

CARTOGRAPHIC SUPPORT FOR COLLABORATIVE SPATIAL DECISION-MAKING

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ABSTRACT

Collaborative spatial decision-making environments in which group members individually and collectively pursue solutions to ill-structured problems have a unique set of cartographic visualization requirements. In this paper we restrict our focus to the domain of facility location problems and describe several new map types that are designed to support the process of making comparisons among alternative scenarios. Facility frequency maps depict the stability of sites chosen in a collection of scenarios. Allocation consistency maps show the stability of allocations from demand to supply locations. Alternative forms of these maps are described and examples are presented.

Keywords: Collaborative spatial decision-making, computer supported cooperative work, cartography, group displays

1.0 INTRODUCTION

Complex public policy problems often are addressed by groups. Because group members may represent a diverse set of constituencies and may come from different disciplines, they will have considerably different perspectives on the way questions should be addressed. To proceed, decision-makers also may need to integrate knowledge and data from a variety of sources. For example, a residential development proposal that impacts a wetland, might arouse considerable interest among existing landholders as well as environmental advocates, including ecologists and geologists. Each of these stakeholders, however, might support or attack different aspects of the proposal. When such groups are brought together specifically to address a particular problem, group members may be unfamiliar with these different perspectives and with the different decision-making styles that may be pursued. To complicate matters further, we can expect different group members to have varying levels of expertise and training in the use of computers. In such cases, it is common to abandon computer-based analyses because current software is unable to support the types of computation that are required by group members when they begin to search for solutions to complex, ill-structured public policy problems. Moreover, methods to resolve a divergence of views on what constitutes a good solution are not widely available.

Computer supported cooperative work (CSCW) environments have been developed to help groups of individuals work together to address ill-structured questions (Armstrong, 1994). In the geographical domain, collaborative spatial decision-making (CSDM) environments serve the same purpose. CSDM environments use CSCW principles to implement interactive, group-based spatial modeling and decision-making tools. Such environments include methods for eliciting, capturing and manipulating knowledge bases that support individual and collective development of alternative solutions to spatial problems. Other capabilities are used to manage spatial models and support the use of multicriteria decision-making methods to evaluate alternative solutions to ill-structured problems. Because of their spatial orientation, an essential characteristic of CSDM environments is the use of maps to present the geographical aspects of ill-structured problems. The purpose of this paper is to develop a conceptual framework and a set of illustrations that describe the types of cartographic displays that are required to support decision-making in CSDM environments. A series of prototypical examples from location selection problems are used to illustrate the discussion.

2.0 THE ROLE OF MAPS IN CSDM

As decision-makers struggle with ill-structured problems, they often generate and evaluate a large number of possible solutions. In fact, we have found that decision-makers often have an incomplete understanding of a problem and that it is only after they go through this process of exploration that they begin to gain insights into its true nature. In this process of solution generation and evaluation, decision-makers discover relationships among the various components of a problem and see how criteria may conflict. Given the complexity of supporting even a single user in this iterative process, it is clear that supporting a group of decision-makers introduces additional levels of complexity (Armstrong, 1993). The number of ways in which alternative solutions are evaluated and compared, for example, may increase greatly in a group context because each person may have a different level of training and experience as well as a different perspective on the problem-solving process to be followed.

In CSDM environments, maps serve as a basic token of exchange among group members. Although they communicate the form and structure of a scenario, maps are the metaphorical tip-of-the-iceberg. In a location selection context, for example, maps are constructed from the contents of a set of data structures that support locational analysis operations (Densham and Armstrong, 1994). The contents of these data structures are themselves derived from the system's database and users' knowledge. Although maps depict many characteristics of a scenario in an accessible form, a map is not a scenario. To explore a scenario, and possibly to modify it, users require access to its underlying data. Consequently, while maps are used as tokens, and may be thought of as scenarios by users, to the system designer a scenario consists of a set of user inputs and analytical operations, the contents of the analytical data structures and their linkages back to the database, and scenario displays.

Several types of maps that have been designed to support locational decision-making (Armstrong *et al.*, 1992) can serve as tokens of exchange.

- *Location maps* supply basic information about the geographical context of a decision; they may include, for example, highway maps and political maps.

- *Supply maps* show a set of facility locations.

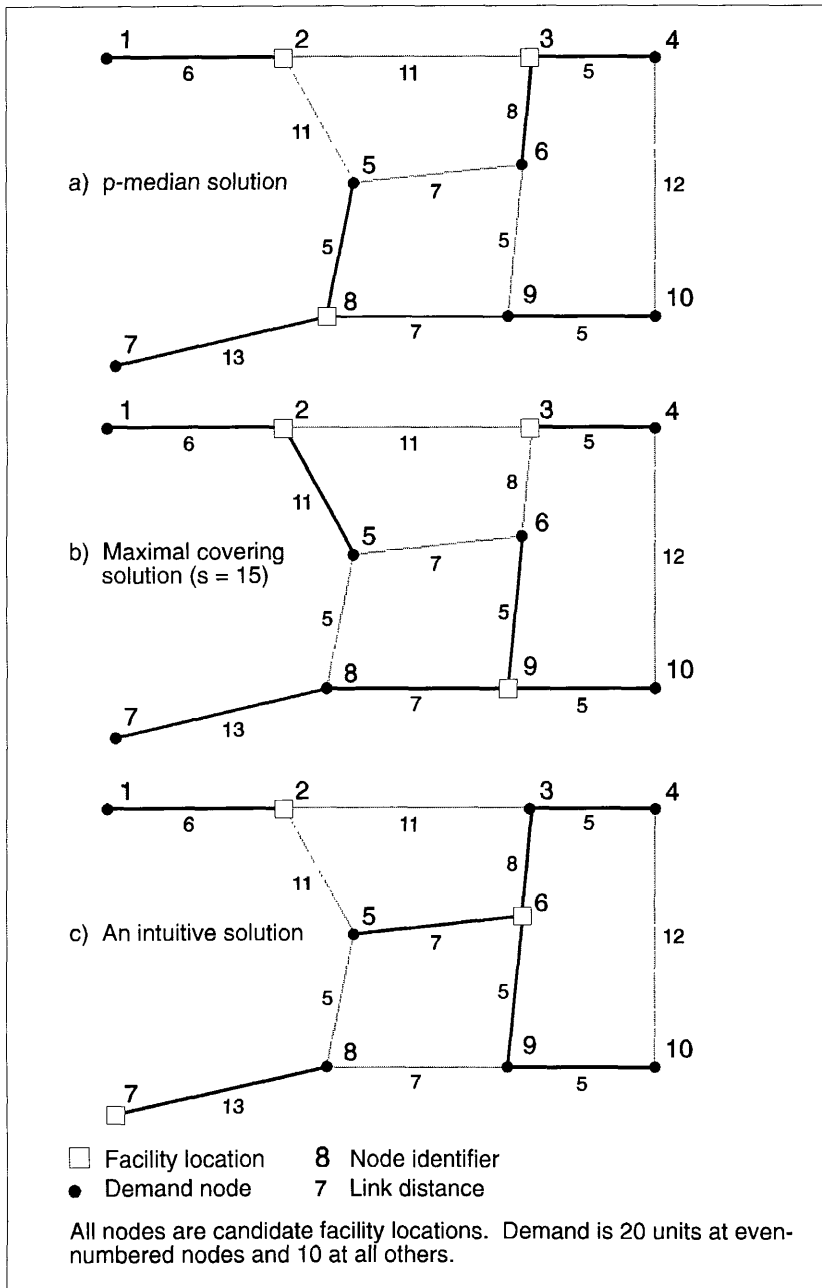


Figure 1. Network-based spider maps of three solutions to a location problem

- *Demand maps* depict the geographical distribution of demand for services.
- *Spider maps* show linkages between supply and demand, either for an existing scenario or for one of change - see Figure 1.
- *Delta maps* depict differences between a pair of scenarios, one of which may represent the existing system.

When these map types are used to explore ill-defined location selection problems, they are often used privately, by an individual, during the process of generating a scenario. Supply maps, for example, may enable a decision-maker to identify an underserved area; this problem would then be addressed in subsequent scenarios, leading to the generation of further maps. When assembled into a collection, these maps are used to convey the form and substance of a scenario-based decision process to other members of the group. Consequently, for each of the tasks that must be completed at each step during problem-solving, CSDM environments must provide users with appropriate types of maps.

Although the five types of maps described above are well-suited to individual use, the need to compare and evaluate scenarios during collaborative decision-making has generated a new set of display requirements. Thus, an additional set of displays are required to convey the degree of similarity among a set of scenarios: these *summary* displays are specialized forms of delta maps. While considerable amounts of work are required to refine the tools needed to create individual cartographic displays used by individuals, in this paper we will focus on these summary displays.

3.0 CREATING GROUP MAPS

In the context of group locational decision-making, we have identified two new summary map types: *facility frequency* maps and *allocation consistency* maps. Given two or more scenarios that are to be compared, a facility frequency map communicates two important dimensions of the robustness of facility locations - the number of times a given candidate location is selected as a facility site under differing criteria, and the volume of demand that it serves. In contrast, an allocation consistency map depicts the linkages among supply and demand points across two or more scenarios. Several dimensions can be displayed on different forms of an allocation consistency map, including the volume of demand served by each facility, the demand that is allocated to the same facility under a range of criteria, and the areal extents of facility service areas.

A map can be thought of as an organized collection of geographical features that are represented using symbols. Different hierarchical levels of organization of these primitive elements are used to communicate information to the map reader. For example, symbols can be manipulated to define regions or to ensure that data are perceived at a higher visual level than the base material. These same primitive map elements also can be used to support the development of summary maps that define the geographical dimensions of the degree of similarity that exists among alternative solutions to problems. If maps are viewed in this way, the level of decomposition determines the methods that can be used to make comparisons among different maps. When digital maps are disassembled into collections of constituent primitive elements, these cartographic components can be manipulated to determine similarity among alternatives simply by performing basic arithmetic operations on them. This "map display algebra" can be made operational in a simple accounting framework. For

example, the number of linkages between demand and supply locations that are held in common across a set of alternative solutions can be summed to generate a spider map that shows the degree of similarity in the allocation of demand to supply locations. In general, we can focus on various aspects of a scenario, enumerate these components and symbolize them to depict similarity using a standard set of visual variables, including symbol size and intensity.

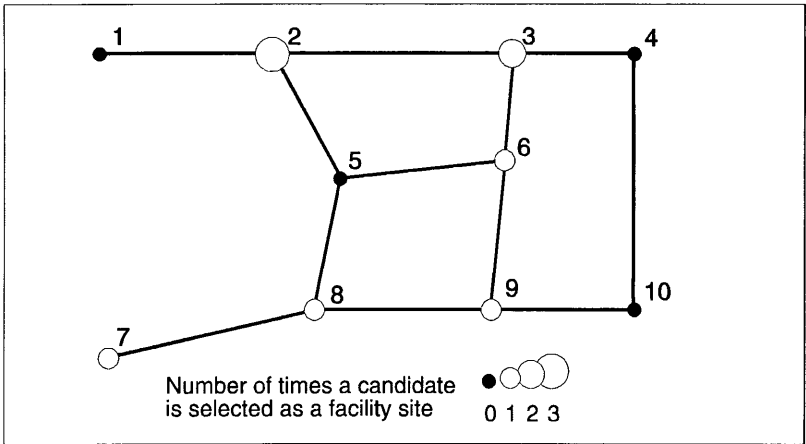


Figure 2. A facility frequency map for scenarios a, b and c (Figure 1).

3.1 Facility Frequency Maps

A facility frequency map indicates the degree of similarity among the facility locations in different scenarios. Decision-makers often wish to change policy variables as they explore an ill-structured problem, including the number of facilities to be located and the maximum distance that is traveled to a facility. In each scenario, therefore, a different set of facility locations might be selected from the set of candidate locations. As the number of scenarios grows, the set of choices can become confusing. To facilitate fruitful discussions among group members about the merits of alternative solutions, a parsimonious means to synthesize alternatives is required. We have developed two generic map types for comparing and evaluating scenarios.

The first map type focuses on each candidate location and the number of times it is selected as a facility location. Using size to symbolize this value leads to the creation of a typical graduated symbol map (Figure 2). While monochrome versions of this map can be included in laser-printed reports, color could be used to reinforce the size variable or indicate a second dimension to the solution, such as the amount of service provided. The use of classed or continuous (classless) color depends primarily on the number of scenarios to be compared. Because a facility may be located at the same candidate location in every scenario, there must be at least as many classes as there are scenarios to be compared. Consequently, classed maps might be used when the number of scenarios is small and continuous color when the number is large. The point at which one type is chosen over the other depends on, amongst others, the color range of the display device and the preferences of the user. An alternative approach to symbolizing this aspect of the collaborative process is best used when a small number of scenarios is being considered. This might occur when a group has narrowed its focus to a small set of choices, for example, and individual scenarios must be

identified. Each scenario is assigned a color and bars with the requisite colored segments are built at each facility location. A variation on this approach can be used when the number of individuals participating in the decision is small (fewer than 10) and inter-personal differences are to be highlighted. Each individual is assigned a color that is used to identify the scenario that they wish the group to consider. If each individual is told only which color has been assigned to them, such displays facilitate a form of group Delphi process. If the full range of color assignments is made available, individuals could determine where points of difference arise with some stakeholders, and possibly form coalitions with others.

3.2 Allocation Consistency Maps

An allocation consistency map shows which allocations of demand to facilities recur in two or more scenarios. The resulting map is similar to a delta map and, when only two scenarios are to be contrasted, two variants are possible. In the first case, the actual allocations of demand to supply locations are suppressed so that emphasis is placed on the demand locations. The map is created simply by coloring green (white) everything that goes to the same facility, and all the demand nodes that go to different facilities in red (black). Unless at least one facility location is common to both scenarios, however, it will consist entirely of red nodes. Although an allocation consistency map highlights those areas that are most affected by the differences in facility locations, it may not provide any information about the service areas of different facilities. Consequently, the second type of map provides information about both service areas and the consistency of demand allocations. One scenario is chosen as the "base scenario" and its allocations are depicted using a spider map. Each facility and its allocated demand nodes in the "alternative scenario" are represented by a colored symbol, to differentiate demand nodes and facilities, the latter are assigned larger symbols. Since the base scenario may be given an inordinate amount of "weight", it may be wise to reverse the ordering. One possibility is to display the two maps side-by-side (Figure 4), a second is to "overlay" the two maps and fade continuously between them - providing a dynamic display.

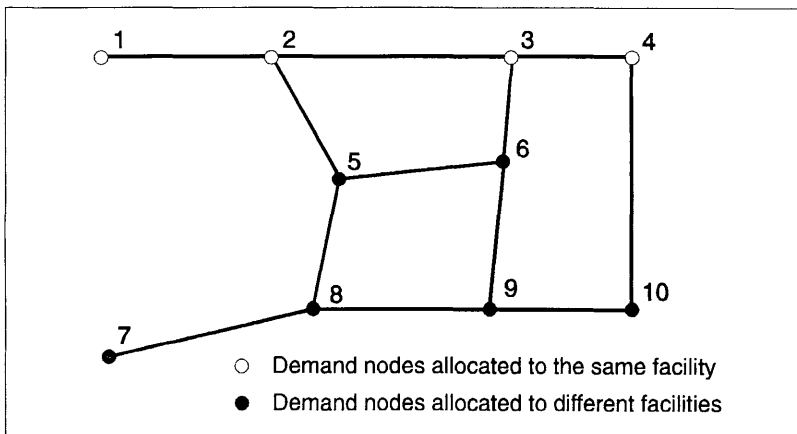


Figure 3. Allocation consistency map comparing scenarios a and b in Figure 1.

It is important to note that allocation consistency maps quickly become complex if dissimilar scenarios are compared, this occurs because the different allocations often

cross one another. Consequently, while all allocations can be symbolized using an accumulator logic - similar to that used in facility frequency maps - a better approach is to symbolize only salient allocations, such as those that occur in all, or a large number of, scenarios. Where allocations are depicted as routes through a network, for example, attributes also can be symbolized on this type of map. When coupled with allocation volumes, these maps might help decision-makers identify problems caused by traffic congestion or negative externalities, including levels of noise and particulate emissions.

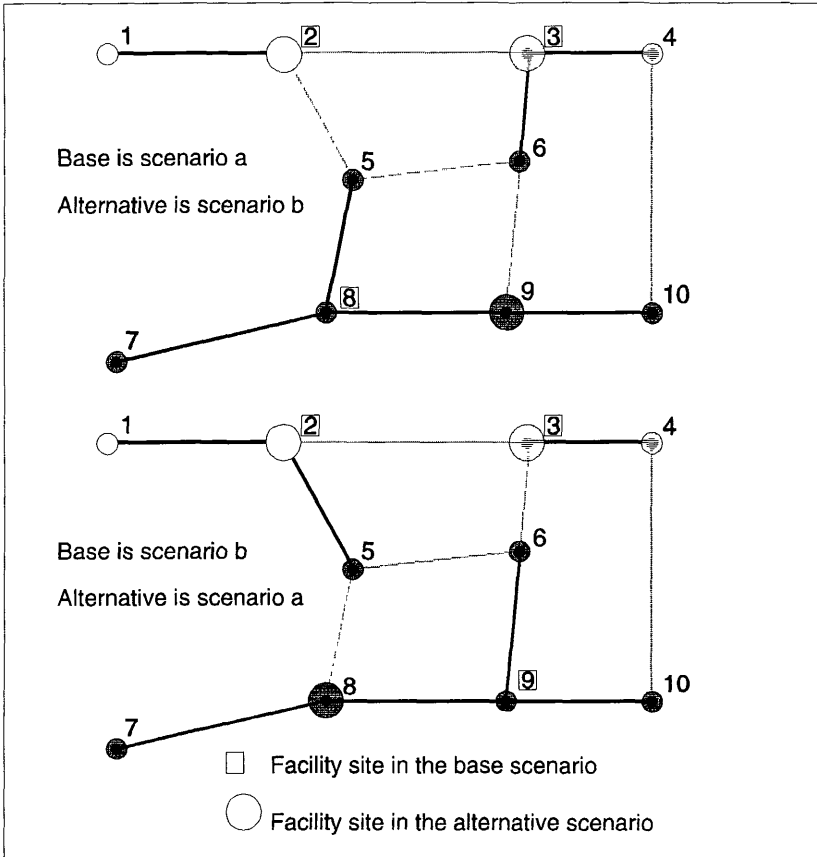


Figure 4 Allocation consistency map for scenarios a and b (Figure 1).

A further pair of map types are used when three or more scenarios must be compared. The first uses graduated symbols to depict the number of different facilities to which a demand node is allocated. Such a map can be produced using either monochrome or color symbols to enhance its effectiveness. The second type of map uses a network-based spider map to represent the impact on the transportation system of the selected scenarios (Figure 5). This display depicts the number of times that a transport link is traversed in the scenarios being compared. Maps of this type are useful for identifying potential choke points in the transportation network. This is particularly important if the activity being examined can alter the existing patterns of

movement of large numbers of people. For example, the bridges linking Manhattan to other parts of New York would have high values in such displays.

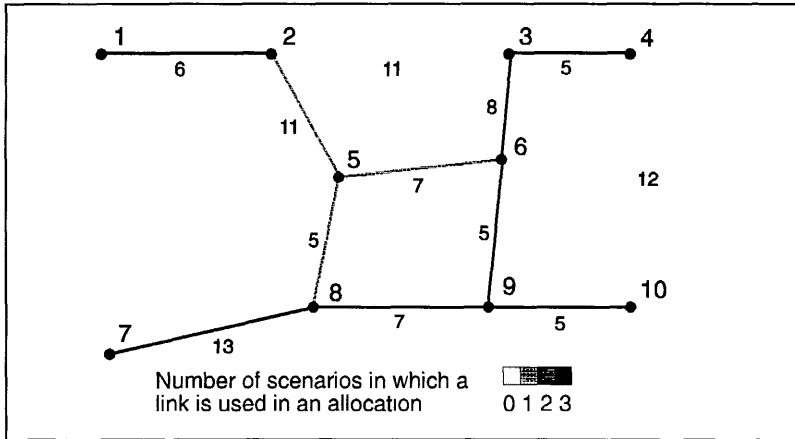


Figure 5. An allocation consistency map showing the number of times a link is used in allocations for scenarios a, b and c in Figure 1.

4.0 OTHER TYPES OF CARTOGRAPHIC SUPPORT

When an exploratory and iterative group problem-solving style is employed, it is often useful to be able to track and, if necessary, re-create the process of exploration. Two capabilities are useful in this regard. First, users need scenario management tools to trace the decision-making process. The sequence of solutions to a problem might be generated and captured so that it could be replayed as a slide show under user control. In this way, it would be possible to understand where points of divergence or convergence among group members occurred. Maps also must be supplemented with lineage information and meta-data to support this capability.

Lineage data tracks the process of decision-making. The capture and maintenance of lineage data can be achieved using a collection of data structures that supplement conventional cartographic data structures. In an object-based representation, each map would have several lineage objects to define the name and creator of the mapped

Structure: Group_lineage
Slot: Name_of_scenario
Slot: Name_of_creator
Slot: Creation_time_and_date_stamp
Slot: Name_of_last_modifier
Slot: Modification_time_and_date_stamp
Slot: Comment

scenario, the identity of the person who last modified it, and the date and time of these activities. In addition, space would be made available for comments - if multimedia capabilities are supported, these comments could be spoken rather than typed.

Scale of analysis and display is an important characteristic of complex locational problems. Because such problems often contain aspects that are straightforward, it is only in selected locations that potential conflicts occur. In such cases, system users normally wish to examine the different dimensions of a problem in greater detail. Consequently, the pan and zoom capabilities of the system assume a prominent role in user needs. Furthermore, this may necessitate real-time suppression or uncovering of map features, and possibly their generalization.

The use of map decomposition strategies also can provide insights into the problem solving process and the design of user interfaces (Armstrong and Densham, 1994). In visual interactive modeling (VIM; Hurrión, 1986, Densham, 1994), it is possible to enumerate the number of times that display and analytical objects are manipulated. Areas that are not manipulated can be treated as stable: there is a high-degree of similarity among alternatives (both within an individual's scenarios and across several individuals' scenarios). By summing the number of times objects are moved, it is possible to determine which areas are investigated by users. Users may be focusing their attention on these areas because they are poorly-served in a series of scenarios, for example; whatever the cause, such areas are potential sources of disagreement. To resolve situations of this kind, users typically apply judgment that is exogenous to the system, including personal, *ad hoc* knowledge about the problem.

To meet the needs of a disparate range of users—some group members may have formal cartographic training while others have none—the system must provide a set of cartographic design and production tools that accommodates the needs of novices and experts alike. Thus, not only must the system provide a rigorous set of defaults for use by novices and a much less constraining set of tools for experts, it also must integrate these tools with the system's analytical capabilities (Densham and Armstrong, 1994). For example, iconic map types similar to chart types in Microsoft Excel could be used to structure the map creation process for novice users. In addition to these multiple levels of access and support, the system also can provide users with a customizable map-production environment, rather like the use of style-sheets in a word processor—the use of "themes" in GisPlus (Caliper Corporation, 1992), for example, goes some way towards meeting this need. Thus, users can apply their favorite style of colors and symbolism to information, even to maps produced by other group members. While individuals create displays using standard cartographic tools, group displays will be manipulated using a set of specialized group tools. Such tools include generic whiteboard highlighting tools (lasso and pointer), as well as editing tools (scissors), that enable users to capture and edit privately scenarios that have been submitted to the group.

5.0 CONCLUSIONS

The support of interactive, group decision-making processes requires the development of new kinds of cartographic displays. We have developed two new kinds of summary display that are used to compare scenarios: facility frequency maps and allocation consistency maps. By synthesizing the characteristics of two more scenarios in a single display, the various forms of these maps enable decision-makers to understand the differences that separate scenarios. As with other forms of displays developed for use in locational problem solving (McKinney, 1992), further research is

required to evaluate the utility of both virtual and hard-copy versions of the various forms of these maps to decision-makers.

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