial group choice

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together with ArcView 2 (AV-2) we call Spatial Group Choice. The software integration is based on a loose-coupling strategy (Jankowski 1995).

We decided to use the Microsoft Windows for Work Groups operating system because of its built-in networking capabilities, broad support of commercial mapping software, and the ease of interfacing commercial software with the specialized software that we had to write. We decided to create Group Choice because of our review of MCD models showed no comprehensive and flexible set of models available. In the Windows-based implementation of the system, the integration between Group Choice (i.e., MCDM and Consensus) and AV-2 is handled by the dynamic data exchange (DDE) protocol. The DDE protocol facilitates the data transfer from MCDM program and Consensus to AV-2 where the data can be visualized. The Windows for Work Groups facilitates data transfer between the facilitator and group participants, and among the individual group participants.

The MCDM and Consensus programs are implemented in Borland C++ under Windows for Work Groups 3.11, whereas the customization of AV-2 uses Avenue (an object-oriented programming language developed by Environmental Systems Research Institute Inc.). The DDE links between MCDM, Consensus, and AV-2 are implemented in Avenue, and within MCDM they are implemented in Borland C++. The software requires 32-bit Windows extensions and an Intel 386 processor or its equivalent.

Spatial Group Choice in its current format can analyse decision problems up to 100 alternatives by 100 criteria.

4.2. Spatial Group Choice capabilities

Spatial Group Choice can be used in two modes, private and public. In the private mode the MCDM programme has tools and methods to assist an individual group member in the evaluation of decision alternatives and the submission of his/her opinion to the whole group. The submission is done through a vote and can be open or anonymous. In the public mode the Consensus programme has tools to calculate and display voting results including a measure of group agreement/disagreement. Both programmes (MCDM and Consensus) can be used in the public mode using a large screen computer display.

The spatial data visualization module can be used in both private and public modes, and serves as the database repository and data visualization tool. The decision problem database is organized in a project directory comprised of coverages, and orthophoto image files in the ArcInfo data input format, and project files in AV-2 format. The problem-related data is organized in an AV-2 project in themes where every theme is represented by a customized Thematic Map. For the support of problem solving using multiple criteria evaluation, we developed graduated symbol-based symbolization schemes and a new, histoframe thematic map type using Avenue scripts to display the decision criterion values. The thematic maps for a problem-specific AV-2 project can represent either decision criteria or background information.

The Spatial Group Choice functionality includes the following capabilities:

- **Importing decision data from AV-2.** These data characterize alternatives on a number of attributes in AV-2, and when imported in MCDM they become decision criteria.
- **Selection of decision criteria.** Any or all attributes can be selected as decision criteria from an imported AV-2 file.
— **Specification of criterion type.** The decision criteria can be of three types: benefit criteria (the higher alternative score on criterion the better), cost criteria (the lower alternative score on criterion the better), and threshold range (minimum and/or a maximum thresholds determine the preferred range of criterion values). The user can set the criterion type for every selected evaluation criterion.

— **Enumeration of criterion priorities.** Priorities are established by calculating preference weights. Weights express how important every criterion is in relation to other criteria. Three different techniques of calculating criterion weights are available for the user in the MCDM program. They include: Pairwise Comparison, Ranking, and Rating. These techniques can accommodate different styles of expressing preferences. Pairwise Comparison technique generates weights based on direct comparisons of one criterion with another criterion (pairwise) in which the user expresses the level of preference by selecting a rank from an ordinal rank scale (Saaty, 1990). In Ranking technique one generates criterion weights by assigning a rank from an ordinal rank scale to each criterion (Voogd 1983). Rating technique allows the user to assign weights explicitly to each criterion by redistributing 100 points, which is the sum of all weights (Voogd 1983).

— **Map display.** Several map displays are available to depict the achievements of alternatives on selected decision criteria. The visualization of achievements of alternatives on selected criteria, using histoframe maps, can aid the enumeration of criterion priorities.

— **Ranking the choice alternatives.** The ranking position is calculated by an aggregation function. The aggregation function combines the achievements of alternatives on criteria with criterion preferences into one overall measure of alternative performance. Two aggregation techniques are offered for users in the MCDM program: Weighted Summation and Rank Order.

The weighted summation technique is based on a linear combination of criterion scores and weights (Voogd 1983). The evaluation score is calculated for each alternative by multiplying each criterion score by the corresponding criterion weight and adding the products. The sum of the products calculated for each alternative gives the evaluation score.

The Rank Order technique uses weighted summation with linear combination of weights and scores, but with rank ordering as the basis for calculating criterion scores. Instead of using the ratio scale properties of the criterion scores, an alternative’s criterion score is based on the alternative’s position in an ordered list of all the alternative scores for a criterion. Alternatives at the top of the list, that is alternatives with better scores for the criterion, receive higher scores than alternatives at the bottom of the list. The criterion scores are based on the position in the ordered list (ordinal scale) and not on the criterion scores (ratio scale) used to determine the ordered list. Since the scores are normalized, an interval level of measurement actually exists among the scores.

— **Map display of rank-ordered alternatives.** Ranks from the MCDM program can be depicted graphically using graduated symbol maps in AV-2.

— **Sensitivity analysis.** Sensitivity analysis is used to check the robustness of rankings among the alternatives. The purpose of performing sensitivity analysis is to check the stability of rank-order to changes in criterion weights. If
small changes in criterion weights have no influence on the ranking of alternatives, one may have more confidence in the rank-order of alternatives.

— Voting. Analysts can vote on any aspect of multiple criteria evaluation including the selection of criteria, criterion weights, method of ranking the alternatives, and the order of ranked decision alternatives. Voting can be open and anonymous. A generic voting function, using simple majority, can be used to clarify positions without divulging whose position.

— Viewing the voting results. Voting results for the group and/or for individuals can be displayed. The latter, of course, by prior agreement of the group. The voting results can be calculated by a Ranked Vote technique and Non-ranked Vote technique. The Ranked-Vote technique assigns ranks to candidates (e.g., alternatives) based on the following rationale: the higher position of a candidate on the voter’s list the higher the rank assigned. The voting position of a candidate is determined by adding the ranks for each candidate from every voter using the Borda social preference function (Hwang and Yoon 1987). This type of vote aggregation prevents a contentious candidate who ranks very high with some group members and very low with others from winning, and promotes a consensus candidate. The Non-ranked Vote option applies a simple majority rule by counting the number of times that each candidate received a vote. The candidate with the most number of votes wins. This method, even though democratic, may lead to a mediocre candidate winning if more than two candidates receive votes (Arrow and Raynaud 1986). As an example, imagine three vote files for alternative ranking: (a,b,c), (d,b,c), (a,e,c). According to the non-ranked vote aggregation the alternative c wins despite the fact that it is placed last in all three votes.

— Map display of rank ordered alternatives from the Consensus programme. Consensus maps using graduated symbols can be displayed based on ranks from the consensus program. The representation in this map display uses circle size to reflect site ranking and circle color fill to reflect consensus on that site rank position.

5. Application of spatial group choice to environmental restoration

Spatial Group Choice has been developed to facilitate the computer-supported interactions of small-groups in meetings. Using the decision-making setting, described in §2.1, we provide below a descriptive tour of Spatial Group Choice features.

As described earlier, the Spatial Group Choice software has two modules, one for multi-criteria evaluation called Group Choice (MCDM/Consensus) and one for interactive map visualization called ArcView 2 (AV-2). Note that the software coupling has been designed such that a decision-maker has flexibility in starting and using the software. A decision-maker can use the modules independently or together. In the tour below, we start with AV-2, then use MCDM/Consensus, and then use both modules to exchange data. Also, note that some of the non-group activities (e.g., some of the data exploration) described below could be performed independently by individuals prior to a formal meeting in a ‘private mode’.

As a group (with five decision-makers as in our research design), decision-makers are confronted with the task of selecting three sites in which to invest resources for habitat development. Decision-makers meet in a room in which each has a computer keyboard, mouse, and display, and each is provided access to relevant data on a local area network. All decision-makers are seated in a U-shaped arrangement facing
a public display. Further, the meeting process and the management of the public display are assisted by a facilitator/chauffeur. Given that each of the decision-makers, as stakeholders, have different values, interests, and positions, somehow the group must come to a consensus.

The locations of the twenty potential habitat development sites are depicted as an analyst opens the AV-2 module (see the left side of figure 3(a)).

The AV-2 module includes the following pull-down menus: FILE (file management), SITUATION (background information about the region), SITEATTR (attribute data about each site), RANKS (for site rank displays), and HELP. The software has a detailed help utility and data dictionary to assist decision-makers with informing themselves, as well as providing helpful information displayed on the status line in the lower part of the window.

As a decision-maker zooms in and out in the display view, the scale-dependent display of aerial orthophoto information is activated when the map scale is larger than 1:12 000. Also in this window, through the help of tool buttons and the mouse, a decision-maker can display a database record about one or more sites, display a text window with hotlinked information about site-specific habitat development opportunities, or measure distances. The database contains site information on the following: ability for the site to address injury, distance to nearest contamination, ecological suitability, estimated cost for development, existing land use, potential (future) land use, property ownership, proximity to nearest existing habitat, proximity to public access, proximity to nearest public facility, and site size.

Figure 3. (a) The initial windows in the Spatial Group Choice software (AV-2 module on the left, MCDM/Consensus module on the right). The twenty possible sites for habitat development are displayed in the AV-2 window.
As an independent activity a decision-maker can explore those site attribute data, as well as explore the situation surrounding the sites. Using the SITUATION pull down menu, one can toggle themes of map information on and off for easy display. For the surrounding area, this menu provides access to background information on the location of streets, wildlife and habitat areas, water resources, land use and zoning, property ownership, parks and greenbelts, combined sewer overflows, and other pollution sources. Figure 3(b) shows a view of the region with the location of wetlands and wildlife areas displayed.

Figure 3(c) displays another view of polluting industries and contaminated sites in the region. The activated text window in the lower left-hand corner provides additional information about the Duwamish Waterway Park site.
To continue exploring the habitat site data in the AV-2 module, a decision-maker might decide to further investigate the site attributes via a map display using histogram bars (see figure 3(d)).

The software provides a feature in which a decision-maker can select for each attribute, whether higher data values, lower data values, or a range of data values will result in higher (or taller) bars displayed in the map view.

Furthermore, a single attribute or multiple attributes can be displayed in this format. This tool allows one to compare the attributes at, and among, sites in a user-defined, map-based manner. This data exploration technique can let a decision-maker see which sites might be of interest from the standpoint of their own stake-
Figure 3. (d) A site attribute map displaying histoframe bars to represent the attribute data. For this display, the user has assigned lower costs and higher site sizes to be represented by higher (or taller) bars.

holder values and interests. Figure 3 (d) shows that the cost of development at the Duwamish Waterway Park site is good, but the site size is not good (i.e., a decision-maker has selected lower costs and larger site sizes to be represented by higher bars).

At this point, we have completed our exploration of the habitat site data and feel ready to begin the decision-making activity. To initiate this process, a decision-maker first exports site data from the AV-2 module. Using the file management features in the AV-2 module, one would export the necessary data, and these data are automatically saved in a software format compatible with the MCDM/Consensus
module. Then, one would open up the MCDM/Consensus module (see figure 3(a) with both modules open).

When a decision-maker imports the site data file into MCDM/Consensus, he is prompted to select the site attributes (the selected attributes will be called the decision criteria in MCDM/Consensus) which are important in the decision problem (see figure 4(a)).

After the criteria are selected, then one performs a valuation on each of these criteria (see figure 4(b)).

![Figure 4](image)

(a) The dialogue box in the MCDM/Consensus module which allows the user to select the decision criteria for the modelling. (b) The criteria valuation dialogue box in MCDM/Consensus. The user selects how the standardized criterion scores will be calculated.
The valuation step determines how the attribute data will be normalized to create standardized criterion scores. Here, an opportunity exists to select either ‘higher value is better’, ‘lower value is better’, or ‘range values are better’. The dialogue box displays the maximum and minimum criterion values in the database and one can select a minimum and/or a maximum threshold value to modify the shape of the valuation function.

At this point, each of the decision-makers has selected a (presumably different) set of criteria which he/she thinks is important. The group may decide to focus the discussion and the meeting direction by first coming to some agreement on which criteria should be used in the group decision-making activity. The Consensus tool can be used to assist with this task. Each decision-maker submits a vote file to the facilitator which contains his/her decision criteria with the order of the criteria indicating importance. The group facilitator can then display these results in a ranked or non-ranked manner on the public display. Figure 5 displays a ranked vote example.

Ecological suitability, site size, distance to nearest contamination, and development cost are the four most preferred decision criteria based on these voting results. Thus, this public display can provide a good basis for the group to discuss stakeholder values and concerns directly relevant to the decision-making task at hand.

Once the group comes to some consensus on the criteria that will be used (or maybe tested), the group, or each decision-maker alone, may go back to MCDM

![Figure 5. A display of the consensus tool in MCDM/Consensus. This window would be presented on a public display screen so that all members of the group can see voting results. The score (0 to 100) is a summary value which shows how well each criteria performed in the overall voting. The variance (0 to 100) indicates whether the overall rank position in this display agreed well (low variance) or poorly (high variance) with the rank positions of the individual decision-makers.](image-url)
to clarify priorities. This effort will involve selecting the criteria weighting method (from pairwise comparison, ranking, and rating), selecting the aggregation method (weighted summation or rank order), selecting the criteria weights redistribution method (equal or proportional, used to maintain the sum of the weights equal to 100 when one weight is changed), and performing a sensitivity analysis to determine the stability of the decision modelling results. Figure 6(a) shows the dialogue box which allows you to set the criteria weights via the ranking method and figure 6(b)
Figure 6. (c) The dynamic sensitivity analysis tool in MCDM/Consensus. The horizontal bars on the left represent the magnitude of the weights for the selected criteria. The bars on the right represent the resulting total score for each site in the decision problem. When a bar on the left is adjusted with a mouse click-and-drag operation, which changes the criterion weight, all other bars in the display are dynamically updated.

shows the ease with which the circle-shaped radio buttons (in the Aggregation window) can be used to select the aggregation method.

The dynamic sensitivity analysis feature is presented in figure 6(c). Here, the criteria weights are represented by horizontal bars on the left-hand side of the display and the alternatives (i.e., the sites/total site scores) are represented by similar bars on the right-hand side.

The longer the bar, the larger the weight or site score. With this feature a decision-maker can use a mouse to click and drag any criterion weight bar to change the criterion weight. As this is performed, the selected bar turns green and the weights are automatically adjusted according to the selected redistribution scheme. More importantly, one can automatically see the effect of this manipulation on the site scores on the right-hand side of the display. This dynamic sensitivity analysis tool lets a decision-maker observe whether a model is robust for decision-making purposes. If a small change in a criterion weight leads to visibly large fluctuations in the site scores (and relative site rankings), then one might suspect that the decision model is a weak justification for a decision because the results are not stable. When finished, one can close the window and save, or expunge, the results of analysis.

Once a decision model has been chosen as a reasonable approach to the problem, a decision-maker can decide to see the results in a map display. Figure 7 displays a
Figure 7. The exchange of data between the MCDM/Consensus and AV-2 modules. The total site (alternative) scores in MCDM have been automatically passed to the AV-2 module for display. The spatial distribution of decision model rankings is represented with graduated (proportional) circles.

map which can be created by simply going to the RANKS pull-down menu and first selecting UPDATE SITE RANKS and then DISPLAY SITE RANKS.

The map display uses graduated circles which are proportional to rank (the highest ranked site is represented by the largest circle) and the site ranks are displayed in text form (‘1’ is the text label for the highest ranked site). This display provides an easy way to observe the spatial distribution of a decision model scenario.

Let us now assume that we are satisfied with the results and are ready to identify the top three sites for habitat development, but others in the group may have some different results because of different criteria weighting, etc. The group may decide to vote on the three sites to be selected by submittal of the individual site rankings to the facilitator. Figure 8 shows in the lower-left corner window the ranked voting results from the voting of Alan, Emory, Piotr, Tim, and TJ, as presented on a public display screen.

The group shows a strong preference for the Kellogg Island and City Light North sites; the variance results indicate that the Kellogg Island site were generally voted as no. 1. Based on the variance, there appears to be less group consensus about the rank of City Light North as the no. 2 site. While these tabular results might be helpful to the group discussions, the group might also want to consider the spatial distribution of their consensus (or lack thereof). For the case depicted in the lower-left window of figure 8, the centre-right window (in figure 8) presents a consensus map shown on the public display. The representation in this map display
Figure 8. The lower left window presents the public display of voting results on site selection by five decision-makers. The centre-right window presents consensus map for the voting results. The larger and darker circles represent sites which are better, from the standpoint of overall voting rank and group consensus on rank position.

uses circle size to reflect site ranking and circle fill, according to a grey scale-ramp from dark to light, to reflect consensus on that site rank position. So, the larger and darker sites are those that are most preferable in this group decision-making context. In this case, through group discussions and negotiations, the group may decide to select Kellogg Island, Turning Basin, and Seaboard Lumber because they are high ranking sites and because the group seems to have greater consensus on their ranks than on some of the ranks of the other high ranking sites. The consensus map might also lead a group to depart from expectations based on the tabular consensus window results if, for example, the results appear spatially clustered; a more geographically dispersed solution may resonate with some perceived and overall group value (e.g., distribution of funding to different neighbourhood areas, a logic built upon habitat ‘seeding’, etc.).

In this brief tour of the Spatial Group Choice software we showed how it is useful in CSDM activity by way of a real world problem. There are a number of features which we have not discussed in detail, but we hope the tour provided a good sense for the possible utility of this prototype SDSS-G. Through preliminary usability tests with students at the University of Washington and faculty/students at the University of Idaho, we have received a number of very favourable and helpful comments. Also, the software design has benefited tremendously from usability tests
conducted with a number of the real world decision-makers involved in the Duwamish habitat site-selection project.

6. Conclusion

The surge of interest in collaborative spatial decision-making stems from the growing realization that effective solutions to pervasive spatial decision problems require collaboration and consensus building among people representing diverse areas of competence, political agendas, and social interests. GIS, in order to become a foundation of an effective spatial decision support environment, has yet to embrace a collaborative work paradigm. To address this need, we presented Spatial Group Choice—a prototype SDSS-G (spatial decision support system for groups) for collaborative work in a conference room setting. Spatial Group Choice, however, is not a production software that can be used off-the-shelf for any type of spatial decision problem requiring collaborative work. It is more of a flexible research tool used to discover the dynamics of collaborative spatial decision-making processes that make use of SDSS-G. The understanding of how and why SDSS-G affects collaborative decision processes and outcomes is essential not only for improving SDSS-G tools but also for an effective use of information technology supporting collaborative spatial decision-making.

The future research issues concerning the development of SDSS-G tools include: (1) better integration of decision models with map visualization components—this may involve a tight coupling of modules within GIS, (2) a richer palette of techniques to accommodate different styles of expressing preferences and prioritizing choice alternatives, (3) new techniques of fostering consensus convergence, and (4) the development of an extension of a multi-criteria evaluation methodology for selecting site locations based on both attribute and spatial constraints. Last, but not least, new SDSS-G tools are needed to operationalize two other spatio-temporal arrangements of the collaborative work paradigm not addressed in this implementation of Spatial Group Choice; these being a meeting where participants are attending at different locations, but the same time, and a meeting where participants are attending at different locations and different times.

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