GIS-Supported Collaborative Decision Making: Results of an Experiment

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This article addresses research questions about the sociobehavioral dynamics of geographic information system (GIS) use during collaborative decision making in small interorganizational groups. Using an experimental design of a conference room setting, a study of human-computer-human interaction was conducted with 109 volunteer participants formed into 22 groups, each group representing multiple organizational stakeholder perspectives. The experiment involved the use of GIS integrated with multiple criteria decision models to support group-based decision making concerned with the selection of habitat restoration sites in the Duwamish Waterway of Seattle, Washington. Findings representative of four categories of investigation are presented. In the first category, the experiment demonstrated that groups used maps predominantly to visualize the evaluation results and much less to structure/design the decision problem. Maps played only a limited support role in various decision stages of the experiment. In the second category, while the use of multiple criteria decision models by groups remained steady throughout different phases of the decision process, the use of maps was much lower during the initial exploratory-structuring phase than during the later analytic-integrating phase. In category three, the amount of prior and acquired group member experience with computer tools had no influence on the appropriation of decision aids. In category four, different phases of the decision process had two different levels of conflict: the exploratory-structuring phase was characterized by a lower level of conflict, and the analytic-integrating phase was characterized by high conflict level. The higher level of conflict during the analytic-integrating phase tells us that analytical decision aids aimed at conflict management are likely to help work through conflict, such conflict now being recognized as a necessary part of making progress in public decision problems. *Key Words: collaboration, GIS, group, site selection, spatial decision support, stakeholder.*

An increasing number of problems in public policy formation and implementation are being recognized as candidates for public-private collaborations. Examples of such problems in a geographic domain include locally unwanted land uses (LULUs) that instigate "not in my back yard" (NIMBY) controversies, such as landfill and hazardous waste facility siting (Popper 1981; Lake 1987; Susskind and Cruikshank 1987; Couclelis and Monmonier 1995; Schneider, Oppermann, and Renn 1998), polluted urban land use (so-called brownfield) redevelopment projects (Bartsch and Collaton 1997; Davis and Margolis 1997), and salmon habitat restoration plans (NOAA 1993; Brunell 1999). Most of those public-private problems are called "wicked" and "ill-structured" (Rittel and Webber 1973) because they contain intangibles not easily quantified and modeled, structures only partially known or burdened by uncertainties, and potential solutions mired by competing values, interests, and perspectives (Susskind and Cruikshank 1987). Public-private problems involve a mix of concerns, some public (like those about legitimacy and credibility) and some private (like those about financial efficiency due to the expenditure of large amounts of funds). Locational conflict often arises over public-private problems due to differences in values, motives, and/or locational perspectives with respect to what is to be accomplished (Popper 1981; McGrath 1984; Susskind and Cruikshank 1987; Gregory 1999). In this context, the *spatial* character of problems is special due to externalities that arise from adjacent locations being "valued" and perhaps used differently. Locational conflict arises from those spatial externalities. In such situations, conflict—and therefore negotiation management in shared decision making—is a fundamental concern in coming to consensus about choices to be made (Duffy, Roseland, and Gunton 1996; Susskind and Field 1996; Simosi and Allen 1998).

Dealing with locational conflict in an open manner is becoming more important as citizen (stakeholder) participation increases in land use, natural resource, and environmental decision making (Parenteau 1988; Crowfoot and Wondolleck 1990; Gregory 1999). The primary rationale for enhanced stakeholder participation in public land planning is based on the democratic maxim that those affected by a decision should participate directly in the decision making process (Smith 1982; Parenteau 1988; Gregory 1999). It has been said that decision

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making groups are both fundamental building blocks and agents of change within organizations, communities, and society (Poole 1985). Further, Zey (1992, 22) states ". . . that decisions [in society] are most frequently made by groups within the context of larger social collectives." In Zey's 1992 book on decision making, a group of experts in decision making research conclude that ". . . the resolution of conflicts of values (individual and group) and of inconsistencies in belief will continue to be highly productive directions of inquiry, addressed to issues of great importance to society" (Simon et al. 1992, 53).

The above perspectives indicate a broad-based need for research on both group decision making in general and collaborative spatial decision making (CSDM) more specifically. Research about collaborative spatial decision making is being encouraged by the research agenda of the National Center for Geographic Information and Analysis (Densham, Armstrong, and Kemp 1995). That agenda is linked to an international research effort concerning the development and use of group-based GIS (geographic information systems) technology that can be integrated with other computer technologies to facilitate group collaboration, problem-solving, and decision making on projects with an inherently geographical character. Thus, the general goal of our research is to develop geographic information technology that can address the needs of a diverse set of participants involved in CSDM.

In undertaking such research it is important to recognize at least four cumulative levels of "social interaction" during group decision making that can be described under the umbrella term of "participation": *communication*, *cooperation*, *coordination*, and *collaboration*. At a basic level of participation, people *communicate* with each other to exchange ideas in a fundamental process of social interaction. In public decision contexts, the traditional forum of a public meeting provides for communicative interaction—but only at this basic level, a drawback in meetings at which truly constructive comments are desired (Schneider, Oppermann, and Renn 1998). At the next level of social interaction, building on a set of ideas developed through basic communication can be considered to be *cooperative* interaction. Participants in a cooperative activity each agree to make a contribution that can be exchanged, but each can also take the results of the interaction away with them and act on the results as they see fit, with no further interaction required. A *coordinated* interaction is one whereby participants agree to cooperate and they agree to sequence their cooperative activity for mutual, synergistic gain. A *collaborative* interaction is one whereby the participants in a group agree to work on the same task (or subtask) either simultaneously or in a near-simultaneous manner with a shared understanding of a situation (Roschelle and Teasley 1995). Working in a collaborative manner, participants create synergy, and each comes away with a sense of the way in which to undertake decision making.

In this article we emphasize collaborative decision making, including a negotiated understanding of issues, because this context demands the most of participants' effort and time. Furthermore, we emphasize collaborative spatial decision making because of a growing interest in understanding societal impacts of the development and use of geographic information technology that can represent "value differences" related to spatial externalities and locational conflict. Representing value differences is important to "idea differentiation," which in turn is necessary as a step toward "idea integration." Stakeholder behavior involving conflict requires both idea differentiation and integration before conflict resolution can occur (Susskind and Cruikshank 1987; DeSanctis and Poole 1994).

The background literature in our area of research relies heavily on material and developments in the management and decision sciences regarding concepts and findings related to group work and decision support. Development of group support systems (GSS) technology (Coleman and Khanna 1995), including group decision support systems (GDSS; DeSanctis and Gallupe 1987; Hwang and Lin 1987), as well as theoretical and empirical studies of the use of both (Gray, Vogel, and Beauclair 1990; Gray et al. 1992; Jessup and Valacich 1993; Chun and Park 1998), have been carried out in the management and decision sciences since the early 1980s. Most of the empirical studies have been laboratory experiments conducted in conference room settings with subject-groups using GDSS software. A major purpose of the experiments was to understand the implications for group decision processes and decision outcomes of using decision support software. Although these experiments have yielded mixed and inconclusive results, they provide valuable insights into the effects on group performance, group member attitudes, level of participation, and group conflict of using such software (Chun and Park 1998).

As expected, the results suggested that group performance—represented by decision time—depends on the familiarity of users with GDSS tools, but that a skillful group facilitator can compensate for the lack of user experience with these tools. According to the results, there is no advantage to using GDSS for improving decision quality in simple problems. However, its use becomes advantageous in complex decision problems. The quality of decisions in such problems was higher in the experimental groups that used GDSS software than in groups without GDSS support. User attitudes toward the computer-supported decision process, measured by user satisfaction with GDSS, depended strongly on the presence or absence of a group facilitator; the facilitator's presence enhanced users' satisfaction with the process.

Another interesting finding concerned heightened conflict level among groups supported by GDSS, in contrast to earlier supposition that the anonymity of electronic communications would increase the number of interpersonal exchanges and reduce the chance of one or a few "strong" individuals dominating a meeting. The anonymity feature, enabled by computer network-driven GDSS, did often embolden group members to communicate more forcefully, thus increasing the perception of conflict in the group (Chun and Park, 1998).

In contrast to laboratory experiments, the results of the few field studies conducted in the 1980s are much more consistent and positive. They demonstrate both increased decision quality and shortened meeting time when using GDSS as compared to conventional meetings (Chun and Park, 1998). They also demonstrate high user satisfaction and enhanced decision confidence independent of prior user experience with GDSS. Field studies dealing with multiworkstation-based GDSS show enhanced participation and—like laboratory experiments—increased conflict from the use of the system. In contrast, field studies of single workstation-based GDSS led by a facilitator reported both enhanced participation and consensus in arriving at decision recommendations.

Because the development of commercial group support systems and group decision support system software in the 1990s (e.g., Lotus Notes from IBM, GroupSystems from Ventana Corp., and MeetingWorks from Enterprise Solutions) was preceded by studies in the 1980s on group use of computer technology, one would presume that similar studies on group use of GIS systems are needed before commercial GIS software for groups can be developed. A noted GIS researcher wrote more than a decade ago, "I conclude that a GIS is best defined as a decision support system involving the integration of spatially referenced data in a problem solving environment" (Cowen 1988, 1554). Others who argued that GIS technology fell short of providing decision analysis capabilities quickly disputed this definition (Densham and Goodchild 1989). A few years later Lake (1993) offered another perspective, arguing that GIS might be a step backwards due to its positivistic approach, encouraging rational planning in the decision process rather than opening the decision process to participatory behavior.

Has any progress been made in the 1990s with regard to GIS technology's role in decision support? If we measure the progress in terms of tool development, the answer is a resounding "yes." During the 1990s, GIS (Godschalk et al. 1992; Faber et al. 1994; Faber, Wallace, and Cuthbertson 1995; Faber, Wallace, and Miller 1996), their offspring, spatial decision support systems (SDSS) (Carver 1991; Densham 1991; Armstrong 1993; Eastman et al. 1995; Heywood, Oliver, and Tomlinson 1995; Jankowski 1995; Reitsma 1996; Jankowski et al. 1997; Nyerges et. al. 1998b; Jankowski, Lotov, and Gusev 1999; Malczewski 1999; Thill 1999), and spatial understanding (and decision) support systems (SUSS/SUDSS) (Couclelis and Monmonier 1995; Jankowski and Stasik 1997) were suggested as information technology aids to facilitate geographical problem understanding and decision making for groups, including groups embroiled in locational conflict.

Clearly, research concerning collaborative decision making for geographically oriented public policy problems continues to gain momentum (Godschalk et al. 1992; Shiffer 1992; Faber et al. 1994; Couclelis and Monmonier 1995; Densham, Armstrong and Kemp 1995; Faber, Wallace, and Cuthbertson 1995; Golay and Nyerges 1995; Faber, Wallace, and Miller 1996; Reitsma 1996; Reitsma et al. 1996; Jankowski et al. 1997; Nyerges and Jankowski 1997; Nyerges, Moore, Montejano, and Compton 1988; Nyerges, Montejano, Oshiro, and Dadswell 1998). Reducing the complexity of a decision process by reducing the cognitive workload of decision makers is one goal of developing collaborative decision support systems by integrating capabilities from group decision support systems, GIS, and multiple criteria decision models (MCDM). Hopefully, reducing this workload will lead to a more thorough treatment of information, exposing initial assumptions more clearly and resulting in more participatory decisions (Obermeyer and Pinto 1994). Unfortunately, most of the research on collaborative spatial decision making is about GIS development rather than about GIS use, without a strong theoretical link between the two. Until recently, little had been done to study the use of GIS technology at a decision group level. Even though the case can be made for transferability of research results from group decision support system experiments to collaborative spatial decision making, unlike the case of a business decision problem such as the selection of product marketing plan, spatial decision problems are unique in making location and associated spatial relationships an explicit part of a spatial decision situation.

Our study was partially motivated by this gap between the understanding of the implications of using decision support software in nonspatial group decision processes and the understanding of the implications of using such software in spatial situations. The study was further motivated by the need to develop an understanding of how GIS software, combined with multiple criteria evaluation techniques, is used in group decision processes, and which components of computer technology fulfill decision support tasks and which do not. We believe that this knowledge will enable a better understanding of how GIS can successfully be used to support collaborative work involving spatial decision making and problem solving. We also believe that participatory and collaborative decision making and problem solving will play an ever-increasing role in public-private decision situations of the future.

From a social and behavioral science perspective, a major goal of our research agenda is to broaden and deepen the conceptual underpinnings of GIS-supported collaborative decision making by considering social-behavioral aspects of geographic information use. This is an important part of geographic information science that concerns itself with the implications of geographic information (system) use within organizations, community, and society. The study reported in this article fuels the discourse about the role of GIS as "tool or science" (Pickles 1996; Wright, Goodchild, and Proctor 1996a), but along different emphases from those articulated in the discourse to date. Wright, Goodchild, and Proctor (1996a) provide a service to GIS researchers by writing about the multiple roles of GIS, which is sometimes viewed as a tool and sometimes viewed as a science. Like Pickles (1996), however, we doubt the usefulness of an analysis of e-mail dialogue about GIS as "tool or science," as reported by Wright, Goodchild, and Proctor (1996a) because of a lack of reflective thought on the topic in terms of theoretical and philosophical grounding. We believe that a more productive discourse involves unpacking the links between substance, theory, and method.

In this article, we demonstrate that tool development, information (tool) use, and scientific examination involving tool development and/or information use all have their place. However, when that place is grounded explicitly in theory, research on it may be more recognizable as a contribution to science. In other words, we support research that is ready to ". . . engage directly and more substantially the complexities and abstractions of philosophies of science and the theories of knowledge and society associated with them" (Pickles 1996, 396).

To ground our contribution to geographic information science, we point out that research concerned with GIS—including its social implications, as in any social and behavioral science research—should explicitly recognize the balance and intimate interplay among three research domains: substance, theory (concept), and methodology (Brinberg and McGrath 1985; Silvey and Lawson 1999). All three domains are present in any study; however, the strength of each one's presence is a matter of emphasis. The "tool versus science" debate parallels a "methodology versus theory" debate. The difficulty lies with the concept of "versus." Even a discourse about this concept is a misplaced pursuit for encouraging developments in science! Recognition of a balance between substance, theory, and methodology is what is needed to make the theoretical turn (Pickles 1996; Wright, Goodchild, and Proctor 1996b). Achieving such a balance involves implementing a research design that includes all three research domains, with one domain taking the lead to set the stage while the others follow but with all present as part of the overall contribution (Brinberg and McGrath 1985).

Our study about the dynamics of GIS use in small groups intentionally balanced substance, theory, and methodology in a meaningful way, recognizing the constraints on interpreting research outcomes. We chose a substantive public/private problem regarding the selection of habitat redevelopment sites, with concerns about legitimacy, credibility, and efficiency (NOAA 1993). The task of decision making was addressed using various information structures provided by a collaborative spatial decision support tool.[1] As the topic of habitat restoration, the concern about collaborative group decision making, and the adoption of GIS technology continue to grow in significance, we need to better understand the dynamics of each individually and all three in mutual dependence.

From a theoretical perspective, we used Enhanced Adaptive Structuration Theory (Nyerges and Jankowski 1997) to motivate certain research questions and subsequent hypotheses about social dynamics of collaborative decision making in small groups. We were confident that this theory would provide a good starting place from which to understand the relationships among several significant aspects of group interaction during use of GIS motivated by a complex, practical, public-private problem. From a methodological perspective we chose to use a somewhat unconventional approach to data capture, videotape coding. For analysis, however, we chose a conventional statistical approach. Given the combination of substance, theory, and method, our empirical results can tell only a partial story about the potential impacts of GIS use in collaborative decision making for a site selection problem. Other research designs providing a different balance of substance, theory, and method will of course be needed to provide other valuable insights.

This article is directed toward making a balanced contribution to the theoretical understanding of GIS as geographic information science. In the next section, we present the theoretical framework that guided our articulation of research questions for examining the use of maps and multicriteria decision aids in a group setting. In the context of that framework, we introduce a substantive problem setting that deals with group-based site selection for salmon habitat redevelopment. Next, we outline the methodology we used in undertaking this study, providing insight into the way we organized the experiment and collected data about group participation. That leads us to a presentation of the findings for nine hypotheses clustered into four categories, with a follow-up discussion of each hypothesis to interpret those findings. We conclude this article by situating its concepts and findings in the broader research literature about geographic information and society. We offer prospects for future areas in which our own and other research endeavors might be well worth the effort.

Theoretical Framework for the Study

Our collaborative spatial decision making research agenda presumes that decision making groups are both fundamental building blocks and agents of change within a variety of organizational, community, and societal settings. We recognize that groups as decision actors can be studied at intraorganizational, organizational and interorganizational levels of aggregation within those settings. As we move into the twenty-first century, it is often said that we are experiencing information overload—i.e., the cognitive workload is increasing for individuals and groups alike when it comes to complex problem solving. The issue of what motivates groups to make use of certain types of information and not others, thus creating a certain decision dynamic, is an important one in bringing about change related to complex problems.

To help orient our research, we enumerated twenty-one aspects of groups, information technology use, and/or decision making for complex problem solving in a review and synthesis of fifteen theoretical frameworks (Nyerges and Jankowski 1997). No aspect of any theoretical framework was intentionally left out of the enumeration; that is, the list is inclusive. Of the theoretical frameworks, adaptive structuration theory (AST) treated the most number of aspects (fifteen), including core concerns regarding use of advanced information technology in a group setting. AST was originally developed to explain the dynamics of advanced information technology use to help structure information development for decision making, directing change at the intraorganizational and organizational levels concerned with private organization problems (DeSanctis and Poole 1994). Furthermore, AST was created from a reconstructionist perspective, which is why the term "adaptive" is used in the name (Orlikowski 1992). Enhanced AST (EAST) broadens AST by adding the remaining six aspects from the inclusive list (Nyerges and Jankowski 1997); hence, all aspects of all fifteen theoretical frameworks in the review are represented in EAST.

EAST's twenty-one aspects are significant because they comprise the details of a conceptual domain that correspond to potential variables in a methodological domain, forming the basis of theoretically informed em-

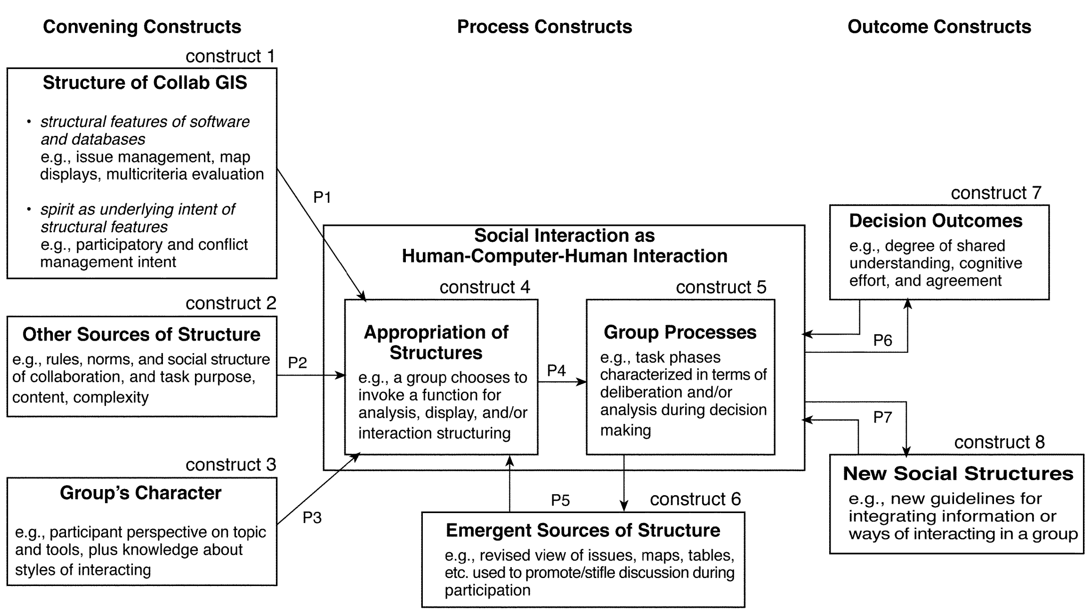

Figure 1. The EAST framework, consisting of convening, process, and outcome constructs (including example aspects) plus the respective premises (see Table 1), provides a conceptual map for understanding a group decision support situation.

Table 1. Research Questions Motivated by Aspects and Premises in EAST

Premises	Research Questions
Convening Concerns	
Premise 1. Various information structures can be appropriated.	• What is the relationship between the usage of maps and decision models? (**Hypothesis 1**) • What kinds of decision models are appropriated in relation to maps? (**Hypothesis 2**)
Premise 2. Social rules guide the type of information structure appropriation.	• What social norms or rules from various stakeholder organization(s) influence appropriation? • How does task complexity (as established by number of sites and criteria used) influence what maps and decision models are appropriated? (**Hypothesis 9**)
Premise 3. A group's internal social system influences appropriation.	• How do the different stakeholder perspectives influence the types of decision aids appropriated? • Does prior knowledge/experience with decision aids promote more use of maps and decision models? (**Hypothesis 3**) • Does knowledge acquired through group decisionmaking participation promote more effective use of decision models? (**Hypothesis 4**)
Process Concerns	
Premise 4. Appropriation during decision phases influences dynamics of decision (social) interaction	• What is the relationship between maps usage and decision phases? (**Hypotheses 5 and 6**) • What is the relationship between decision model usage and decision phases? (**Hypothesis 7**) • Are there differences in the level of group conflict associated with different decision phases? (**Hypothesis 8**) • Does task complexity influence appropriation during a given phase?
Premise 5. Emergent structures influence the dynamics of the decision process.	• What new kinds of information structures are called for as a result of group interaction at the inter-organizational level? • What new information emerges as a result of changes in task management?
Outcome Concerns	
Premise 6. Appropriation and phasing during decision process influences decision outcomes	• Do differences in stakeholder (organizational) perspectives and lower or higher levels of group conflict result in continued collaboration? • What is the general consensus about the use of information technology in a meeting environment?
Premise 7. Initial conditions and decision processes influence reproduction of social structures.	• Does the relative percentage of time committed to map use during a decisionmaking process have any influence on decision outcomes? • Does the relative percentage of time committed to multiple criteria decision model use during a decisionmaking process have any influence on decision outcomes?

Note: Research questions addressed in the article are denoted by their respective hypotheses. Premises 5, 6, and 7 are not addressed in this article.

pirical research studies (Brinberg and McGrath 1985). Among the most significant of the six EAST aspects not present in AST are those that deal with stakeholder groups at the interorganizational level whose main concern is public problems, where a spatial component is quite often part of the decision problem. Thus, the conceptual domain for EAST includes at least the three kinds of settings and three levels of aggregation mentioned above, as well as an orientation toward public-private problems, some of the biggest challenges facing applications of GIS in society as we enter the twenty-first century.

The eight constructs of EAST are grouped according to *convening*, *process*, and *outcome* categories to communicate their role in decision situations (Figure 1). The *convening* constructs articulate what is important in setting up a decision task: the organizations to be represented, the people from those organizations who are to participate, and the information technology that can be made available. The *process* constructs include the dynamics of invoking decision aids, managing decision tasks from phase to phase, and the emergence of information structures such as maps, models, and databases. The *outcome* constructs and associated aspects include direct outcomes related to the specific decision task, and the social relations created, evolved, and/or destroyed when the task is complete. Each of the eight constructs is presented with example aspects of a decision situation, fostering a better understanding of the particular concerns associated with decision support.

The design, implementation, and analyses of our experimental study about human-computer-human interaction made use of the EAST constructs and aspects in a direct manner. The constructs and respective aspects guided development of research questions (articulated in Table 1, to be discussed later), whereas the variables corresponding to the aspects formed the basis of the hypotheses to be tested. As such, EAST helped us link conceptual aspects of human-computer-human interaction to experimental variables that focused on the selection of habitat redevelopment sites in the Duwamish Waterway of Seattle Washington—an interorganizational decision task. Since our interest during the experiment concentrated on the interaction between decision support tools and decision situation, the EAST framework helped to illuminate the potential influences of a decision situation on the use of decision aids, and the reverse influence of decision aids on the decision situation. Researching this mutual influence is the crux of a reconstructionist approach, i.e., the adaptive nature of information technology use (Orlikowski 1992). Each of the eight constructs, together with the more detailed aspects thereof, is described below.

Convening Constructs and Aspects in Collaborative Spatial Decision Making

Among the convening constructs of a decision situation are the group of people who come together to resolve a decision situation(s) (construct 3), the social structures and institutional arrangements that provide an organizing context for the situation (construct 2), and the information structures that people will use to address the issues that are part of the situation (construct 1). There are several aspects to each of these constructs.

In this study, the participants responded to a flier that called for people to participate in an "environmental decision making experiment focusing on habitat redevelopment site selection in the Duwamish Waterway of Seattle, while making use of GIS." The research team counted on participants' familiarity with phrases in the flier to encourage them to investigate the activity. Not all people who investigated the activity became a part of the participant pool, usually due to either lack of further interest or time constraints. Those that did participate in the experiment were probably attracted by the one or more of the following phrases: "environmental decision making," "habitat site selection," and/or "GIS use." Aspects (variables) of a group include the type of background they have in the subject of a problem, their expertise with software tools, and the personalities they bring. Together, these aspects form the character of a group. Getting the appropriate people together to address a situation is as challenging as the situation itself, because it is the people who will turn the collaboration into a success or failure (Wood and Gray 1991). We suspected that participants with interest and/or background in environmental decision support would be able to at least try to work together, although they had no mandate to do so other than interest. To help with this background and perspective issue, we asked participants to adopt one of five stakeholder perspectives, which included a regulatory agency representative, elected official, technical expert, environmentalist, and business leader. Each perspective was described in terms of stakeholder values in a concept document compiled by a habitat restoration panel organized by the National Oceanic and Atmospheric Administration (NOAA 1993).

Social and organizational structuring (construct 2) is likely to have a major influence on decision making. Aspects of that structuring include the task goal and structure as well as the organizational rules adopted by a group. Research on interorganizational collaboration suggests that one of the most significant reasons people (organizations) collaborate is because they share a concern (goal) about a topic and want to see something done, even if for different reasons (Wood and Gray 1991). Using that finding to frame our approach, we stated in our fliers that the purpose of the experiment was to better understand "habitat redevelopment site selection," a topic that is somewhat popular among citizens of the Pacific Northwest. We had a reason to believe that manipulating the complexity of the task might have an effect on the types of decision support tools used and the nature of the process (Renn, Webler, and Wiedemann 1995). From a theoretical perspective, each new task definition brings about a different decision situation; thus, we encourage readers of this article to imagine reapplying the EAST framework (Figure 1) to our attempts to characterize decision processes relevant to those tasks.

The information technology (construct 1) available to a group can foster or hinder the way information is created and used. It has been shown that group-based information technology can help larger groups come to a quicker understanding of an array of ideas than is possible without such technology (Vogel 1993). GIS technology has been growing in popularity as a data integration tool. Decision modeling technology has been growing in popularity since its introduction on a PC platform. We presumed that group support technology that integrates these two kinds of technology would be an interesting combination of tools that could provide significant synergy for efficient, effective, and more equitable participation in decision making processes. In this project we developed a software extension for ArcView2 (1995) to generate specialized maps, linked that to a set of multiple criteria decision models, and linked a group voting tool to both of those to create a software system called Spatial Group Choice (Jankowski et al. 1997). Comparing a variety of information structures generated by that tool formed the basis of the decision support aspects treated in this construct.

Process Constructs and Aspects in Collaborative Spatial Decision Making

Among the process constructs of a decision situation are the way sociotechnical structures are invoked at any given time (construct 4), the way a decision process (task) is managed (construct 5), and the type of information that emerges during the process (construct 6). Together, these constructs form the basis of human-computer-human interaction during information use.

Invoking the structures for technology and rules is called *appropriation* (construct 4). The way technology is invoked includes exactly what software and databases are put to use. Hence, we intended to sample the group uses of all maps and tables invoked through the Spatial Group Choice software. Technology is often appropriated and put to use in ironic, i.e., unexpected ways, but these are not understood as right and/or wrong (DeSanctis and Poole 1994). We expected to be able to sample such uses.

As information technology is put to use, in whatever form, planning/decision tasks are managed in various ways to enhance/hinder the chance of successful outcomes (construct 5). Decision processes are commonly managed as a set of task activities that require social interaction. Thus, sampling these "social moves" was important to sampling the decision process. Several researchers have described decision processes in group settings that helped frame our understanding. Simon (1977, 1979) describes managerial decision making in organizations as a rationally bounded process involving four steps: intelligence gathering, design of a problem structure, choice of a set of alternatives, and review of the process. Renn et al. (1993) describe a public participatory decision making process, used in both the U.S. and Germany, consisting of three steps: values-criteria development, alternatives assessment, and alternatives evaluation (see also Schneider, Oppermann, and Renn 1998). There is also evidence that many people perform decision making in something akin to cycles, i.e., as an iterative process (Poole and Roth 1989; Bhargarva, Krishnan, and Whinston 1994). Part of the study involved investigation of the dynamics of decision process in the context of geographic information technology use.

As technology is put to use, and as project tasks are managed, certain information emerges from the process (construct 6). The emergence of information during the process reinforces whether technology should be continually put to use. New databases and/or maps may emerge from the social interaction. When information emerges that is useful, this intermediate result encourages the continued appropriation of technical capabilities and rules. Sampling these requests of the group was part of the data gathered for "emerging information."

Several researchers (e.g., Rohrbaugh 1989; Todd 1995) recommend that decision research should emphasize "process" rather than "outcomes," which were emphasized in the 1980s, particularly in experimental settings. In terms of outcomes that can be compared to other studies, because experimental settings are contrived, researchers are less likely to identify meaningful results than to identify spurious ones. For this reason, our experimental study also focused on process dynamics, as opposed to outcomes. Nonetheless, the EAST framework is still useful for casting the character of outcomes because the framework as presented here can be used for framing studies using any research strategy, including field experiments, case studies, sample surveys, usability studies, and laboratory experiments.

Outcome Constructs and Aspects in Collaborative Spatial Decision Making

The outcome constructs of a decision situation include the decision outcomes (construct 7) as well as the social relationships among participants (construct 8). Sampling the character of outcomes can provide researchers with valuable information to use in understanding the directed nature of processes. Given the multiple criteria by which a group decision outcome (construct 7) can be assessed, it is likely that no single "correct" decision exists. Consequently, there are several aspects of decision outcomes that are important. Among them are the substantive nature of results discovered, the satisfaction with and consensus regarding those results, and the efficiency, effectiveness, and equity associated with the results.

Changed participant relationships (construct 8) are often seen as outcomes of decision processes due to the intense social interaction involved. Some relationships are created, others reinforced, others tarnished, and still others broken. Change in social relations is an inherent part of decision situation interaction. As with decision outcomes, social outcomes are less meaningfully observed in an experimental setting than in a field setting. Consequently, this study did not directly pursue research on this aspect of the collaborative decision situation.

Research Questions Motivated by Premises in EAST

The constructs and aspects of EAST provide a guideline for sampling data. However, the principal reason the constructs and the aspects of them exist in the way they do is that each pair of constructs is related through a "premise" (sometimes called a proposition in various pieces of literature). DeSanctis and Poole (1994) articulated seven premises in AST related to the use of advanced information technology in decision settings. Although we retain those same premises in EAST, the interpretation is somewhat broadened due to the enhancements of the constructs as described above. Each premise motivates a series of research questions (see Table 1) and subsequent hypotheses. It is these premises and related research questions that comprise the explanatory character of EAST. Without the premises, the framework is simply a descriptive task model.

Research Design

Our research design involved a laboratory experiment setting in which we were able to videotape participants in groups working with computer-oriented geographic information. The following description of the research design includes the sociobehavioral setting, subjects, decision tasks as treatments, and research instruments for data capture.

The sociobehavioral setting involved groups of five participants assisted by a facilitator/chauffeur using specially developed collaborative spatial decision making software in a decision laboratory. Our choice of five-person groups stems from Vogel's (1993) review of several experiments in GSS research that showed mixed results with groups of three or four, but beneficial results starting with a group size of five. The facilitator/chauffeur provided less mediation than would a facilitator in a large group, and more software (technical) support with the overall problem than would a chauffeur. (In the remainder of this article, we will refer to this role simply as "facilitator.")

The CSDM software, called Spatial Group Choice, is a research prototype described elsewhere in greater detail (Jankowski et al. 1997). The software has two modules. The *Spatial* component is a GIS/mapping module comprised of ArcView 2.1™ software from Environmental Systems Research Institute (ESRI), with a specially configured, simplified user interface and a set of functionality developed with the aid of ESRI's Avenue™ scripting language. The following maps are available in the GIS/mapping module:

Bar Map: display of site attribute values using bars, as in a bar chart
Consensus Rank Map: display of consensus rankings of the sites using circles
Graduated Circle Rank Map: display of site ranks using graduated circles
Site Location Map: site locations and names only
Orthophoto Image: shows area using a photo image
Previous Rank Map: display of current and previous site ranks using bars
Situation/Context Map: situational/contextual characteristics for the sites

The decision modeling component, Group Choice, uses multiple criteria decision models for prioritizing alternatives using various weighting and aggregation schemes, together with a group voting capability. The following multiple criteria modeling aids are available in this module:

Select Criteria: dialog box used to select the criteria, which the group uses for decision modeling
Criteria Valuation: dialog box used to value the criteria
Pairwise Comparison: weighting method where each criterion is compared against every other for preference
Ranking: weighting method that assigns ranks to each criterion on a scale from 1 to 9
Rating: weighting method that allocates 100 points across all criteria
Select Alternatives: dialog box that reduces the number of alternatives considered in the decision modeling
MCDM Window: use of the weights or the decision model evaluation scores and rank list
Sensitivity Analysis Window: use of the sensitivity analysis window

The maps in the Spatial component are meant to provide a synoptic view of information about habitat sites, taken to be the options in the decision task, that are described by attributes of those options. The MCDM tables in the Group Choice component depict options and priorities based on criteria (selected attributes from the Spatial component) as the fundamental basis of decision making from an analytical perspective. In addition, the Spatial component links to the Group Choice component to depict graduated symbols that show rank priority. Decision research is about sorting through criteria associated with "values" and options described in terms of those criteria and setting priorities for those options.

The decision lab used for the experiment, located in the Department of Geography at the University of Washington, included six 486 PC stations with seventeen-inch graphics monitors connected to a local area network (LAN). The six PCs were configured in a U-shaped layout so that the five participants and the facilitator/chauffeur (the latter played by the same research assistant throughout the study) could see each other and the public display screen with relative ease. One station was specially configured for use by the facilitator/chauffeur to drive the public display screen. The Spatial Group Choice software installed on the facilitator/chauffeur's station contained several special features to facilitate group interaction.

The study used 109 participants formed into twenty-two groups (one group had only four members). They were recruited from across the University of Washington campus, and in a few cases from off campus, through announcements in classes and fliers posted on bulletin boards around campus.[2] No special competence was sought, only an interest in the environmental decision task to be undertaken.

Of the 109 participants, 104 finished the study. The average age of the participants was 28 years. The average education attainment was close to completion of an undergraduate degree, although there were several graduate students and participants from off campus with an interest in GIS and habitat restoration. Rating "attitude toward working in groups" on a 5-point Likert scale (−2 = strong dislike, 0 = indifferent, and 2 = strong like), the participants rated an average of .72. Rating "previous work-group experience" on a 4-point Likert scale (0 = none, 1 = experiment group only, 2 = some work experience, and 3 = management), the participants rated an average of 2.12. Rating "working with computers on a per week basis" on a 4-point Likert scale (0 = none, 1 = 1–5 hours/week, 2 = 6–20 hours/week, 3 = greater than 20 hours/week), the participants rated an average of 2.02. Rating "experience with using GIS maps" on a 4-point Likert scale (0 = do not know, 1 = heard about it and tried, 2 = use some, 3 = use frequently), the participants rated an average of 1.21, which indicates that overall the participants were GIS map novices. Rating "experience with using MCDM models" on a 4-point Likert scale (0 = do not know, 1 = heard about it and tried, 2 = use some, 3 = use frequently) the participants rated an average of 0.90, which indicates that overall the participants were also MCDM model novices. Rating "experience with habitat restoration" on a 4-point Likert scale (0 = none, 1 = education only, 2 = work only, 3 = education and work experience) the participants rated an average of 0.95, which indicates the vast majority of participants were novices in experience with habitat restoration, as well as in use of both GIS tools.

We adopted a realistic decision task to structure our treatments about site selection for habitat restoration (development) in the Duwamish Waterway of Seattle, WA (see Figure 2). The decision task was being performed by the National Oceanic and Atmospheric Administration (NOAA) Habitat Restoration Panel (NOAA 1993) as a result of a lawsuit settled against the city of Seattle and King County for inappropriate storm sewer drain management. For years, storm sewer drains had been releasing unfiltered storm water containing highway gasoline and oil contaminants into Puget Sound (Elliott Bay), degrading fish and wildlife habitat. A GIS database for this site selection problem was compiled from Seattle and King County sources. The site selection decision process was expected to involve conflict management during social interaction due to the different perspectives inherent in the views of participating members. Thus, these site selection activities were particularly interesting from the standpoint of software tool use and its interplay with group interaction.

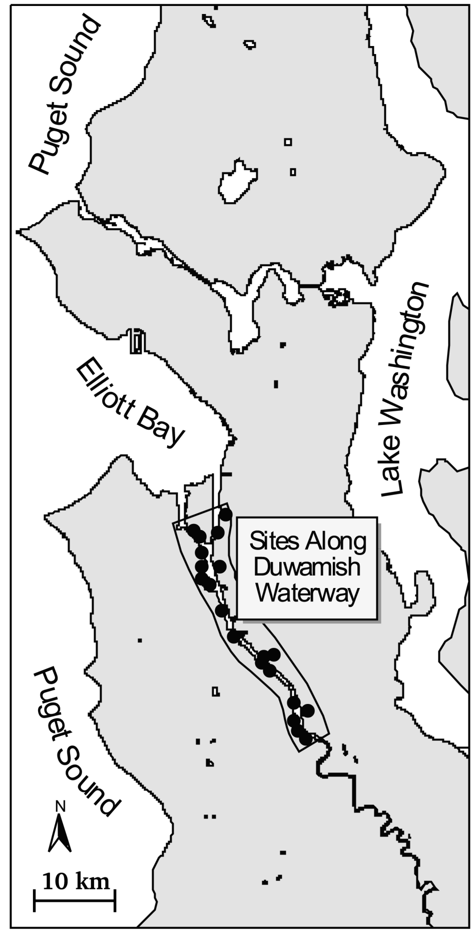

Figure 2. Map representing the decision situation area used in the experiment, the Duwamish river corridor with twenty restoration sites. The gray-shaded land area represents the city of Seattle.

Each decision group met for five sessions, one in each of five consecutive weeks (or as close as possible to that schedule), and worked on a different version of the habitat site-selection task.[3] In each of the five sessions we asked each group to work toward consensus on the selection of three preferred sites (or as many as the $12 million budget would allow) out of the total number of sites presented to them. The total number of sites varied from eight to twenty. At the end of each session, we asked each group to fill out a questionnaire, which provided a means for the individuals to assess group use of the tools, group interaction, and the level of satisfaction with the overall group selection.

We used a counterbalanced repeated measure design for the treatments (Girden 1992). The treatments involved varying: task complexity as the number of sites (eight versus twenty), cognitive conflict as the number of criteria (three versus eleven per site), and access to technology (group and individual access versus group-only access). With the group-only access to technology, the number of sites was set at twenty and the criteria at eleven. A total of five tasks were constructed and numbered from one to five. Groups were randomly assigned a task number for their first session. They were given a new task sheet in task sequence at the beginning of each of the five sessions, and thus cycled through all five tasks by the fifth session. Although we set up the experiment to examine cognitive conflict by varying criteria, we later deduced that this was a change in task complexity as well. Consequently, we did not bother to examine cognitive conflict, but instead looked at task complexity as a variation in both number of sites and number of criteria, with the simplest task involving eight sites and three evaluation criteria per site the most complex task involving twenty sites and eleven evaluation criteria per site. In general, we expected that the information technologies would have more positive influences as the task complexity increased.

Data were collected by session (and hence by task) using questionnaires and coding interaction of videotapes. Each participant filled out a background questionnaire (education, sex, age, etc.) and attended a two-hour collaborative spatial decision making software training session. At that time, we passed out materials introducing the overall wildlife habitat site-selection task, assigned the participants to groups based on schedule availability, and handed out stakeholder roles that they could adopt by the time their first decision session convened. Based on interviews completed by the NOAA Restoration Panel (NOAA 1993), these roles included those of business/community leader (twenty participants adopted it), elected official (ten adopted it), regulatory/resource agency staff member (twenty-two adopted it), technical/academic advisor (twenty-three adopted it), or environmental group representative (twenty-nine adopted it). Roles were self-selected to encourage subjects to participate based on their inherent interests. We made sure that no less than three different stakeholder roles were represented in each of the groups.

Group interaction was videotaped in each session. A total of seventy-four sessions were used for coding, due to group participant attrition within the requirement for five-person decision sessions. Our data sources for our eventual data analyses were this videotaped record and the session questionnaires. As we were interested in both software tool use and the overall group interaction, we focused one video camcorder on the public display screen and another camcorder (with a remote microphone that hung overhead in the middle of the participants) on the group interaction.

We developed and used a set of interaction coding systems to perform data capture from videotapes on which we recorded the use of CSDM software as a process of group interaction. An interaction coding system is a set of keywords that reliably summarizes the character of a process from a thematic perspective. We make use of three coding systems developed for this research: a decision aid coding system to describe what decision aids are being used, a decision phases coding systems to describe what phases exist, and a group working relations coding system to describe group conflict (Nyerges, Moore, Montejano, and Compton 1998). Each of the coding systems is described in more detail in the section of this article where we report our findings.

Coding was implemented at the level of "group attention." Group attention is a level of attention whereby at least four out of five participants show head-directed awareness of a group conversation/discussion underway as the predominant activity in a given time cell. A time cell is a one-minute interval (called a count) using which the predominant event/activity occurring is observed and coded to a database. Thus, for each coding system we created an event/activity sequenced track, observing the videotape three times to code the three coding system tracks needed to create entries in the database for each videotape session. Although we used a code category called "individual work" in the group working relations coding system, we did not code any details about such work, since our focus was on "group attention." Group attention leads to "social cognition," which is different than "individual cognition" (Golay and Nyerges 1995). Therefore, the research associated with "individual attention"—individual map use coding as reported throughout the cartography literature—was not applicable to our work on "group attention" coding. We devised a "map use coding" system in our initial work on coding systems, but did not implement it because of our focus on decision aid "appropriation." We leave work on map use and its relation to appropriation to a near future research effort.

To create the database, a SVHS video recorder was connected to a Macintosh computer running the MacSHAPA software (Sanderson et al. 1994). This software is specialized to perform exploratory sequential data analysis, which is defined by Sanderson and Fisher (1994, 225) as

> . . . any empirical undertaking seeking to analyze systems, environmental, and/or behavioral data (usually recorded) in which the sequential integrity of events has been preserved. The analysis of such data (a) represents a quest for their meaning in relation to some research or design question, (b) is guided methodologically by one or more traditions of practice, and (c) is approached (at least at the outset) in an exploratory mode.

However, in addition to data analysis, MacSHAPA also provides an outstanding set of capabilities for sequential data collection from videotape. An interpreted data observation created by MacSHAPA, a concept used frequently in the analyses below, is termed a "move." MacSHAPA can aggregate several one-minute counts of the same contiguous code into an interval-event. A move is a change in an event within a coding system, e.g., a move from one type of map to another type of map, or one decision phase to another decision phase. Thus, moves are "social event-coding changes" that are coded at the level of "group attention." We recognize that "map moves" in particular and "decision aid moves" in general are not strictly speaking the same as "use," if we interpret use to be a "set of operations on a decision aid." However, as mentioned earlier, the map use coding system not yet implemented has been left for a future research effort. Consequently, we use "moves" and "cell counts" as the basis of our analysis to mirror what has been used in other group decision support research (DeSanctis and Poole 1994).

Findings

The research questions outlined in Table 1 guided the development of hypotheses, which cluster into four categories. The categories are associated with EAST premises 1 to 4 respectively. Under premise 1, we report on the relationship between appropriation of maps and appropriation of decision models during human-computer-human interaction. Under premise 3, we report about group member experience and its influence on appropriation of decision aids. Under premise 4, we report on appropriations of decision aids and the dynamics of the decision process, described in terms of phases. Finally, under premises 2 and 4, we report on the relationship between decision processes and group conflict. In all sections, we express a hypothesis in terms of a null hypothesis.

Our selection of hypotheses to be tested was driven by the experimental treatments allowing us to control for task complexity and group access to decision support tools. In general, we expected that maps and decision models would have more positive influences on group decision processes as the task complexity increased. In this research, we were interested in a group response to a spatial decision task considering varying groups' familiarity with decision support tools. We did not collect data on gender, because we randomized this variable, trying not to bias male and female participation in a group. However, some groups had more males and some groups had more females due to scheduling preferences.

The selection of hypotheses for this study does not incorporate research questions about new information structures likely to emerge from group interaction during the course of solving a spatial decision task (premise 5 in Table 1) because groups were limited to the technology provided to them. A hypothesis around these questions could be formulated more readily for a field experiment or a case study where participants are free to identify new information structures at will. Our hypotheses concentrate on the group use of technology during a decision process. They do not address research questions about process outcomes (premises 6 and 7 in Table 1) because researchers seem to agree that testing such concerns in a laboratory experiment is a meaningless endeavor due to the absence of consequences (Rohrbaugh 1989; Todd 1995). Again, such hypotheses could be included in a future field experiment or a case study involving an organizational setting with real stakeholders and decision makers.

Appropriating Maps and Decision Models

The hypotheses in the first group, derived from premise 1 focus on appropriations of maps and decision models during collaborative spatial decision making. The frequency and type of interaction between maps and multiple criteria decision models used during group decision process have not been reported in the literature.

Hypothesis 1: *No relationship exists between the number of map moves and the number of MCDM moves.* We tested hypothesis 1 using a Pearson correlation statistic. The value of the Pearson correlation coefficient ($r = -0.124, p = 0.001$) is statistically significant, but the correlation is very low. Although we reject the null hypothesis, the result indicates a very weak inverse relationship, meaning that the map moves and MCDM moves are not likely to occur in a systematic manner across tasks. To determine whether task complexity had any effect on the interaction between the number of map moves and the number of MCDM moves, we used a General Linear Model (GLM) statistical procedure (SPSS Base 8.0 1998). A GLM procedure provides regression analysis and the analysis of variance for one dependent variable by one or more factors and/or variables. The dependent variable was map moves, the covariate was MCDM moves, and the factor was task complexity. Task complexity ranged from task 1 (the least complex, 8 sites and 3 evaluation criteria) to task 4 (the most complex, 20 sites and 11 evaluation criteria). The model explains only 8% of the variability between the use of maps and multiple criteria decision model aids (adjusted $R^2 = .081$, $F = 10.682$, $p = 0.000$), and task complexity is not a significant effect in explaining variability ($F = 1.368$, $p = .252$). However, there is an interesting relationship between map moves, MCDM moves, and task complexity that is not captured by the above model (see Figure 3). The increasing task complexity is accompanied by an increasing number of MCDM moves and decreasing number of map moves. This indicates a dichotomy between multiple criteria decision model aids and maps: multiple criteria decision model aids were used more frequently in more complex collaborative decision tasks, whereas maps were used more often in simpler tasks.

Discussion of findings for Hypothesis 1. We were especially interested in the extent to which maps were used concurrently with MCDM aids. However, based on our findings, we can only conclude that participants used maps more often independently from MCDM aids than in concert with them. During the entire experiment (74 sessions), maps and MCDM aids were used together 34.4% of the time (conjunctive map use). In the remainder of cases (65.6%), maps were used independently from MCDM aids (disjunctive map use).

The four types of map most frequently used were the bar map, site location map, situation map, and orthophoto images (see Figure 4). The bar map was used most frequently in conjunction with the MCDM functions that support criteria selection, criteria valuation, and prioritization (67% of the total conjunctive use of this map in the experiment). This finding validated our intended use of the map: i.e., the bar map was included in Spatial Group Software to help support decision criteria selection and the elicitation of criterion weights. The other three maps (site location map, situation map, and orthophoto) were used most often in conjunction with the tabular output of ranked sites (71% of the total conjunctive use of these maps). This finding tells us that general-purpose maps are used predominantly to visualize the locations of decision alternatives and can potentially be used to evaluate tradeoffs among these alternatives.

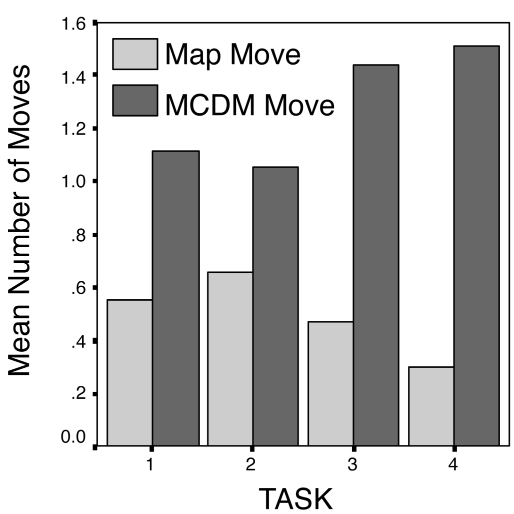

Figure 3. Mean of map moves and MCDM moves by experimental task.

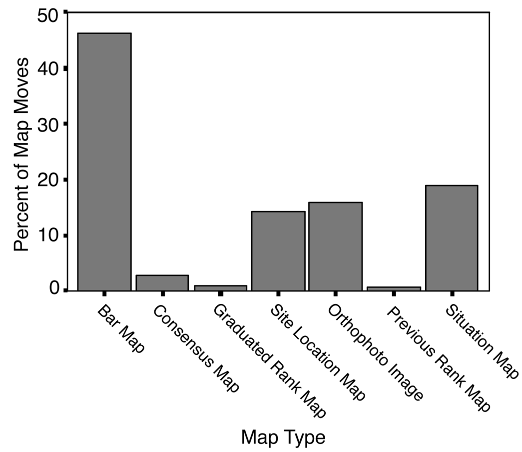

Figure 4. Frequency of map use expressed as the percentage of map moves by map type.

The combined use of two maps intended for the presentation of site evaluation results—graduated circle rank map and previous rank map—comprised less than 2% of the total map use. This was surprising, because these maps were designed to combine rank information from the multiple criteria tables with the site locations. Furthermore, a third map, called the consensus rank map, was intended to combine the results of consensus voting, which we thought would provide significant information for the participants, but its use comprised only about 3% of the map moves. Perhaps the groups did not need to make use of rank and consensus maps very often in their conversation because of the "rich information display." Alternatively, perhaps a basic map showing site locations together with a list of ranked sites is easier to interpret than a map that includes both the location and the rank. The more complex maps, such as the graduated circle rank map, previous rank map, and consensus rank map, might have been harder to use for those not accustomed to using specialized maps. Another alternative explanation for this finding might be that individuals used these maps at their own workstations, but the group as a whole did not have the facilitator project the maps on the public display. Since we coded "group attention"—that is, what was on the public display—we do not have data on individual map use at each workstation. Either keystroke logging or a minimum of three more video cameras would have been needed to capture and code individual map use.

Hypothesis 2: *No relationship exists between specific MCDM aids used by participants and the number of map moves accompanying the use of these aids.* The value of Pearson's correlation coefficient between the MCDM aids used by the participants and the corresponding map moves ($r = -0.048$, $p = 0.213$) was not statistically significant; hence, we accept the null hypothesis of a lack of a relationship. To determine whether the use of specific MCDM aids had any effect on the interaction between the number of MCDM moves and map moves, we used a GLM statistical procedure. The dependent variable was MCDM moves, the covariate was map moves, and the factor was MCDM aids. MCDM aids were encoded by 12 categories. These categories included 8 aids as described above under the capabilities of Geo Choice module, 3 combinations of these aids, and the category "None" to represent the absence of using MCDM aids at a given observation interval. The model explains 58% of the variability of MCDM moves (adjusted $R^2 = .575$, $F = 26.714$, $p = 0.000$); however, almost all of it is explained by the category of MCDM aid used ($F = 26.792$, $p = 0.000$). The covariate—i.e., map moves—is insignificant ($F = 0.011$, $p = 0.917$) and does not contribute to explaining the variability of MCDM moves.

By far the most map moves were invoked independently of any MCDM aid. There were three multiple criteria decision model aids that attracted a higher number of map moves than others: MCDM Window, Select Alternatives, and Select Criteria. Combined with the frequency of map use (see Figure 4), this suggests that specialized thematic maps (graduated symbol maps), reference maps representing the distributions of auxiliary data themes (other than the decision criteria), and high resolution areal images (orthophotos) can be useful in selecting evaluation criteria and evaluation tradeoffs among the sites options.

Discussion of findings for Hypothesis 2. There is little or no evidence to support an assertion that maps included in Spatial Group Choice software were effective in prioritizing evaluation criteria, displaying the results of sensitivity analysis, and affecting the position of the group on the final ranking of decision alternatives. The questions of how to improve the existing maps and which direction should be taken in the design of new types of maps and visualization aids are open ones. We offer some suggestions in this matter in our conclusions below.

Group Member Experience and Its Influence on Decision Aid Appropriation

The hypotheses of the second category, following from premise 3, focus on the relationship between prior knowledge and acquired experience (the latter during group decision making sessions) in relation to the frequency of use of maps and decision models. Previous experiments with nonspatial group decision support systems found a "learning effect," in that the frequency and effectiveness of decision aid appropriations increased with prior experience with computer-supported group decision making processes (Chun and Park 1998). In addition, previous studies report a learning effect in the use of decision aids that results from frequent participation in a single computer-supported group decision making task (Chun and Park 1998). However, the transferability of those research results to collaborative spatial decision making is questionable because of differences between business decision problems used in the past research experiments and the spatial decision problem used in this study.

Hypothesis 3: *No relationship exists between the frequency of decision aid moves—both MCDM aids and maps—and the prior knowledge of/experience with decision support aids of group members.* To address this hypothesis, we classified all participants into four levels of prior knowledge/experience. The classification was based on participants' responses to a background survey questionnaire completed by each one prior to the experiment. The questions included "What is your experience with using GIS-generated maps?" and "What is your experience with multiple criteria decision models?" The responses were summarized using the frequencies of rank codes corresponding to "do not know," "heard about," "used some," and "used frequently." We used an analysis of variance (ANOVA) procedure to analyze the differences in the means of the variable representing user's knowledge/experience. The dependent variable was the frequency of decision aid use and the independent variable was the level of user knowledge/experience. The differences in the means were not significant for all levels of knowledge/experience ($F = 0.742$, $p = 0.531$); hence, we accept the null hypothesis.

Discussion of findings for Hypothesis 3. The result might be explained in several ways. Perhaps we did not have a sufficient range or data to distinguish participant expertise. Perhaps, unexpectedly, the use of decision support aids in the experiment (maps and simple analytical evaluation techniques, at least) is independent of user experience with decision support aids. That is, maybe a certain minimum level of computer competency is all that is needed to make use of such aids. Another issue that may have influenced the result is educational background of an average computer user. Our participants came from different academic fields, but at a minimum they had completed one year of university-level studies. All participants were computer-literate, and over one half of them made use of a computer six or more hours per week.

Hypothesis 4: ***Knowledge and competency in using computerized decision aids, acquired through participation in the group decision sessions, do not promote more effective use of decision aids.*** We used as a measure of effectiveness the frequency of decision aid moves (MCDM aids and maps), in which higher effectiveness of using decision aids is characterized by fewer moves to access decision aid functions. To test this hypothesis, we performed a one-way ANOVA. The frequency of decision aid moves was the dependent variable and session number (SESSION) was the factor. The difference of means was significant for one pair only, i.e., the first session (1) and last session (5), respectively (see Table 2). Therefore, we reject the null hypothesis for that pair only. Remember that "session" is the sequence order 1, . . . , 5 of the randomized tasks 1–5; hence, the complexity of tasks 1–5 is not at issue. The bar graph of the mean frequency of decision aid moves per session (see Figure 5) shows a trend hinting at a learning effect. The effectiveness of using decision aids increases with the number of decision sessions. This observation is supported by a weak but significant negative correlation between the frequency of decision aid moves and session number (Pearson's $r = -0.3$, $p = 0.023$).

Table 2. Results of ANOVA for Session 1 and Sessions 2, 3, 4, and 5

(I) SESSION	(J) SESSION	Mean Difference (I − J)	Std. Error	p 95%
1	2	.7821	1.845	.673
	3	2.6154	1.939	.183
	4	2.6923	1.808	.142
	5	3.9154*	1.939	.048

* The mean difference is significant at the .05 level.

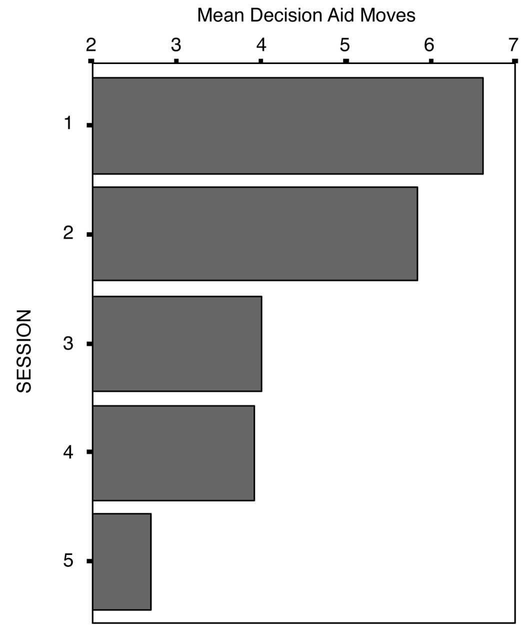

Figure 5. Mean number of decision aid moves per decision session.

Discussion of findings for Hypothesis 4. Although we did find a learning effect, we are skeptical of the results due to the limited number of sessions. More sessions in sequence and better measurements of effectiveness can provide data for a better test of the learning effect. Nonetheless, a recognizable diminishing number of decision aid moves was observed across the experimental sessions.

Decision Support Aids in Relation to Decision Phases

The hypotheses of the third category, following from premise 4, focus on relationships between the use of decision support aids, both maps and MCDM, and the phase of alternatives evaluation in the group decision process. Alternatives evaluation is the last phase of the three-step public participatory decision making process described above. During values-criteria development, stakeholders articulate what is important to them in a decision situation. During alternatives assessment, experts assign data values to alternatives that best characterize those alternatives in the context of the decision situation. During alternatives evaluation, stakeholders, the public, and/or experts identify what criteria are important and examine the tradeoffs among alternatives to prioritize them for a recommended solution to a decision situation. The Renn and Schneider studies (Renn et al. 1993; Schneider, Oppermann, and Renn 1998) reported only the results of noncomputer-supported decision processes. Consequently, little is known about how computer-supported groups might use aids at each phase of the decision process.

Our experiment implemented the alternatives evaluation phase of a participatory decision task as presented by Renn et al. (1993). Within the alternatives evaluation phase, we would expect to see four activities—perhaps better thought of as microphases—undertaken, as articulated by Simon (1977, 1979): intelligence (gather information), design (organize the information), choice (select alternatives), and review (reassess what was done). Consequently, we coded the decision phases based on the following activities:

FUNCS (Function Structuring): Group and/or facilitator activity with a focus on "what's next?" and "how do we want to do this?" with respect to which decision function to enter. This would include periods in which the group develops possible approaches to navigating through the decision functions or to deciding which function should be visited next.

PE (Problem Exploration): Periods in which the group attempts to gain a better understanding of the overall problem. The focus of the discussion is on learning about or investigating, the problem.

CI (Criteria Identification): Group and/or facilitator activity with a focus on identifying, discussing, and selecting criteria that are potentially important for the decision problem.

CV (Criteria Valuation): Group and/or facilitator activity with a focus on selecting the preferred method of valuing the criteria.

CP (Criteria Prioritization): Group and/or facilitator activity with a focus on differentiating the criteria to determine the relative importance of the criteria for the decision problem, or to gain a better understanding of individual priorities.

EA (Evaluate Alternatives): Group and/or facilitator activity with a focus on comparing and contrasting the alternatives.

SA (Select Alternatives): Group and/or facilitator activity involving statements about the group's actions that explicitly refer to the selection of alternatives, voting, or the reduction of the set of alternatives for the decision selection.

Hypothesis 5: *No difference exists in map moves with respect to decision phases*. We were interested to find out if the frequency of map appropriations differed in different phases of the decision process within the constraints of the predefined task. We tested this hypothesis using a one-way ANOVA procedure. The dependent variable was map moves and the factor was decision phase. The decision phases included 1) function structuring; 2) problem exploration; 3) criteria identification, valuation, and prioritization; and 4) evaluation and selection of alternatives. We also included category "none" to represent the lack of activity. The differences in map move means were statistically significant for evaluation/selection of decision alternatives, i.e., EA/SA only in comparison to other phases (see Table 3). Thus, only in the case of evaluation/selection of decision alternatives can we reject the null hypothesis and accept the alternative hypothesis suggesting significant differences in the mean of map moves with respect to decision phases.

Table 3. ANOVA of Map Moves by Decision Phases

(I) Dec Phase	(J) Dec Phase	Mean Difference (I − J)	Std. Error	*p*
EA/SA	CI/CV/CP	1.6486	.227	0.000
	FUNCS	1.9730	.227	0.000
	NONE	1.6157	.228	0.000
	PE	1.6757	.227	0.000

Note: Only the significant differences are presented in the table.

Discussion of findings for Hypothesis 5. The finding highlights an observation that groups used maps predominantly to visualize the evaluation results and much less to structure/design the decision problem. The question then arises: were the maps provided in Spatial Group Choice simply not adequate for problem exploration, criteria identification, valuation, and prioritization? Based on the analysis of variance, maps implemented in Spatial Group Choice played only a limited support role in the decision stages of the experiment. In an attempt to find an answer we examined the frequencies of map use by decision phase. We discovered that the two decision phases in which group participants used maps most frequently were evaluation and selection of alternatives (EA/SA) and identification, valuation and prioritization of criteria (CI/CV/CP; see Figure 6). The three maps used most frequently were bar map (BM) representing attribute values, site situation map (SM), and orthophoto image (OI). The high frequency of bar map use, especially in EA/SA and CI/CV/CP decision phases, demonstrates that participants found this specific type of multivariate graduated symbol map useful in elucidating tradeoffs among criterion priorities and in illuminating the ranking of decision alternatives. A bar map allows the user to visualize both quantitative relationships among the multiple decision criteria and their spatial distribution (Jankowski et al. 1997). The participants found this type of visualization helpful in making judgments about the rel-

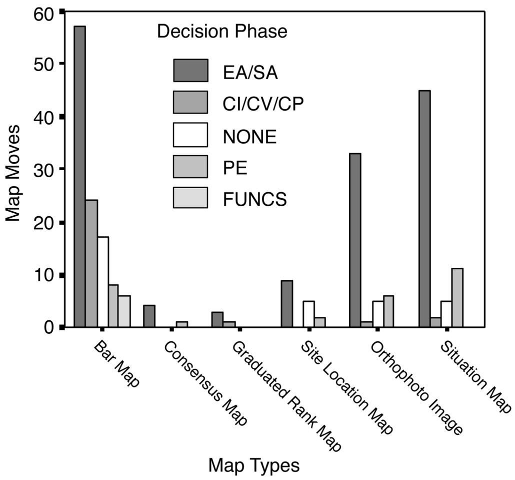

Figure 6. Frequency of map moves by decision phase.

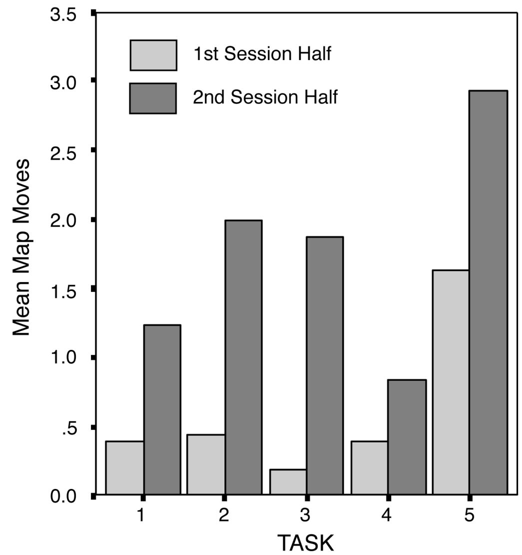

Figure 7. Mean of map moves in the two session halves of the experiment.

ative importance of decision criteria. We posit that the relative judgments about the importance of decision criteria are influenced by spatial relationships among the decision criterion values, and the visualizations of criterion outcomes in geographic space help elucidate these judgments. The high frequency of map moves for situation maps and orthophoto images, especially during evaluation/selection of decision alternatives, shows the usefulness of the general reference situation map and the very realistic orthophoto image in these areas.

Hypothesis 6: ***No difference exists between session halves in the frequency of using map aids.*** We tested this hypothesis with a paired-samples T-test statistical procedure. The results of the T test, with the first half mean = 0.62 and the second half mean = 1.84 ($t = -4.570$, $p = 0.000$), allow us to reject the null hypothesis and indicate a difference in the pattern of map use between the two session halves. In all tasks, maps were used much more frequently during the second, more analytical half of the experiment than during the first exploratory half (see Figure 7).

Hypothesis 7: ***No difference exists between session halves in the frequency of using MCDM aids.*** We expected to see less use of MCDM (analytical) aids during the first half of the session than during the second half, since the first half of each experimental session was expected to involve more exploratory discussion than analysis. We used a paired-samples T-test statistical procedure to test the hypothesis. The results of the T test were not significant ($t = -0.427$, $p = 0.670$), thus validating the null hypothesis and indicating a lack of difference between the session halves in MCDM moves. Additionally, the comparison of means of MCDM moves across the tasks confirmed that MCDM aids were used with similar frequency in both session halves.

Discussion of findings for Hypotheses 6 and 7. In contrast to the mean of MCDM moves, regardless of task complexity, the mean of map moves markedly differs between the two session halves for each task. We were surprised to find that the participants used MCDM aids without much difference between the two halves of the experiment in the frequency of moves. The Spatial Group Choice software used during the experiment offered the participants both analytical functions useful for alternative evaluation and exploratory/visualization functions that could potentially be used during the problem exploration phase. We speculated that the first, more "exploratory" half of the experiment would be marked by more frequent use of maps than the second half—but only because of anecdotal evidence about maps as exploratory aids in various literature. The much less frequent use of maps during the first half of experimental sessions indicates the possible need for new types of maps, such as those charting the lineage of collaborative discourse and problem structuration, as in a spatial understanding and decision support system (Jankowski and Stasik 1997; Moore 1997). However, it also points out the need for analytical visualization aids that might help in exploratory decision situations.

Group Conflict by Decision Phase

The hypotheses of the fourth category, following from premises 2 and 4, use as a point of departure the results of

Table 4. Group Work Conflict Code and Its Interpretation Source

Group Work Conflict—periods when the group is organized and working together, but members disagree with each other or express a different perspective on the topic. This may include attempts by group members to manage or diffuse the conflict (as listed below), or periods when the group is in disagreement because of a misunderstanding.

- **Opposition:** periods in which disagreements are expressed through the formation of opposing sides
- **Accommodation:** a mode of resolution of opposition in which one side gives in
- **Tabling:** a mode of resolution of opposition in which the subject is tabled or dropped
- **Negotiation:** a mode of resolution in which the group negotiates to manage conflict
- **Compromise:** a mode of conflict resolution in which the group compromises
- **Justification:** periods when a supporting rationale for a particular position is posed to the group for consideration

Note: The codes were extracted from the coding guide developed within the project and reported in Nyerges et al. (1998a).

many previous studies on group decision support systems, studies which analyzed the effect of computerized group decision support on conflict management (Chun and Park 1998). The findings were based on comparisons between nonsupported and supported groups. Based on these studies, there is strong evidence that electronic mail and anonymous voting, prominent features of group decision support systems, reduce conflict in collaborative decision making. Since we did not have control groups solving the decision problem without computerized decision support (i.e., nonsupported groups), we decided to analyze the relationship between decision phase and group conflict. We measured the level of conflict by the length of time during which the participants were engaged in conflictual activity as coded using the group work conflict (GWC) code within the group working relations coding system (Nyerges, Moore, Montejano, and Compton 1998). This code included several types of group work conflict (see Table 4).

Hypothesis 8: *No difference exists in the level of conflict by decision phase.* To test this hypothesis we used a one-way ANOVA in which the dependent variable was conflict level (measured by the length of time the groups were engaged in conflict situations) and the factor was decision phase. The results revealed an interesting dichotomy between the "intelligence gathering" phases (FUNCS and PE) and the "criteria or alternative evaluation" phases (CI/CV/CP and EA/SA; see Table 5). Both types of phases are internally homogeneous in terms of the conflict level, meaning that the differences within the intelligence gathering and evaluation phases are not significant. However, statistically significant differences in conflict level appear between the decision phase groupings.

Discussion of findings for Hypothesis 8. The finding indicates that different phases of computer-supported group decision making have different levels of conflict, an analytical-detail phase characterized by high conflict level and an exploratory-structuring phase characterized by low conflict level. Perhaps there was less conflict during problem exploration because interests and values were not at odds with each other. There was more conflict during criteria selection and alternative evaluation because specific interests surfaced. The higher level of conflict during evaluation phase tells us that analytical decision aids aimed at conflict management are likely to help move through conflict; such conflict now being rec-

Table 5. Results of ANOVA for Conflict Level by Decision Phase

(I) Decision Phase	(J) Decision Phase	Mean Difference (I − J)	Std. Error	*p**	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
CI/CV/CP	EA/SA	−.36	.375	.766	−1.33	.60
	FUNCS	2.31	.375	.000*	1.35	3.28
	PE	2.35	.375	.000*	1.39	3.32
EA/SA	CI/CV/CP	.36	.375	.766	−.60	1.33
	FUNCS	2.68	.375	.000*	1.71	3.64
	PE	2.72	.375	.000*	1.75	3.68
FUNCS	CI/CV/CP	−2.31	.375	.000*	−3.28	−1.35
	EA/SA	−2.68	.375	.000*	−3.64	−1.71
	PE	4.05E-02	.375	1.000	−.92	1.01
PE	CI/CV/CP	−2.35	.375	.000*	−3.32	−1.39
	EA/SA	−2.72	.375	.000*	−3.68	−1.75
	FUNCS	−4.05E-02	.375	1.000	−1.01	.92

* The mean difference is significant at the .05 level.

ognized as a necessary part of making progress in environmental disputes (Simosi and Allen 1998). This is an important finding for future designs of collaborative spatial decision support software.

Hypothesis 9: *No difference exists in the level of conflict between task 1 (least complex) and task 4 (most complex).* To test this hypothesis, we used a one-way ANOVA in which the dependent variable was conflict level (measured by the length of time the groups were engaged in conflict situations) and the factor was task complexity (tasks 1 and 4). The results showed the lack of statistically significant difference between the group conflict in tasks 1 and 4; hence, we accepted the null hypothesis. We then modified our hypothesis to include only tasks 4 and 5, assuming that the level of conflict between these tasks is different because of the difference in the organization of the collaborative decision making process (access to individual workstation and the presence of facilitator in task 4 versus the access to public screen only and the presence of facilitator in task 5). The results of the ANOVA indicate a statistically significant difference in conflict level between tasks 4 and 5 ($F = 5.504$, $p = 0.02$); hence, we rejected the modified null hypothesis.

Discussion of findings for Hypothesis 9. Our findings that task complexity was not associated with the level of conflict between task 1 (simpler) and task 4 (more complicated) are somewhat contrary to current literature. Renn, Webler, and Wiedemann (1995) present a diagram indicating that high levels of complexity are associated with higher levels of environmental conflict. However, their diagram also takes into consideration higher conflict being associated with a difference among three levels: knowledge level, experience and trust level, and worldviews and values level. Since all participants volunteered to take part in this experiment, and the experiment was situated in an environmental context, it is likely that most participants had similar environmental perspectives, even though we asked each participant to choose from four different stakeholder perspectives. Perhaps this finding results from the influence of a contrived, experimental setting versus a more realistic setting. A review of the participant database indicates that 28% of all participants chose to be aligned with an environmental stakeholder perspective. The results of the difference between task 4 and task 5 might be explained by the fact that people are more likely to voice conflict when they are talking to each other than when they are not talking to each other. Since task 5 probably involved more "public discussion" than task 4, given its use of only a public screen, observation of increased conflict was to be expected; participants had to talk through differences, rather than use individual work to examine alternatives before posing suggestions.

Conclusion

Our research helps fill a gap in knowledge about group use of geographic information systems applied to value-laden, public-private problems. The question of testing differences in information use versus software use often arises. To address this concern, we chose a "classic" site selection preference problem that dealt with emerging concern about habitat restoration in the context of nature-society debates. The geographic information used in the experiment was adopted from the realistic Duwamish Waterway decision task. The information was conveyed to participants through somewhat common map and decision table information structures (Nyerges 1991), and those information structures were implemented in GIS software. We purposely narrowed the information structures to those two to be able to address differences in the classic "tables" and "maps" concern: which is better for what activity? The information structures are general enough in nature that any GIS could implement them. Thus, we believe our findings address differences in information use as much as differences in software use, the two being intimately connected.

The findings reported here broaden and deepen our understanding of the conceptual underpinnings of GIS-supported collaborative decision making by way of empirical analysis linked to a theoretical base. Examining the premises and their respective hypotheses in EAST provides a way of systematically addressing research questions and subsequent hypotheses about the dynamics of geographic information (system) use in groups. Addressing research questions using an experimental design provides a foundation for examining details about decision process dynamics involving geographic decision aids. The existing research literature encouraged us to focus on decision process rather than decision outcomes. Researchers working on decision support topics in the management sciences suggest that process-based research is more meaningful than outcomes-based research in a laboratory setting, since the latter fosters little ownership of results (Rohrbaugh 1989; Todd 1995). From a case study perspective, Yin (1994) recommends a process-based approach for research contexts, even for field studies, and an outcomes-based approach for program evaluation contexts. Because outcomes in public (group) problems are often difficult to predict, Renn, Webler and Wiedemann (1995) and Wood and Gray (1991) also recommend process-oriented research.

Findings representative of four categories were developed in this study. One category of findings demonstrated that groups used maps predominantly to visualize the evaluation results and much less to structure/design the decision problem. Maps played only a limited support role in various decision stages of the experiment. The simplicity of the task might have constrained a more creative role for maps. In the second category of findings, while the use of multiple criteria decision models by groups remained steady throughout different phases of the decision process, the use of maps was much lower during the initial exploratory-structuring phase than during the later analytic-integrating phase. This was a bit surprising, since maps are thought to be idea generators. However, the simplicity of the task might again have accounted for the difference. In the third category of findings, neither the amount of prior group member experience with computer tools nor the amount of acquired group member experience with such tools had any influence on the appropriation of decision aids. The group backgrounds of participants were reasonably homogeneous in comparison to those of a cross-sample of the general population. We had very few "spatial professionals" with multiple years of experience. In the fourth and final category of findings, different phases of the decision process had two different levels of conflict. The exploratory-structuring phase was characterized by a lower level of conflict, whereas the analytic-integrating phase was characterized by a higher level of conflict. The higher level of conflict during the analytic-integrating phase suggests to us that analytical decision aids aimed at conflict management are likely to help move through conflict, since such conflict is now recognized as a necessary part of making progress in public decision problems. Conflict early on indicates that people are likely aware of each other's valued interests.

Claims about the validity of our findings are guided by the considerations of human-computer-human laboratory experiments (Kidder and Judd 1986). With regard to our claims about external validity, the participant group we used is admittedly a sample from a student population, with a few community walk-ons. We did not try to enlist professionals, but relied on those who were interested to self-select, having interest in environmental decision making and the time for a battery of five decision sessions. However, we claim that we can generalize to other groups that are characterized by containing a majority of novices in tool use and habitat restoration. We can argue that the participants we used are likely to use such technology in the future because of their interests, as evidenced by their volunteering for the project.

As in most laboratory experiments, we opted to emphasize construct validity and internal validity. We were interested in the influence of task complexity and technology exposure (construct validity) on the fine-grain dynamics of human-computer-human interaction as expressed through relationships between aspects of EAST (internal validity). The experimental design allowed us to set up and control tasks; the videotape allowed us to capture the fine-grain dynamics. Getting professional analysts to do this is a very difficult endeavor. However, we promoted external validity by adopting a realistic decision task for participants to address, thereby attracting student subjects with a sincere interest in environmental decision tasks. As further evidence of the external validity of the professional abilities of students, for the past three years, in the winter quarter offering of a wetlands restoration class taught by one of the NOAA panelists at the University of Washington, we have made use of our database and software to conduct the Duwamish Waterway habitat restoration decision experiment. Each year, five groups of five students, each group playing a stakeholder role consistent with the NOAA panel, have come together in consensus on choosing two of the top three sites that have been restored.

To our knowledge, only three major experiments have been conducted that make use of spatial decision support technology: one by Reitsma et al. (1996), one by Stasik (1999), and this one. In terms of comparability across all experiments, like the GDSS experiments and the Reitsma et al. (1996) resource negotiation experiment, it appears that groups would rather have facilitators and/or chauffeurs help them work through problems. Individuals having access to technology in the Reitsma experiment were frustrated with the complexity of the software, but in our experiment we did not detect such frustration. Admittedly, the water resource simulation model in the Reitsma study was probably more difficult to understand than our multicriteria models. Ranking options is an activity people do quite often. In land use planning experiments conducted by Stasik, the role of facilitator was partially fulfilled by a computer server, which managed the collaboration process. The participants expressed a strong preference for making complex collaborative spatial decision support software, which they used, as easy and as familiar to use as standard Web browser. Many of them essentially wanted the software to look and act like such a browser. However, regardless of whether the support comes through software and/or humanware, the advantage of facilitation and technical assistance is undeniable at the current time.

The theoretical approach and findings reported in this article are intended to fuel the debate about the intended and unintended impacts of geographic information technology on society, particularly in the context of small-group work. As geographic information technologies diffuse through society, they are being criticized because they might in fact support a one-sided story. Lake (1987, 141) warns that "... ultimately at issue is whether the integrative capacity of GIS technology proves robust enough to encompass not simply more data but fundamentally different categories that extend considerably beyond the ethical, political, and epistemological limitations of positivism." In a special issue of *Cartography and Geographic Information Systems*, Sheppard (1995) and others echo the same concern, since use of GIS based on efficiency and effectiveness might result in opposite outcomes from an equity perspective. Others who are researching public participation GIS, as reported in a more recent special issue of *Cartography and Geographic Information Systems*, recognize a number of those shortcomings but are suggesting GIS-based solutions that can broaden the voice of societal participants (Obermeyer 1998). It is important to recognize that "[d]ifferential access to GIS data, hardware, software, and 'humanware' is a significant component of the political economy of spatial decision making" (Harris and Weiner 1998, 69).

Regardless of where one stands in this debate, a better understanding about the impacts of geographic information technology use in collaborative decision making settings is needed, whether we are investigating use of GIS, SDSS, SUSS, SUDSS, or the "umbrella category" of participatory geographic information systems. We hope that our framework and findings motivate others to pursue, or at least encourage a critical interest in, sociobehavioral studies about geographic information (system) use.

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Notes

1. Note that the tool in this case is part of the "substantive" domain and not the "methods" domain, since the tool itself is an aspect of study—an important point recognized by Pickles (1996).
2. Not all participants were students; many were community members who had seen the flyer. Participants received a voucher for a four-hour training session in ArcView GIS upon completion of all five sessions. Groups received a prize of $25 per group member from a random drawing after completing all five sessions. If students wanted, they received two credit hours of independent study. Only about 10 out of 109 opted for the credit, so this was not seen as a main motivating factor for participation.
3. To motivate students to return to subsequent sessions, we awarded monetary prizes and training only upon completion of all five sessions. Another motivation factor for many participants was the chance to work with GIS in an environmental decision making setting.

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