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Mobile Maps and More - Extending Location-Based Services with Multi-Criteria Decision Analysis

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1 Mobile Maps and More – Extending Location-Based Services with Multi-Criteria Decision Analysis

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Abstract. Maps are often used as decision support tools in both, desktop geographic information systems (GIS) and mobile GIS environments. The decision support capabilities of current location-based services (LBS) are limited to navigation support and database querying with no analytic evaluation of the attractiveness of alternative destinations being offered. This chapter demonstrates how LBS can be extended with specific decision support functionality, namely multi-criteria decision analysis (MCDA). MCDA was recently transferred to the mobile GIS platform illustrating how LBS user preferences can be represented by the parameters in a MCDA method and will lead to personalized decision outcomes. An extension to a collaborative crisis management scenario is proposed, in which mobile decision-makers have MCDA tools at hand to help them make more informed choices. This chapter describes the scenario and derives a client/server architecture as well as the user interface and map design for a mobile decision support system for emergency response.

1.1 Introduction

In both, desktop geographic information systems (GIS) and mobile GIS applications, maps often serve as decision support tools. At present, the decision support capabilities of location-based services (LBS) are limited to navigation support and database querying. For example, an LBS may indicate a nearby point of interest to the mobile user and the shortest way to access it. However, the choice between different possible destinations will be left to the user, and no analytic evaluation of the attractiveness of the alternatives is being offered.

GIS have been described as generators for spatial decision support systems (SDSS), which are specialized applications providing decision support tools to decision-makers. Multi-criteria decision analysis (MCDA) methods form a group of such decision support tools. MCDA aggregates standardized attributes of decision alternatives into an evaluation score for each alternative, thus making it possible to rank alternatives based on their performance. MCDA was introduced to GIS in the context of site selection and land-use allocation in the 1990s (Malczewski 1999).

MCDA concepts were recently transferred to the mobile GIS platform. Raubal & Rinner (2004) have shown that mobile user preferences can be represented by the parameters in a MCDA method and these will lead to personalized outcomes in mobile decision-making. Rinner & Raubal (2004) have extended the concept of personalized multi-criteria decision strategies using the ordered weighted averaging method that supports different approaches to decision risk and criterion trade-off. Finally, in Rinner et al. (2005), alternative user interface designs for location-based multi-criteria decision services were tested to simplify mobile decision-making processes.

Emergency situations are characterized by the need to make important decisions quickly and in collaborative situations. Cai et al. (2004) describe a hypothetical crisis management scenario, in which a first responder team uses mobile map-based communication with the emergency operations centre to find a shelter for hurricane victims. Here, an extension to this scenario is proposed, in which mobile decision-makers have multi-criteria tools at hand to help them make more informed choices. The parameters for decision-making could be shared between emergency teams to allow personal as well as group-default preferences.

After introductions to MCDA from a Geoinformatics perspective (section 2) and to location-based decision support using MCDA methods (section 3), the scenario is presented in detail (section 4) and a client/server architecture (section 5) as well as the user interface and map design (section 6) for a mobile decision support system for emergency response are derived. A make-up implementation using ESRI's ArcPad is also discussed and an outlook on further research provided (section 7).

1.2 Multi-Criteria Decision Analysis in Geoinformatics

Simon (1977) suggests a structure for analyzing human decision-making processes by distinguishing the *intelligence*, *design*, and *choice* phases. In the intelligence phase, a situation is examined for conditions calling for a decision. In the design phase, managers and planners develop alternative solutions to the decision problem identified in the intelligence phase. In the choice phase, decision-makers choose the best decision alternative. In the context of decision problems with a spatial connotation, Malczewski (1999) examines the potential for applying spatially enabled methods in Simon's decision phases. While the intelligence and design activities can mostly be covered by multi-purpose spatial analysis methods, the choice phase requires specific methods still missing in most GIS.

The choice phase is "what many people think of as making a decision" (Malczewski 1999). It requires formal methods (decision rules) to select feasible alternatives and to rank them with respect to the decision-makers' preferences. As humans tend to base rational decisions on an assessment of multiple decision criteria, MCDA methods have become important tools in management sciences and operations research. By incorporating quantifiers for the decision-maker's preferences (e.g. criterion importance weights), these types of decision rules are capable of solving semi-structured decision problems.

GIS have been described as spatial decision support systems (SDSS) per se, or as generators for more specific SDSS (Keenan 1997, Rinner 2003). On a conceptual level, Malczewski (1999) defines the necessary components of an SDSS in the narrower sense as

- Geographic database
- Model base
- Dialog (user interface)

MCDA methods are a specific type of model within SDSS. Janssen & Rietveld (1990) and Carver (1991) were among the first to analyze the benefits and potential traps of integrating MCDA with GIS. Among the methods that have been used in conjunction with GIS are location-allocation algorithms (ArcInfo), linear programming, ideal point analysis (CommonGIS), weighted linear combination, and the analytic hierarchy process (Idrisi). Different integration strategies have been presented ranging from loose coupling (data transfer between GIS and decision support tools via files or user input) to full integration (implementation of decision rules in GIS macro language).

Figure 1 presents a schematic workflow for GIS-based multi-attribute decision-making, the simpler type of MCDA procedures. First, decision-makers have to agree upon a set of feasible decision alternatives (e.g. possible destinations in the case of LBS). Next, evaluation criteria have to be selected, upon which a rational selection of an alternative can be based. The criteria have to be metric and standardized in order to make them commensurate. The relative importance of each criterion in the criterion set has to be quantified using criterion weights. A decision rule defines the way in which the standardized criterion scores are weighted and combined into an overall evaluation score for each decision alternative. Finally, from the evaluation scores, a ranking of alternatives can be derived and the top-ranked alternative represents the suggested decision. The decision process may also involve iterations in which the previously determined input parameters are revised.

In comparison to unstructured decision-making and to structured paper and pencil methods, GIS-based MCDA offers obvious benefits: The formal approach to establishing decision criteria and assessing alternatives on this basis allows for objectivity and reliability in a rational decision process. Alternatives can be screened efficiently in order to pre-select feasible options. Finally, the sensitivity of the outcomes can be analyzed, thus contributing to a *review* phase in an extended decision-making model.

On the other hand, rational decision-making in planning exercises has been criticized in general. Formal methods often cannot account for stakeholders' knowledge and intuition, and may result in a misleading reliance in decision outcomes. Also, the decision-makers' preferences often shift and remain unstable throughout a decision-making process. Critical technical issues include problem complexity due to the often large volume of spatial data. In practical use, preference input for MCDA methods is limited to a small number of decision criteria and weights may be difficult to elicit. Previous research also found that applying different MCDA methods to the same decision problem generates diverging results that leave decision-makers stunned (Heywood et al. 1995).

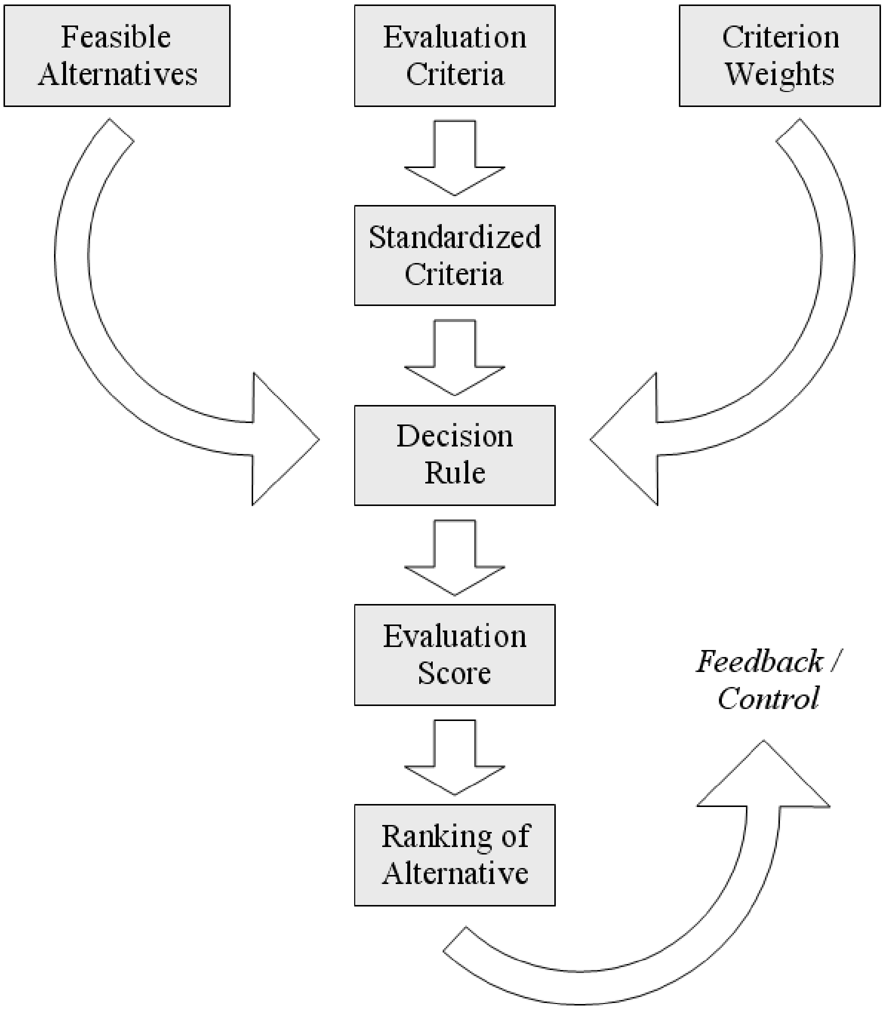

Fig. 1. Workflow for GIS-based multi-criteria decision analysis

To address inconsistency between evaluation results from different multi-criteria decision rules, decision support toolkits are being developed, which offer access to several methods for comparison of results. Models from other disciplines such as fuzzy set theory are also being adapted to spatial decision-making problems, e.g. the *ordered weighted averaging* (OWA) method (Yager 1988, Jiang & Eastman 2000, Rinner & Malczewski 2002, Malczewski & Rinner 2005).

Changes in the use of maps also influenced usage patterns for spatial decision support tools. DiBiase (1990) and MacEachren & Ganter (1990) were among the first to identify new map uses in the scientific process. They argued that increasingly, maps are not only used to present results of spatial analysis, but to explore spatial data and discover patterns, based on which scientific hypotheses can be developed. MacEachren (1994) introduced the cube model of map use in which he associates visualization with the use of interactive maps to reveal new insights into data. Parallel to the shift in map use from presentation to visualization, exploratory MCDA tools have been presented recently (Jankowski et al. 2001, Rinner & Malczewski 2002, Malczewski & Rinner 2005, Rinner & Taranu 2006). In addition, Rinner (in press) discusses the move from map-based exploration of spatial data to map-based exploration of the outcomes of spatial analysis processes such as MCDA processes.

1.3 Location-Based Decision Support

Location-based services (LBS) assist people while they move through the physical environment. Current research on LBS addresses a variety of topics such as network architectures and information technology standards (Adams et al. 2003, Peng & Tsou 2003, Ahn et al. 2004), positioning techniques and data collection (Mountain & Raper 2001, Miller 2003, Spinney 2003), human-computer interface (Pundt & Brinkkötter-Runde 2000, Meng 2005), map design adaptation and personalization of services (Hjelm 2002, Zipf 2002a, 2002b, 2003, Gartner et al. 2003, Sarjakowski & Nivala 2005), market opportunities and business cases for LBS (Beinat 2001, Benson 2001, Barnes 2003), as well as locational privacy (Armstrong 2002, Myles et al. 2003). Typical applications of LBS are found in areas such as navigation services (Winter et al. 2001, Chincholle et al. 2002, Winter 2002, Choi & Tekinay 2003, Smith et al. 2004) and tourist information systems (Zipf 2002a, 2002b, Berger et al. 2003, Hinze & Voisard 2003). In the area of emergency response, Erharuyi & Fairbairn (2003) present a conceptual framework for mobile spatial data handling in an oil spill management case study.

To a certain degree, LBS support decision-making by answering spatial queries. For example, the shortest route from the user’s current location to a target location (e.g. restaurant) may be suggested. In addition, spatial queries can be combined with attribute queries, e.g. to further specify properties of the target location (e.g. Greek restaurant). However, multi-criteria methods in GIS go beyond querying by enabling users to evaluate and rank decision alternatives based on user preferences and the combination of multiple criteria.

Raubal & Rinner (2004) introduce a mobile hotel finder application that uses MCDA principles. Users specify decision-relevant attributes to be used as evaluation criteria. Next, users identify good, fair, and poor criterion scores or ranges to allow for comparison of standardized criterion scores. Finally, users define the relative importance of criteria by assigning weights. The weighted criterion scores are then combined based on a decision rule, resulting in an evaluation score for each decision alternative.

Rinner & Raubal (2004) extend the hotel finder application using the OWA decision rule that allows users to specify a personal decision strategy as part of their decision-related preferences. OWA defines a continuum from optimistic to pessimistic decision strategies in a mathematical sense and uses a second set of weights to emphasize high or low standardized criterion scores. For example, with a pessimistic strategy users would focus on the lower scores of each decision alternative (representing poor performance), while with the optimistic strategy, users would focus on the higher scores (representing good performance).

In a pub finder variant developed by Rinner et al. (2005), alternative user interface designs for location-based MCDA were developed to simplify mobile decision-making processes. For example, the manual standardization of decision criteria from the hotel finder application was replaced by automatic criterion standardization, and the continuous sliders used for criterion weighting in the hotel finder were replaced by a limited number of qualitative weight labels ("really want" to "really don't want").

1.4 Scenario of Mobile Decision-Making in Emergency Response

Emergency management involves four phases: mitigation (prevention), preparedness, response, and recovery. GIS and related methods and tools, including positioning technology (GPS) and remote sensing imagery, are being used to various extents in those phases (Cutter 2003). For example, spatial analysis methods can help with hazard identification and risk assessment in the mitigation phase. During the response to an emergency event, GIS is often used for data integration and mapping to support rescue and recovery operations (ESRI 2002). Similar to desktop GIS, the use of mobile GIS in emergency response has also been limited to map creation to support field operations. In this chapter, an extension of mobile GIS with explicit decision support functionality, namely MCDA, is proposed and illustrated with an emergency response scenario.

Cai et al.'s (2004) hypothetical scenario of "geo-collaborative crisis management" is used to demonstrate this functionality. After a hurricane hit the coast of Florida, a first responder team uses mobile map-based communication with the emergency operations centre to find appropriate shelter for hurricane victims. The first responder team finds a group of elderly people that need to be evacuated from the flooded region to a shelter that provides certain services and has enough capacity. In Cai et al.'s scenario, the emergency operations centre compiles a map with shelter and background information that is shared with the first responders. The first responders request information on the capacity and caregiver staffing of an ad-hoc selected shelter and then decide to use that one as it "looks practical". This decision is based on the first responders' geographic intuition and facilitated by viewing the collaborative map.

As an extension of this scenario, we will assume that the emergency operations centre adds a shelter layer to the base map with shelter information as in the scenario by Cai et al. (e.g. current capacity, staffing). Further, the emergency operations centre sends a default decision strategy to the first responders' mobile GIS that consists of default importance weights for decision criteria such as the travel distance to shelters and the shelter attributes. Other settings for an MCDA method such as the decision risk could also be transmitted (e.g. low risk in the case of elderly hurricane victims). The first responders activate the MCDA process with a click and receive a suggested target shelter. On the map, several other shelters appear to be much closer to the first responder team's location. The first responders vary the decision strategy, for example by increasing the decision risk slightly above the suggested default. Soon, one of the nearby shelters becomes the top-ranked option and the first responder team takes measures to guide the victims to that shelter.

While this extension of Cai et al.'s scenario is not necessarily collaborative, it requires a server component that provides updated datasets and, possibly, organizational decision-making defaults. The scenario extension provides for more analytical structure in the location decision to be made by the first responder team than Cai et al.'s scenario.

1.5 Architecture of a Map-Based Mobile Decision Support System

A mobile decision support system (MDSS) could be implemented as a standalone application on a handheld computing device. A snapshot of a geographic dataset together with decision models and a user interface would be installed on the handheld in a similar way to the setup of a car navigation system from a CD-ROM.

However, a few factors suggest conceiving of an MDSS as a client/server rather than a standalone application. Geographic data forms the basis of decision-making and needs to be as up-to-date as possible. For example, in the above scenario, capacities and staffing of shelters may change dramatically during a disaster. Therefore, it seems advisable to locate the geographic database component of the MDSS on a server under control of an emergency management centre as sketched in Figure 2. The dashed database on the client side in Figure 2 represents a local copy of data that is regularly updated and possibly extended with data that was collected by the current user of the handheld during the emergency.

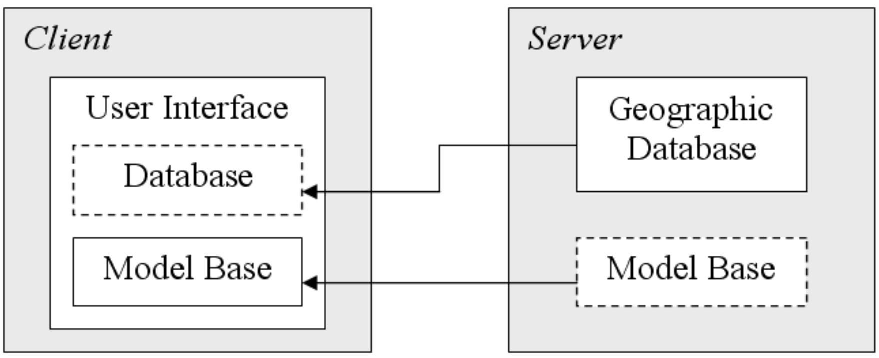

Fig. 2. Architecture schema for mobile decision support systems showing distribution of SDSS components over client and server

The multi-criteria methods contained in a model base of an MDSS can be mathematically as simple as a weighted averaging. This would suggest locating them on the client side as shown in Figure 2. However, the server may play a role with respect to the model base when it comes to more complex simulation models that may be updated more frequently than MCDA methods, and for the storage and sharing of model parameters. On the one hand, personalized multi-criteria modelling as suggested by Rinner & Raubal (2004) requires storage of parameters such as importance weights and decision strategies. On the other hand, such parameter sets could be exchanged between users, or default settings could be offered by institutions as outlined in the scenario above. For example, an emergency operations centre may require a risk-averse (conservative) multi-criteria decision strategy when dealing with elderly people.

The user interface (UI) of an MDSS is naturally located on the mobile client. To provide access to the other two MDSS components, the UI needs a mapping component to display geographic data, and a dialog component to elicit the user's input of MCDA parameters such as the selection of decision criteria and the setting of criterion weights. Rinner et al. (2005) discuss UI elements of a common mobile GIS package that can be useful for representing the MCDA method on the mobile device screen. These include buttons, list boxes, combo boxes, sliders, and checkboxes. Rinner et al. have further examined options to simplify the UI by streamlining the MCDA process. For example, the choice of decision criteria could be automated and thus removed from the UI, and the standardization of criterion scores could be simplified to three levels chosen from a combo box rather than arbitrary level determined using sliders.

Figure 3 shows the user interface of HotelFinder (Rinner & Raubal 2004), which consists of a series of tabs representing some of the steps in the MCDA workflow (Figure 1). By contrast, Figure 4 illustrates the simplification of the decision-maker's preference input in PubFinder (Rinner et al. 2005) with just one tab and qualitative labels for importance weighting. A design for the user interface of an MDSS of emergency response is presented in the following section.

Another component that has been identified as characteristic for SDSS is a report generator (Densham 1991). However, we can assume that decisions made while moving are not of a scope for which a report is of importance, and therefore, the report generator does not appear to be a necessary component of an MDSS. In contrast, maps can serve as intuitive reporting tools in SDSS. Maps have been shown to aid individual and group decision-making, in particular in the reporting and presentation phases (Jankowski & Nyerges 2001). In addition, interactive maps can be used to support data exploration (DiBiase 1990, MacEachren 1994, Andrienko & Andrienko 1999) and spatial decision-making (Jankowski et al. 2001, Rinner & Malczewski 2002, Malczewski & Rinner 2005, Rinner & Taranu 2006). Therefore, the user interface design for a mobile SDSS described in the following will include interactive mobile maps for the presentation and review of MCDA results.

Fig. 3. Multi-tab user interface of HotelFinder (Rinner & Raubal 2004)

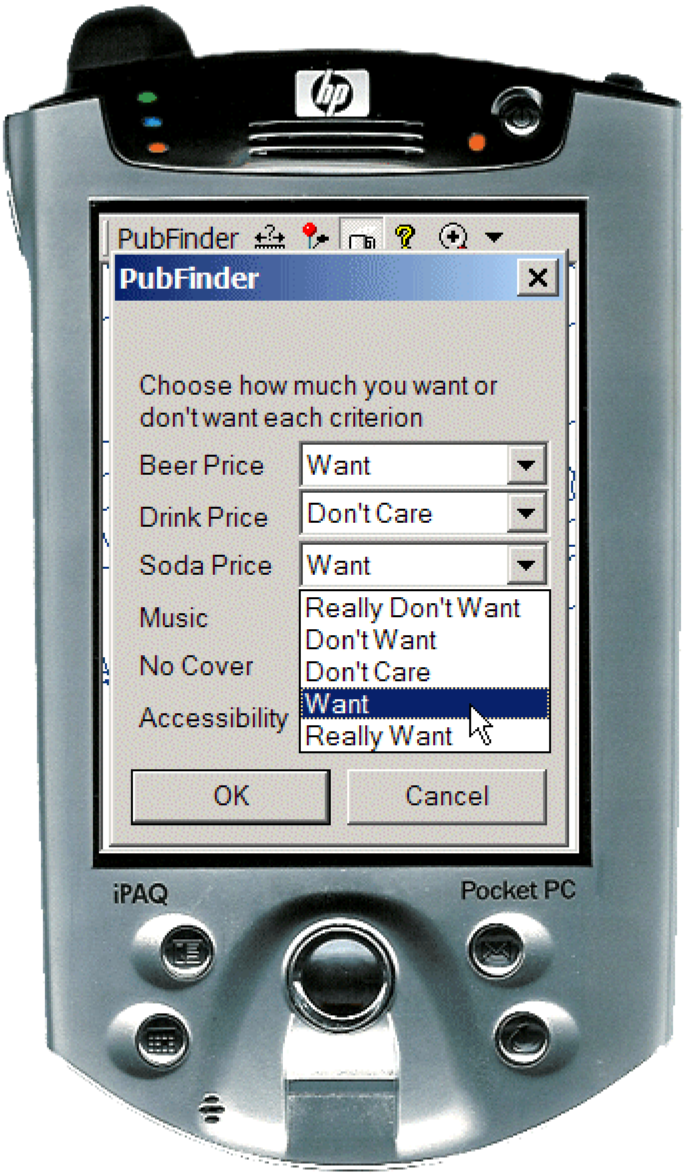

Fig. 4. Simplified preference input in PubFinder (Rinner et al. 2005)

1.6 User Interface Design for a Mobile Decision Support System for Emergency Response

Through the ArcPad Studio application, ESRI's mobile GIS ArcPad can be used as a generator for an MDSS. Extensions to ArcPad are provided through so-called "applets" (not to be confused with Java applets) which define new toolbars and forms. However, the available user interface elements are quite limited and the UI design shown in Figures 5 to 7 and described in the following could not fully be implemented in ArcPad.

The UI design for this MDSS is centred on a map of the area surrounding the present position of the emergency response crew. As outlined in the introductory scenario, a first responder team is looking for the best shelter to evacuate a group of elderly people from a flooded area after a hurricane hit the coast of Florida. The emergency operations centre uploads a general reference map with facility locations and a multi-criteria decision support tool – Shelter Choice – to the first responders' mobile device.

The toolbar of Shelter Choice (top of mobile display in Figure 5) provides basic mapping functions such as zoom to full extent, zoom in, and pan, as well as identify and layer management functions. A custom button enables the user to start the MCDA process.

The MCDA tool shown at the bottom of the map in Figure 6 lets the user select criteria for determining the best shelter location from among the attributes of the facilities layer. Criteria shown in this make-up implementation include travel distance, capacity, staffing, and safety from being affected by the flood. The proposed design keeps the focus of the application on the mobile map by limiting the MCDA tools to an absolute minimum: the selection among available criteria and the weighting of the selected criterion. This approach requires the user to select criteria one after the other as long as he or she wants to modify their importance weights. In the example of Figure 6, all four criteria start at a default weight of 25% that may have been determined by the emergency operations centre as an organization-wide default for this particular decision problem and this set of criteria. The fact that the map stays visible during the MCDA process allows the user to calibrate the MCDA results with his or her perception of the current situation as represented on the map.

Figure 7 illustrates an option for the display of MCDA results. Locations from the facilities layer that are not in the top-ranked decision alternatives have been removed from the display in order to allow the user to focus on the best shelter locations. In the example, the three best shelters under the current, user-determined MCDA weighting scheme are shown by the school symbol and highlighted with a circle. The 'identify' tool is used to retrieve information about the top-ranked shelter. This information is reported with a label in the style of a tool tip.

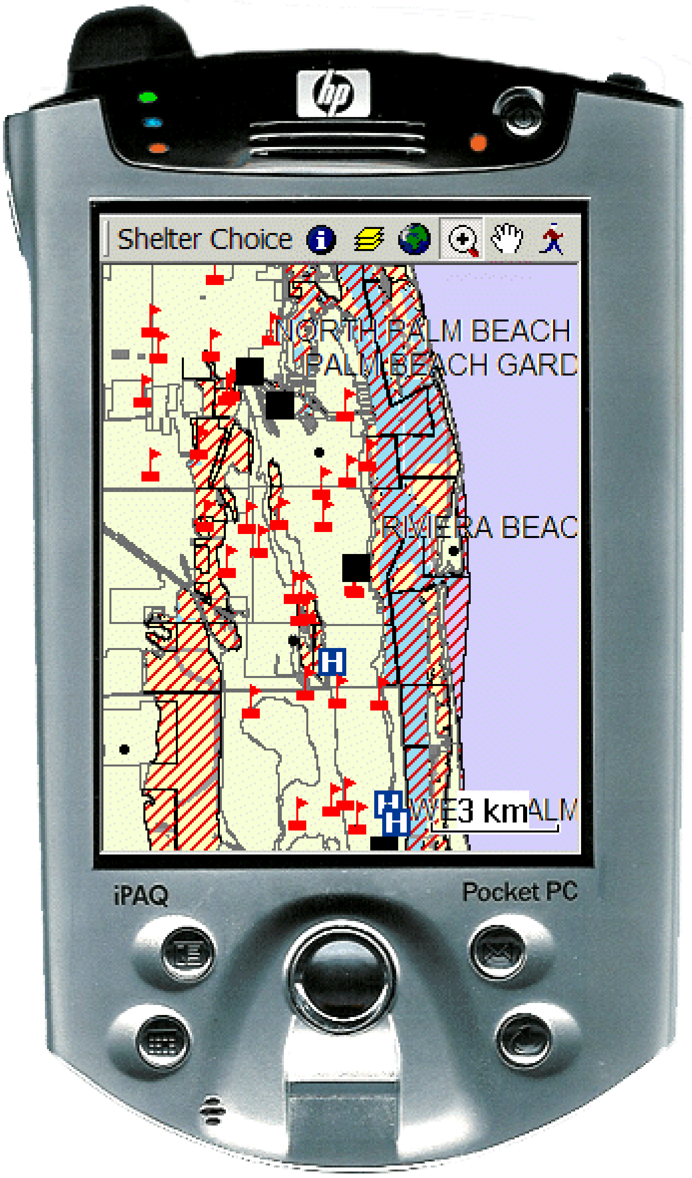

Fig. 5. User interface design for a mobile decision support system for emergency response – map of possible shelters (schools, hospitals). Source of map data: Florida Geographic Data Library, http://www.fgdl.org/.

Fig. 6. User interface design for a mobile decision support system for emergency response – multi-criteria weighting. Source of map data: Florida Geographic Data Library, http://www.fgdl.org/.

Fig. 7. User interface design for a mobile decision support system for emergency response – display of results. Source of map data: Florida Geographic Data Library, http://www.fgdl.org/.

1.7 Conclusions and Outlook

This chapter describes multi-criteria decision analysis as a useful addition to mobile decision support tools in an emergency response scenario. A client/server architecture for a mobile spatial decision support system was outlined and a map-centred user interface developed on the basis of the ArcPad mobile GIS. The ArcPad platform proved not to be flexible enough so that the MCDA interface had to be made up.

While Rinner & Raubal (2004) used a multi-page, modal form to gather user input for a large number of decision-making parameters, Rinner et al. (2005) suggested reducing user input by simplifying the MCDA method and criterion scales. Here, an even more efficient version of multi-criteria tools is proposed that is limited to setting the importance weight of one decision criterion at a time. This approach enables focussing on the situation map, thus it supports the first responder team in an emergency with calibrating the mobile tool with the current situation and their implicit spatial knowledge. Following a suggestion of Rinner et al. (2005), MCDA results are now also displayed in text form as labels on top of map symbols.

Through the application in emergency response, the proposed concept could demonstrate the utility of mobile mapping to support locational decision-making. According to the principles of geographic visualization, the MCDA result map ideally should be updated at every user action (i.e. changing the importance weights). In this way, the mobile map enables the decision-makers to quickly explore their choice options and thus becomes an efficient location-based decision support tool.

User tests are a top priority for further research on mobile decision support. The usability and utility of explicit spatial decision support tools such as MCDA needs to be demonstrated in realistic, or near-realistic, case studies. A second avenue for future development is the combination of multi-criteria methods to select a destination (such as a shelter) with navigation support methods that assist in reaching the selected destination. Of particular interest here is the combination with open standards such as the Open Geospatial Consortium's OpenGIS Location Service (OpenLS) specification.

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