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INTERACTIVE VISUALIZATION FOR GROUP DECISION-ANALYSIS

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Abstract

Identifying best solutions to large infrastructure decisions is a context-dependent, multi-dimensional, multi-stakeholder challenge in which competing objectives must be characterized and trade-offs made. We aim to identify and explore features in an interactive visualization tool to make group decision-analysis more participatory, transparent, and comprehensible. We extended the interactive visualization tool, ValueCharts, to create Group ValueCharts. Using a qualitative approach, the tool was tested in two real-world scenarios where stakeholders were wrestling with infrastructure investment decisions. We modeled alternatives and criteria, and facilitated use of the tool. Discussions were audio-recorded and participants were surveyed to evaluate usability. Participants expressed that the ability to visualize individual preferences improved the ability to analyze decision outcomes. Participants strongly concurred that the tool revealed both disagreements and agreements, and helped identify sticking points. Results suggest Group ValueCharts made the decision-making process more participatory, transparent and comprehensible, and increased the quality and quantity of information exchange.

Keywords: Information Visualization, Decision Support, Decision Analysis, Interactive, Group

1. Introduction

Decision makers dealing with wicked planning problems (Rittel and Webber, 1973; Andersson et al., 2014) struggle to identify the best solution for their specific context; and often settle on a traditional solution because they do not have sufficient resources to carry out an integrated analysis of alternative solutions (Guest et al., 2009; Brown et al., 2010; Balint et al., 2012). Structured Decision Making (SDM) and Multi-Criteria Decision Analysis (MCDA) are increasingly used to facilitate municipal and environmental decision-making for these kinds of complex problems (Huang et al., 2011; Gregory et al., 2012; Reichert et al., 2007). The fundamental steps in SDM are: 1) define the decision context, 2) identify objectives and criteria, 3) generate alternatives, 4) identify consequences, 5) compare alternatives, and 6) implement and monitor the alternatives. It has been shown that using MCDA in support of group decision-making can facilitate communication, learning, and consensus building across multiple stakeholders (Dias and Clímaco, 2005; Salo and Hämäläinen, 2010; Shih et al., 2004). In this paper, we present a novel interactive decision tool, called Group ValueCharts, that allows group members to input their individual preferences and then collectively probe into any differences. We built on an existing interactive visualization tool, ValueCharts (Carenini et al., 2004). ValueCharts was designed to support the inspection of linear preference models, which are the key mathematical model for multi-attribute utility functions MAUT. ValueCharts thus allows users to interactively define and refine MAUT models (Keeney et. al., 1976). The original design of ValueCharts was driven by a detailed model of data and task abstractions for MCDM (Carenini et al., 2004). Since its creation, such design has been tested and refined in several studies; in two analytic evaluations (i.e., with respect to a task model) (Bautista and Carenini, 2006; Yi, 2008), two user studies (Bautista and Carenini, 2008; Pommeranz et al., 2012), as well as several applications (e.g. Wongsuphasawat, et al., 2012). In retrospect, the design of ValueCharts was rather foresighted. LineUp (Gratzl et al., 2013), a system very similar to ValueCharts was presented at the IEEE InfoVis 2013 conference, where it won the Best Paper Award (the authors were unaware of ValueCharts – personal communication, Oct. 2nd, 2013). Finally, a very recent empirical evaluation of different multidimensional visualizations for decision support (Evanthia et al., 2017) shows that tabular visualizations, like ValueCharts, are superior to others used in similar systems, like parallel coordinates (e.g. Brodbeck and Girardin, 2003) and scatterplot matrices (e.g. Elmqvist et al., 2008; Dragicevic, 2016). Given all this positive evidence of the effectiveness of ValueCharts over more than a decade, we decided to extend it to group decision-making by building Group ValueCharts.

In this study, we specifically set out to develop infovis that would facilitate consensus building by supporting the exploration of differences between individual and group preferences. The reason being that such techniques, in contrast to purely algorithmic-based approaches like (Li et al., 2016), hold the promise to illuminate differences in values and priorities more expediently, helping focus discussions around specific sticking points that impede progress toward an outcome. This assumption is grounded in a large body of previous work within infovis that shows how dynamic visualization of complex data can effectively support exploration and analysis by leveraging the pattern recognition and pre-attentive capabilities of the human visual system (for overview see: Munzner, 2015). In our review of the literature, we have not found any tools that can quantify and dynamically visualize differences in preferences within a group, highlighting where these differences exist and identifying the extent of these differences.

Our aim was to design a tool that makes trade-offs explicit, striving to ensure transparency by highlighting the range of preferences, consensus and disagreements within a group. The tool is thus not simply aiming to identify features that might help group members quickly reach consensus, but instead to support a well-informed understanding which may necessitate a deeper discussion about differences. To accomplish this goal, we used an iterative process of tool development and user feedback. We iteratively developed features that showed potential to support the decision analysis based on individual group members' responses when using the tool. We tested the effectiveness of these features by analyzing the groups' collective responses in light of the tool's ability to make the decision-analysis more participatory, transparent and comprehensible. Due to the qualitative and exploratory nature of the design process we worked

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with two different groups. The first group consisted of staff at the University of British Columbia (UBC) who were engaged in decisions surrounding storm-water management at a proposed building site on their Vancouver campus. The second group consisted of software engineers within a software analytics company (hereafter referred to as SAC) who were engaged in the purchasing of software licenses.

The user studies presented in this paper are intended to address the core question: *can Group ValueCharts facilitate identification of (dis)agreements and thus support a more transparent and efficient decision process?* To accomplish this, we tested Group ValueCharts with two groups, each engaged in a real-world decision-problem: (i) infrastructure planning at our university; (ii) selecting software to procure for business operations in an IT company. Each group was trained using the software with a hypothetical example of choosing a hotel, which is used as a running example in this paper. The real-world problems are further described in their relevant sections with outcomes and future work presented.

2. Theory and notation

We use multi-attribute utility theory (MAUT) for the quantitative representation of subjective preferences (Keeney et. al., 1976) and use ValueCharts, which supports MAUT, to construct, refine, and visualize the individual group members' preferences (Bautista et al., 2006; Carenini et al., 2004). We chose to use MAUT out of several approaches for the quantitative representation of subjective preferences of group members, as it is theoretically well motivated and has been used in several environmental decision-making problems (Linkov et. al., 2006; Reichert et al., 2007; Schuwirth et al., 2012). Additionally, there has been work done in developing visual analytical tools to help apply these methods for practical decision support (French and Xu, 2005; Carenini et al., 2004; Chamberlain et al., 2014; Reichert et al., 2013). The Analytical Hierarchy Process (AHP) is the main contemporary contender to MAUT (Saaty, 1988). However, it is susceptible to the rank-reversal problem, which means that adding a new alternative to the set may cause the relative ranks of two other alternatives to change (Velasquez et al., 2013). For literature on decision support in the context of AHP and the related pair-wise comparison matrix technique (e.g. Kou et al., 2016; Kou et al., 2014; Wu and Kou, 2016).

We assume the following definitions of core-concepts of a decision-problem, and use examples from the problem of choosing a hotel:

- **Alternatives** are what the decision makers are choosing between. In the running example, the alternatives are the actual hotels from which to choose.
- **Criteria** are used to judge the alternatives. In the literature these are sometimes called objectives or attributes. We allow the criteria to be hierarchically organized (see below). Let C be the set of all lowest-level criteria. In the hotel example, there were five lowest-level criteria: *rate*, *internet access*, *room size*, *distance* to the Skytrain, and *area* (near the nightlife

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area, beach or airport). The Skytrain *distance* and the *area* were grouped into the higher-level criterion *location*.

- A **user** is a person who uses the tool and has preferences. The preferences of multiple users are what we want to elicit and compare. These users may or may not be the actual decision maker(s). The users for the running example are people who would be impacted by the decision and whose input the organization will want to consider.
- The **outcome** of a criterion on an alternative is the value of the criterion on the alternative. The outcome is meant to be objective or at least something that we can argue whether it is true or not. The outcome does not depend on the user. We use the notation $o(a, c)$ to denote the outcome of alternative *a* for criterion *c*. In the running example, the value of *o*(*Sheraton, area*) was "nightlife" as the Sheraton hotel was assumed to be in the nightlife district, and the value of *o*(*Sheraton, room size*) was 300 as the room size for the Sheraton option was (assumed to be) 300 square feet.
- The **score** specifies a real-valued measure of the preference of an outcome for an alternative for a user. We use the notation $s_u(out,c)$ for the score of outcome *out* for a criteria *c* for user *u*. The scores are in the range [0,1]. For each criterion and user the best outcome(s) for the user has a score of one and the worst outcome(s) has a score of zero. Other outcomes are scaled between these. Different users have differing scores which reflect their personal preferences. For example, one person may really like the nightlife district, thereby give the nightlife district a value of one, whereas another person may like the nightlife the least of the areas and score the nightlife district as a zero.
- The **weight** specifies a non-negative real-valued importance for a user and a criterion. $w_u(c)$ is the weight of criterion *c* for user *u*. The weights for a user *u* sum to one; that is, $\sum_c w_u(c)=1$. The weights reflect the relative importance to a user of changing the outcome of an alternative from its worst to its best value. For example, someone may think that the difference between the areas is very significant and give *area* a high weight, whereas someone else may think the difference is not very significant and give *area* a low weight.
- The **total score** (often called multi-attribute utility function) for a user *u* and alternative *a*, written $S_u(a)$, specifies a measure of how desirable alternative *a* is for user *u*. We assume an additive independence model (Keeney et. al., 1976):

$$S_u(a)=\sum_{c\in C} w_u(c) * s_u(o(a,c),c), \tag{2.1}$$

where: $w_u(c) * s_u(o(a,c))$ is *u*'s weighted score of alternative *a* for criterion *c*. The additive independence assumption implies that for each user the scores of an outcome do not depend on the outcomes for the other criteria.

As mentioned above, the criteria are hierarchically structured. Each higher-level criterion is a set of lower-level criteria, and receives aggregated values from these lower-level criteria. For instance, for the running example, the Skytrain *distance* and the *area* are grouped together to form a *location* criterion, where the weight for *location* is the sum of the weights of the lower-level criteria.

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In MCDA, after the outcomes and criteria have been identified, the outcomes of the alternatives on the criteria need to be assessed in consultation with experts including scientists, engineers and local traditional knowledge holders (see e.g. Gregory et al., 2010).

3. Initial Design of Group ValueCharts

The design of Group ValueCharts was based on an iterative process of tool development and user feedback. This section primarily highlights the initial design of the tool, while the next two sections provide details about the two user studies and the corresponding findings. ValueCharts (Carenini and Loyd, 2004) is a set of visualizations and interactive techniques intended to support decision analysis in MCDA with MAUT; more specifically, in inspecting linear preference models created to select the best option(s) out of a set of alternatives for a single user. Linear models are popular decision-making techniques designed to help the user rank available alternatives based on a set of multiple attributes. However, as models and their domain of application grow in complexity, the analysis of the resulting rankings becomes challenging. Systems like ValueCharts (Carenini and Loyd, 2004) and LineUp (Gratzl et al., 2013), the latter of which won the IEEE InfoVis 2013 Best Paper Award, are intended to help decision makers deal with this complexity. The effectiveness of ValueCharts and related tools has been shown in two analytic evaluations of task models (Bautista and Carenini, 2006; Yi, 2008), and in two user studies (Bautista and Carenini, 2008; Pommeranz et al., 2012), as well as several applications (e.g. Wongsuphasawat, et al., 2012). The implementation of stacked bar charts to compare alternatives has been shown to be well understood by a general audience, allowing for a rapid comparison between alternatives (Lipkus, 2007; Spiegelhalter, Pearson, & Short, 2011; Woloshin, Schwartz, & Ellner, 2003).

To assess each user's utility, users follow this protocol:

- Initially, users provide their scores for each lowest-level criterion, such as hotel location, by identifying the best and the worst outcomes for that criterion and then scaling the other outcomes between these.
- To initialize the weights, users are asked to rank the criteria. For this, we use the subjective weighting method the Simple Multi-Attribute Rating Technique Exploiting Ranks or SMARTER (Edwards and Barron, 1994). The information elicited by the SMARTER method is purely ordinal. From this ordinal information, initial values for the weights for that user are obtained.
- The users can then use ValueCharts to refine the weights and the scores. Although ranking using SMARTER reduces cognitive load on users, its output may not accurately reflect the values of the users. ValueCharts therefore allows users to refine their weights for a more reliable preference model that reflects their preferences more accurately (Riabacke et al., 2012), as we will describe later.

Figure 1 shows an example of ValueCharts for the simple preferential choice of selecting one of six hotels for hypothetical travel to a new city. For the sake of simplicity, in this paper we

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describe just the key features of ValueCharts, but the full experience can be found by using the software itself at: http://www.cs.ubc.ca/group/iui/VALUECHARTS. The chosen hotel criteria (e.g., *area*, Skytrain *distance*, *internet access*, etc.) are arranged hierarchically and are represented in the bottom-left quadrant of the figure, forming the rows in ValueCharts display. The height of each row indicates the relative weight assigned to the corresponding criterion for the user (e.g., difference in Skytrain *distance* is more important than difference in *area* for this user). The available alternative hotels are represented as fully customizable columns in the display. A cell, which is the intersection of a column and row, is filled with color in proportion to the score of the outcome for the given alternative and criterion. The height of the cell is proportional to the product of the score times the weight. For instance, since the Sheraton is far from the Skytrain and thus a lower value, its cell shows as almost empty. However, the Sheraton is located in the most preferred area, so the corresponding cell is completely filled. Internet access is mediocre, with a score of 0.5, so the corresponding cell is half-filled. All values for each alternative are accumulated and presented as vertical stacked bars, displaying the overall value of each alternative (e.g., in Figure 1, the Hilton is the best alternative).

The score function of each criterion is shown in a box beside the corresponding criterion, but is also available as a large resizable window if the user double clicks the box. Recall that the score function returns a score of one for the best outcome for the user and zero for the worst outcome, with all other possible outcomes scaled between these two Figures. For example, in Figure 2 (close-up of criterion: *area*) the corresponding score function specifies that for this user: being close to nightlife is the best outcome, being close to the airport is the worst, and being close to the beach has a value of 0.5 (between best and worst). Notice that by layout design, the values returned by the score function are automatically scaled according to the weight of the corresponding criterion, since the weight determines the height of the box. For example, the height of the box for *area* is 10.5% of the height reserved for all the criteria.

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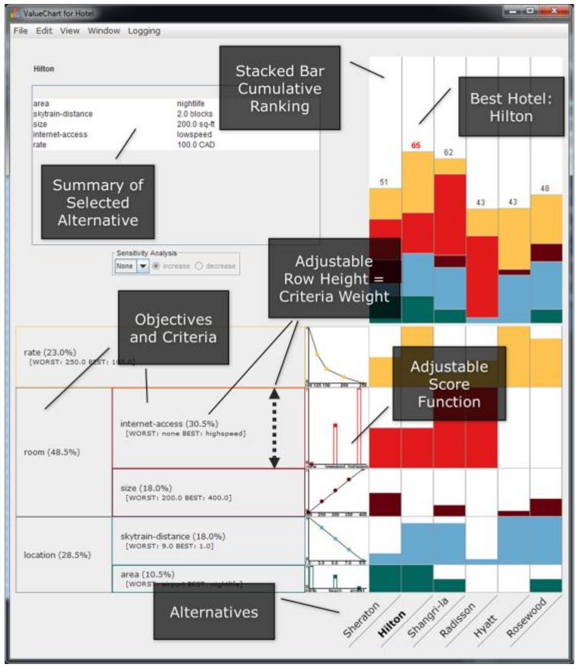

Fig. 1. User-interface for ValueChart showing the fictive decision-problem ‘choosing a hotel’ used to introduce participants to the tool.

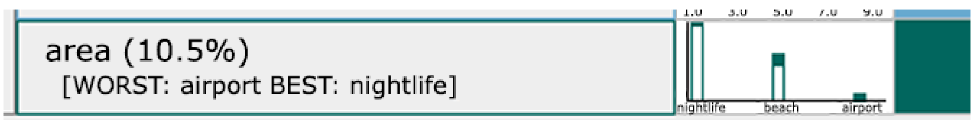

Fig. 2. Detail of the example ‘Choosing a hotel’ visualized in the decision analysis tool ValueCharts zooming in on the criterion *area* (to the left), which is given the weight 10.5%. The corresponding score function for the three alternatives: nightlife, beach and airport, is given as bar charts to the right (1= best, 0=worst).

ValueCharts provides interactive techniques that support multiple visualization manipulation methods to enable the inspection of a preference model. The tool can be used across a diverse range of problems where MCDA processes are used to identify alternative evaluations, identify criteria and quantify their relative importance. Criteria and weighting can be identified by experts or focus groups through various decision processes (see Belton & Stewart, 2002). For instance, users can inspect the specific domain value of each criteria (e.g., actual distance from the Skytrain of the Hilton), which can be viewed by clicking on an alternative. Double-clicking on a row heading *sorts* the alternatives according to how valuable they are with respect to the corresponding criterion. Also, the position of a criterion can be interchanged with another criterion position through *swap*, performed by dragging. For example, to see the aggregated weight of all alternatives based on two criteria (*room size* and

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area), the user can drag *size* to bring it adjacent to *area* in the criteria tree. This will cause the related colored bars to be stacked adjacently in the stacked bar charts representing the overall values of the available alternatives. Finally, sensitivity analysis of criteria' weight is enabled by allowing the user to change the width of the corresponding row. This can be performed using the *pump* action (another instance of *change*), where the user clicks on an objective to change it by a certain increment, which changes all other objectives accordingly.

For this study, ValueCharts is extended to produce Group ValueCharts. The aim is to make it possible for group members to compare multiple users' preferences for multiple alternatives across multiple criteria, and thus elucidate the impact of the elicited values explicitly and transparently. A key principle that informed the design of Group ValueCharts was to maximize its consistency with ValueCharts (in term of visual design and interactive techniques), so that users could transfer their understanding and expertise with ValueCharts to the new visualization. Thus, Group ValueCharts mirrors the visual layout of ValueCharts and displays the same information with the same visual encodings. Group ValueCharts (shown in Figure 3) maintains criteria as rows and alternatives as columns, with aggregate values shown at the top. Group ValueCharts does, however, differ in that it displays the preferences of all group members not just one user. This is achieved as follows:

(1) While in ValueCharts each cell for a given alternative/criterion pair displayed the preference of an individual as a single bar, now in Group ValueCharts we have a bar chart with a bar for each group member. Also, color is now used to identify a user instead of a criterion.

(2) While in ValueCharts the height of each row encoded the weight of the corresponding criterion for an individual, now in Group ValueCharts the height of each row encodes the maximum weight assigned to the corresponding criterion by a group member, and the weights assigned to a criterion by all group members are encoded by a bar chart with a red outline, one for each cell. In this way it is possible to see for each group member how much each alternative fare is with respect to each criterion in the context of how much that group member weighted that criterion. For instance, in the group ValueChart of Figure 3, the "blue" user gave the second highest weight to the criterion *area* and the Sheraton hotel is in the best *area* for this user. In contrast, although the "blue" user gave the highest weight to the *size* criterion (compared to other group members), the Sheraton hotel fares poorly on this criterion for this user.

The Group ValueCharts view described above (later called Detailed View of Group ValueCharts) represents our initial design of the tool. This initial design was refined and extended based on inputs from the two user studies, as described in the next section.

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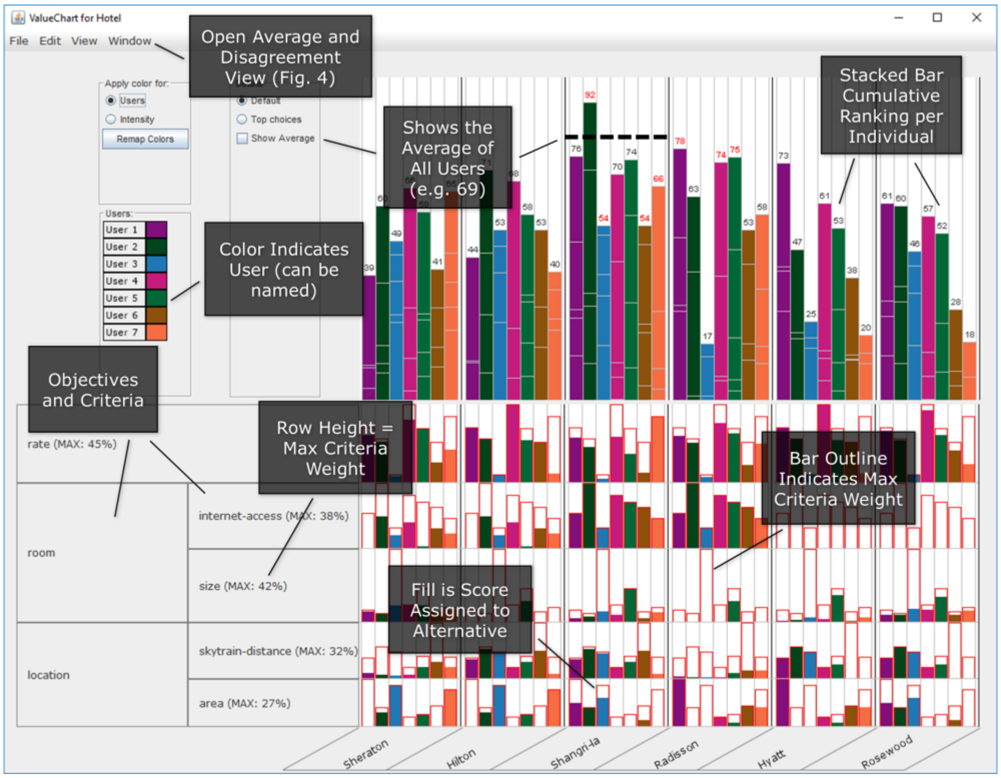

Fig. 3: User-interface for the Detailed view in Group ValueCharts showing individual preference models for a group of participants discussing an infrastructure problem. See Figure 4 showing Average View layout and disagreement index which are accessible using Group ValueCharts menu. Improvements were made following initial tests (section 4.1) and are show in Figure 6.

4. Case Studies

To evaluate and iteratively (re-)design Group ValueCharts, two user studies (UBC and SAC) were conducted. The studies were conducted with two groups that were each dealing with a real-world decision-problem. The groups consisted of a variety of individuals ranging in degrees of technical expertise, leadership experience and academic backgrounds. None of the individuals had seen Group ValueCharts before our initial meetings. These studies allowed us to probe into the perceived usefulness of various aspects of the tool in realistic high-stakes decisions (Cresswell, J.W., 2013). While a hypothetical lab study could have been conducted in order to collect quantitative data about individual usage of the tool, a qualitative evaluation of the tool's usage by actual decision-makers considering real decisions provides a more real-world evaluation of the tool.

The UBC case study involved decision-makers formally engaged in infrastructure planning for the university. In dialogue with the university's director of infrastructure planning, we

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identified four staff members in leading positions at departments that are involved in infrastructure planning. These staff members were consulted as expert advisors when designing the study. We gave a quick overview of the tool to these staff members and asked them to identify a current decision-problem that could be used to test the effectiveness of the tool. The decision-problem we choose as our case-study was rainwater management (also called storm-water or run-off) at a site on campus where a building was to be built in the very near future. Four alternatives and six criteria were developed through an iterative exchange with those four staff members and additional staff we were advised to contact.

Eight staff members in leading positions were invited to participate in the study, including the four used as expert advisors and the director of infrastructure planning. The eight participants were directly engaged in decisions regarding the chosen case, with responsibility for different aspects (e.g. land-scape design, storm-water infrastructure, sustainability, energy and water). We held two meetings, each of which were two hours in duration. Seven of the invited participants attended the first meeting and five of those participants also attended the second meeting. During the meetings, participants sat around a U-shaped table with a screen at the front end of the room. Each participant was given a laptop with the software installed. At the start of both meetings participants were asked if they would be comfortable with the conversation being audio-recorded and their interaction with the software being tracked. We assured them that the data would be anonymized before publication. All participants agreed verbally.

The aim of the first meeting was for participants to become familiar with the tool, provide feedback on the strengths and weaknesses of the tool, and make concrete suggestions on improvements. The aim of the second meeting was to probe into participants' perceptions on the usefulness of the tool and to collect their feedback on changes made to the tool since the first meeting. Participants were asked to fill out a survey in three parts: one before using the tool, one after discussing an Average View of Group ValueCharts (Figure 4), and the third after discussing a Detailed View of Group ValueCharts (Figure 3)[1]. The survey was designed to evaluate the process and outcome effectiveness of the tool. The questions asked in the first part relate to the individual's experience making collaborative decisions, their understanding of decision analysis techniques and their usage of decision support tools and data visualization techniques. The questions in the second and third parts of the survey are shown in Table 1. These questions were designed based on the framework developed by Schilling et al. (2007).

The user study with SAC followed the same procedure as the UBC study, the exception being that there was no pilot study. During the SAC meeting, the revised version of the tool was used (the same version used in the second round for the UBC group). In the SAC case study, there were six participants who were involved in recommending software for purchase. The criteria were developed by one of the employees in consultation with fellow employees. The group was asked to fill out the same survey as the UBC group.

[1] The differences between these two views will be clarified later.

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4.1. *UBC first meeting: Initial Trials and Software Review*

In the first meeting participants were introduced to ValueCharts through a PowerPoint presentation, using 'choice of hotel room' as a fictional decision-problem. The general introduction included Figure 2, which shows the preferences of an imaginary user.

After the introduction, participants were asked to imagine that the university had decided to rent a hotel room permanently in a city where staff and faculty members often traveled. They were then asked to imagine that the VP Finance wanted this group to advise on which hotel to select based on the five criteria used in the running example. Group ValueCharts was to be used to help them analyze the decision-problem. The meeting facilitator guided participants through the different steps that allowed them to construct their individual preference models. First, they were asked to determine their score function for each criterion. For example, for a one person, for the criterion *area*, a hotel near nightlife could be the best outcome, one near the airport could be the worst outcome, and the beach might then be assigned a value between. Once individual score functions had been constructed for all criteria, the participants were asked to weight the criteria using the SMARTER method (Edwards and Barron, 1994). Participants then visualized their preference models in ValueCharts where they could fine-tune their weights and score functions.

While the participants carried out these tasks, members of the research group moved around the room to help answer questions and solicit feedback on participants' actions, in order to understand participants choices and motivations, as well as which features they found useful or lacking. Participants varied in terms of the speed in which they learned to use the software, and initial instruction by the research group was necessary in order to facilitate this learning. However, for the majority of the session, time was spent with participants creating their individual preference models. As suggested by our survey results, all participants were able to understand the value of the software. Once participants had constructed their individual preference models, they were asked to save their work. Then the group took a short break while the individual ValueCharts were aggregated into a Group ValueChart (Figure 3).

After the break a PowerPoint presentation was used to explain the basic features in Group ValueCharts (Figure 3), in which each user is identified by a color-coded legend. The facilitator explained that criteria and alternatives are arranged as in ValueCharts. The group was shown the Group ValueChart and the director of infrastructure planning was asked to lead the group discussion. The meeting was ended by a short introduction to the real decision-problem to be used in the next meeting.

During the first meeting, three main features emerged as highly desirable (Table 1). The first was the possibility of viewing the average weighted scores, which led to the development of Average View (Figure 4, left), showing a Group ValueChart that is based on the average weights and scores across all users. Note that this gives the average weighted score which is different than averaging the weights and averaging the scores. Given this new View, we refer to the original View of Group ValueCharts as the Detailed View and the new as Average View.

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A second desired feature was the possibility of visualizing potential sticking points, which led us to develop 'heat maps' (Figure 4, right), which illustrate the level of disagreement. A third desired feature that was implemented between the two meetings was the ability to view the distribution of score functions over all users for each criterion. This was implemented using box plots as shown in Figure 5, which shows the aggregated score functions for one of the criteria. This feature makes it possible to display extreme users, and it is also possible to view the preferences of a particular user for this criterion, as illustrated in Figure 6 where the pink circle shows user 3. These three features were implemented prior to the second meeting with the UBC group (Table 1, Figures 4 and 5).

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Table 1. Features that emerged as highly desirable during discussions in a group that had been guided to use Group ValueCharts to collectively identify an (imaginary) preferable hotel. The features were incorporated in the tool prior to a second meeting. Each feature could be turned on and off.

Requested feature	Implemented by	Illustrated in
Aggregated ValueCharts showing average values	'Average View' – a ValueChart consisting of group members' aggregated average values	Figure 4 (right)
Level and type of disagreement	Heat maps	Figure 4 (left)
Aggregated score functions for all individuals	Box plots	Figure 5

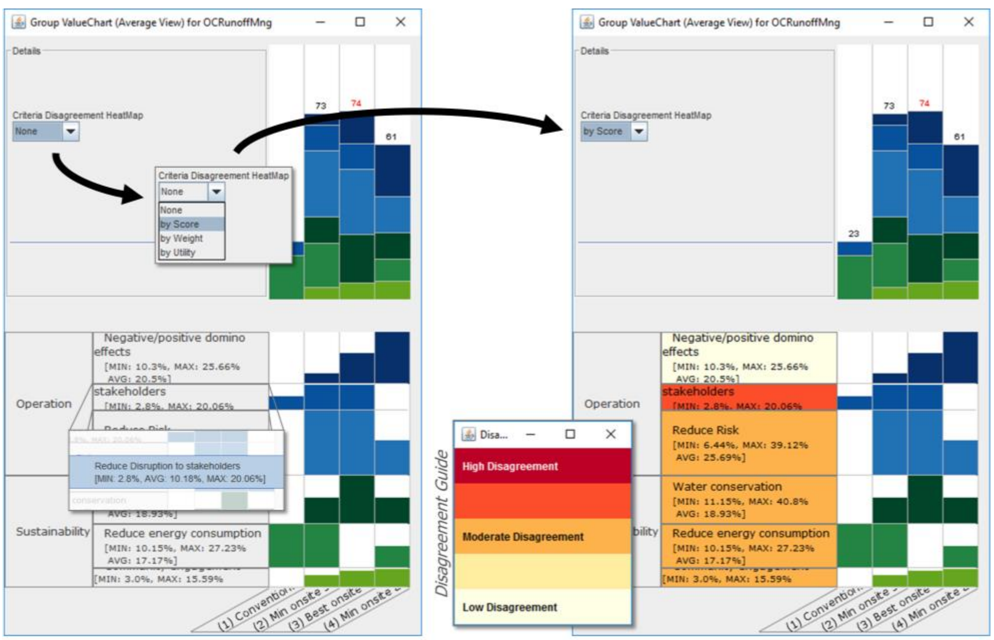

Fig. 4. Average view of Group ValueChart with 'heat maps' (left) illustrating the level of disagreement among users

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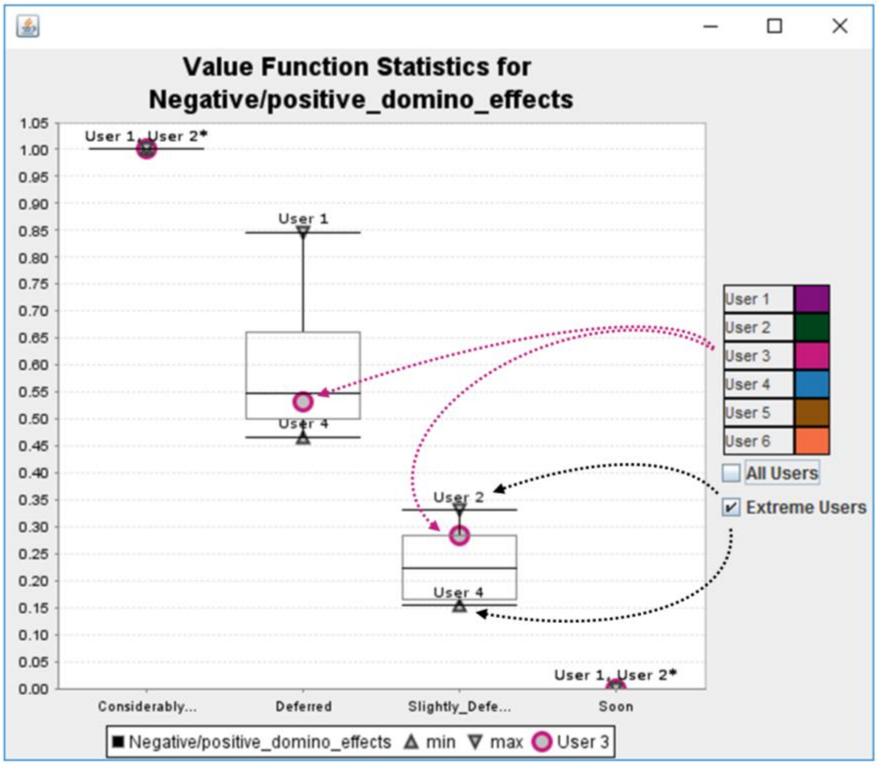

Fig. 5. Box plot for score function distribution for criterion 'Negative/positive domino effects' showing extreme users

4.2. *UBC second meeting: Applying the tool to a real-world problem*

The second meeting with the UBC infrastructure group started with a presentation of the decision-problem related to rainwater management for a building that was currently in the planning stage. In short, the university had decided to construct a building complex. As mentioned above, the alternatives were developed in dialogue with four of the participants. The entire group was very familiar with the case, as they were directly involved in the planning process. The (obsolete) solution used in older buildings on campus was used as a baseline and referred to as alternative 1. The three other alternatives were being considered by the planning team and can be summarized as: 1) meeting the regulatory standards, 2) maximizing sustainability efforts beyond regulatory standards, and 3) move the rainwater to an adjacent site that was being developed as a sustainability showcase. After the introduction, participants were asked to fill out the first part of the survey.

Participants were then asked to construct their individual preference models using ValueCharts, as they had learned to do in the first meeting using the hotel example. As in the previous meeting, members of the research group moved around the room to help answer questions and solicit feedback on participants' actions. The group took a short break when the participants had constructed their individual preference models and submitted it to Group ValueCharts. After the break the group was shown the Average View (Figure 4, left) and the director of infrastructure planning was again asked to lead the discussion while a facilitator demonstrated different features of the interfaces on the projector. The group then discussed the outcome. After the discussion the group was asked to fill out the second part of the survey. Next, the group was shown the Detailed View (Figure 3), and the director of infrastructure planning was again asked to lead the discussion. At the end of discussion the participants were asked to fill out the third part of the survey.

4.3. *SAC meeting: Applying the tool to a software procurement problem*

The SAC decision-problem involved selecting software to procure for business operations. The decision costs hundreds of thousands of dollars in licensing fees, as well as the staff time to learn and use the software. The criteria, the alternatives and the outcomes were developed by one of the employees of the company in consultation with fellow employees. Nine criteria were established, including the upfront cost, the ease of implementation, and the ability to reverse the solution. There were ten alternatives under consideration. One two-hour long meeting was held in Richmond, British Columbia with the employee who developed the criteria and alternatives, as well as five other employees who, as their job, help the company select which software to license. In this study the group used the revised version of Group ValueCharts (the same used in the second UBC meeting, results in Figure 6). As the participants were more computer-savvy than the UBC group, less time was spent on explaining the features of the tool, and the participants were introduced to ValueCharts and Group ValueCharts using the software purchasing domain directly (rather than with the simplified hotel example first). The procedure followed was then the same as for the second meeting of the infrastructure group.

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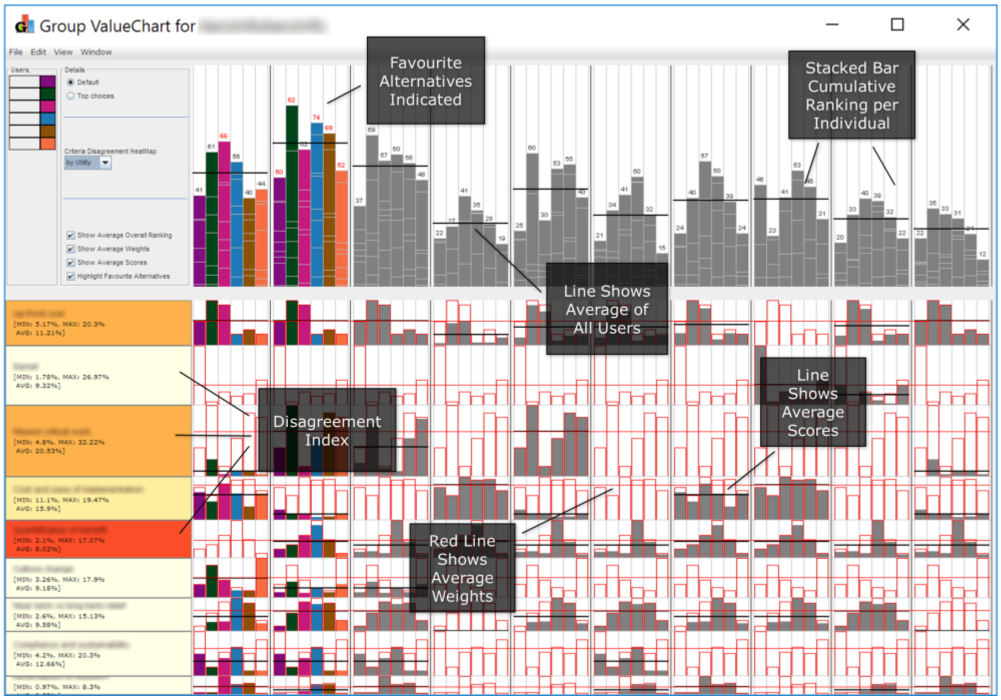

Fig. 6. Group ValueChart for SAC meeting. Updates created during the case studies are shown. Users, criteria and alternatives have been removed or blurred.

5. Results

5.1. *UBC first meeting: Introducing ValueCharts and Group ValueCharts*

The UBC participants were initially quite passive during the presentation of the ValueCharts software and while constructing their individual preference models in relation to the fictional hotel example, asking only a few questions for clarification. For example, one participant asked, “Who are we playing? Are we playing ourselves? Personal or business?”. Participants were asked to play themselves and that VP Finance had told them to be mindful of the costs.

The dynamics changed dramatically when the Group ValueCharts was shown after the break. At this point all participants engaged actively in a discussion on how to interpret the chart. The assigned chair (UBC head of infrastructure development) used the chart to probe into the reasons underlying the differences among the group members. Group ValueCharts revealed that the hotel Shangri-La came out as a clear winner as it was the preferred choice for four of the seven group members, and the second choice for the remaining three participants.

In the hotel example, the group discussed issues related to the decision context as well as features of the tool and provided various suggestions as to how the tool could be improved to meet their needs. They expressed appreciation for existing features, such as the ability to quickly and clearly see on which points the group diverged. They also suggested changes to some of the existing features, such as the ability to highlight the top-choice for all participants and to view the average total scores. Other comments and suggestions ignited discussions that led to consensus in the group regarding features they felt would be useful to add. At the end of the meeting, most participants expressed interest in the tool and said they thought it could be a powerful aid in identifying points of contention and agreement, thus enabling probing into underlying causes of the former.

5.2. *UBC second meeting: Eliciting feedback on the usability of the Group ValueCharts and its features*

The introductory presentation of the case initiated discussions on several points, particularly in relation to the selection of criteria and the scales and units used to measure the outcomes. Several participants expressed that they appreciated that we had incorporated their feedback from the first study and made it possible to view the group average (Figure 4, left). Showing the Average View induced a discussion in which all participants were engaged. The intensity in the discussion increased when the aggregated individual ValueCharts was shown (Detailed View, Figure 5). The facilitator demonstrated some of the new features, such as 'heat maps' to illustrate the degree of disagreement with regards to weights, scores, and the product of these two (Figure 4, right). The infrastructure director, who was the assigned chair and also the person who in the end was to make the final decision, expressed that he very much appreciated this feature. Another feature that received positive comments was box plots for displaying score function distribution (Figure 5).

It seemed as if the chart interfaces helped identify disagreements and this became the focal points for the discussion. One of the participants commented that he was surprised by the small difference between alternatives 2 and 3, as he was expecting alternative 2 to be the clear winner. He was also surprised that the disagreement in the group was small with respect to this result. The rest of the group agreed either verbally or by nodding, and they expressed an explicit interest in continued exploration of these two alternatives.

5.3. *SAC meeting to elicit feedback on the usability of the Group ValueCharts and its features*

The SAC participants discussed the alternatives and the criteria during the discussion (rather than the tool). After discussion, it was apparent that the alternatives were not exclusive, but were different aspects that could be chosen in various combinations. Participants would have preferred fewer extreme alternatives (pruning the least desirable earlier), because there were some alternatives that – in retrospect – were clearly dominated by others.

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5.4. *Survey results*

The survey results for the UBC study suggest that the participants felt that the tool was useful (Table 2). All participants indicated that they 'Agreed' or 'Strongly Agreed' with the statement, 'I believe that Average/Detailed ValueCharts helps make our discussions more participatory.' The interest in using the tool as a support for group decision-analysis increased after seeing and discussing the Detailed View. The participants were asked to describe what they liked about the tool in an open-ended question. As is commonly done in qualitative studies, we use quotes from the participants as evidence in support of our claims regarding their perception of and reaction to the tool and its different features. The comments strongly suggest that the tool was appreciated. For example, comments on the ValueCharts included:

- *The different criteria are clearly shown and the utility functions are well-defined. I like the fact that the user can easily manipulate different values and weights* (participant #6, infrastructure group)
- *I personally liked the level of detail and the degree to which you can interact with the tool* (participant #1, software group)

For the Group ValueCharts, comments show that the participants felt that the tool facilitated the discussions:

- *Based on the group discussion, the tool really allows exchange of ideas and comments among group members, and helps reveal the disagreements and agreements.* (participant #5, infrastructure group)
- *That it uncovers a lot of information regarding each individual's responses and opinions about the different alternatives. This is really helpful to drive discussions and allow for people to express why or why not they agree with something.* (participant #5, software group)

When asked about things they disliked about the tool, the SAC participants focused on features of the tool and its functionality. This was expected as it is their domain of expertise. Suggestions for improvement included:

- *I think visualization can be improved by removing white bar charts (for signifying weights variation). Instead, the user should be able to pick which metric to use - weight, Utility, or the product.* (participant #3, software group)
- *It looks like scale would rapidly become an issue if there were a lot of participants. Also, it takes a fair amount of explanation - it is open to the risk of people misunderstanding and sinking a lot of time into either debating how to read the chart or debating the topic at hand but doing so under false premises.* (participant #4, software group)

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- *Minor cosmetic changes could yield a much clearer and more legible interface. Clearer colors, font changes etc would help quite a bit. XX's suggestion of wiping out the totally "blank" alternative-criteria cells is a good one. It would reduce visual noise and highlight interesting features. A simple feature might be to allow the exporting of data in a common format so that people could use the data in their own visualizations or keep it for later use*. (participant #6, software group)

Interestingly, rather than commenting on the features of the tool and its functionality, the UBC participants highlighted aspects related to the content of the case study, such as choice of criteria, and the type of scales and score functions used to assess the alternatives. This indicates that the tool helped the participants in the group scrutinize the assumptions underlying the preference model. For example:

- *The value functions should be created to minimize confusion about 'directionality' of the criteria. e.g., for risk, the x-axis values should be consistent; if the criteria is 'reduce risk' then the scoring value should mean higher number = reduced risk.* (participant #2, infrastructure group)
- *It should be possible to make all the criteria point in the same direction i.e., higher number is better*. (participant # 2, infrastructure group)
- *Some of the criteria scoring was not intuitive. Cost or willingness to pay should be included as a criteria.* (participant #4, infrastructure group)
- *I need to see the dollars, the time lines, NPV and the potential of alternatives to be synergized or leveraged with other projects in their area. At the moment the tool doesn't capture this.* (participant # 5, infrastructure group)

Table 2. A summary of survey results from participants in two user studies investigating the perceived usefulness of Group ValueCharts, based on ValueCharts (Carenini et al., 2004). The five participants in the UBC case are university staff members engaged in water infrastructure planning. The six participants in the SAC case were all employees of a software analytics company who were involved in decisions regarding which software to license. The survey is based on the framework developed by Schilling et al. (2007). The values in the Table are the *min-max* (shown in parentheses) and *average* (dis)agreement of the participants on the corresponding statements reported in the first column, on a scale of 1 to 5 (with 1 = Strongly Disagree; and 5 = Strongly Agree).

Survey Question	**UBC**		**SAC**		**Measured dimension**
	Avg. View	Detailed View	Avg. View	Detailed View	Based on framework by Schilling et al. (2007)
	Average (Min-Max)				
I believe that (Average/Detailed) Group ValueCharts helps make	4.3 (4-5)	4.3 (4-5)	4 (3-5)	3.3 (2-4)	Participation

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our discussions more participatory. 1 = strongly Disagree 5 = strongly Agree					
Please rate the tool's potential to improve group interaction 1 = worse group interaction 5 = better group interaction	4 (3-5)	4.3 (4-5)	3.7 (1-5)	3.8 (2-5)	Quality of information exchange
Please rate the tool's potential to improve information exchange among participants 1 = less exchange of information 5 = more exchange of information	4 (3-5)	4.5 (4-5)	3.5 (1-5)	3.8 (3-5)	Quantity of information exchange
The tool helps identify agreements and disagreements 1 = strongly disagree 5 = strongly agree	4.2 (3-5)	4.7 (4-5)	3.8 (2-5)	4.5 (4-5)	Transparency and comprehensibility
The tool helps make informed decisions based on everyone's preferences 1 = strongly disagree 5 = strongly agree	3.5 (3-4)	4.3 (4-5)	3.5 (1-4)	4.2 (2-5)	Transparency and comprehensibility
I would be happy if the alternative with the highest average score was chosen 1 = strongly disagree 5 = strongly agree	2.8 (1-4)	3.2 (2-4)	3.2 (2-4)	3.5 (3-4)	Transparency
I would like to use Group ValueChart for collaborative decision making at work in the future. 1 = strongly disagree 5 = strongly agree	3.6 (3-4)	4.2 (3-5)	4.3 (4-5)	4.7 (4-5)	

6. Discussion

6.1. *Level of Participation*

Previous studies have shown that active participation in MCDA-based decision processes can increase participants' trust in the process, improve learning, and increase decision accuracy and preference certainty (Nunamaker and Deokar, 2008; Salo and Hämäläinen, 2010; Woudenberg, 1991). Dalal et al. (2011) argue that judgments made by groups where the members actively interact to reach an agreement are more accurate than "the statistical aggregation of individual judgments". As mentioned in the results section, the participants in both groups were engaged in a lively discussion as soon as they were shown their aggregated results. This is a strong indication that the tool supported or even induced active participation. The survey results support this conclusion as all six participants in the infrastructure group and all but one in the

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software group checked 'Agree' or 'Strongly Agree' to the statement, 'I believe that Average Group ValueCharts helps make our discussions more participatory.'

The survey results and comments strongly indicate that the tool facilitated information exchange and group interaction, which are both closely tied to the level of participation. The survey responses also suggest that the combination of the Detailed View and the Average View was powerful in facilitating both exchange of information and group interaction (Table 1). The fact that participants were able to identify their disagreements and agreements across the group and in light of the group average appears to be a reasonable explanation to this finding.

In line with previous studies, it appears that the tool reduced the ability of some participants to dominate the discussion (Nunamaker and Deokar, 2008). For example, Group ValueCharts gave everyone an equal opportunity to express their values and assured every participant that their preferences were seen/heard along with others. Several visualizations were provided in the tool to facilitate analysis and deeper group discussions such as box plots of score functions, average scores, and heat map for level of disagreement.

6.2. *Transparency*

Transparency is a central factor for group decision-analysis as it conveys a sense of fairness and increases the trust in the process (Mustajoki et al., 2004). Salo and Hämäläinen (2010) argue that deploying MCDA in group decision-analysis can enhance transparency and legitimacy as it leaves an 'audit trail' that enables tracking the process, and also fosters learning through enhanced understanding about others' perspectives and about the decision problem. Existing group decision- analysis visualization tools either display only summary statistics for the group (Dalal et al., 2011) or compose a group view by aggregation of opinions or providing averaged values (Mustajoki et al., 2004; Reichert et al., 2013).

One overarching finding of the study is that the combined use of the detailed and aggregated views was most appreciated by the participants. No doubt the ability to compare individual preferences on a single visualization interface made the decision process transparent, as it equally included all users in the evaluation of the alternatives. This conclusion is supported by comments made in the open questions of the survey:

> *It's clear, transparent, and easy to use.* (participant #5, infrastructure group)
> *[I like] that it uncovers a lot of information regarding each individual's responses and opinions about the different alternatives.* (participant #5 software group)

The combined results of the survey responses, the open-ended questions and the discussions, suggest that the Detailed View can increase the transparency of the group decision process. The Detailed View received high scores for most of the survey questions, and the responses indicate that it increases transparency by explicit presentation of the participants' preferences underlying the summary statistics. This is, for example, reflected in the survey question, 'The tool helps make informed decisions based on everyone's preferences'. This

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question had the greatest number of participants (five of six) increase their rating by one point between the views.

The Detailed View was also rated high on '[helping] identify agreements and disagreements'. The ability to identify agreements and disagreements was used by the chair to encourage individuals to justify their differing values. For instance, after the chair confirmed that everyone agreed on alternatives #2 and #3 being the most preferred, he began making observations that focused attention on the two alternatives. This spurred a discussion on the differences, particularly in water conservation, between the two alternatives. The fact that the individual preferences are visible for scrutiny by the group is likely to prevent participants from manipulating their preferences to bias certain alternatives.

6.3. *Comprehensibility*

According to Matheson and Matheson (1998), comprehensibility is one of the major aspects that determine the quality of a decision process. It is defined as the ability to use meaningful and reliable information, to make clear value trade-offs, to use logically correct reasoning and to pinpoint disagreements (Matheson and Matheson, 1998). Our results suggest that Group ValueCharts may be used to increase the comprehensibility of the decision process, especially pertaining to the ability to make clear value trade-offs and to pinpoint disagreements.

The study also suggests that ValueCharts can facilitate the decision-making process, by enabling an accelerated comparison of alternatives through investigating the influence of criteria and their associated weights. While the process of systematic comparison of alternatives is important in decision-making processes (e.g. Structured Decision Making Gregory et al. (2012)), our results indicate that Group ValueCharts enables a more rapid understanding of the trade-offs or sticking points which slow the decision process – including illustrating the diversity of individually held values. This is because the combination of stacked bars, with annotated group values provides a quick delivery of descriptive information, and the simultaneous comparison of an individual within the group. When asked the question, "What did you like most about the tool?", participants' responses inferred that the tool enabled them to make clear, value-based trade-offs by giving them the opportunity to visualize personal preferences, quantify their valuations and perform trade-offs analytically. In response to what they liked the most, participants said:

- *The opportunity to compare options and adjust values and weight factors to reflect personal preferences.* (participant #1, infrastructure group)
- *It provides an opportunity to review/question decisions and preferences* (participant #2, infrastructure group)
- *I really like the fact that based on the opinions of all the team members, the tool helps put the discussion on track and shortlist the alternatives that most of the team have strong feelings on. So, it narrows and focuses the decision-making process.* (participant #6, software group)

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This conclusion is further supported by the responses given to the statement,'The tool helps make informed decisions based on everyone's preferences', in which all but one of the participants in the infrastructure group increased their rating when they were allowed to see the Detailed View. When it came to the ability to identify disagreements participants commented:

- *Based on the group discussion, the tool really allows exchange of ideas and comments among group members, and helps reveal the disagreements and agreements* (participant #5, infrastructure group).
- *The ability to see where the strongest disagreement lies. Also, the ability to filter by a user and find out what she/he feel the strongest about.* (participant #3, software group)

The survey results suggest that this opinion was shared among the participants and indicate that they felt that the Detailed View a powerful feature. These results are aligned with that of Hostmann et al. (2005), who used MAUT as a framework for conflict resolution in river rehabilitation. Their study indicates that MAUT can be used as a framework for pinpointing sources of disagreement and interpersonal conflict between different stakeholder groups.

Although our study was not designed to probe into the ability to use meaningful and reliable information, the responses from the infrastructure participants to the two open-ended questions in the survey suggest that the tool was helpful in identifying these participants' assumptions, as well as pre-set model assumptions. For example, when these participants were asked to write about features that they liked most, two of them wrote:

- *The ability to isolate participants and engage in discussion about assumptions was very powerful* (participant #3, infrastructure group)
- *It provides a useful mechanism to be clear on the project objectives, and to not overlook important issues for decision making* (participant #2, infrastructure group)

In response to the question, 'What did you dislike most about the tool?' another participant wrote:

> *That some assumptions about changing worst to best appear unrealistic* (participant #1, infrastructure group)

These responses, in combination with the discussions surrounding the criteria and the performance measures, indicate that it may be worthwhile exploring whether the tool could be extended to facilitate identification of questionable assumptions and unreliable information. During discussion, a participant commented:

> *I think this tool will actually allow us to zero in on where we think there might be issues and that's real value here. ... We're drilling in on specific areas. So whether*

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> *it's been set up slightly off or not, it doesn't matter. The fact that you're able to have a real discussion here about it is the valuable part of the tool, then make adjustments accordingly* (audio recording during 2nd meeting with infrastructure group)

This suggests that the tool also has potential to make participants focus on information pertinent to the decision.

7. Conclusions

The present study indicates that an interactive visualization tool that allows group members to construct individual preference models and show individual and aggregated values in complementary views may be used to enhance the participation, transparency and comprehensibility in a decision process.

Our tool consists of an individual preference construction module, ValueCharts (Carenini et al., 2004), which allows users to visualize and analyze their preference model as well as explore how changing values influences their preferred alternative ranking. The second module of our tool allows individual preferences, constructed using ValueCharts, to be collectively visualized in a single interface (Group ValueCharts). There are two aggregated views in the second module: Average View (shows only average value of all participants) and Detailed View (shows individual values of each participant).

We aim to further develop the software to seamlessly integrate the individual ValueCharts interface with the Group ValueCharts, so that any change a user makes to their own individual model can be immediately reflected in the group interface. This would allow users to quickly cycle between building their preference model with ValueCharts, viewing and discussing the group and aggregate values with Group ValueCharts, and then revising their individual models with ValueCharts. Such a framework would better align with the results of Ewing and Baker (2009), who developed an Excel-based decision tool to support decisions around investment in green energy technologies. They found that participants, "appreciated the idea that they can revisit their values as they have time to reflect and further discuss them", especially,"if a specific value was decisive" Ewing and Baker (2009). Group ValueCharts was developed to quickly identify key areas of agreement and disagreement. Research has shown that consensus building can lead to more satisfaction and continued collaboration (Schweiger, 1986). Group ValueCharts could be modified to increase group satisfaction by visualizing areas of consensus first, and by providing a mechanism to usher the group through increasing levels of disagreement methodically. This would offer an opportunity to help build trust within the group, and identify growing inconsistencies between individuals that could be addressed outside of the group context.

Even without these potential modifications, the survey responses and discussions suggest that Group ValueCharts may facilitate identification of agreements and disagreements in weights and scores among the participants, thus helping the group have a useful discussion on

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the most significant areas of the decision problem. The combined use of the detailed and aggregated views was complementary; participants liked seeing the overall average preferences of the group, but felt that the ability to identify individual preferences transparently was vital to the decision process.

In conclusion, the study provided evidence that Group ValueCharts can effectively help decision makers explore alternative solutions. The tool appears to have the ability to help focus attention to information significant to the decision-problem as well as important issues and contention, while encouraging active participation from all involved.

8. Acknowledgements

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