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Choice Behaviour in a Computer-Aided Multiattribute Decision Task

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ABSTRACT

Choice behaviour in an interactive multiple-criteria decision-making environment was examined experimentally. The main purpose was to investigate whether subjects are more comfortable in processing criterion/attribute information simultaneously (in parallel) or sequentially. As a research instrument, three different interactive software systems were used on a microcomputer by management students at the Helsinki School of Economics and Business Administration and the Institute of National Economy in Moscow to solve essentially the same problem of buying/leasing a home tailored to the respective decision environments. The experiments also provided us with a possibility to learn useful lessons about how human subjects make computer-supported choices. The results of the experiments are discussed. Furthermore, questions for future research are suggested. © 1997 by John Wiley & Sons, Ltd.

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1. INTRODUCTION

The question of how humans make decisions has attracted the attention of behavioural decision theorists and cognitive psychologists for quite some time. Human decision making cannot be understood by studying only final decisions. Therefore several techniques, such as eye fixation (Russo and Rosen, 1975), think-aloud protocols (Montgomery, 1977; Ericsson and Simon, 1984) and information boards (Payne, 1976), have been developed and used to trace the process that leads to the choice of a decision alternative. See also Svenson (1979) and Larichev (1980, 1984). The order in which a decision maker (DM) seeks and processes information in a given problem context is related to the cognitive process that leads to the final decision.

What do we know about information search patterns and human choice behaviour? Before answering the question, we must define what we mean by intra-alternative and intra-attribute search. The investigation of all the attributes for one alternative before proceeding to the next alternative is an instance of intra-alternative search; in contrast, the investigation of one attribute for all the alternatives before proceeding to the next attribute is an instance of intra-attribute search. Typically, information search patterns are characterized by alternating sequences of intra-alternative and intra-attribute search (Payne, 1976). Also, intra-alternative search tends to increase with increasing number of choice alternatives (Svenson, 1979). Presentation format also affects information search patterns (Bettman and Kakkar, 1977). Furthermore, humans often use simplifying decision rules to come up with a decision (Tversky and Kahneman, 1974). These rules can roughly be divided into two classes, namely compensatory rules and elimination rules. When using compensatory rules, people trade off criteria against each other; some less-than-satisfactory criterion values may be compensated with other more-than-satisfactory criterion values. When using elimination rules, people exclude alternatives from further consideration that do not satisfy their requirements in terms of one or several criteria. It

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has been shown that compensatory rules are most often used when choosing from a fairly small set of alternatives. If the number of alternatives is large, people most often use elimination rules (Montgomery and Svenson, 1976). There is also a tendency for humans to start with simple decision rules, and if they do not lead to a decision, to apply more complex rules (Montgomery and Svenson, 1976). However, many of the inferences about decision rules and information search patterns still lack precision and could benefit from further validation.

All this research in behavioural decision theory and cognitive psychology has had little impact on computer-aided multiple-criteria decision research and the development of decision support systems. See, for example, Von Winterfeldt and Edwards (1986), Larichev *et al.* (1988), Korhonen *et al.* (1990) and Korhonen and Wallenius (1996).

In this paper we describe the results of a joint Finnish–Russian investigation into computer-aided choice among multiattribute alternatives, where we use computer-generated protocols to document human choice behaviour. Our approach is experimental. We conducted two co-ordinated, controlled experiments, one in Helsinki and one in Moscow, to study computer-aided choice behaviour. In both experiments, three decision support systems were used as research instruments: VIMDA (a Finnish system), SCP and SCPPAR (Russian systems). The experiments were run independently and the results are now merged and analysed in this paper. A major focus of our research was to investigate whether humans would be more comfortable in processing criterion/attribute information simultaneously (in parallel) or sequentially. Another purpose was to learn useful lessons about how human subjects make choices using the respective software systems.

2. EXPERIMENTS

Preliminaries

We consider a discrete multiple-criteria decision problem. In general we assume that there is a single DM and a set of n deterministic decision alternatives and p criteria/attributes ($p > 1$) which define an $n \times p$ decision matrix X. The jth column (criterion vector) of X is denoted by x_j and the ith row (alternative vector) of X is denoted by X_i. In the behavioural decision theory literature, criteria (in this context) are often referred to as attributes. In this paper we use the terms 'criterion' and 'attribute' synonymously. The title of this paper uses the expression 'multiattribute decision task', since it is commonly used in the behavioural literature.

In this paper we frequently discuss dominated and non-dominated decision alternatives. We refer to the standard usage of the term. An alternative X_k dominates alternative X_h if $x_{ki} \geqslant x_{hi}$, $\forall i = 1, 2, \ldots, p$, and $x_{kj} > x_{hj}$ for some $j \in \{1, 2, \ldots, p\}$.

Research hypotheses

Based on psychological research, we have formulated two hypotheses.

(1) In decisions having a *large* number of alternatives and attributes, subjects *do not* process the attributes in a purely parallel manner.
(2) In decisions having a *large* number of alternatives and attributes, subjects eliminate unacceptable alternatives but leave dominated alternatives in the final set of most preferred alternatives.

(*Note*. Our problem has five attributes and 98 alternatives. They are considered large numbers.)

The theoretical justification of the first hypothesis derives from Simon (1969), who, based on the limited span of short-term memory, argues strongly that humans process attributes sequentially, in particular when the number of attributes is large. The theoretical justification of the second hypothesis derives from Tversky's Elimination By Aspects (EBA) model (Tversky, 1972) and Simon's concept of bounded rationality (Simon, 1955), based on cognitive and other limitations of human information processing.

Task

Helsinki experiment

The problem consisted of choosing one or a small subset of most preferred homes out of 98 actual homes in the Helsinki metropolitan area. The data were collected from the main daily newspaper (*Helsingin Sanomat*) published in Helsinki. Five different criteria were used to evaluate the alternatives: price, location, area, number of rooms, condition of the unit. When using VIMDA, price was measured in FIM, location and condition on a 1–6 scale (6 best) and area in square metres. The scale for the number of rooms is self-explanatory.

All criteria except price were to be maximized. Since SCP and SCPPAR operate with ordinal criterion scales, the criterion values were rescaled when these systems were used. Price was expresssed on a 1–7 scale (1 least expensive; class intervals were of equal size, end classes open), location on a 1–3 scale (1 best), area on a 1–7 scale (1 largest), number of rooms on a 1–8 scale (1 largest) and condition on a 1–3 scale (1 best). All criteria were to be minimized.

Moscow experiment

In the Moscow experiment the same data (set of alternatives) were used as in the Helsinki experiment. The problem description was, however, tailored to the local decision environment. Accordingly, the problem consisted of choosing one or a small subset of most desirable homes for a summer lease out of a total of 98 alternatives in the Moscow metropolitan area. Leasing a summer home, or a dacha as it is called in Russian, is a common practice in Moscow. The alternatives were the same as in the Helsinki experiment, although price was rescaled and expressed in roubles. The values for all other criteria remained the same as in the Helsinki experiment, altough the meaning of some of the criteria was altered.

Subjects

Helsinki experiment

A group of 43 management students at the Helsinki School of Economics and Business Administration participated in the experiment. Most of the students were lower-division undergraduates. They had prior experience in using microcomputers.

Moscow experiment

A group of 42 students at the Institute for National Economy, University of Moscow, participated in the experiment. The students were upper-division undergraduates majoring in economic cybernetics. They also had prior experience in using microcomputers.

Performance measures

The following performance measures were used in both experiments:

(a) subjective evaluation of the ease of use of the system;
(b) satisfaction with the chosen alternative/alternatives;
(c) speed of convergence (subjective evaluation/perception and objective measurement of time consumed);
(d) percentage of dominated alternatives in the final set, a proxy for decision quality;
(e) consistency of subjects' choices when two different systems were used or the same system was used twice to solve the same problem.

Research instruments: three software systems

VIMDA

A visual reference direction method for solving discrete multiple-criteria decision problems was implemented on an IBM/PC1 microcomputer under the name VIMDA (Korhonen, 1988).

The VIMDA software system has four main functions: Data Management Function, Data Operations Function, Problem Solving Function and Solution Output Function. Each function consists of some subfunctions, all of which are accessed from the main menu. We describe the Problem Solving Function in some detail.

- The Problem Solving Function allows the DM to specify how he/she wants the problem to be solved. It then solves the problem interactively with the DM. The decision-relevant criteria are defined and a sufficient number of iterations are executed to find the most preferred alternative.
- At each iteration the DM specifies aspiration levels for the criteria and the system uses the aspiration levels to define a reference direction, which is a direction that emanates from the current alternative and passes through the point defined by the aspiration levels. By projecting this direction on the set of efficient solutions, a subset of alternatives is generated for the DM's evaluation. This subset is presented graphically and numerically (Figure 1) to the DM, who is asked to choose the most preferred solution from this set. The DM can respecify the aspiration levels for the criteria as many times as he/she desires. The search is terminated when no better alternatives are found.
- (The criterion values in Figure 1 are shown on the ordinate. The current alternative is shown in the left-hand margin. The criterion values of

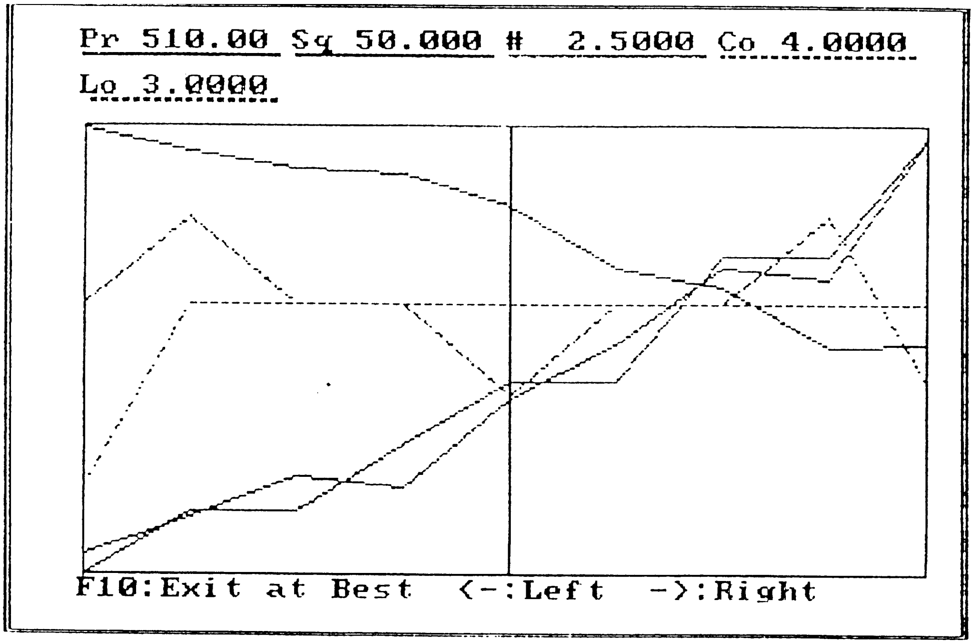

Figure 1. Example of a VIMDA screen

consecutive alternatives have been connected with lines using different colours and patterns. The cursor characterizes the alternative whose criterion values occur numerically on top of the screen. The cursor moves to the right and to the left and each time the criterion values are updated. The DM is asked to choose his/her most preferred alternative from the screen by moving the cursor to point to such a solution.)

(VIMDA assumes monotonicity of the DM's underlying value function.)

SCP

SCP (Sequential Choice Procedure) was developed by Larichev, Mechitov and Moshkovich at ISA. It is previously unpublished. SCP is an operationalization of Tversky's Elimination By Aspects model (Tversky, 1972), where we make a choice by successively eliminating alternatives that do not include the selected aspect. In SCP, bounds for the criteria are introduced *sequentially* (one at a time) in order to eliminate alternatives that fall outside such bounds. All criterion/attribute values are expressed on an ordinal preference scale (using verbal descriptions).

The purpose of SCP is to help the DM choose a small subset of most preferred alternatives, not exceeding five to seven alternatives. The main menu allows the DM to review the criteria (step 1), to review selected alternatives (step 2) or to proceed with the Sequential Choice Procedure (step 3). The system also shows (top portion of the screen) the (updated) distribution of the alternatives using the ordinal criterion scales.

The main steps of SCP are as follows.

1. Review the criteria and their corresponding scales.
2. Review selected alternatives on the screen. Reject uninteresting or inferior alternatives (Figure 2).
3. Introduce a bound for a selected criterion to eliminate all alternatives that fall outside this bound (Figure 3).
4. Review rejected (eliminated) alternatives. Reconsider any of them?
5. If the subset of remaining alternatives is small enough and the DM is satisfied with it, stop. Otherwise, continue the procedure.

Steps 1–4 may basically be executed in any order. The subjects were also allowed/encouraged to restart the procedure from the beginning and introduce bounds on the criteria in a different order. The


```
        DISTRIBUTION OF ALTERNATIVES UPON CRITERIA ESTIMATES
CR   PRICE          LOC.  AREA           ROOMS            CONDITION
EST  1 2 3 4 5 6 7 1 2 3 1 2 3 4 5 6 7 1 2 3 4 5 6 7 8 1 2 3
ALT  6  26    9   4  44    9  18  15    9   1   1  23  11  32
ALT    24  27   2  27  27  15  18  14    5  22  24  11  28  38
 ===================ALL THE ALTERNATIVES -  98===================
  1.  779.000  FMK | ENOUGH CONVENIENT | 66.0 sq.m. | 2.5 r. | NICE
  2.  932.000  FMK | CONVENIENT        | 72.3 sq.m. | 2.0 r. | POOR
  3.  798.000  FMK | CONVENIENT        | 70.0 sq.m. | 3.5 r. | MIDDLE
  4.  648.000  FMK | ENOUGH CONVENIENT | 58.0 sq.m. | 2.5 r. | NICE
  5.  690.000  FMK | CONVENIENT        | 52.0 sq.m. | 2.0 r. | MIDDLE
  6.  600.000  FMK | ENOUGH CONVENIENT | 50.5 sq.m. | 2.0 r. | NICE
  7.  575.000  FMK | CONVENIENT        | 41.0 sq.m. | 1.0 r. | MIDDLE
  8.  465.000  FMK | ENOUGH CONVENIENT | 40.0 sq.m. | 1.5 r. | NICE
  9.  450.000  FMK | ENOUGH CONVENIENT | 35.0 sq.m. | 2.0 r. | MIDDLE
  10. 400.000  FMK | ENOUGH CONVENIENT | 30.0 sq.m. | 1.5 r. | NICE
  11. 780.000  FMK | ENOUGH CONVENIENT | 62.5 sq.m. | 3.5 r. | POOR
  12. 610.000  FMK | CONVENIENT        | 42.0 sq.m. | 2.0 r. | POOR
  13. 492.000  FMK | CONVENIENT        | 33.0 sq.m. | 1.0 r. | NICE
  14. 447.000  FMK | CONVENIENT        | 28.0 sq.m. | 1.0 r. | NICE
  CONTINUE OR EXIT

                number of rejected alternatives  -  0
  PRESS <ENTER> AT ALTERNATIVE TO REJECT IT AND <ESC> TO GET MAIN MENU
```

Figure 2. Reviewing alternatives in SCP

```
        DISTRIBUTION OF ALTERNATIVES UPON CRITERIA ESTIMATES
CR   PRICE          LOC.  AREA           ROOMS            CONDITION
EST  1 2 3 4 5 6 7 1 2 3 1 2 3 4 5 6 7 1 2 3 4 5 6 7 8 1 2 3
ALT  6  26    9   4  44    9  18  15    9   1   1  23  11  32
ALT    24  27   2  27  27  15  18  14    5  22  24  11  28  38
 CHOOSE A CERTAIN CRITERION -     <ENTER>; <ESC> - TO GET MAIN MENU
  =Criteria=
   PRICE
   LOCATION
   AREA
   ROOMS              CHOOSE A CERTAIN ESTIMATION -   <ENTER>
   CONDITION          <ESC> - TO CHANGE CRITERION

                  ===========Estimates upon criterion===========
                   Price is less than 400.000 FMK.
                   Price is in the range of 401.000-500.000 FMK
                   Price is in the range of 501.000-600.000 FMK
                   Price is in the range of 601.000-700.000 FMK
                   Price is in the range of 701.000-800.000 FMK
                   Price is in the range of 801.000-900.000 FMK
                   Price is more than 900.000 FMK
```

Figure 3. Defining bounds in SCP

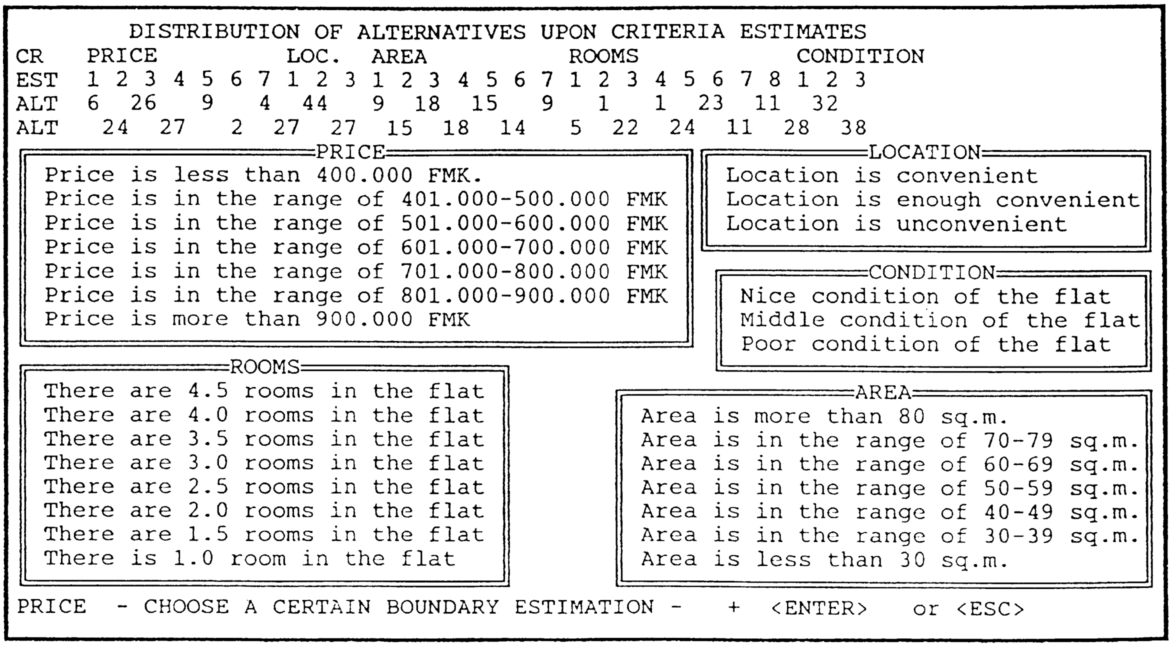

Figure 4. Simultaneous definition of bounds in SCPPAR

idea was to choose the intersection of the final subsets of alternatives for subsequent analysis.

SCPPAR

SCPPAR is a variation of SCP, also developed by Larichev, Mechitov and Moshkovich at ISA. Using SCPPAR, the DM determines bounds for all criteria *simultaneously* (Figure 4). Once such bounds have been determined, the system will show the rejected alternatives. Then the DM is given a chance to reconsider some of them. In all other respects the system is the same as SCP.

This variant of SCP was specifically developed for our experiments to investigate the parallel versus sequential mode of processing criterion/attribute information. Note that although the way VIMDA was used in the experiments represents a parallel approach to processing criterion/attribute information, comparing VIMDA and SCP does not shed much light on the fundamental question of 'parallel versus sequential' because of confounding effects due to profound differences in the respective software systems.

Design of the experiments

The subjects in the Helsinki and Moscow experiments were divided into four groups, the sizes of which varied from six to 14. As explained in Table I, the subjects in group 1 (M1 and H1) used VIMDA and SCP, the subjects in group 2 (M2 and H2) used VIMDA and SCP but in reverse order, the subjects in group 3 (M3 and H3) used SCP and SCPPAR and the subjects in group 4 (M4 and H4) used SCP and SCPPAR but again in reverse order. The Moscow and Helsinki experiments were not identical. In the Moscow experiment each subject used only one software system in each session, whereas in the Helsinki experiment each subject used two software systems in each session. The sessions were 2 weeks apart. The results of both experiments were expected to be the same, but the more complex design in the Helsinki experiment enabled us to control learning and the quality of the decisions in a more systematic manner.

At the beginning of each session the subjects were provided with one-page problem descriptions and written instructions about using the software system(s) in question. During the first session a demonstration of the software systems was also

Table I. Design of experiments

	Group	1st session	2nd session
Moscow	M1 $(n = 14)$	VIMDA	SCP
	M2 $(n = 14)$	SCP	VIMDA
	M3 $(n = 8)$	SCP	SCPPAR
	M4 $(n = 6)$	SCPPAR	SCP

	Group	1st session		2nd session	
Helsinki	H1 $(n = 9)$	VIMDA	SCP	SCP	VIMDA
	H2 $(n = 10)$	SCP	VIMDA	VIMDA	SCP
	H3 $(n = 13)$	SCP	SCPPAR	SCPPAR	SCP
	H4 $(n = 11)$	SCPPAR	SCP	SCP	SCPPAR

Table II. Subjective relative evaluation of ease of use of system

	Group	1st session		2nd session
Moscow	M1	VIMDA	eq.	SCP
	$(n = 14)$	4	7	3
	M2	SCP	eq.	VIMDA
	$(n = 14)$	3	8	3
	M3	SCP	eq.	SCPPAR
	$(n = 8)$	1	6	2
	M4	SCPPAR	eq.	SCP
	$(n = 6)$	1	1	4

	Group	1st session			2nd session		
Helsinki	H1	VIMDA	eq.	SCP	SCP	eq.	VIMDA
	$(n = 9)$	3	3	3	4	3	2
	H2	SCP	eq.	VIMDA	VIMDA	eq.	SCP
	$(n = 10)$	4	5	1	2	4	4
	H3	*SCP*	eq.	*SCPPAR*	SCPPAR	eq.	SCP
	$(n = 13)$	*0*	7	*6*	3	7	3
	H4	SCPPAR	eq.	SCP	SCP	eq.	SCPPAR
	$(n = 11)$	1	5	5	2	5	4

made on a PC. The subjects then made choices using the respective software system(s). They were allowed to ask clarifying questions and to iterate as long as they desired. Their choices during the solution process were documentd by the computer generating protocols for subsequent analysis. After each session the subjects were asked to fill out a questionnaire. The questionnaire focused on the subjects' choices, their subjective evaluations about the software systems, etc.

'Solving' the problem implied identifying the most preferred home to buy/lease (VIMDA) or identifying the most preferred subset of homes to be considered for purchase/lease (SCP and SCPPAR).

3. EXPERIMENTAL RESULTS

The main results of the experiments are presented in Tables II–VI.

Tables II–IV describe the subjects' relative attitudes in terms of the first three performance measures. The numbers indicate how many times

Table III. Relative satisfaction with chosen alternative(s)

	Group	1st session		2nd session
Moscow	M1	VIMDA	eq.	SCP
	($n = 14$)	2	5	7
	M2	SCP	eq.	VIMDA
	($n = 14$)	5	7	2
	M3	SCP	eq.	SCPPAR
	($n = 8$)	0	6	2
	M4	SCPPAR	eq.	SCP
	($n = 6$)	0	6	0

	Group	1st session			2nd session		
Helsinki	H1	VIMDA	eq.	SCP	SCP	eq.	VIMDA
	($n = 9$)	4	4	1	2	5	2
	H2	SCP	eq.	VIMDA	VIMDA	eq.	SCP
	($n = 10$)	4	5	1	1	8	1
	H3	SCP	eq.	SCPPAR	SCPPAR	eq.	SCP
	($n = 13$)	2	6	5	3	10	0
	H4	SCPPAR	eq.	SCP	SCP	eq.	SCPPAR
	($n = 11$)	0	8	3	1	9	1

the respective software system was found preferred; 'eq.' indicates the number of ties. For example, in Table II, the numbers 4, 7 and 3 in the first row mean that VIMDA was found easier to use than SCP by four subjects, SCP was found easier to use than VIMDA by three subjects, and seven subjects felt that both systems were equally easy/difficult to use. In Tables II–IV, for all pairwise comparisons separately, we have hypothesized that there is no difference in performance between the systems, i.e.

$$\mathrm{H}_0:\quad p = 0.5$$
$$\mathrm{H}_1:\quad p \neq 0.5$$

where p is the probability that the first option is preferred. The risk level $\alpha = 0.05$. In Tables II–IV we have italicized the pairs in which H_1 was concluded.

Objective performance measures (d) and (e) in Tables V and VI are given in absolute terms.

In terms of ease of use (Table II), there were no essential differences between the systems, i.e. neither system nor decision style was preferred to the other. The only significant difference was in H3 in the first session. The subjects considered the software system used as the second easier than the first one. This could easily be explained by a learning effect, because in fact SCPPAR is just a modification of SCP. The use of either of them provided training in the use of the other.

In terms of satisfaction with the final outcome (Table III), in the Moscow experiment, but not in the Helsinki experiment, SCP performed somewhat better than VIMDA. This result is due to the fact that SCP generates a set of preferred alternatives, whereas VIMDA is designed for helping to choose one (most preferred) alternative. According to the Helsinki results, using VIMDA and SCP, subjects seemed to prefer the first system, particularly in the first session. This may be explained by the fact that subjects usually pay more attention to the first system and may get a bit tired using the second one, but when the subjects became familiar with the system(s), this difference seemed to disappear. However, the results did not differ significantly.

In terms of the subjective and objective estimation of the time used to solve the problem (Table IV), there was a significant difference in measured time use between the systems VIMDA and SCP (H1), in favour of SCP. It is interesting to note that, on the whole, subjective perception of time consumption for different systems corresponded quite well to the actual time consumption by subjects while working with different systems. The learning effect may explain the more rapid (actual)

Table IV. Relative subjective and actual time use (actual time use in parentheses)

	Group	1st session		2nd session
Moscow	M1	VIMDA	eq.	SCP
	($n = 14$)	5	8	1
		(9)	(0)	(5)
	M2	SCP	eq.	VIMDA
	($n = 14$)	3	8	3
		(6)	(1)	(7)
	M3	SCP	eq.	SCPPAR
	($n = 8$)	1	6	1
		(4)	(0)	(4)
	M4	SCPPAR	eq.	SCP
	($n = 6$)	3	3	0
		(5)	(0)	(1)

	Group	1st session			2nd session		
Helsinki	H1	VIMDA	eq.	SCP	SCP	eq.	VIMDA
	($n = 9$)	4	2	3	2	6	1
		(0)	(0)	*(9)*	*(9)*	(0)	*(0)*
	H2	SCP	eq.	VIMDA	VIMDA	eq.	SCP
	($n = 10$)	6	1	3	3	3	4
		(2)	(1)	(7)	(3)	(2)	(5)
	H3	*SCP*	eq.	*SCPPAR*	SCPPAR	eq.	SCP
	($n = 13$)	*0*	2	*11*	4	5	4
		(4)	(0)	(9)	(4)	(0)	(9)
	H4	SCPPAR	eq.	SCP	*SCP*	eq.	*SCPPAR*
	($n = 11$)	2	2	7	*0*	3	*8*
		(4)	(2)	(5)	(3)	(0)	(8)

convergence of the second system used in H3 and H4.

The quality of choices was studied by calculating the number of dominated alternatives in each final set (Table V). When VIMDA is used to find the most preferred alternative, it is automatically non-dominated. Therefore in the Moscow experiment there were no VIMDA generated dominated solutions. In the Helsinki experiment, when using VIMDA, the subjects were instructed to inform the experimenters not only about their most preferred choice but also about a small most preferred subset of alternatives. Many subjects included dominated alternatives in this set, although VIMDA provided (if desired) a simple way to check dominance. In fact, almost all subjects who incorporated more than three alternatives in the final set chose dominated alternatives from the original data set. SCP and SCPPAR, on the other hand, generated a subset of final alternatives and usually, as the results indicate, this set contained dominated alternatives. Neither SCP nor SCPPAR eliminated dominated alternatives or informed the subjects about the dominance of alternatives.

What can we conclude from the above? Certainly subjects experienced difficulty in knowing which alternatives were dominated and which not. Interestingly, the subjects were quite satisfied with their choices anyway. Perhaps they were unable to find their most preferred alternative(s), although they seemed to believe to the contrary. It is also possible that the subjects, when choosing dominated alternatives in their final sets, considered such solutions near in overall quality (value) to some non-dominated alternatives. Upon closer examination, such dominated alternatives might possess characteristics (not visible in the original data) that could make them attractive (non-dominated).

The overall consistency of subjects' choices was quite low in both experiments (Table VI). Only when the software systems SCP and SCPPAR were used in the same session did subjects exhibit a

Table V. Quality of choices (size of final sets and proportion of dominated alternatives in final sets)

	Group	1st session	2nd session
Moscow	M1 ($n = 14$)	VIMDA	SCP
	Final set	1	4.4
	Domin.	0 per cent	29 per cent
	M2 ($n = 14$)	SCP	VIMDA
	Final set	3.7	1
	Domin.	30 per cent	0 per cent
	M3 ($n = 8$)	SCP	SCPPAR
	Final set	3.5	4.6
	Domin.	24 per cent	43 per cent
	M4 ($n = 6$)	SCPPAR	SCP
	Final set	4.3	3.0
	Domin.	33 per cent	27 per cent

	Group	1st session		2nd session	
Helsinki	H1 ($n = 9$)	VIMDA	SCP	SCP	VIMDA
	Final set	3.9	5.8	5.5	3.9
	Domin.	24 per cent	14 per cent	26 per cent	10 per cent
	H2 ($n = 10$)	SCP	VIMDA	VIMDA	SCP
	Final set	5	3.5	3.8	5.2
	Domin.	22 per cent	3 per cent	0 per cent	9 per cent
	H3 ($n = 13$)	SCP	SCPPAR	SCPPAR	SCP
	Final set	4.6	4.6	4.7	5.0
	Domin.	13 per cent	16 per cent	17 per cent	15 per cent
	H4 ($n = 11$)	SCPPAR	SCP	SCP	SCPPAR
	Final set	3.7	4.7	4.5	3.8
	Domin.	21 per cent	20 per cent	12 per cent	10 per cent

reasonably high degree of consistency. When VIMDA and SCP were used in the same session or the same system was used after 2 weeks, consistency was low. Why? Did subjects change their mind in 2 weeks? Possibly, given some additional information. Did the software system influence the outcome? Possibly, and this certainly warrants additional investigations. For sure, the choice between multiattribute alternatives is complex. In the next section we offer another plausible explanation.

4. DISCUSSION OF RESULTS

To what extent do the data support our research hypotheses?

The results of the Moscow and Helsinki experiments were quite similar. The differences in the way the systems were used and implemented in the respective experiments explain the slight differences in the results. Although VIMDA was tested in a 'parallel mode' (i.e. the subjects operated with the entire set of criteria throughout the process) and SCP primarily represented a 'sequential mode' of processing criteria, owing to confounding software effects, it is difficult to draw conclusions regarding the merits and problems with the processing mode based on comparing VIMDA and SCP. SCP was tested against SCPPAR to eliminate this software bias, but the results showed no significant differences. Hence we were unable to find evidence to reject our first hypothesis. *It is possible that the subjects operated in a 'mixed' rather than a pure sequential or pure parallel mode*. In other words, perhaps subjects initially considered a couple of criteria, then during the process their attention shifted to some other criteria, etc. Such behaviour was also observed by Davey *et al.* (1994), adding credibility to our explanation. Further statements require additional work.

The second research hypothesis was clearly supported. Subjects eliminated unacceptable

Table VI. Consistency of choices (number of overlapping alternatives over maximum number of overlapping alternatives)

	Group		1st session	2nd session
Moscow	M1	($n = 14$)	VIMDA → SCP 3/14	
	M2	($n = 14$)	SCP → VIMDA 4/14	
	M3	($n = 8$)	SCP → SCPPAR 5/39	
	M4	($n = 6$)	SCPPAR → SCP 7/42	

	Group		1st session	2nd session
Helsinki	H1	($n = 9$)	VIMDA → SCP 11/34	SCP → VIMDA 14/34
			VIMDA → VIMDA: 7/30	
			SCP → SCP: 23/46	
	H2	($n = 10$)	SCP → VIMDA 18/34	VIMDA → SCP 17/43
			VIMDA → VIMDA: 17/32	
			SCP → SCP: 26/49	
	H3	($n = 13$)	SCP → SCPPAR 35/51	SCPPAR → SCP 39/58
			SCPPAR → SCPPAR: 33/54	
			SCP → SCP: 26/52	
	H4	($n = 11$)	SCPPAR → SCP 30/41	SCP → SCPPAR 35/38
			SCPPAR → SCPPAR: 16/35	
			SCP → SCP: 19/46	

alternatives but left dominated alternatives in the final set of most preferred alternatives. We can only speculate about the underlying reasons. Perhaps this was due to the cognitive complexity of the task. Perhaps the dominated alternatives were valuewise close to some of the non-dominated alternatives. Or perhaps the subjects possessed hidden criteria. As above, further statements require additional work.

Although all three systems were perceived as useful and attractive, the fact remains that the final most preferred sets of decision alternatives generated with different software systems were, on average, quite different (Table VI). What does this mean? Did the system influence the outcome? Did the subjects experience difficulty in using the systems? Or was the decision task too complex for the subjects to exhibit a high degree of internal consistency? Whatever the answers to the above questions are, without doubt it is difficult for people to choose from a large number of alternatives. What can we do about it? What are the shortcomings of the systems and how can they be overcome from a human DM's perspective?

Regarding VIMDA, if subjects operate in a 'mixed mode', the user should in fact fix certain criterion values during the process and operate with the remaining (smaller) set of criteria. Later he/she can relax some of the previously fixed criteria and fix some other criteria. This option is available in VIMDA (although it was in general not effectively used by the experimental subjects) and represents a 'mixed' mode of processing criterion information. Furthermore, in VIMDA the alternatives shown on the computer screen depend strongly on the aspiration levels provided by the DM. Typically, DMs terminate the search rather quickly (after a few iterations) once having found a satisfactory alternative. Therefore the first couple of aspiration levels provided by the DM play a major role in the process. In fact, they may play a larger role than is often intended, since the initial aspiration levels are proxies (probe ones) and may not have been thoroughly thought out. In fact, what would be needed is a theory of how humans set and revise aspiration levels in the light of new information.

Regarding SCP and SCPPAR, subjects willingly set bounds for the criteria to exclude alternatives. The process is typically terminated once a satisfactory set of alternatives has been found. Additional iterations are usually performed only if the bounds generate an empty set or if bounds for all criteria have not been previously set. In the latter case the 'final' set may contain alternatives that are not satisfactory with respect to all criteria. Here we should make the same comment as we made about VIMDA and the aspiration levels. The initial bounds for the criteria are often proxies (probe ones) and may not have been thoroughly thought out. As far as SCP and SCPPAR are concerned, an idea would be to incorporate 'soft' (fuzzy) bounds or 'conditional' bounds for the criteria to eliminate alternatives. An example of a 'conditional' bound would be the following: 'Eliminate homes that are more expensive than 300,000 FIM unless their location and condition are excellent'. SCP and SCPPAR should also provide information about dominance of alternatives. If the DM wants to incorporate dominated alternatives in the final set, he/she would at least do this knowingly.

5. CONCLUSIONS

In this paper we have described exploratory experiments to study computer-aided choice behaviour in multiattribute settings. In our settings the subjects did not operate in a pure parallel or sequential mode of processing criterion/attribute information. They found it natural to eliminate unacceptable alternatives, as suggested by Tversky's EBA model, but left dominated alternatives in the final most preferred set. Disturbingly, the subjects' consistency across methods was low. The problem is complex and this paper has perhaps generated more questions than answers. In particular, the following research questions deserve further attention.

(1) Investigate how DMs process criterion/attribute information as a function of the number of criterion/attributes. Develop a better research instrument to focus on this fundamental issue.
(2) Investigate the conditions under which learning takes place.
(3) Investigate how DMs set aspiration levels and revise them in lieu of new information in the context of multiple criteria/attributes.
(4) Study cultural differences in the results by using subjects from different nationalities.

Why are we interested in the problem of computer-aided choice? Simply, because the research topic has significant implications for the design and development of multiple-criteria decision support systems. Based on currently available knowledge, our recommendation to the designers of such systems is that they should be able to support both *sequential* and *parallel* modes of processing criteria. This issue has been neglected in the multiple-criteria decision literature, although several existing decision tools have the capability to support both modes of processing criterion information.

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APPENDIX I: CRITERIA FOR EVALUATION OF ALTERNATIVES FOR SCP AND SCPPAR

Criterion 1. Price

1. Price does not exceed 400,000 FIM.
2. Price is in the range 401,000–500,000 FIM.
3. Price is in the range 501,000–600,000 FIM.
4. Price is in the range 601,000–700,000 FIM.
5. Price is in the range 701,000–800,000 FIM.
6. Price is in the range 801,000–900,000 FIM.
7. Price exceeds 900,000 FIM.

Criterion 2. Location

1. Location is convenient.
2. Location is convenient enough.
3. Location is inconvenient.

Criterion 3. Area

1. Area exceeds 80 m^2.
2. Area is in the range 70–79 m^2.
3. Area is in the range 60–69 m^2.
4. Area is in the range 50–59 m^2.
5. Area is in the range 40–49 m^2.
6. Area is in the range 30–39 m^2.
7. Area is less than 30 m^2.

Criterion 4. Number of rooms

1. There are 4.5 rooms in the flat.
2. There are 4 rooms in the flat.
3. There are 3.5 rooms in the flat.
4. There are 3 rooms in the flat.
5. There are 2.5 rooms in the flat.
6. There are 2 rooms in the flat.
7. There are 1.5 rooms in the flat.
8. There is 1 room in the flat.

Criterion 5. Condition

1. The flat is in nice condition.
2. The flat is in mediocre condition.
3. The flat is in poor condition.

APPENDIX II: THE QUESTIONNAIRE USED IN THE MOSCOW EXPERIMENT

(In the Helsinki experiment a similar questionnaire using 1–5 scales was used, although additional questions were incorporated.)

Quesion 1. How convenient was it to work with the system?

1. It was very convenient to work with the system.
2. Experienced some difficulties while working with the system, but on the whole it was convenient.
3. Experienced difficulties working with the system, but the system may be considered convenient enough.
4. Experienced essential difficulties. It was not very convenient to work with the system.
5. It was inconvenient to work with the system.

Quesion 2. To what extent are you satisfied with the final choice?

1. Fully satisfied.
2. Almost fully satisfied.
3. To some extent satisfied.
4. Having doubts about the final choice.
5. Not satisfied with the final choice.

Quesion 3. How quickly did you obtain the solution?

1. The solution was obtained quickly.
2. The solution was obtained quickly enough.
3. The solution was not obtained quickly, but in a reasonable time.
4. It took rather much time to obtain the solution.
5. It took a lot of time to obtain the solution.

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