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On-Line Group Decision Support by Preference Programming in Traffic Planning

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Abstract

Preference programming is a decision support technique which allows decision makers to give preference statements of weight ratios in terms of intervals instead of single numbers in a value tree. Individual preferences, based on single number statements, can be combined into an interval model, and the negotiation proceeds by focusing on decreasing the width of the intervals. The preference programming approach was evaluated with a realistic traffic planning problem by using the HIPRE 3+ Group Link software. The results from nine test groups indicate that preference programming is an operational group decision support technique which initiates negotiations and efficiently directs the discussion towards issues which are relevant in reaching a consensus.

Key words: Multiple Criteria Decision Making, hierarchical weighting techniques, preference programming, Group Decision Support Systems

1. Introduction

Multiple Criteria Decision Making (MCDM) techniques are promising tools in aiding groups to make decisions. Descriptions of various multiple criteria group decision support techniques can be found in Hwang and Lin (1987) and Bui (1987). For example, the normative approach with multiattribute utility functions derives the group's utility function by aggregating the related individual utility functions (Keeney and Kirkwood 1975; Keeney 1976; Keeney and Raiffa 1976). Individual utility functions can also be used to identify efficient solution candidates or to simulate different negotiation strategies (see, e.g., Jarke et al. 1987; Mumpower 1991; Verkama et al. 1992, 1994; Ehtamo et al. 1994). Iz and Gardiner (1993) give a survey of the MCDM techniques and related Group Decision Support Systems (GDSS) which have been tested in cooperative decision-making situations. Yet, the approaches proposed in the literature vary widely, and the choice of the best method for different situations is difficult. In this article, we shall present a new approach which is based on hierarchical weighting. The proposed approach guides the negotiations so that the negotiators focus on the prioritization of objectives in a value tree.

In practice, the main advantages of decision support techniques are presentation of different opinions within a group and aid for structuring the decision problem (Davies 1994; Islei and Lockett 1991; Iz and Gardiner 1993; Hämäläinen and Leikola 1994). The information about individual preferences increases the understanding of the group's decision-making problem (Islei and Lockett 1991; Nunamaker et al. 1991). This is particularly true in negotiations where it is necessary to have information about the issues where the negotiating parties have the most conflicting views. The structuring phase is very important, and the problem is partly solved when the negotiators can agree on and understand the common objectives. These advantages cannot be attributed to the mathematical MCDM technique only. The success of group decision support depends on the interaction between negotiators, computer implementation, and a particular mathematical technique. The tests of group decision support systems require experiments with realistic negotiation situations.

Preference programming is a new value-tree approach (Arbel 1989; Salo and Hämäläinen 1992; Arbel and Vargas 1993; Salo and Hämäläinen 1995), which gives decision makers an opportunity to make imprecise preference statements with intervals of numbers instead of single number estimates. Preference programming was first proposed as a group decision support technique by Hämäläinen et al. (1991) in connection with an energy policy problem. The technique has also been used recently in a case study with Finnish politicians (Hämäläinen and Leikola 1995).

The basic feature of group decision making with preference programming is that the intervals of numbers include all the opinions within the group. The width of the preference interval is then a measure of the disagreement within the group. One approach to using preference programming in group decision support is to direct the discussion to attributes which have the widest preference intervals. The negotiation proceeds as the negotiators reevaluate their statements and decrease the widths of the preference intervals. The progress of the negotiation requires interaction between negotiators, and the final outcome depends on the concessions which the negotiators are willing to make. A simulated example with the preference programming technique would not describe the real use of the technique. This article reports results and observations concerning the use of this approach in the traffic planning of the Helsinki metropolitan area with nine test groups. This experiment further explores the ideas developed in the previous energy policy experiment of Hämäläinen et al. (1991).

One of the purposes of the present study is to continue the analysis of the two working procedures proposed in the energy policy study. These procedures differ, so that the first begins by eliciting the individual value models, and the second starts directly with the group's joint interval model. The energy policy case raised the question of a possible anchoring effect: negotiators who specify their own individual value models explicitly may be more reluctant to change their preferences than those who work directly with a group interval model. Such anchoring, if it exists, would make negotiators less willing to reevaluate preference intervals and thus make the convergence of the process slower. These kinds of behavioral issues are of great interest when we consider the practical use of GDSS.

The unwillingness to change preference intervals may also be due to the nature of the negotiation situation. In a so-called "hard" negotiation (also called "win-lose" or "distributive" negotiation), the goals of the negotiators are strongly opposite (Fisher and Ury 1981; Jelassi and Foroughi 1989; Nunamaker et al. 1991). A more friendly situation is found in a "soft" negotiation (also called "win-win" or "integrative" negotiation) where parties want to reach a jointly beneficial solution. The relationship between the type of decision problem and the progress of negotiation with different negotiation support techniques clearly needs more attention. The preference programming technique, for example, would probably be more effective in a "soft" negotiation situation where group members are willing to reevaluate their preferences and change their preference statements.

One of the goals of the experiment was to test the new group decision support software HIPRE 3+ Group Link (Hämäläinen and Kettunen 1994a; Hämäläinen and Kettunen 1994b). This software enables on-line group decision making based on preference programming. The individual preferences of the group members are combined through a PC network, and the group's model with preference intervals is generated and updated on-line.

2. Negotiation modeling framework

2.1. Preference programming

Hierarchical weighting techniques, such as value-tree analysis (von Winterfeldt and Edwards 1986) and the Analytic Hierarchy Process (AHP) (Saaty 1980), produce weights for the criteria and scores for the alternatives to indicate the preferences of a decision maker or a group. The Simple Multiattribute Rating Technique (SMART) in value-tree analysis (Edwards 1977) and the AHP (Saaty 1980) are based on pairwise ratio comparisons. The decision makers are asked to compare the relative importance of two criteria or the attractiveness of alternatives with respect to each criterion. They give single number estimates to represent the weight ratios. Preference programming can be seen as a generalization of these techniques, since it allows decision makers to give intervals of weight ratios instead of single number estimates in a value tree (Salo and Hämäläinen 1992) or in the AHP (Salo and Hämäläinen 1995). The smallest and largest values in the interval define the boundaries for the feasible region of the weights. The minimum and maximum weights on each level of the hierarchy are results from the minimization and maximization of weights in the feasible region. The local weight intervals are processed through the hierarchy to attain the final weight intervals for the alternatives. Preference programming supports interactive working, since the results, i.e. the weight intervals for the alternatives, are recalculated after each new preference statement.

Value-tree analysis is applied to group decision making by giving each member a weight, and the weighted sum of individual values is the group opinion (Keeney and Kirkwood 1975; Keeney 1976; Keeney and Raiffa 1976). A similar procedure is suggested for the AHP so that the relative importance of each member is also evaluated with AHP (Dyer and Forman 1992; Saaty 1989). In preference programming, we are able to avoid the cumbersome process of selecting weights for group members, as all the group opinions are combined into an interval model. The width of the preference intervals reflects the disagreement among the group members, and thus points out promising topics for further discussion. The technique does not necessarily give a final preferred group choice, since the results are also intervals of weights for alternatives. The idea of using preference programming in the negotiation process is based on narrowing the differences in opinion about weight ratios until a dominating alternative emerges.

The general way of using preference intervals in group decision making is illustrated by a car selection problem shown in Figures 1a and 1b. The example is very simple, as there is only one criterion: the desirability of the car. Group members state their opinions, and all the preference statements are combined into preference intervals. Figure 1a shows that the opinions of the weight ratios concerning Cars 1 and 2 range from 4.0 on the right to 6.0 on the left. This means that the two most opposite opinions within the group are that Car 2 is four times better than Car 1 and that Car 1 is six times better than Car 2. There are also different opinions about Cars 2 and 3, as the interval of ratios ranges from 3.5 on the right to 7.0 on the left. All the members of the group agree that Car 1 is up to five times better than Car 3. The weight intervals for the cars are shown in the top right-hand corner of Figure 1a.

Next, the group concentrates on comparing Cars 1 and 2. Only one of the group members thinks that Car 2 is better than Car 1. The group decides to concentrate on this comparison. During the discussion, the other members of the group are able to clarify their arguments in favor of Car 1, so that the disagreeing member changes his opinion and approves that Car 1 as up to two times better than Car 2. This change of the preference interval is shown in Figure 1b. The weight interval of Car 1 now lies completely above the weight interval of Car 2, and thus Car 1 is preferred to Car 2. Car 1 does not, however, dominate Car 3 absolutely, since the upper bound of the weight interval of Car 3 is higher than the lower bound of Car 1. If we extend the analysis to take into account the so-called pairwise dominance, we find that Car 1 dominates Car 3 pairwisely. In this simple car

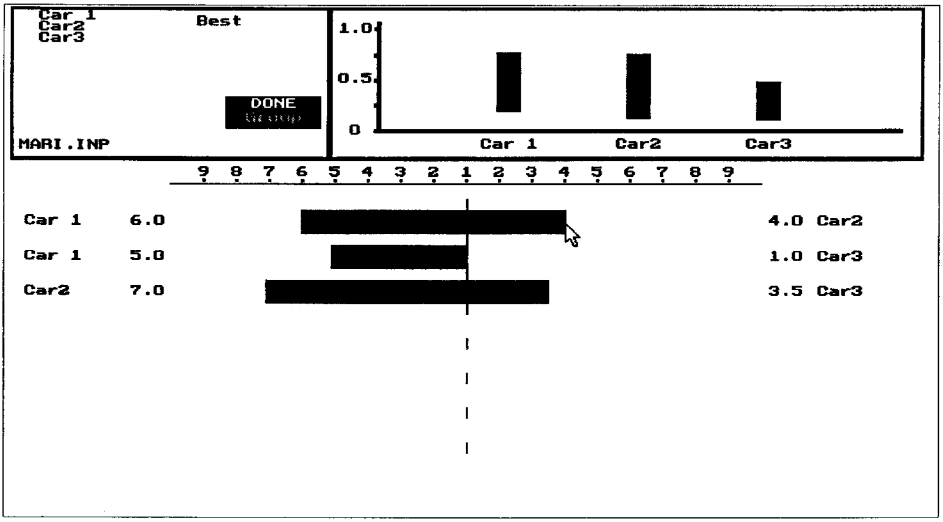

Figure 1a. An example of interval preference statements.

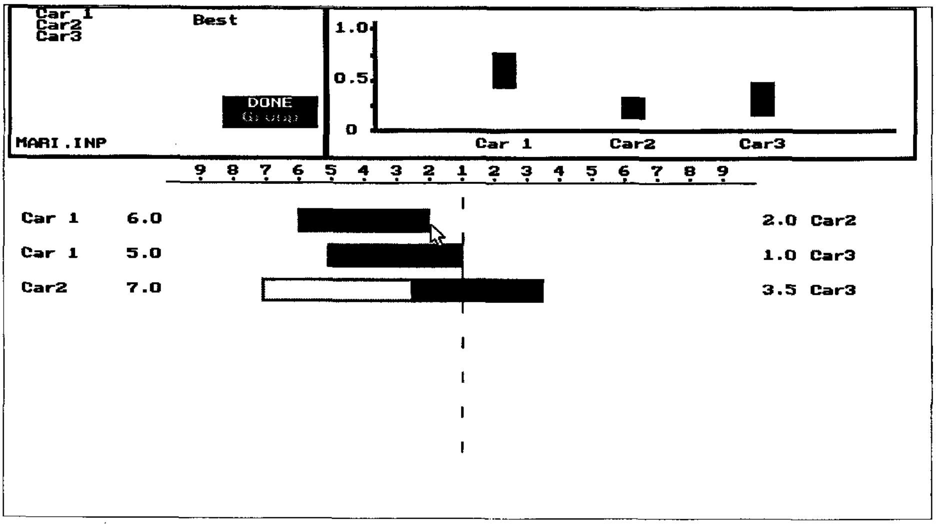

Figure 1b. An example of a change in the preference interval.

selection example, pairwise dominance can be seen directly from Figure 1b, as Car 1 has been evaluated to be better than Cars 3 and 2 pairwisely. (For a more detailed discussion of dominance concepts, see Salo and Hämäläinen 1992; Salo and Hämäläinen 1995).

The given ratio statements are required to be consistent with each other. The white area of the preference intervals in Figure 1b shows the range over which the ratio statements are inconsistent. In this case, for example, it is not consistent to claim that Car 2 is more than 2.5 times better than Car 3 if the decision makers prefer Car 1 over Car 2 more than they prefer Car 1 over Car 3. In the group decision making situation, it may be difficult to maintain consistency. The first solution is that the decision makers agree to take into account only those regions where the ratio statements are consistent with each other. The second way to proceed is to relax and widen some of the statements so that the consistent region enlarges. The implementation of the technique allows the use of the so-called extended regions (Salo 1993). This technique automatically extends the given intervals of weight ratios so that all the ratio judgments given by the decision makers are included in the analysis. The preference intervals which are derived from the extended regions are wider than the original preference intervals.

2.2. Working procedures for the negotiation

In this study, we assume that the group has structured the problem and agreed upon a common value hierarchy, so that the negotiators only deal with the weighting of the criteria and the alternatives. Although we here concentrate on the weighting procedure, we want to emphasize that the structuring phase is important and, indeed, is often the most beneficial part of the process (Hämäläinen and Leikola 1995). It is important that all the group members agree on the structure of the problem, because, otherwise, confidence concerning the final decision suffers.

Preference programming can be used in a number of different ways to support the group decision-making process. Here we shall only consider the following two procedures.

A.

Step 1: Each negotiator elicits a value model of his or her own.
Step 2: Individual prioritizations are combined into a group interval model.
Step 3: The group continues the negotiations based on the common interval model and tries to reduce the disagreements on the ranges of preference statements until a dominating alternative is found.

B.

Step 1: The group starts to negotiate with a common group interval model which originally does not include any preference statements, i.e., the intervals are at first as wide as possible.
Step 2: The group starts to reduce the preference intervals until a dominating alternative is found.

In both procedures, the final group interaction is similar. The negotiation proceeds as the preference intervals in the group model are changed. The discussion is directed towards the attributes which have the widest preference intervals. The widths of the local preference intervals can be evaluated visually. However, the software facilitates this evaluation with the ambiguity index (A.I.), which indicates the relative width of the local preference intervals under each attribute of the hierarchy (Salo and Hämäläinen 1995). It attains the value zero if the interval reduces to a single value and the index is one for the whole range, i.e., when no preference statements have been entered. The negotiators change the group's interval model directly. The negotiations continue interactively until a consensus alternative is found. The two negotiation procedures are illustrated in Figure 2.

In the working procedure **A**, the group's preference intervals are combinations of the individual pairwise preference statements, so that the end points of the local preference intervals are the two most opposite opinions within the group. After the combination of the individual preferences, it is very likely that the resulting interval preferences are not consistent with each other. The group has to consider the opinions which are inconsistent with each other during their discussion. The extended regions can be used to eliminate inconsistencies. In practice, however, groups are most often ready to approve only those statements which are consistent which each other. Generally, the issue of inconsistency should be clarified to the decision makers when applying the preference programming approach.

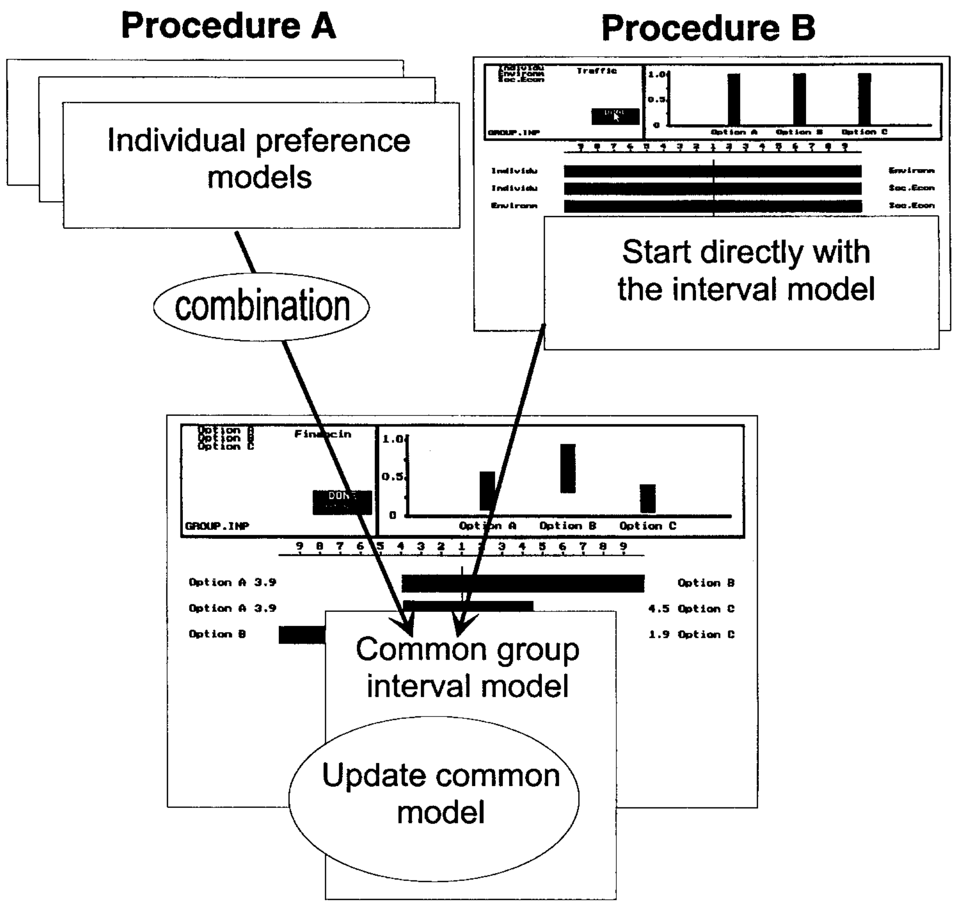

Figure 2. The negotiation process with working procedures **A** and **B**.

Changes in the preference intervals are made directly during the discussion. However, in the working procedure **A**, it is also possible to make changes in the individual prioritizations and update the common interval model by repeating the combination. The combination can be done continuously through a PC-network. However, the option of changing and updating the individual prioritizations was not studied in this experiment.

There are two alternative ways of starting the prioritizations in the working procedure **B**. Initially, the intervals can either cover the whole range, or they can be reduced to the single number one, which refers to the point of equal importance. So far, we have used the first starting strategy where the task is to narrow the intervals. In the second starting approach, the preference intervals are expanded to accommodate all the opinions in the group. With both initial models, the final solution may be achieved before all the preference statements of the hierarchy have been entered. This is a result of the recalculation of the weight intervals after each new preference statement.

3. Information technology

HIPRE 3+ is a decision support software for AHP and value-tree analysis (Hämäläinen and Lauri 1993). The related group decision support software HIPRE 3+ Group Link (Hämäläinen and Kettunen 1994a) can be used for the real-time combination of individual AHP models and for the processing of the resulting preference intervals. The software is available free from the authors. Group Link enables an easy definition and selection of groups, and it controls the on-line updating of individual preference models in the group's PC network. Group Link can also be used without HIPRE 3+ when the group works with the interval approach only.

In group decision making, HIPRE 3+ Group Link is run through a PC network. Each negotiator has his or her own computer for giving the prioritizations with the HIPRE 3+ software. An example of an individual preference profile is presented in Figure 3. Each negotiator can decide when to save his or her model for combination into the group's joint model. The combination procedure can be run automatically by given updating times, or the combination can be done only when desired. The group selection screen of HIPRE 3+ Group Link is shown in Figure 4. It lists all the individual HIPRE 3+ models of the group

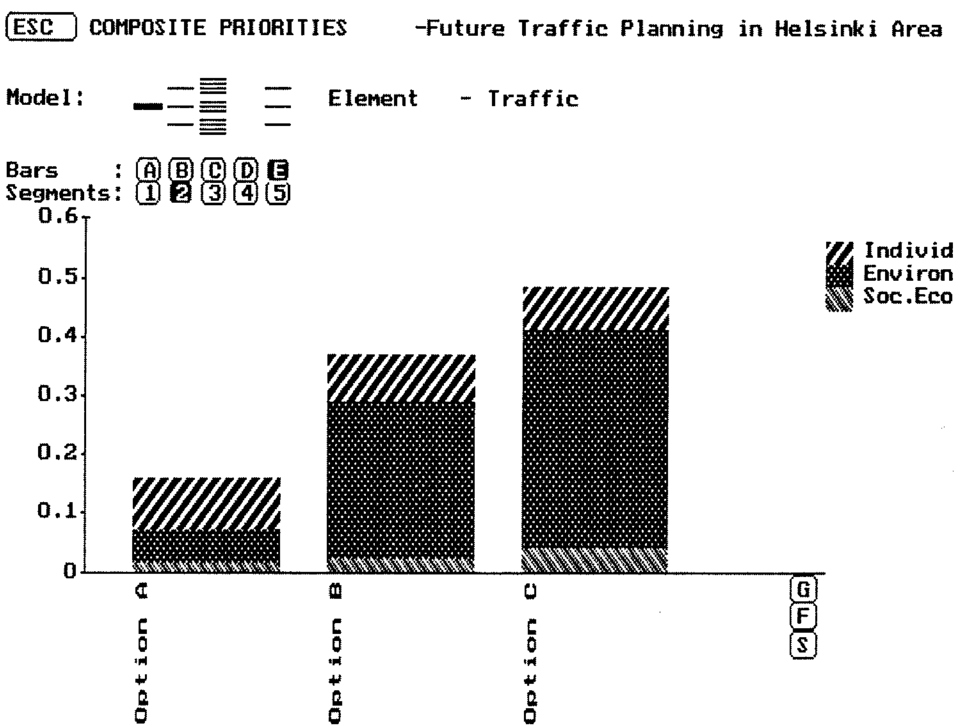

Figure 3. The individual preference profile screen in HIPRE 3+.

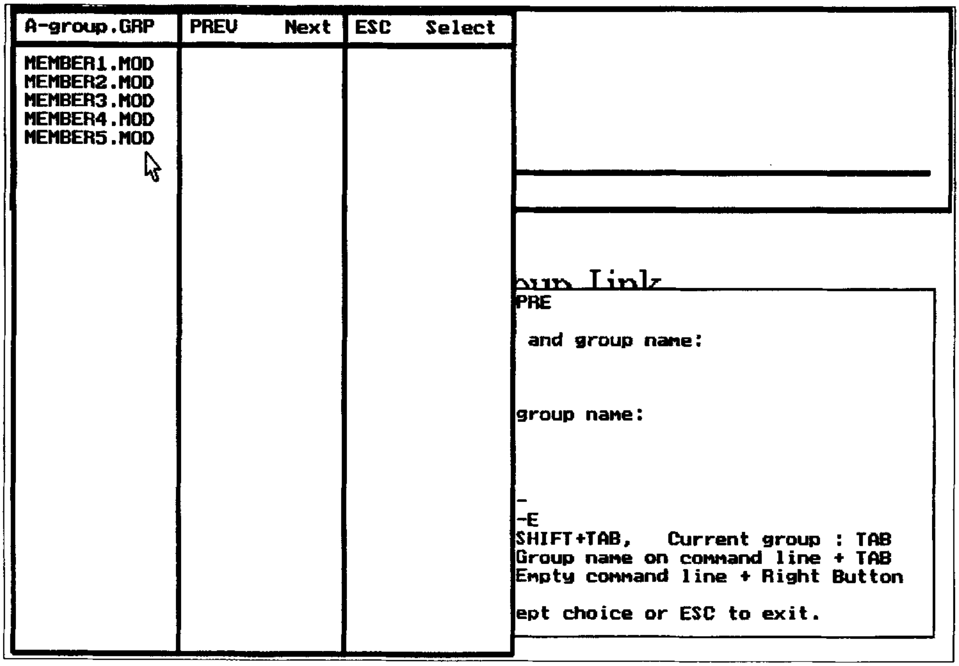

Figure 4. The group selection screen from HIPRE 3+ Group Link.

members. The members of the group are selected with the mouse. It is possible to include or remove new members at any time during the negotiation process. Thus, the software would also allow analysis based on different coalitions.

Figure 5 shows the main screen of the HIPRE 3+ Group Link. The numbers shown in the elements of the hierarchy are the ambiguity indexes. The negotiation process can be started from elements which have the highest ambiguity indexes. In this case, for example, the attribute Timing, which has an A.I. of 0.62, could be a starting point for the discussion.

Working with individual preference models is convenient in a local PC network, each negotiator using his or her own computer. However, it is also possible to use only one computer, especially when the negotiators work with only one common interval model. The minimum requirement for the group support system with preference programming may be just a laptop. This fulfills the requirements that decision conferencing situations should be more flexible, so that it is possible to use group decision support systems in the decision makers' normal environments instead of specific decision rooms (Hämäläinen and Leikola 1995).

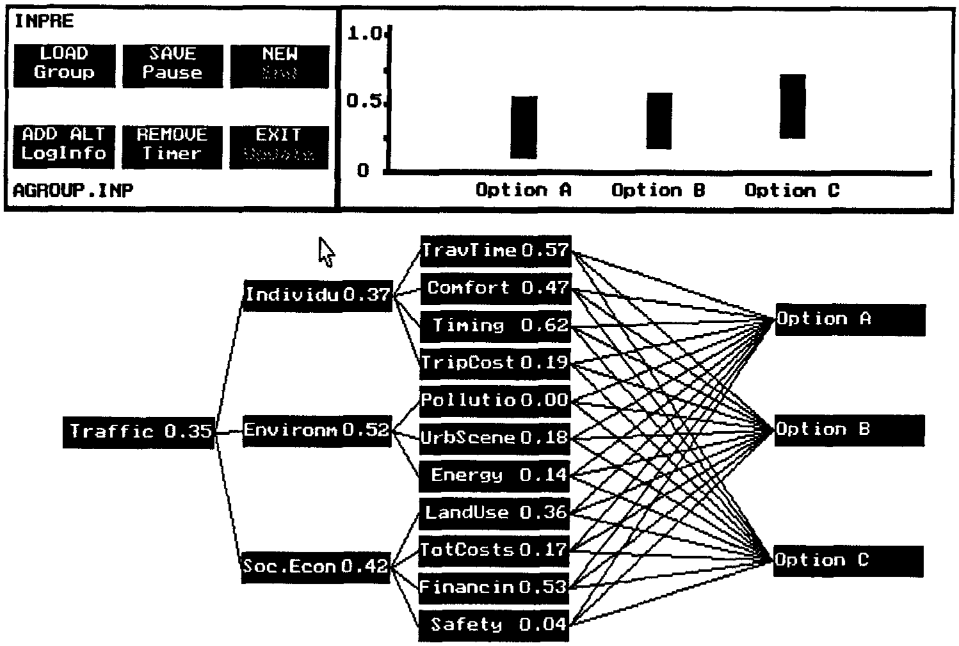

Figure 5. The main screen of HIPRE 3+ Group Link.

4. Negotiation example: traffic plan decision

4.1. Negotiation problem

The Helsinki metropolitan area consists of four cities. These cities are currently negotiating concerning their policies for future traffic system developments. The main goal is to define a common traffic policy for the four cities. The parties have to find a common solution and share the costs. The selected traffic plan should serve all the citizens equally with acceptable costs and also take into account the environmental impacts. The alternatives for the plan were defined earlier by the Helsinki Metropolitan Area Council and the Ministry of Transport. The alternative plans A, B, and C emphasize car traffic, public transportation, and environmental factors, respectively. The alternatives are combinations of several options, including construction of new freeways and subways, increased bus and train services, introducing road tolls and developing new plans for the regional use of land.

The impacts of the three alternatives differ in several aspects. For example, the difference between A and B in terms of the average travelling time to downtown with a car is six minutes. The decision makers are required to make comparisons between alternatives with respect to different impacts and to compare the relative importance of criteria. The hierarchy of the traffic planning problem was first structured with an expert from the Helsinki Metropolitan Area Council. The three major groups of criteria were the level of personal service, environmental impacts, and socioeconomic influences. The problem was then considered together with the participants, and the final hierarchy of the problem was formulated before the actual negotiations about the preferences took place. The problem hierarchy and the descriptions of the attributes are shown in Figure 6.

4.2. Experimental design

The purpose of the experiment was to explore the possibilities and features of the new group decision support technique and to provide an example of a practical decision support situation. The intention was not to achieve statistically significant results. Thus, we did not have a reference group, which would have used some other technique or have worked without any group support.

The experiment was carried out in two separate sessions. The first session was part of a decision analysis seminar for 24 graduate students at the Helsinki University of Technology. In order to form homogenous groups, the participants were divided into five groups, so that the members of each group were residing throughout the Helsinki metropolitan area. It turned out that there were two groups which were already in agreement about the best alternative at the beginning of the negotiation. This was not desirable, as the purpose was to find out how the negotiation support technique helps to reach a consensus. Thus, in the second session with 16 MBA students, the participants were divided into four groups such that in every group the initial opinions about the best alternative were different.

The experiment was conducted in the same way during both sessions. The negotiations were held in a computer class. The groups followed two different working procedures, as explained in section 2. In the working procedure **A** (four groups: A1, A2, A3, and A4), the group members first constructed their own AHP models. Each member ran a computer of his or her own. The individual AHP models were combined, and the discussion continued with a common interval model, which was shown in one of the computers. In the working procedure **B**, the groups (B1, B2, B3, B4, and B5) started with a common interval model which contained no prior preference information. Thus, the preference intervals were left as wide as possible. The groups were given instructions to first make all the comparisons in the hierarchy once and then to continue the discussion based on the resulting group's interval model.

All the groups negotiated independently without a facilitator. They selected one member to use the mouse and enter the interval opinions of the group into the common interval model. The interval models and the individual prioritizations were saved during the negotiations. After the experiment, the participants filled in a feedback questionnaire.

4.3. Observations

A summary of the negotiations is presented in Table 1. Five of the groups reached a consensus solution. Two of the groups thought that alternatives A and C were equally

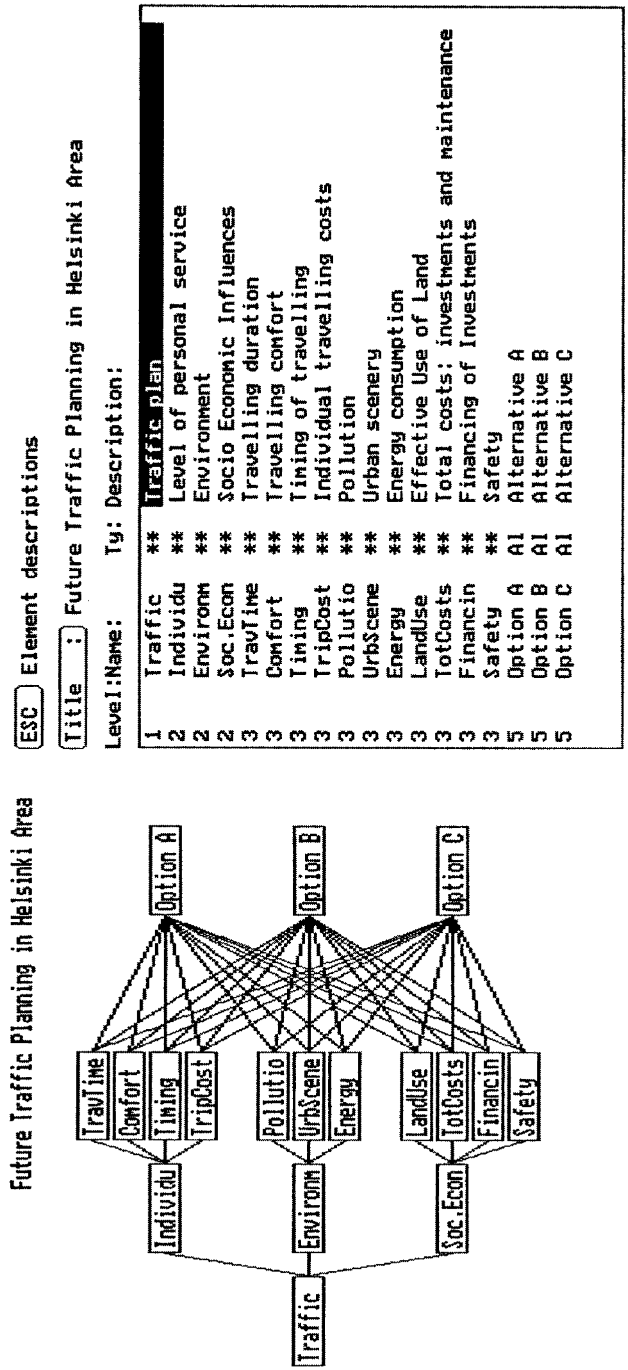

Figure 6. The decision hierarchy for the traffic planning problem.

Table 1. Statistics of the negotiation processes

Group	Opinions in the group before negotiation	Total negotiation time	Time used to give individual prioritizations	Number of attributes considered after combination	Final group choice
A1	C, C, C, C, C	70 min	40 min	10	C
A2	A, B, B, C, C	120 min	45 min	7	no decision
A3	A, B, C, C	85 min	30 min	11	A as good as C
A4	A, B, B, C	80 min	36 min	12	A
Group	**Opinions in the group before negotiation**	**Total negotiation time**	**Time used to make one complete hierarchy evaluation**	**Number of attributes considered after one complete hierarchy evaluation**	**Final group choice**
B1	A, B, B, C, C	120 min	60 min	4	no decision
B2	C, C, C, C, C	50 min	50 min	0	C
B3	B, B, B, C	75 min	35 min	9	C
B4	A, B, B, C	80 min	70 min	0	A as good as C
B5	A, B, B, C	60 min	41 min	16	C

good. The other two groups did not reach a consensus. However, these two groups did discuss and change the preference intervals actively. Generally, the preferences evolved a lot during the negotiations. This can be seen when the final solution is compared with the initial situation. Alternative B would have been the choice of four groups if the group members had only voted on the best alternative at the beginning. However, after the discussion, none of the groups chose alternative B.

Groups following the working procedure **B** used two different strategies for the negotiation. The groups which spent more time for the first complete evaluation of the problem hierarchy (groups B2 and B4) did not return to their earlier preference statements. The groups which used less time for the first evaluation of the hierarchy revised preference intervals under several attributes (groups B3 and B5). For example, group B5 discussed and reevaluated the preference intervals under 16 attributes after the first evaluation of the whole hierarchy. Thus, they considered all the attributes in the decision hierarchy twice. Group B1, which was not able to reach a solution, was an exception. They spent a long time on the first complete hierarchy evaluation and also reevaluated the preference intervals under four elements.

During the discussion, the groups were advised to concentrate on those attributes which had the highest ambiguity indexes. On average, the groups following the working procedure **A** changed preference intervals under ten attributes after the combination of individual prioritization models. None of the group A's considered all the attributes in the hierarchy during the group interaction. Thus, the groups following the working procedure **A** were able to skip over many issues directly after individual prioritizations.

In the future, more attention should be paid to the role of the person who enters the preference intervals into the computer. Some groups criticized the fact that this member dominated the decision making. In a negotiation situation, it would be justifiable to have a neutral facilitator who would be able to enter the preference intervals objectively.

In the study of Hämäläinen et al. (1991), there were two groups which followed the working procedures **A** and **B**. In that experiment, an assumption was raised that the members of the group following the working procedure **A** would be reluctant to change their preferences when they had first elicited their own preference models. This assumption was studied in the traffic planning experiment by measuring the changes made in the preference intervals. This study does not show differences between the two working procedures. Table 2 shows the averages of the ambiguity indexes over all the elements of the hierarchy. These numbers reflect the speed of convergence and the reduction of disagreement during the negotiations. Almost all the groups were able to find ways to proceed and reduce the width of the preference intervals. An exception was group A2, which was not able to change the preference intervals at all. They were stuck with the initial intervals resulting from the combination of the individual preferences.

5. Conclusions

The preference programming technique is a multiple criteria decision support approach which is especially suitable for group decision making. During the negotiations, the group discusses the relative importance of criteria in a value tree. The traffic planning experiment provided an example of the real use of the method and the related information technology. The group decision support software, HIPRE 3+ Group Link, proved to be fully operational for real-life applications. The experiment succeeded in inspiring the participants to use the technique and to actively revise the preference intervals.

Most of the participants thought that the preference intervals were of great help in directing the negotiations. This was the feedback even when the group was not able to reach a consensus. It may be that the participants' comments were very positive, because they encountered the preference programming technique for the first time and they had never worked with an interactive GDSS before. Therefore, it is difficult to say to what extent the positive reactions should be attributed solely to the success of the interval approach. We also face the common problem in the testing of DSS tools: how much can

Table 2. Averages of ambiguity indexes over all the attributes

Group	After combination	At the end
A1	0.34	0.17
A2	0.50	0.49
A3	0.57	0.39
A4	0.42	0.20
Group	After one complete hierarchy evaluation	At the end
B1	0.25	0.25
B2	0.16	0.16
B3	0.28	0.17
B4	0.37	0.37
B5	0.42	0.14

we say when the experiments are not conducted in true decision-making situations and the test subjects are not the real decision makers in the problem? Test negotiators do not really have to commit themselves to the group decision, and they know that their statements will not have real consequences.

The preference programming approach guides the discussion towards the issues with the most conflicting views. Thus, the technique is promising for increasing the efficiency of negotiation processes. The challenge of future research is to find the most efficient ways of using the preference programming approach. Preference programming is most suitable for cooperative decision making when all the group members want to reach a solution and when their responses are truthful. The progress of negotiation requires changes in preference intervals. Negotiators can have too strong impacts on the results by exaggerating their preference judgments, so that their own opinions become the boundaries in the group's preference intervals. Selection of some other combination rule for individual preferences might avoid these problems. On the other hand, it is an advantage that the used combination rule comprises all the opinions of the group as they are stated.

Here we found no clear differences between the two working procedures. This study did not support the assumption (Hämäläinen et al. 1991) that the negotiators may anchore themselves to their individual preference models and become unwilling to change their earlier individual statements. The interval technique worked well in the present group negotiation problem with both working procedures. However, we see this as an interesting research assumption which should be studied further. At this point, it is unclear when it is best to start with the individual preference models and when the group would progress more efficiently if only one common interval model were used.

The proposed group decision support approach is based on an assumption that negotiations proceed effectively when group members focus on the prioritizations of objectives in a value tree. The hierarchical value-tree presentation helps in understanding the decision problem and provides a structure for the negotiations. Yet, there are surprisingly few studies of interactive negotiations in a hierarchical multicriteria framework (see, e.g., Islei and Lockett 1991). This setting remains an interesting topic of future research.

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