MOBIGSS: A Group Decision Support System in the Mobile Internet

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The development of mobile applications is fast in recent years. However, nearly all applications are for messaging, financial, locating services based on simple interactions with mobile users because of the limited screen size, narrow network bandwidth, and low computing power. Processing an algorithm for supporting a group decision process on mobile devices becomes impossible. In this paper, we introduce the mobile-oriented simple interactive procedure for support a group decision making process. The interactive procedure is developed for multiple objective linear programming problems to help the group select a compromising solution in the mobile Internet environment. Our procedure lessens the burden of group decision makers, which is one of necessary conditions of the mobile environment. Only the partial weak order preferences of variables and objectives from group decision makers are enough for searching the best compromising solution. The methodology is designed to avoid any assumption about the shape or existence of the decision makers' utility function. For the purpose of the experimental study of the procedure, we developed a group decision support system in the mobile Internet environment, MOBIGSS and applied to an allocation problem of investor assets.

Keywords : Mobile Internet, Multiple objective decision making, Group decision, Weak order preference

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1. Background and Motivation

Access to the Internet through mobile phones and other handheld devices is growing significantly in recent years. In this age of information, many information-centric applications have been developed for the handheld or mobile devices (Yang & Wang, 2003). UbiCollab (Divitini et al., 2004) is one of applications for collaboration services, which is a groupware platform that can be tailored to the specific groups using it. At present, most of mobile applications are customer-centered applications. However, the mobile computing should not be limited to user-centered applications only. It should be extended to decision supporting applications in a mobile commerce organization. With a fast paced economy, organization is important to make decisions as fast as possible with the help of valuable experts. As a result, there is an urgent need of a tool for supporting decision making processes using interactively mobile devices. The convenience of mobile devices allows a set of interactions without geometric limitation; however, there are other limitations of mobile devices that restrict their capability.

Although the development of mobile devices is fast in recent years, there are many shortcomings associated with these devices, such as screen size, bandwidth, and memory capacity. The typical display size of popular wireless application protocol (WAP)-enabled mobile phones are relatively small in comparison with a standard personal computer. The memory capacity of a mobile phone greatly limits the amount of information that can be stored (Yang & Wang, 2003). A heavy algorithm cannot be entirely performed in the mobile phone to present the solved results to user directly. The current bandwidth available for WAP is relatively narrow. For small display size, limited capacity and narrow bandwidth, it is necessary to support decision making processes based on any simpler algorithm than traditional problem solving approaches.

With the rapid growth in mobile technologies and the cost effectiveness in deploying wireless networks, mobile devices are quickly becoming the standard platform for accessing time-sensitive data. Mobile computers will become the preferred front-end devices for hosting sophisticated business applications. Time-sensitive data is crucial for facilitating informed decision making. Without an effective decision support system, decision makers (DMs) will not be able to exploit opportunities as they appear anywhere and anytime (Sharaf & Chrysanthis, 2002). Decision makers need to count on up-to-date opinions of experts being instantly available to their hand-held and wireless computers. Such opinion are delivered to and aggregated in WAP server. For example, a server may be responsible for gathering expert opinion of stock market and other financial information. The combined use of these technologies enables people to access their personal information, as well as expert support, anytime and anywhere (Sharaf & Chrysanthis, 2002; Varshney & Vetter, 2002).

Nowadays, many important decisions in organizations are made by groups. Managers are increasingly faced with the task of making complex decisions in rapidly changing organizational environments, and spend much of their time in decision related meetings. Managers balancing tradeoffs between objectives are even more important in groups than for individuals, because conflicting objectives and opposing viewpoints are inevitably going to exist. In group decision making situations, multiple individual interpretations of the best solution must be aggregated into the best single group interpretations. Because each DM evaluates alternative solutions based on each own structure of preferences, the individual judgments of the best solution may not coincide (Lewis, Butler, 1993; Davey & Olson, 1998). Although several researchers have designed methods to aid decision making processes among groups, their researches have focused only on comparative study of the proposed methods without consideration for system implementation. Two key forces are currently having a profound impact on managerial decision making processes; (1) a move toward more teambased organizations which necessitates an increased use of group decision making methods, and (2) advancements in mobile communication and computing which increases the geographical and temporal dispersion of organizational members. A net result of these two key forces is an increased reliance on technology-assisted group decision support methods to facilitate rapid decision in organizations in setting where work force is geographically, or temporally dispersed (Slevin et al., 1998).

It is very difficult to perform the interactive group decision processes on the mobile phones because of heavy computation efforts and complex interfaces of traditional multiple objective methods for supporting the above group decision. There are lots of mobile applications that are to support such simple transactions as banking, brokerage and location tracking. But there are few interactive applications for finding solutions through the interactions with mobile users (Varshney & Vetter, 2002). This paper suggests a mobile-oriented group decision making procedure that is modified from Dror-Gass algorithm using the weak order structures of group members' preferences (Dror & Gass, 1987; Dror et al., 1988). The overall procedure of our suggested methodology is as follows: First, each DM uses weak order information to represent DM's preference about objectives and decision variables. The weak order-typed preferences are aggregated into group's one. We attempt to exploit this weak order information in the search for the best solution of compromising group members' solutions. Second, the group members must rank the order of objectives to be improved at next stage. Then our procedure determines a group's rank order of objectives and finds out their preferred solution. Finally, the iteration is continued until predefined stopping conditions are satisfied. The system based on the methodology is implemented in mobile environment and explained step by step with an illustrative example.

The organization of this paper is as follows: Next section briefly reviews the literature related to the multiple objective researches. Section 3 outlines the overall procedure and suggests an aggregation process for mobile-oriented group decision making. Section 4 explains the system characteristics and architecture and suggests a group decision making procedure of MOBIGSS. An illustrative case example is explained at section 4. Finally, section 5 concludes this paper with suggestions for future research.

2. Researches for Multiple Objective Group Decision Making

The multiple objective linear programming (MOLP) model for decision making is expressed in terms of a set of objective functions and a feasible region. The solution set to the problem is the set of all efficient solutions. This solution set is usually very large and the purpose of existing interactive MOLP decision support system is to aid the DM in locating and selecting the most preferred solution from the set of efficient solutions. A variety of MOLP procedures have been proposed in their literature. However, up to date, the development of effective MOLP solution procedures remains a most challenging research area (Sun et al., 2000). Surveys of several of these procedures can be found in the book of Steuer (1986). In the past few decades, a lot of multiple objective decision making (MODM) methods, especially interactive MOLP methods, have been developed to solve conflicting preferences among objectives for single decision maker (Steuer, 1986). With these techniques, the DM sequentially evaluates a limited number of solutions in order to direct movement through objective space toward a good solution. The interactive evaluation process continues until the DM expresses satisfaction with a solution. These interactive methods offer significant benefits because the DM provides only local preference information regarding a small number of solutions at a time. However, researches related to the use of MODM in group decision support processes, although considered to have great potential, fell behind (Davey & Olson, 1998). Several researchers have designed few methods to aid decision making among groups.

A study by Rao and Jarvenpaa (1991) highlighted a framework of group decision support system for addressing multiple DMs in multiple objective problems. Wendell (1980) developed a theoretic approach for the bi-criterion case that allows progressive articulation of DM preferences. NEGO (Kersten, 1985) formulates a goal programming model to find the solution that is closest to the feasible ideal one of the group. Korhonen et al. (1986) adapted the well-known Zionts and Wallenious interactive single DM MOLP technique (Zionts & Wallenious, 1976) to a multiple DMs situation using the implicit weights obtained from group's selection of a given set of extreme points. The quasi-satisfying framework SCDAS (Lewandowski, 1989) supports discrete choice problems through the use of aspiration level, while Wang and Sen (1989) presented a procedure requiring explicit estimation of the individual and aggregated utility functions in order to aid group members in consensus seeking by combining MOLP with the Delphi technique. Franz et al. (1992) proposed three decision-making procedures based on the simplified interactive MOLP methodology (Reeves & Franz, 1985) for facilitating a group of DMs in reaching a collectively acceptable solution to a MOLP problem. Iz and Krajewski (1992) proposed three group decision making procedures, each of which extends the well-known MOLP method for single DM to a group decision making situation, by augmenting with a preference aggregation component in order to capture the preferences of multiple decision makers. Lewis and Butler (1993) also suggested and evaluated the interactive multiple objective, multiple DMs decision procedures which combines the simplified interactive MOLP and/or Tchebycheff MOLP optimization methods (Steuer & Choo, 1983) with a preference ranking tool (Cook & Kress, 1985) and a consensus ranking heuristic (Beck & Lin, 1983).

Dror and Gass (1987; 1988) suggested an interactive scheme that requires only partially ordered set of the variables and objectives involved, and does not require that the DM has an ability to directly evaluate trade-offs at a given point. The methodology uses a DM's expressed weak order preference on decision variables and another on objectives. The weak order preference structure is the primary mechanism by which initial solutions are located for evaluating by the DM. Whatever type of utility function they have, it is not a concern. The simplicity of their methodology does not require much burden of decision maker, so we extend the methodology for solving group decision making problems in mobile client-server environment. Compared with other interactive approaches, our methodology relies on only weak order-typed preference information of group DMs. And the methodology was designed to avoid any assumptions about the shape or existence of the DMs' utility function and Group's utility function. It is also designed to simplify as much as possible the input preference requirements of the DM. Our suggested methodology compares intermediate solutions based on the weak order-typed preference of group DMs. For the minimal assumptions this methodology makes, we suggested an aggregation method of individual DM's weak order preferences. The aggregation method is modified from weak ranking method of Cook and Kress (1990).

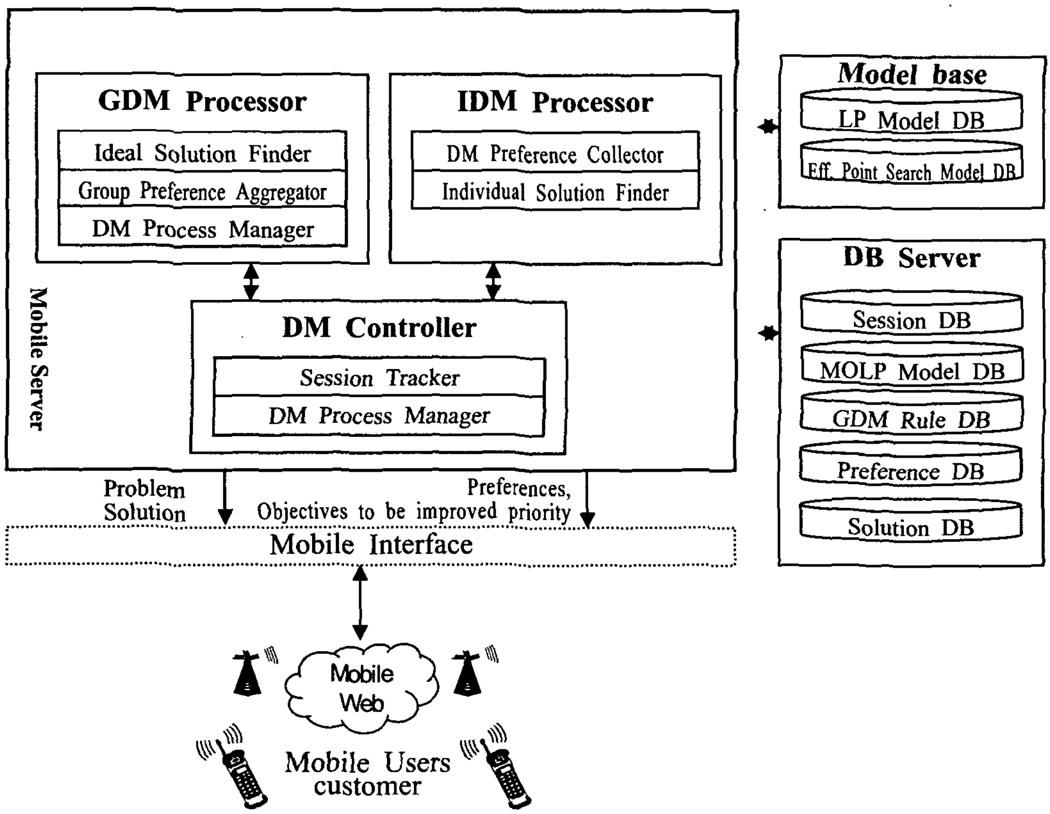
3. System Implementation

3.1 System Characteristics

The existing group decision support systems (GDSS) designed to execute in the mainframe, DOS or the Windows version share weaknesses in common from the viewpoint of both the user and the developer of the system. As far as the user is concerned, the installation of compilers and the system itself is needed. Furthermore, they work on only certain computer environments and operation systems. For the developer, the delivery of the updates of GDSS software is laborious. Keeping up separate versions for different environments also needs extra efforts. Via the mobile environment, there is only one version of the software to be updated and any client mobile device has the capabilities of a sever computer. The mobile server in MOBIGSS developed using the Java technology can easily support decision making processes among group members who are working on heterogeneous platforms, without recompilation or porting of the programs. In this research, we implement the distributed computing environments suitable to group decision making processes using the Java with several advantages in developing the client-server systems. By implementing the mobile user interface using the AnybuilderTM, which is a development tool for easy construction of mobile Web sites, MOBIGSS provides a simple and user-friendly decision environment to decision makers so that DMs with no specific MODM knowledge can be involved in a multiple objective group decision making process.

3.2 Overall System Architecture

MOBIGSS consists of server components and a client interface each of which executes in the mobile server and in the mobile phone display respectively. In the mobile server, it consists of the DM controller which controls and manages the whole group decision making processes, the GDM processor to aggregate DMs' preferences and find the group's solutions and the IDM processor for supporting individual decision making. Each of them accesses database and uses the model-base that contains LP and efficient point search models for finding intermediate solutions. MOBIGSS uses individual DM's weak order preferences on decision variables and objective functions as the input of MOLP model. The DM controller of MOBIGSS collects the preferences that mobile users enter through mobile phones and then activates either GDM processor or IDM processor. The GDM processor in the mobile server performs the role to iteratively find a group's solution through the interaction with DM controller and collection of preference information from group members. The aggregation procedure which combines each DM's weak order preferences to the group's one is suggested in section 3.3. The IDM processor in the mobile server makes each individual DM to iteratively search an individual solution under control of DM controller. The search process of individual solutions is based on the Dror-Gass algorithm. The role of model-base is to provide mathematical programming algorithms to GDM processor and IDM processor for finding an efficient solution of MOLP model, iteratively. In order to solve a MOLP problem, a number of LP problems have to be solved. The efficient point search model modified from Ecker-Kouada's algorithm is frequently used to determine adjacent efficient basic solutions during the solution search



[Fig. 1] Overall Architecture of MOBIGSS process. In the viewpoint of mobile clients, the simple text-based interaction with mobile users is required for overcoming low memory capacity and the delayed feedback from the users is allowed for narrow bandwidth. The client module sends information from decision makers to the server and then presents to each decision maker the results from server. As it requires few information from decision makers and displays simple text information to decision makers in the interaction processes, DMs with no specific MODM knowledge can easily be involved in the processes. [Fig. 1] shows the overall system architecture.

3.3 Group Preference Aggregation Scheme

MOBIGSS uses only weak order information of decision variables and objectives as the input of DM's preferences and integrates DM's weak order preferences to get the group's collective preference. Our suggested aggregation process is composed of three phases: Phase I is to obtain group's preferences of decision variables based on individual DM's preferences. Phase II is to obtain a group's composite preference rank based on group's preferences of decision variables. The rank is used to select a group's compromising solution among adjacent efficient extreme points. Phase III is to get group's preferences of objective functions.

Phase I. Group's preferences of decision variables.

Step 1 : At first each DM's weak order preference is obtained according to individual preference ranking scheme (for more detailed description see in (Dror & Gass, 1987)).

For an illustrative purpose, consider the example of three decision makers denoted as DM1, DM2, and DM3, and six decision variables, x_1, x_2, x_3, x_4, x_5, x_6. Based on a weak preference ranking scheme, it is assumed that each DM's weak order preference is given as follows.

DM1 : $x_1 \prec x_2 \prec x_4 \prec x_3 \prec x_5, x_6.$

DM2 : $x_3 \prec x_2 \prec x_5 \prec x_1, x_6 \prec x_4.$

DM3 : $x_6 \prec x_5 \prec x_4 \prec x_1 \prec x_2 \prec x_3.$

In DM1's preference, x_5 and x_6 are in the same class, so their rank is same.

Step 2 : From the result of each DM's preference class, it is obtained a pairwise comparison matrix $\mathbf{A}_k = (a_{ij})$, where $k = 1, \ldots, p$ and p is the number of DMs.

$$a_{ij} = \begin{cases} 1, & \text{if variable } x_i \text{ is preferred to variable } x_j \\ 0.5, & \text{if variable } x_i \text{ and variable } x_j \text{ are indifferent} \\ 0, & \text{if variable } x_j \text{ is preferred to variable } x_i. \end{cases}$$

We use Kendall scores method to rank the variables based on their preference records. The Kendal scores method amounts simply to determining the row sums of matrix $\mathbf{A}_k$, $PV_{k,i}$, where $i = 1, \ldots, n$, and n is the number of decision variables. $PV_{k,i}$ means preference rank of decision variables of DM k. In the illustrative example, $\mathbf{A}_1$ and $PV_{1,i}$ are as follows. $\mathbf{A}_2$ and $\mathbf{A}_3$ are obtained similarly.

$$A_1 = \begin{array}{c|ccccccc} & x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & PV_{1,i} \\ \hline x_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ x_2 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ x_3 & 1 & 1 & 0 & 1 & 0 & 0 & 3 \\ x_4 & 1 & 1 & 0 & 0 & 0 & 0 & 2 \\ x_5 & 1 & 1 & 1 & 1 & 0 & 0.5 & 4.5 \\ x_6 & 1 & 1 & 1 & 1 & 0.5 & 0 & 4.5 \end{array}$$

Step 3 : Group's aggregated preference rank of *i*-th decision variable, GPV_i is defined as the sum of individual DM's preference rank, $PV_{k,i}$,

$$GPV_i = \sum_k PV_{k,i}.$$

If the importance weights of individual DMs are different, the weight multiplied score sum becomes GPV_i. We assume that the weights of all DMs are equal. If the weights of DMs are different, GPV_i becomes the weighted average of $PV_{k,i}$. In the illustrative example, group's aggregated preference ranks of decision variables, GPV_i, are as follows; $GPV_1 = 6.5$, $GPV_2 = 6.0$, $GPV_3 = 8.0$, $GPV_4 = 9.0$, $GPV_5 = 7.5$, $GPV_6 = 8.0$. Based on the group's ranks, group's preference is represented as follows, $x_2 \prec x_1 \prec x_5 \prec x_3, x_6 \prec x_4$. Please compare this result with those of individual DMs in step 1.

Phase II : Group's composite preference rank of efficient basic solutions.

Our suggested algorithm finds a group compromising solution among adjacent efficient extreme points using the group's preference rank. Group's composite preference rank of *j*-th solution, $\mathbf{X}^j$ is defined as follows;

To find a next group compromising solution, we should calculate group's composite $GR(\mathbf{X}^j) = \sum_{i \in \text{basis of solution } \mathbf{X}^j} GPV_i$ that is, the sum of preference ranks of each adjacent efficient basic solution. In the illustrative example, let $\mathbf{X}^1 = (0, 1, 2, 0, 0, 1)^T$ to be one of the adjacent efficient basic solutions of current solution. Then $GR(\mathbf{X}^1) = GPV_2 + GPV_3 + GPV_6 = 6 + 8 + 8 = 22$. Among adjacent efficient basic solutions, the solution with the highest group's composite preference rank is selected as a new candidate solution.

Phase III : Group's preferences of objective functions to improve most.

This preference measure is used in order to determine which objectives to improve further in our proposed algorithm.

Step 1 : Each DM represents one or more objectives with which DM is dissatisfied using weak order-typed information. For an illustrative example, it is assumed that there are six objectives and DM1 is most dissatisfied with the value of f_2 and next that of f_1. DM2 and DM3 represent also the following weak order information.

DM1: $f_1 \prec f_2$
DM2: $f_2 \prec f_3 \prec f_1$
DM3: f_2

The preference of unidentified objectives is lower than that of identified ones, and the preferences among unidentified ones are assumed to be equal. Therefore, each DM's preference of objectives is represented as follows:

DM1: $f_3, f_4, f_5, f_6 \prec f_1 \prec f_2$.
DM2: $f_4, f_5, f_6 \prec f_2 \prec f_3 \prec f_1$.

DM3: $f_1, f_3, f_4, f_5, f_6 \prec f_2$.

Step 2 : From the result of each DM's preference class, it is obtained a pairwise comparison matrix $\mathbf{B}_k = (b_{ij})$, where $k = 1, \ldots, p$ and p is the number of DMs.

$$b_{ij} = \begin{cases} 1, & \text{if objective } f_i \text{ is preferred to objective } f_j \\ 0.5, & \text{if objective } f_i \text{ and objective } f_j \text{ are indifferent} \\ 0, & \text{if objective } f_j \text{ is preferred to objective } f_i. \end{cases}$$

$PO_{k,i}$ means preference rank of objective f_i of DM k. In the illustrative example, $\mathbf{B}_1$ and $PO_{k,i}$ are obtained as follows. $\mathbf{B}_2$ and $\mathbf{B}_3$ may be obtained similarly.

$\mathbf{B}_1$ =

	f_1	f_2	f_3	F_4	f_5	f_6	$PO_{1,i}$
f_1	0	0	1	1	1	1	4
f_2	1	0	1	1	1	1	5
f_3	0	0	0	0.5	0.5	0.5	1.5
f_4	0	0	0.5	0	0.5	0.5	1.5
f_5	0	0	0.5	0.5	0	0.5	1.5
f_6	0	0	0.5	0.5	0.5	0	1.5

Step 3 : Group's aggregated preference rank of objective function, GPO_i is defined as the sum of individual DM's preference rank, $PO_{k,i}$, $GPO_i = \sum_k PO_{k,i}$.

In the illustrative example, group's aggregated preference rank of objective functions, GPO_i , is as follows; $GPO_1 = 11$, $GPO_2 = 13$, $GPO_3 = 7.5$, $GPO_4 = 4.5$, $GPO_5 = 4.5$, $GPO_6 = 4.5$. Based on group's rank, group's preference may be represented as follows: $f_4, f_5, f_6 \prec f_3 \prec f_1 \prec f_2$. Please compare this result with those of individual DM's in step 1.

3.4 The procedure of MOBIGSS

Our procedure is suggested for group decision making processes in mobile computing environment. So each step of the procedure is processed at two areas, client system and server system. Client systems give intermediate results to each DM, receive DM's response, and transfer each DM's response into server system. Most part of our suggested procedure is processed at server system area.

Step 0: Specify the problem, and define group decision making environment.

This stage is performed by the coordinator of group decision making processes. One of group DMs or the analyst may be the coordinator. The coordinator can enter a new problem specification or load an existing one. The process of entering or updating a problem is interactive, and driven at server system. Considering the problem type and group members, a stopping rule is defined. Two type of stopping rules are used in this procedure. One is a predefined voting rule. A half agreed ratio is an example of the rule. The other rule is a maximum number of iterations. The coordinator of group decision making initializes the procedure by selecting the maximum number of iterations, t, or the voting rule.

Step 1: Find "ideal" solutions.

After a problem is loaded, the server system checks if there are any feasible solutions. If the solution doesn't exist, the coordinator updates (changes) the problem. If a feasible solution exists, the system computes the "ideal solutions", i.e. it solves the k single objective linear programming problems and obtains k ideal solutions $\mathbf{X}^i$ (i = 1, … ,k) and their associated images, the k ideal criterion vectors $\mathbf{f}(\mathbf{X}^i)$ (i = 1, … ,k). And then the server presents the problem and ideal solutions to each DM.

Step 2 :Input preferences of decision variables and objective functions.

Each DM participating in the group decision making process is asked to specify the preference of the variables and the objective functions by the weak order form. The weak order form specifies the variables (objectives) with groups according to DMs preferences. Each DM is asked to specify groups of variables and later group of objectives. The first group of variables is considered to be preferred to the second group and so on. The preferences from group DMs are sent to the server system.

Step 3: Calculate group's preference of decision variables.

After having collecting the preference of decision variables and objectives from all DMs, group's aggregated preference rank of decision variables, GPV_i (i = 1, …, n) are calculated according to the scheme outlined in phase I of section 2.

Step 4: Obtain initial candidate solution.

Set h = 0, where h is an iteration counter. The initial candidate solution, $\mathbf{W}^{(h)}$ is selected according to the procedure outlined in phase II of section 2. Given the ideal solutions $\mathbf{X}^1$, $\mathbf{X}^2$, ..., $\mathbf{X}^k$, group's composite preference rank is calculated and $\mathbf{X}^j$ with max $_j$ $GR(\mathbf{X}^j)$ is set to be $\mathbf{X}^*$. Then it generates an initial candidate solution $\mathbf{W}^{(h)}$, which is efficient, basic and has the highest group's preference rank among all the basic efficient solutions reached from $\mathbf{X}^*$ by the 'Edge' algorithm of Ecker-Kouada (1978).

Step 5: Present the solution to DMs.

Present $\mathbf{W}^{(h)}$ to each DM with the values of the objective function, $\mathbf{f}(\mathbf{W}^{(h)})$. The current values of objective functions are shown to DM with "ideal" and the level of attainment $\mathbf{a}^{(h)}$, where $\mathbf{a}_j^{(h)} = [\mathbf{f}_j(\mathbf{W}^{(h)}) - \min \mathbf{f}_j(\mathbf{W}^{(h)})]/[\max \mathbf{f}_j(\mathbf{W}^{(h)}) - \min \mathbf{f}_j(\mathbf{W}^{(h)})]$ (j $\in$profit objectives) and $\mathbf{a}_j^{(h)} = [\mathbf{f}_j(\mathbf{W}^{(h)}) - \max \mathbf{f}_j(\mathbf{W}^{(h)})]/[\min \mathbf{f}_j(\mathbf{W}^{(h)}) - \max \mathbf{f}_j(\mathbf{W}^{(h)})]$ (j $\in$cost objectives). It can be used as a normalized objective value for each objective.

Step 6: Confirm if the solution is satisfactory.

Each DM is asked if the candidate solution $\mathbf{W}^{(h)}$ is satisfactory or not. The response of each DM is transferred and aggregated at server system.

Step 7: Stopping rule is satisfied?

Summarize satisfactory DMs' responses, and calculate the agreed ratio. Check whether the ratio satisfies the pre-defined voting rule or not. If it is, go to Step 13; otherwise, compare the parameter h with t. If $h < t$, go to step 8; otherwise, choose the solution with the highest GR among all the searched candidate solutions and set it to be $\mathbf{W}^{(h)}$, and then go to Step 13.

Step 8: Specify objective(s) to improve, and change their preferences.

Any DM who is not satisfied at the objective values of current solution, has to indicate the objective function(s) below his/her satisfaction level. DM has an option to specify more than one unsatisfactory objective function. The DM satisfied at current solution needs not specify objective(s) to improve. Each DM has the option of changing the weak order of variables and/or objectives at this step.

Step 9: Find a new candidate solution.

According to phase III, server system recalculates GPV_i (i = 1, …, n) and GPO_i (i = 1, …, n) considering DM's changed preference information. And it is checked whether there is a new solution adjacent to the $\mathbf{W}^{(h)}$, which improves the functions indicated by group DMs.

Step10: There is a new solution?

As a result of step 9, there are four possible cases:

(a) There is a case where the server can not determine which objective to improve. In this case, the server system notifies the DMs and gives them opportunity to enter a new selection while indicating their previous choice. If such a process gives a same result, choose the solution with the highest GR among all the basic efficient solutions adjacent to the current solution, and then set $h = h + 1$ and set the solution to be $\mathbf{W}^{(h)}$. Go to step 13.

(b) There is no adjacent solution that improves the objectives indicated by group DMs. Go to step 13.

(c) There is more than one new solution improving the objectives indicated by DMs. Set $h = h + 1$. Choose the solution with the highest GR, and set the solution to be $\mathbf{W}^{(h)}$. Go to Step 5.

All improvements in the direction indicated by DM have already been reviewed, so none of them are new. Set $h = h + 1$, and go to Step 11.

Step 11: Cycle occurred?

This step is executed in case of cycle where there exists a cyclic sequence of efficient basic solutions that presented to DMs in Step 5. The procedure examines whether the cyclic sequence belongs to one or more efficient faces of our problem (Ecker & Kouada, 1978).

(a) In the case where the cyclic sequence belongs to more than one efficient face, the procedure halts. At this point, more information about the problem is required in order to solve it. Go to step 0.

(b) In the case where the cyclic sequence belongs to one efficient face, go to step 12.

Step 12: Calculate a compromise solution.

The compromise solution is obtained as a weighted linear sum of the solutions in the cycle. The weights are normalized and directly proportional to the group's composite preference rank, *GR* of solutions in the cycle. Let p and $\mathbf{X}^k$ be the number of solutions and the *k*th candidate solution in the cycle sequence, respectively. The compromise solution is denoted by $\mathbf{W}^c$, where

$$\mathbf{W}^c = [w_j^c]_{j=1,2,\ldots,n}, \quad w_j^c = \frac{\sum_{k=1}^{p} GR(\mathbf{X}^k) \times x_j^k}{\sum_{k=1}^{p} GR(\mathbf{X}^k)}, \quad j = 1,\ldots,n.$$

Set $\mathbf{W}^c$ to be $\mathbf{W}^{(h)}$. This new compromise solution is presented to each DM, and go to Step 13.

Step 13: STOP.

Terminate the solution search process with ($\mathbf{W}^{(h)}$, $\mathbf{f}(\mathbf{W}^{(h)})$) as the final group solution.

4. Case Study

For illustration, we present an experimental example, modified from Schniederjans et al (1993). It deals with a case of investor who has a wealth of \$183,000 which he wants to allocate among seven assets: home equity (x_1), life insurance (x_2), IRAs (x_3), business equity (x_4), mutual funds-bonds (x_5), mutual funds-stocks (x_6), and savings (x_7). Each of the seven possible assets in which the investor can allocate wealth is assigned to a decision variable in the MOLP model that defines the number of dollars of total wealth that should be allocated in the optimal portfolio. The investor in this problem also has four objectives of maximizing return on investments, maximizing investments in retirement-oriented alternatives, minimizing taxes and maximizing liquidity. He/She wants to get supports from financial advisors (FAs). Three FAs are included in this group decision making process and represent three different interests/objectives: returns (f_1, f_3), long-term life plan (f_2) and financial liquidity objective (f_4). The DMs participated in the group decision making consist of an investor and three FAs. The FAs provide weak order preferences about seven assets and four objectives and the investor selects a solution based on the FAs' preference-based supports. They are difficult to come together to discuss this problem. The investor decides to ask their preferences about his/her objectives and variables to be promptly allocated using the mobile system, MOBIGSS. In the first stage, the investor formulates the seven variables, the five objective functions and the constraints. The variable, x_j is the number of dollars to be allocated in each of the *j*th investment alternative, where $j = 1, 2, \ldots, 7$. The objectives and constraints are followings.

(a) Objectives

f_1 (Return on investment) = maximize $12.5x_1+5.85x_2+8.25x_3+19.2x_4+11.1x_5+18x_6+5x_7$

f_2 (Retirement investment) = maximize x_2

$+ x_3 + x_7$

f_3 (Tax burden) = minimize $x_1 + x_2 + x_3$

f_4 (Investment liquidity) = maximize $70x_1 + 70x_2 + 10x_3 + 70x_4 + 98x_5 + 97x_6 + 97x_7$

(b) Constraints

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 \leq 183{,}000$ (total wealth and income)

$x_2 \geq 4{,}000$ (lower bound on life insurance)

$8{,}000 \leq x_3 \leq 12{,}000$ (bounds on IRAs)

$x_4 \leq 100{,}000$ (upper bound on business equity)

$137{,}250 \leq 1.5x_1 - 0.5x_2 + 0.2x_3 + 2x_4 + 1.9x_5 + 2x_6 - 0.3x_7 \leq 228{,}750$

(lower and upper boundaries beta exposure for risk factor 1)

$x_1 + 0.8x_2 + 0.3x_3 + 2.7x_4 + 0.5x_5 + 2x_6 + 0.4x_7 \leq 228{,}750$

(upper boundary beta exposure for risk factor 2)

$0 \leq -0.5x_1 + 0.2x_2 + 0.5x_3 - 0.5x_4 - x_5 + x_7 \leq 45{,}750$

(lower and upper boundaries beta exposure for risk factor 3)

$0 \leq 0.3x_2 + 0.5x_3 + 0.3x_4 - 0.5x_5 - 1.2x_7 + x_7 \leq 45{,}750$

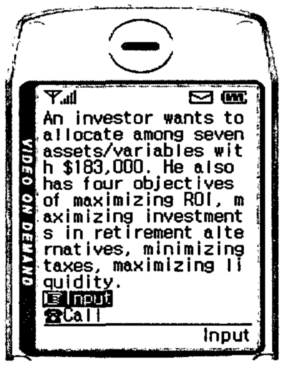
(lower and upper boundaries beta exposure for risk factor 4)

$x_2 + x_3 + x_7 \geq 37{,}500$ (minimum retirement investment)

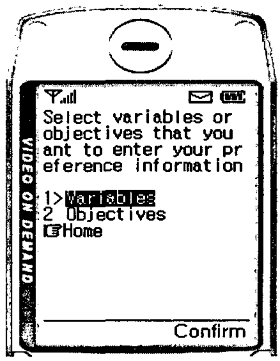
$x_1 + x_2 + x_3 \geq 66{,}500$ (minimum investment in tax deferred alternatives)

$x_7 \geq 66{,}500$ (minimum investment in saving alternative)

At step 1, the mobile server finds ideal solutions of each objective, X^1, X^5, X^6, X^7. At step 2 all FAs are asked to specify the preferences of the variables and the objective functions using their each own mobile phone as shown in [Fig. 2] First step of the mobile group decision support is to explain decision problem to the FAs who decide to participate in the group decision process as shown in (a) of [Fig. 2] They can call the person who is take charge of the problem by pressing a call button. Each FA understands the problem and participates in the group decision process showing the screen (b) of [Fig. 2].



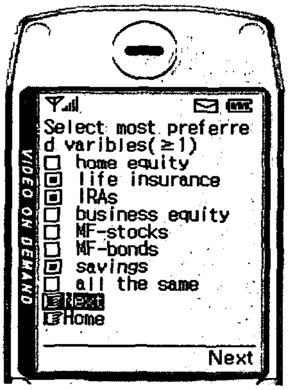
(a) Problem explanation



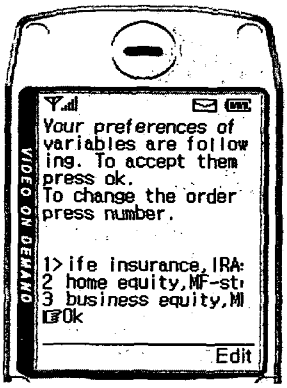
(b) Preference input start

[Fig. 2] Problem explanation and input start screens

They enter the preference of variables and objectives by selecting the most preferred variables/objectives, the next most preferred ones, and so on. The screen (a) of [Fig. 3] shows a sample of entering the most preferred variables. They can select more than one variable as the most preferred variables because we allow them to enter weak orders between variables. First FA's final weak orders of variables are shown in (b) of [Fig. 3] and he/she can change the order by selecting the weak order number. The preference information of objectives is entered in the same way.



(a) Preference input



(b) Final weak order and Edit

[Fig. 3] First FA's preference input and edit screens

Finally, the weak orders on asset alternatives and objectives that each FA sends to the mobile server system are summarized at <Table 1>.

<Table 1> Weak order preference

	FA 1	FA 2	FA 3
Variables	$x_2, x_3, x_7 \prec x_1, x_5 \prec x_4, x_6$	$x_1, x_5 \prec x_4, x_6 \prec x_2, x_3, x_7$	$x_3 \prec x_1, x_2, x_4 \prec x_5, x_7$
Objectives	$f_2, f_4 \prec f_3 \prec f_1$	$f_1, f_3, f_4 \prec f_2$	$f_2, f_3 \prec f_1 \prec f_4$

A_1 =

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	$PV_{1,i}$
x_1	0	1	1	0	0.5	0	1	3.5
x_2	0	0	0.5	0	0	0	0.5	1
x_3	0	0.5	0	0	0	0	0.5	1
x_4	1	1	1	0	1	0.5	1	5.5
x_5	0.5	1	1	0	0	0	1	3.5
x_6	1	1	1	0.5	1	0	1	5.5
x_7	0	0.5	0.5	0	0	0	0	1

A_2 =

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	$PV_{2,i}$
x_1	0	0	0	0	0.5	0	0	0.5
x_2	1	0	0.5	1	1	1	0.5	5
x_3	1	0.5	0	1	1	1	0.5	5
x_4	1	0	0	0	1	0.5	0	2.5
x_5	0.5	0	0	0	0	0	0	0.5
x_6	1	0	0	0.5	1	0	0	2.5
x_7	1	0.5	0.5	1	1	1	0	5

A_3 =

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	$PV_{3,I}$
x_1	0	0.5	1	0.5	0	0	0	2
x_2	0.5	0	1	0.5	0	0	0	2
x_3	0	0	0	0	0	0	0	0
x_4	0.5	0.5	1	0	0	0	0	2
x_5	1	1	1	1	0	0	0.5	4.5
x_6	1	1	1	1	1	0	1	6
x_7	1	1	1	1	0.5	0	0	4.5

Based on our suggested aggregation method of Phase I of section 3, we get the pairwise comparison matrix $\mathbf{A}_K$ as follows:

Based on preference ranks of decision variables of three FAs, GPV_i, the group's aggregated preference rank of variable i, is as follows:

GPV_i = (6, 8, 6, 10, 8.5, 14, 10.5)

The group preference ranks of three ideal solutions are as follows:

$GR(\mathbf{X}^1) = GPV_1 + GPV_2 + GPV_3 + GPV_4 + GPV_5 + GPV_6 + GPV_7 = 63$

$GR(\mathbf{X}^5) = GPV_2 + GPV_3 + GPV_4 + GPV_5 + GPV_6 + GPV_7 = 57$

$GR(\mathbf{X}^6) = GPV_1 + GPV_2 + GPV_3 + GPV_6 + GPV_7 = 44.5$

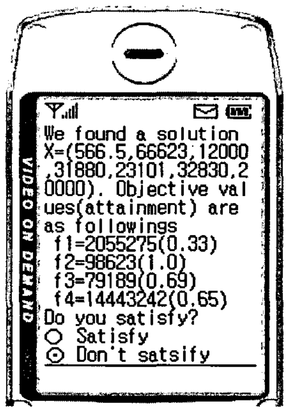
$GR(\mathbf{X}^7) = GPV_1 + GPV_2 + GPV_3 + GPV_4 + GPV_6 + GPV_7 = 54.5$

The ideal solution with the highest group preference rank is X^1, and its group preference rank is 63. Denote this solution as an initial candidate solution, $\mathbf{W}^0$ (566.5, 66623, 12000, 31880, 23101, 32830, 20,000). For this initial candidate solution, we have the values for the four objective functions as shown in <Table 2>.

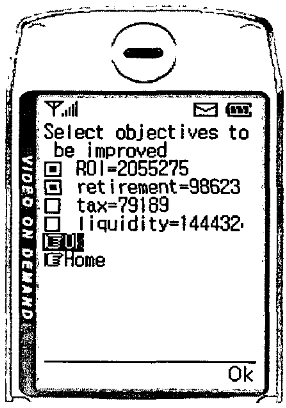
<Table 2> Objective values of 1st phase

Objectives	Current	Ideal	Attainment
$f_1(\mathrm{W}^0)$	2,055,275	2,193,790	0.33
$f_2(\mathrm{W}^0)$	98,623	98,623	1.00
$f_3(\mathrm{W}^0)$	79,189	66,500	0.69
$f_4(\mathrm{W}^0)$	14,443,242	15,109,248	0.65

The solution is presented to all FAs according to step 5. Each FA is asked to judge it, taking a vote whether the current solution is satisfactory or not. Screen (a) of [Fig. 4] shows the intermediate solution of variables, objectives values and level of attainment to ideal solution values. After examining the solution the FA decides whether satisfy with it or not. If the FA doesn't satisfy with the result, then select 'Don't satisfy' option and go to preference input screen as shown in (b) of [Fig. 4]. The FA selects the objectives to be improved in a later process.



(a) Intermediate solution and interaction



(b) Objective selection for improvement

[Fig. 4] Intermediate result and interaction screens

The response of each FA is transferred and aggregated at the server system. All FAs' responses are summarized and the agreed ratio is calculated. The FA 2 is satisfied but FA 1, FA3 and investor are not satisfied at the current solution, so the agreed ratio is zero. At step 8, each FA selects the objectives to be improved as follows:

FA1: f_1, f_3 ($f_3 \prec f_1$)

FA2: f_1

FA3: f_4

Based on Phase III (group's preferences of objective functions to be most improved) of section 3, the server computes a group's aggregated preference rank of objective functions.

GPO_1 = 5

GPO_2 = 2.5

GPO_3 = 4

GPO_4 = 1.8

Now the server finds an adjacent solution, $\mathbf{X}^2$, as a new candidate solution $\mathbf{W}^1$ (8716, 65778, 12000, 0, 3467, 77039, 20000), and gets four objective values for $\mathbf{W}^1$ as shown in <Table 3>.

<Table 3> Objective values of 2nd phase

Objectives	Current	Ideal	Attainment
$f_1(W^1)$	2,117,937	2,193,790	0.63
$f_2(W^1)$	97,778	98,623	0.96
$f_3(W^1)$	86,494	66,500	0.52
$f_4(W^1)$	15,087,128	15,109,248	0.99

The solution $\mathbf{W}^1$ increased significantly the value of the ROI objective, f_1. The value of f_4, investment liquidity, is also increased, but that of f_2, retirement investment, is reduced and tax burden is increased. When this solution is presented to FAs and the investor as shown in a similar screen to (a) in [Fig. 4], FA 2 and FA 3 are satisfied, but FA 1 and investor are not satisfied. FA 1 and investor want to increase the value of f_1 continually. The server finds an adjacent solution, $\mathbf{X}^3$, as a new candidate solution $\mathbf{W}^2$ (20850, 60000, 12000, 0, 0, 74150, 20000). <Table 4> shows objective values for $\mathbf{W}^2$.

<Table 4> Objective values of 3rd phase

Objectives	Current	Ideal	Attainment
$f_1(W^2)$	2,145,325	2,193,790	0.77
$f_2(W^2)$	92,000	98,623	0.72
$f_3(W^2)$	92,850	66,500	0.36
$f_4(W^2)$	14,912,050	15,109,248	0.90

Finally, FA 1 and FA 3 are satisfied with the solution $\mathbf{W}^2$, but FA 2 is not satisfied. The investor would like to accept the solution. The group decision support process using mobile environment is finished with the final solution.

Examining the intermediate and final solutions showed the characteristics of our group decision process. For the variables the values of mutual funds-stocks (x_6) and savings (x_7) were much higher than the other variables. It is because all FAs gave higher ranks for those variables at the initiation step. For the objectives the value of f_1, return on investment is continuously improved from 0.33 to 0.77 in the viewpoint of level of attainment. It is because FA1 and FA2 selected the objective to be improved at second step and FA1 did it at third step. Our algorithm helps a decision group to improve specific objective functions through iterative steps and the solution is selected among basic efficient solutions.

5. Conclusion

Mobile application is an interesting and challenging area of researches and development. However, there are many shortcomings of the mobile devices, such as limited screen size, narrow bandwidth and low capacity. In order to overcome the shortcomings, the simple interactive procedure based on weak preferences of objectives and variables are proposed in this paper. The interactive procedure suggested for MOLP problems help the group enter easily their preferences and select a compromising solution in the mobile environment. Only the partial weak orders of variables and objectives from the group members are enough for searching the best compromising solution. The mobile client-server architecture is presented to reduce the computing load of the mobile phones. The developed system, MOBIGSS, uses the simple text interface to avoid the existing shortcomings of mobile devices. The experimental example shows the advantages.

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References

[1] Beck, M. P. and B. W. Lin, "Some heuristics for the consensus ranking problem", *Computers and Operations Research*, Vol.10, No.1 (1983), 1-7.

[2] Cook, W. D. and M. Kress, "An m^{th} generation model for weak ranking of players in a tournament", *Journal of the Operational Research Society*, Vol.41, No.12(1990), 1111-1119.

[3] Cook, W. D. and M. Kress, "Ordinal ranking with intensity of preference", *Management Science*, Vol.31, No.1(1985), 26-32.

[4] Davey, D. Olson, "Multiple criteria decision making models in group decision support", *Group Decision and Negotiation*, Vol.7(1998), 55-75.

[5] Divitini, M., B. A. Farshchian, and H. Samset, "UbiCollab: Collaboration support for mobile users", Proceedings of the 2004 ACM Symposium on Applied Computing (March 2004), 1191-1195.

[6] Dror, M., S. I. Gass, and A. Yellin, "Experiments with an interactive procedure for the MOLP given weak orders on variables and objectives", *European Journal of Operational Research*, Vol.34(1988), 78-85.

[7] Dror, M. and S. I. Gass, "Interactive scheme for a MOLP problem given two partial orders: one on variables and one on objectives", *Applied Mathematics and Computation*, Vol. 24(1987), 195-209.

[8] Ecker, J. G. and I. A. Kouada, "Finding all efficient extreme points for multiple objective linear programming", *Mathematical Programming*, Vol.14(1978), 249-261.

[9] Franz, L. S., G. R. Reeves, and J. J. Gonzalez, "Group decision processes: MOLP procedures facilitating group and individual decision orientation", *Computers and Operations Research*, Vol.19, No.7(1992), 695-706.

[10] Iz, P. and L. Krajewski, "Comparative evaluation of three interactive multiobjective programming techniques as group decision support tools", *INFOR*, Vol.30, No.4(1992), 349-363.

[11] Kersten, G. E., "NEGO-group decision support system", *Information and Management*, Vol.8(1985), 237-246.

[12] Korhonen, P., H. Moskowitz, J. Wallenius, and S. Zionts, "An interactive approach to multiple criteria optimization with multiple decision-makers", *Naval Research Logistics Quarterly*, Vol.33(1986), 589-602.

[13] Lewandowski, "SCDAS - decision support system for group decision making: decision theoretic framework", *Decision Support Systems*, Vol.5(1989), 403-423.

[14] Lewis, H. S. and T. W. Butler, "An interactive framework for multi-person, multiobjective decisions", *Decision Science*, Vol. 24, No.1(1993), 1-22.

[15] Rao, V. S. and S. L. Jarvenpaa, "Computer support of groups: theory-based models for GDSS research", *Management Science*, Vol. 37, No.10(1991), 1347-1362.

[16] Reeves, G. R. and L. S. Franz, "A simplified interactive multiple objective linear programming procedure", *Computers and Operations Research*, Vol.12 No.6(1985), 589-601.

[17] Schniederjans, M. J., T. S. Zorn, and R. R. Johnson, "Allocating total wealth: a goal programming approach", *Computers and Operations Research*, Vol.20(1993), 679-685.

[18] Sharaf, M. A. and P. K. Chrysanthis, "Facilitating mobile decision making", Proceedings of the 2nd international workshop on Mobile commerce (September 2002), 45-53.

[19] Slevin, D. P., L. W. Boone, E. M. Russo, and R. S. Allen, "CONFIDE: A collective decision-making procedure using confidence estimates of individual judgement", *Group Decision and Negotiation*, Vol.7(1998), 179-194.

[20] Steuer, R. E., *Multiple Criteria Optimization: Theory, Computation, and Application*, John Wiley & Sons, New York, 1986.

[21] Steuer, R. E. and E. U. Choo, *An interactive weighted Tchebycheff procedure for multiple objective programming, Mathematical Programming*, Vol.26, No.3(1983), 326-344.

[22] Sun, M., A. Stam, and R. E. Steuer, "Interactive multiple objective programming using Tchebycheff programs and artificial neural networks", *Computers and Operations Research*, Vol.27(2000), 601-620.

[23] Varshney, U. and R. Vetter, "Mobile commerce: framework, applications and networking support", *Mobile Networks and Application*, Vol.7(2002), 185-198.

[24] Wang, H. F. and S. Y. Shen, "Group decision support with MOLP applications", *IEEE Transactions on Systems, Man and Cybernetics*, Vol.19, No.1(1989), 143-152.

[25] Yang, C. C. and F. L. Wang, "Fractal summarization for mobile devices to access large documents on the Web", Proceedings of the twelfth international conference on World Wide Web (May 2003), 215-224.

[26] Wendell, R. E., "Multiple objective mathematical programming with respect to multiple decision makers", *Operational Research*, Vol.28, No.5(1980), 1100-1111.

[27] Zionts, S. and J. Wallenius, "An interactive programming method for solving the multiple criteria problem", *Management Science*, Vol.22 No.6(1976), 652-663.

요약

MOBIGSS: 모바일 인터넷에서의 그룹의사결정지원시스템

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최근들어 모바일 환경에서 운영되는 많은 응용시스템들이 개발되고 있다. 대부분의 시스템들은 모바일 사용자와의 단순한 상호작용만을 필요로 하는 메시지 전송, 은행 거래, 위치 서비스 등을 위한 것들이다. 단순한 기능만을 지원하는 이유는 모바일 장치가 스크린 크기가 제한적이고, 네트워크 대역폭이 좁으며, 컴퓨팅 능력이 낮기 때문이다. 이와 같은 이유로 모바일 장치를 활용하여 그룹의사결정을 지원하는 복잡한 알고리즘을 구현하는 것은 거의 불가능하였다. 본 연구에서는 모바일 환경에서의 그룹의사결정 과정을 지원하기 위하여 간결한 상호교호적 절차를 제시하고자 한다. 이 상호교호적 절차는 모바일 환경에서 그룹의 절충해를 선택하도록 돕기 위한 다목적 선형계획 프로그램에 기반을 두고 있다. 이 절차를 활용하게 되면 그룹의사결정자들의 정보제공의 부담을 줄여줄 수 있다. 최선의 절충해를 찾기 위해서 변수 및 목적식에 대한 부분적 순위 정보만을 활용하였다. 본 방법론은 의사결정자의 효용함수에 대한 형태 혹은 존재 여부에 대한 어떠한 가정도 하지 않고 있다. 본 절차의 실험적 연구를 위해서 모바일 환경에서의 그룹의사결정지원시스템인, MOBIGSS를 개발하였으며, 이 시스템을 개인 투자자의 자산 투자 문제에 적용 하였다.

Key words : 모바일 인터넷, 다목적 의사결정, 그룹의사결정, 부분적 순위 선호정보

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