Composite Strategy for Multicriteria Ranking/Sorting (methodological issues, examples)
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The paper addresses the modular design of composite solving strategies for multicriteria ranking (sorting). Here a “scale of creativity” that is close to creative levels proposed by Altshuller is used as the reference viewpoint: (i) a basic object, (ii) a selected object, (iii) a modified object, and (iv) a designed object (e.g., composition of object components). These levels maybe used in various parts of decision support systems (DSS) (e.g., information, operations, user). The paper focuses on the more creative above-mentioned level (i.e., composition or combinatorial synthesis) for the operational part (i.e., composite solving strategy). This is important for a search/exploration mode of decision making process with usage of various procedures and techniques and analysis/integration of obtained results.

The paper describes methodological issues of decision technology and synthesis of composite strategy for multicriteria ranking. The synthesis of composite strategies is based on “hierarchical morphological multicriteria design” (HMMD) which is based on selection and combination of design alternatives (DAs) (here: local procedures or techniques) while taking into account their quality and quality of their interconnections (IC). A new version of HMMD with interval multiset estimates for DAs is used. The operational environment of DSS COMBI for multicriteria ranking, consisting of a morphology of local procedures or techniques (as design alternatives DAs), is examined as a basic one.

Keywords: Decision making technology; Multicriteria ranking; Sorting; Decision support system; System architecture, Problem solving strategies; Combinatorial synthesis; Software engineering; Multiset

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1. INTRODUCTION

In recent years, there has been considerable interest in complex DSS consisting of the data bases (including descriptions of decision making situations), model bases, user interface, and knowledge bases (e.g., [3, 13, 18, 41, 42, 43, 44, 51, 69, 77, 115, 116, 119, 122, 126, 142, 145, 151, 152, 154, 159, 165]). The structures of multicriteria DSS were described in (57, 58, 113, 90, 42, 43, 52, 68, 72, 92, 110, 151, 159, 161, 165). Jelassi has proposed five generations of multicriteria DSS ([72, 159]).

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Main tendencies of decision support technology are presented in ([111], [152], [155]). Saxena investigated computer-aided decision support engineering including six stages methodology for DSS development (problem definition, task analysis, requirements engineering, system design, system prototype, user evaluation and adaptation [152]. Four models for a decision support system are analyzed in [123]: (i) the symbolic DSS, (ii) the expert system, (iii) the holistic DSS, and (iv) the adaptive DSS. Adaptive decision support systems have been examined in ([10], [67]). Howard has described the decision analysis process [68]. An object relational approach for the design of DSS has been proposed by Srinivasan and Sundaram [162]. A special framework to support the design of a DSS for some new decision problem was suggested in [144]. Some contemporary trends are targeted to the following: (a) distributed cooperative DSS (e.g., [19], [54], [155], [174]); (b) spatial DSS (SDDS, i.e., integration of DSS and GIS) (e.g., [29], [133], [140], [144]); (c) multi-agent DSS (e.g., [19], [24], [62], [130]); (d) mobile DSS (e.g., [45], [65], [122], [134]); and (e) Web-based DSS (e.g., [15], [88], [144], [149], [171], [175]). A classification of DSS is described in [137].

Issues of model management have been widely studied and used in DSS engineering (e.g., [5], [16], [17], [18], [25], [30], [35], [59], [66], [71], [113]). The research domain involves various directions, for example: 1. model selection (e.g., [117]), e.g., selection of a package for multi-attribute decision making that is more compatible with the user’s needs [53]; 2. usage of model libraries (e.g., [118]); 3. building (construction, composition, integration) of models (e.g., [10], [11], [26], [69], [87]); 4. an object-oriented framework for model management (e.g., [137]); 5. meta-modeling approaches (e.g., [128]); 6. manipulation of composite models (e.g., [57], [90]); 7. knowledge-based model management (e.g., [114]), and 8. applying machine learning to model management (e.g., [156]).

In the field of algorithms/algorithms systems the following interesting trends can be pointed out:

1. Automatic algorithm design as a combinatorial meta-problem [169]. Here typical entries (for algorithm design) are: (i) choice of problem variables, (ii) choice of constraints, and (iii) choice of search method and constraint behavior. The approach realizes a joint design of problem formulation and algorithm.

2. Adaptive algorithms/software (e.g., [121]).

3. Usage of generic library of problem solving methods/algorithms (e.g., [86], [139], [143]).

4. Algorithm portfolio (e.g., [53], [58], [135], [177]).

5. Reconfiguration or self-organizing algorithms (e.g., [63], [176]).

6. Cooperative/hybrid meta-heuristics for combinatorial optimization (e.g., [70], [143]).

Some special research projects focus on the design of problem solving environments (e.g., [59], [117]). For example, in [139], a generic two-level library of problem solving is described which consists of two parts for the following: (a) basic task and subtasks problem solvers (task level), (b) problem solving technique (method level). Note special studies are needed for the problem formulation phase (e.g., [39]).

In the field of DSS, planning of decision making processes is a vital part of decision making engineering. In this case, design/building of solving strategies is often under examination: (1) selection and integration of models from a model base (e.g., [35], [59], [77], [113], [168]); (2) intelligent strategies for decision making (e.g., [68]); (3) MCDM techniques selection approaches (e.g., [21], [61], [84], [131]); (4) expert-based hierarchical planning (e.g., [168]); (5) usage of decision making method families and their configuration (e.g., [32], [85]); and (6) visual and interactive support for multicriteria decision making process (e.g., [164]).

In this paper, an operational part of DSS for multicriteria ranking (sorting) and composition of corresponding composite solving strategies is examined. Usually, planning the decision support process is based on the selection and integration of models from a model base. These procedures use special model knowledge including descriptions of basic submodels and their connections, etc. (e.g., [35], [77], [113], [168]). In general, four “creative levels” can be considered: (i) a basic object, (ii) a selected object, (iii) a modified object, and (iv) a designed composite object (as composition of local elements/components). The levels are close to a “scale of creativity” that has been suggested by G.S. Altshuller (e.g., [3]). The levels may be applied to various parts of DSS (information, operations, user). Here, composition of solving strategies for multicriteria ranking (sorting) from some local techniques or procedures is studied. Our morphological composition approach is close to the strategy-generation table suggested by Howard [68]. Note here issues of creativity in decision making are not considered [78].

The morphological approach for the design/planning of composite solving strategies is based on “hierarchical morphological multicriteria design” (HMMD) which involves a series and/or parallel composition of
the design alternatives (DAs) for data processing while taking into account interconnections (IC) among DAs ([98],[99],[102],[105]). In the case of model management/engineering, DAs correspond to alternative models or algorithms/interactive procedures. HMMD is based on the following assumptions: (1) tree-like structure of a designed system; (2) system effectiveness (excellence) is represented as an aggregation of two parts: effectiveness of subsystems (components), and effectiveness of compatibility among subsystems; (3) monotone criteria (Cr) for DAs; (4) ordinal coordinated priorities of DAs ($\iota = 1,7, 1$ corresponds to the best one); and (5) ordinal coordinated estimates of compatibility for each “neighbor” pair of DAs ($w = 1,\nu, \nu$ corresponds to the best one). In the case of interval multisets estimates (a generalization of ordinal estimates [104]), qualities of DAs and/or their compatibility are evaluated with usage of this kind of estimates (i.e., a special new type of poset-like scales).

HMMD consists of the following main phases:

**Phase 1.** Top-Down design of tree-like system model including Cr and factors of compatibility.

**Phase 2.** Generation of DAs for leaf nodes of model.

**Phase 3.** Bottom-Up hierarchical selection and composition (iterative): (a) assessment of DAs on Cr, (b) assessment of IC, (c) computing the priorities of DAs, and (d) composing DAs for a higher hierarchical level.

Note that similar approaches have been used in engineering design as combinatorial optimization models and morphological analysis (e.g., [7],[14],[60],[75],[180]).

Our study is based on the experience in the design and implementation of DSS COMBI for multicriteria ranking (joint project of the author and Andrew A. Michailov; 1984...1991) ([93],[99],[110]). This DSS was based on a series-parallel transformation of preference relations ([92],[93],[110]). Operational environment of DSS COMBI includes a morphology of the composite solving strategy for forming-transforming the preference relations, linear orderings, and rankings. DSS COMBI corresponds to DSS generation 4.5 of 5-level classification of Jelassi ([72],[159]). The following is described: (i) methodological issues in decision making technology for multicriteria ranking, (ii) a scheme for designing a series solving strategy.

## 2. METHODOLOGICAL ISSUES

### 2.1. Decision Making Framework, Solving Scheme, Problems

Generally, decision making process is based on the following basic parts (e.g., [99],[102],[157]): (i) alternatives, (ii) criteria and estimates of the alternatives upon the criteria, (iii) preferences over the alternatives, (iv) solving method(s), (v) decision(s), and (vi) specialists (decision maker, support experts). Fig. 1 depicts a basic framework of the decision making process.

![Fig. 1. Basic framework of decision making](image)

H. Simon has suggested a rational decision making based on the choice problem [157]: (i) the identification and listing of all the alternatives, (ii) determination of all the consequences resulting from each of the alternatives, and (iii) the comparison of the accuracy and efficiency of each of theses sets of consequences. A modified version of the approach is the following ([92],[102]):

**Stage 1.** Analysis of the examined system/process, extraction of the problem.
Stage 2. Problem structuring: (2.1.) generation of alternatives, (2.2.) generation of criteria and scale for each criterion.

Stage 3. Obtaining the initial information (estimates of the alternatives, preferences over the alternatives).

Stage 4. Solving process to obtain the decision(s).

Stage 5. Analysis of the obtained decision(s).

Fig. 2 depicts an extended decision making scheme including some feedback lines.

Fig. 3 depicts the basic decision making problems ([49],[79],[92],[99],[124],[148]):
(a) choice/selection (e.g., [2],[49],[79],[124],[157],[169]),
(b) linear ordering (e.g., [49],[50],[79],[124]),
(c) sorting/ranking (e.g., [22],[28],[49],[99],[110],[124],[148],[178],[179]), and
(d) clustering/classification (e.g., [27],[70],[124],[125],[179]).

In general, it is reasonable to extend the decision making process by additional management/monitoring and support analysis/learning of user(s) (Fig. 4). This approach was implemented in DSS COMBI ([92],[93],[99],[107],[108],[109],[110],[111]), for example: (i) special hypertext system for learning and support, (ii) analysis and diagnosis of user(s), (iii) library of typical DM problems for various domains, (iv) basic typical solving composite strategies, and (v) possibility for retrieval and analysis of intermediate information/solutions.
2.2. Multicriteria Ranking (Sorting)

Let $A = \{1, \ldots, i, \ldots, n\}$ be a set of alternatives (items) which are evaluated on criteria $K = \{1, \ldots, j, \ldots, d\}$, and $z(i, j)$ is an estimate (quantitative, ordinal) of alternative $i$ on criterion $j$. The matrix $Z = \{z(i, j)\}$ may be mapped into a poset on $A$. We search for the following resultant kind of the poset as a partition with ordered subsets (a layered structure): $B = \{B_1, \ldots, B_k, \ldots, B_m\}$, $B_k \cap B_{k_2} = \emptyset$ if $k_1 \neq k_2$, and each alternative from $B_{k_1}$ (layer $k_1$) dominates each alternative from $B_{k_2}$ (layer $k_2$), if $k_1 \leq k_2$. Thus, each alternative has a priority which equals the number of the corresponding layer. This problem is illustrated in Fig. 5. This problem belongs to a class of ill-structured problems by classification of H. Simon. In general, the resultant ordered subsets can have intersections (i.e., the problem can be targeted to obtain interval priorities for the alternatives) (Fig. 6). In this case, the “fuzzy” decision will be denoted by $\tilde{B}$ (a layered structure with intersection of the layers). Let $B$ be a linear ordering of alternatives.

The basic techniques for the multicriteria ranking (sorting) problems are the following (e.g., [23], [38], [173]):

1. statistical approaches [23];
2. multi-attribute utility analysis (e.g., [50], [79]);
3. multi-criterion decision making (e.g., [83]);
4. analytic hierarchy process (e.g., [150]);
5. outranking techniques (e.g., [22], [28], [49], [79], [124], [124], [148], [178], [179])

These techniques are typically used to analyze and select the best alternatives from a set of options based on multiple criteria. Each technique has its own advantages and is suitable for different types of problems. The selection of a technique depends on the specific requirements and constraints of the decision-making process.
(12), (148)); (6) knowledge bases (e.g., [112]); (7) neural network (e.g., [170]); (8) logical procedures (e.g., [109]); (9) expert judgment (e.g., [89]); and (10) hybrid techniques (e.g., [47]). In the main, the above-mentioned techniques correspond to one-phase problem solving framework.

Fig. 5. Multicriteria ranking (sorting)

Fig. 6. Ranking with interval priorities

The following numerical example illustrates the examined multicriteria problem.

Let \( A = \{A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, A_9\} \) be a set of initial alternatives. The alternatives are evaluated upon 2 criteria \( K = \{K_1, K_2\} \), an ordinal scale is used for each criterion (\([0, 1, 2, 3, 4]\) and 4 corresponds to the best level). The ordinal estimates of alternatives are presented in Table 1, a space of estimates is depicted in Fig. 7. Three types of solutions are presented:

(a) linear ordering \( \mathcal{B} \) (Fig. 8; e.g., additive utility function is used);

(b) ranking (sorting, four linear ordered subsets) \( \mathcal{B} \) (Fig. 9; e.g., expert judgement is used); and

(c) “fuzzy” ranking \( \tilde{\mathcal{B}} \) (Fig. 10; e.g., expert judgement is used).

Table 2 integrates the obtained priorities of alternatives.

| Alternative | Criteria |
|-------------|----------|
|             | \( K_1 \) | \( K_2 \) |
| \( A_1 \)   | 2        | 3        |
| \( A_2 \)   | 2        | 4        |
| \( A_3 \)   | 1        | 3        |
| \( A_4 \)   | 4        | 4        |
| \( A_5 \)   | 1        | 1        |
| \( A_6 \)   | 4        | 3        |
| \( A_7 \)   | 2        | 2        |
| \( A_8 \)   | 0        | 2        |
| \( A_9 \)   | 2        | 1        |
An approach for decision making as series or series-parallel processing (transformation, articulation) of preferences (combinatorial models for decision making) for suggested in [91]. In DSS COMBI, a functional graph has been suggested as implementation of the approach for multicriteria ranking ([92], [99], [110]). The graph was realized as a graphical menu. In this case, the solving strategy is combined from a set of basic operations (local techniques or procedures) (e.g., forming preference relations over the alternatives, forming the intermediate linear ordering of the alternatives, forming the resultant decision structure over the alternatives) (Fig. 11).

**Table 2. Resultant priorities**

| Alternative | Linear ordering | Ranking | “Fuzzy” ranking |
|-------------|----------------|---------|-----------------|
| A1          | 4              | 3       | 3               |
| A2          | 3              | 2       | 2               |
| A3          | 5              | 3       | 3               |
| A4          | 1              | 1       | 1               |
| A5          | 8              | 4       | 4               |
| A6          | 2              | 2       | [1, 2]          |
| A7          | 6              | 3       | 3               |
| A8          | 9              | 4       | 4               |
| A9          | 7              | 4       | [3, 4]          |

**Fig. 10. “Fuzzy” ranking B**

**Fig. 11. Decision making as preferences processing ([92], [99], [110])**

### 2.3. Towards Reconfigurable Problem Solving Framework

Here a generalized problem solving framework is examined. An algorithm system (e.g., for data processing) is considered as a basic example.

The basic parts of the framework are the following: (a) problem (problem structuring/formulation) (b) algorithm (operational part) (c) data part (obtaining data, elicitation of preferences, ...) (d) human part (preliminary learning, learning based on solving process)

First, a statal strucure of the algorithm system is analyzed. The following versions the algorithm/algorith systems can be considered:

1. usage of the basic algorithm(s) (Fig. 12);
2. selection of the best algorithm from an algorithm base (while taking into account an input information) and its usage (Fig. 13);
3. modification of the basic algorithm(s) (while taking into account an input information) and its usage (Fig. 14); and
4. design of the new algorithm(s) (while taking into account an input information) and its usage (Fig. 15).

A simplified hierarchy of solving process components is depicted in Fig. 16.

In general, the following problem solving frameworks can be considered:

1. One-phase framework: problem solving.
2. Two-phase framework: (i) problem structuring/formulation and (ii) problem solving.
3. Three-phase framework: (i) problem structuring/formulation; (ii) problem solving; and (iii) analysis of results.
4. Adaptive three-phase framework with feedback: (a) problem structuring/formulation; (b) problem solving (including analysis of intermediate results and problem reformulation and resolving); (c) analysis of results (including analysis of results and problem reformulation and resolving).
The following three illustrative examples of multistage solving strategies are presented for sets consisting of nine initial alternatives (Table 1): (i) two-stage series ranking strategy with preliminary linear ordering (Fig. 17); (ii) two-stage series ranking strategy with preliminary preferences (Fig. 18); (iii) three-stage series ranking strategy (Fig. 19); and (iv) three-stage series-parallel strategy (with aggregation) (Fig. 20).

Fig. 21 depicts adaptive three-stage framework for problem solving. In addition, it is possible to consider a solving framework in which problem formulation/structuring is executed during the solving process for a preliminary problem.

The stage “Reconfiguration of problem solving process” can be considered as the following: (i) selection of another algorithm (solving scheme) (Fig. 13), (ii) modification of the algorithm (solving scheme) (Fig. 14), (iii) design of a new algorithm (solving scheme) (Fig. 15). Concurrently, information operations (searching/acquisition/usage) can be used (e.g., new/additional preferences, new/additional reference points of intermediate decisions).

In the case of a man-machine procedure, it is possible to examine change or re-organization of an expert team and types (e.g., mode, support procedure(s)) of man-machine interaction.
The stage “Problem reformulation/restructuring” can be considered as the following: (i) change of the initial problem, (ii) modification of the initial problem (e.g., change of the problem parameters, initial data), (iii) building of a new problem framework (i.e., a composite problem).

Fig. 22 depicts an example to illustrate a series process with problem reformulation.
2.4. History of DSS COMBI

A preliminary version of DSS COMBI was implemented as a set of multicriteria techniques (Fortran, mainframe, methods: several types of utility functions, Electre-like technique). Analysis, comparison and aggregation of results, obtained via different techniques, was widely used. Further, DSS with method composition was designed. DSS COMBI was targeted to three type of resultant decisions (Fig. 23): (a) linear ranking (mainly, an intermediate result) $\overline{B}$, (b) multicriteria ranking as sorting (ordinal priorities of alternatives, i.e., a layered structure) $B$, and (c) multicriteria ranking as a layered structure with intersection the layers (ordinal priorities of alternatives over an ordinal decision scale) $\overline{B}$. 

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Fig. 20. Three-stage series-parallel ranking strategy (with aggregation)

Fig. 21. Problem solving with reconfiguration
Table 3 presents a brief description of DSS COMBI generations with method composition. A functional graph menu was realized in DSS COMBI (since generation 1) (Fig. 24).

| Generation of DSS COMBI | Type of computer | Type of interface | Domain | Learning | Year | Reference | Presentation at conference | Usage in teaching |
|-------------------------|------------------|-------------------|--------|----------|------|-----------|---------------------------|-----------------|
| 0. COMBI (Pascal-based) | Mini-computer    | Language-based    | Various| None     | 1987 | [107], [108]| None                      | None            |
| 1. COMBI PC (Pascal-based) | PC              | Knowledge-based  | Various| Yes      | 1988 | [92], [110]| SPUUDM-89                 | None            |
| 2. COMBI PC (C-based)  | PC               | Graphical menu   | Various| Yes      | 1989 | [93], [94], [99], [110]| MCDM-90            | None            |
| 3. COMBI PC (C-based)  | PC               | Graphical menu   | Various| Yes      | 1991 | [93]       | EWHCI-93                  | None            |
2.5. Main Components of DSS

Here, the following DSS parts are considered: 1. information part as data, knowledge; 2. operational part as tools for information processing; and 3. human part as user or group of users (including experts, decision maker, etc.).

Usually information part includes the following: (1) data (alternatives or basic items, criteria, multicriteria estimates of alternatives upon criteria, preference relations); (2) tools for maintaining data (DBMS and interfaces with other commercial DBMSs); (3) support information for learning (e.g., a helper, etc.).

In this paper (as in DSS COMBI), the following series (or series-parallel) framework of information (a preference relation or a matrix) processing is examined ([93], [99], [110]): (1) basic data as alternatives (items) (A), criteria (K), multicriteria estimates of alternatives upon criteria (Z); (2) preference relation of alternatives (G); (3) an intermediate linear ordering of alternatives (B) (4) an preliminary ranking of alternatives as a layered structure(s) (B'); and (5) resultant ranking of alternatives as layered structure (B) (an ordinal priority for each alternative) or fuzzy ranking (\tilde{B}) (with intersection of layers).

The following kinds of basic operations are considered: (i) data processing (series and/or parallel); (ii) data aggregation. In addition, parallelization of the solving process on the basis of various components (alternatives, criteria, techniques, experts) can be used. The solving process may be presented as a hierarchy with the following functional/operationlal layers ([93], [99], [110]): (1) algorithms and man-machine interactive procedures for data transformation (bottom layer); (2) strategies (step-by-step schemes of data transformation, particularly series-parallel ones); (3) scenarios (complexes of strategies with their analysis and feedback).

Thus, the following alternative series frameworks (composite solving strategies) of information processing are considered (Fig. 11, Fig. 24):

1. Basic series framework: \( E \): \( A \Rightarrow G \Rightarrow B' \Rightarrow \{B'\} \Rightarrow B \) or \( \tilde{B} \).
2. Compressed series frameworks:
   2.1. \( W^1 \): \( A \Rightarrow \{B'\} \Rightarrow B \) or \( B' \).
   2.2. \( W^2 \): \( A \Rightarrow G \Rightarrow \{B'\} \Rightarrow B \) or \( \tilde{B} \).
   2.3. \( W^3 \): \( A \Rightarrow G \Rightarrow B' \Rightarrow B \) or \( \tilde{B} \).
   2.4. \( W^4 \): \( A \Rightarrow B' \Rightarrow \{B'\} \Rightarrow B \) or \( \tilde{B} \).
   2.5. \( W^5 \): \( A \Rightarrow B' \Rightarrow \{B'\} \Rightarrow B \) or \( \tilde{B} \).
3. Direct solving process: \( D \): \( A \Rightarrow B \) or \( \tilde{B} \).

Thus, the solving process can be considered as the following four-part system (Fig. 25): \( S = H \ast T \ast U \ast X \), where the following four stages are basic ones: (i) stage H corresponds to forming a preliminary preference relation G (over alternatives A) (an algorithm or a procedure); (ii) stage T corresponds to forming a preliminary linear ranking \( B' \) (an algorithm or a procedure); (iii) stage U
corresponds to forming some preliminary rankings \(\{B\}\) (an algorithm or a procedure); and (iv) stage \(X\) corresponds to aggregation of the preliminary rankings \(\{B\}\) into the resultant decisions \(B\) (or \(\tilde{B}\)) (an algorithm or a procedure). The following basic local techniques (as processing units) have been used in DSS COMBI \([93, 99, 110]\):

1. Stage \(H\): absent \((H_0)\), pairwise comparison (a simple expert-based procedure) \((H_1)\), dominance by of Pareto-rule \((H_2)\) (e.g., \([124, 132]\)), outranking Electre-like technique (a special Electre-based interactive procedure with feedback, designed by M.Sh. Levin \([110]\)) \((H_3)\).

2. Stage \(T\): absent \((T_0)\), line elements sum of preference matrix \((T_1)\), additive utility function (e.g., \([50, 70]\)) \((T_2)\).

3. Stage \(U\): absent \((U_0)\), step-by-step revelation of maximal elements \((U_1)\), step-by-step revelation of Pareto-efficient elements (e.g., \([124, 132]\)) \((U_2)\), dividing the linear ranking \((U_3)\), expert procedure for ranking (expert-based direct solving procedure (e.g., \([89]\)) \((U_4)\), direct logical method for ranking (direct solving method based on logical approach, designed by A.A. Mikhailov) \([109, 110]\) \((U_5)\).

4. Stage \(X\): absent \((X_0)\), simple election-like procedure \((X_1)\), aggregation model based on special knapsack-like problem \((X_2)\) \([99]\).

\[
\begin{align*}
\text{Solving strategy } S = H \ast T \ast U \ast X \\
\text{Example: } S_1 = H_1 \ast T_2 \ast U_2 \ast X_1
\end{align*}
\]

\[
\begin{array}{cccc}
H_0 & T_0 & U_1 & X_0 \\
H_1 & T_1 & U_2 & X_1 \\
H_2 & T_2 & U_3 & X_2 \\
H_3 & & U_4 & \\
& & U_5 & \\
\end{array}
\]

Fig. 25. Morphology of solving strategy

Here the index 0 corresponds to absence of the precessing at the stage. Thus, the following examples can be considered (symbol \& corresponds to parallel integration of processing operations):

1. a series solving strategy \(S_1 = H_1 \ast T_2 \ast U_2 \ast X_0\);
2. a series-parallel solving strategy:
   \[
   S_2 = (S' \& S'' \& S'''') \ast X_1 = ((H_3 \ast T_1 \ast U_1) \& (H_3 \ast T_1 \ast U_2) \& (H_1 \ast T_2 \ast U_3)) \ast X_1.
   \]

Parallelization of the solving process is based on three approaches:

1. concurrent usage of different experts in the same interactive procedure (e.g., in \(U_4\));
2. concurrent usage of different methods at the same solving stage (e.g., \(H_3\));
3. concurrent usage of the same method with different parameters at the same solving stage (e.g., in \(U_4\)).

The design of solving strategies consists of two problems \([99]\): (a) selection of local techniques and (b) combinatorial synthesis of the selected techniques. The requirements to the composite solving strategies are based on the following: (i) kinds of task and of users; (ii) available resources (e.g., human, computer, time); (iii) features of the decision situation (e.g., kind of uncertainty, required precision and robustness of result). Thus, the following six criteria are examined \([99]\): (1) required computer resources; (2) required human resources; (3) quality of ranking (robustness, etc.); (4) possibility for data representation; (5) possibility for an analysis of intermediate data; and (6) usability (easy to learn, understanding, etc.).

Two direct solving strategies are as follows: (a) direct expert based ranking (e.g., \([89]\)) \(D_1 = H_1 \ast T_5 \ast U_4 \ast X_0\); (b) direct logical method for ranking (suggested and designed by A.A. Mikhailov \([110]\)) \(D_2 = H_1 \ast T_5 \ast U_5 \ast X_0\) or for the case of several experts: (a) \(D'_2 = H_1 \ast T_6 \ast U_5 \ast X_1\), (b) \(D''_2 = H_4 \ast T_6 \ast U_5 \ast X_1\). In our design approach, the strategies are based on defined top-level compatibility between their components (and zero compatibility between the components of the strategies and other components).

Note, some traditional approaches to build a solving process for decision making are oriented to the selection of the best method (or algorithm, model) (e.g., \([8, 61, 131, 156]\)). A model composition on the basis of a filter space is described in \([25]\). A non-linear recursive process consisting of four steps is analyzed for multicriteria decision aid in \([61]\).

In general, human part consists of the following: (a) user or group of users (experts, decision makers); (b) techniques for the modeling, diagnostics, selection, and assignment of specialists; (c) subsystem for
user training; (d) user interfaces and tools for their adaptation. In recent years, many authors have been investigated user modeling (e.g., [5], [51], [93], [117]). Issues of adaptation of user interfaces are considered in (e.g., [51], [57], [101], [129], [153]). Graphical interaction in multicriteria decision making is considered in ([74], [82], [120], [138], [167]). The effectiveness of different representations for managerial problem solving has been studied in [106]. Note a special prospective class of graph-based modeling systems for decision making processes has been proposed in ([73], [74], [90]). A hierarchical process of the user interface design for DSS COMBI on the basis of HMMD, and comparing some system versions are described in details in ([91], [99]).

3. SYNTHESIS OF COMPOSITE STRATEGY

3.1. Combinatorial Synthesis with Interval Multiset estimates

Interval multiset estimates have been suggested by M.Sh. Levin in [106]. The approach consists in assignment of elements (1, 2, 3, ...) into an ordinal scale [1, 2, ..., l]. As a result, a multi-set based estimate is obtained, where a basis set involves all levels of the ordinal scale: Ω = {1, 2, ..., l} (the levels are linear ordered: 1 ⊀ 2 ⊀ 3 ⊀ ... ) and the assessment problem (for each alternative) consists in selection of a multiset over set Ω while taking into account two conditions:

1. cardinality of the selected multiset equals a specified number of elements η = 1, 2, 3, ... (i.e., multisets of cardinality η are considered);

2. “configuration” of the multiset is the following: the selected elements of Ω cover an interval over scale [1, l] (i.e., “interval multiset estimate”).

Thus, an estimate е for an alternative A is (scale [1, l], position-based form or position form): е(А) = (η₁, ..., ηₙ, ηₙ), where ηᵢ corresponds to the number of elements at the level i (i = 1, l), or е(А) = {1, 2, ..., 1, 2, ..., l}. The number of multisets of cardinality η, with elements taken from a finite set of cardinality l, is called the “multiset coefficient” or “multiset number” (80, 172): μₙ|ₗ = η(l+1)...(l+η-1). This number corresponds to possible estimates (without taking into account interval condition 2). In the case of condition 2, the number of estimates is decreased. Generally, assessment problems based on interval multiset estimates can be denoted as follows: Пₙ|ₗ. A poset-like scale of interval multiset estimates for assessment problem Пₙ,ₜ is presented in Fig. 26. The assessment problem will be used in our applied numerical examples.

In addition, operations over multiset estimates are used [106]: integration, vector-like proximity, aggregation, and alignment.

Integration of estimates (mainly, for composite systems) is based on summarization of the estimates by components (i.e., positions). Let us consider n estimates (position form): estimate е₁ = (η₁, ..., ηₖ, ..., ηₙ), ..., estimate еₙ = (ηₖ, ..., ηₖ, ..., ηₙ). Then, the integrated estimate is: estimate е∫ = (η₁, ..., ηₖ, ..., ηₙ), where ηₖ = Σ₁ₙ=1 ηₖ, ∀l = 1, l. In fact, the operation ∨ is used for multiset estimates: e = e₁ ∨ e₂ ∨ ... ∨ eₙ.

Further, vector-like proximity is described. Let А₁ and А₂ be two alternatives with corresponding interval multiset estimates е(А₁), е(А₂). Vector-like proximity for the alternatives above is: δ(е(А₁), е(А₂)) = δ₋(А₁, А₂), δ₊(А₁, А₂), where vector components are: (i) δ₋ is the number of one-step changes: element of quality i + 1 into element of quality i (i = 1, l, t) (this corresponds to “improvement”); (ii) δ₊ is the number of one-step changes: element of quality i into element of quality i + 1 (i = 1, l, t) (this corresponds to “degradation”). It is assumed: |δ(e(А₁), е(А₂))| = |δ₋(А₁, А₂)| + |δ₊(А₁, А₂)|.

Now let us consider median estimates (aggregation) for the specified set of initial estimates (traditional approach). Let E = {e₁, ..., eₖ, ..., eₙ} be the set of specified estimates (or a corresponding set of specified alternatives), let D be the set of all possible estimates (or a corresponding set of possible alternatives) (E ⊆ D). Thus, the median estimates (“generalized median” M₉ and “set median” Mₑ) are: M₉ = arg minₙₑ∈D Σ₁ₙₑ=1 δ(M, eₑ); Mₙ = arg minₙₑ∈E Σ₁ₙₑ=1 δ(M, eₑ).

A brief description of combinatorial synthesis (HMMD) was presented in introduction.

Let S be a system consisting of m parts (components): R(1), ..., R(i), ..., R(m). A set of design alternatives is generated for each system part above.

The problem is:
Find a composite design alternative $ S = S(1) \star \cdots \star S(i) \star \cdots \star S(m) $ of DAs (one representative design alternative $ S(i) $ for each system component/part $ R(i) $, $ i = 1, m $) with non-zero compatibility between design alternatives.

A discrete “space” of the system excellence (a poset) on the basis of the following vector is used:

$$ N(S) = (w(S); e(S)) $$

where $ w(S) $ is the minimum of pairwise compatibility between DAs which correspond to different system components (i.e., $ \forall R_{j_1} $ and $ R_{j_2}, 1 \leq j_1 \neq j_2 \leq m $) in $ S $, $ e(S) = (\eta_1, ..., \eta_i, ..., \eta_l) $, where $ \eta_i $ is the number of DAs of the $ i $th quality in $ S $.

Further, the problem is described as follows:

$$ \max e(S), \quad \max w(S), \quad s.t. \quad w(S) \geq 1. $$

As a result, we search for composite solutions which are non-dominated by $ N(S) $ (i.e., Pareto-efficient). “Maximization” of $ e(S) $ is based on the corresponding poset. The considered combinatorial problem is NP-hard and an enumerative solving scheme is used.

Further, combinatorial synthesis can be based on usage of interval multiset estimates of design alternatives for system parts. For the resultant system $ S = S(1) \star \cdots \star S(i) \star \cdots \star S(m) $ the same type of the interval multiset estimate is examined: an aggregated estimate (“generalized median”) of corresponding interval multiset estimates of its components (i.e., selected DAs). Thus, $ N(S) = (w(S); e(S)) $, where $ e(S) $
is the “generalized median” of estimates of the solution components. Finally, the modified problem is:

$$\max e(S) = M^* = \arg \min_{M \in D} \sum_{i=1}^{m} | \delta(M, e(S_i)) |, \quad \max w(S), \quad \text{s.t.} \quad w(S) \geq 1.$$  

Here enumeration methods or heuristics are used \cite{102,105,106}.

The next version of combinatorial synthesis problem will be the following. Let $w(i, j)$ will be an interval multiset estimate for compatibility between two selected design alternatives $S_i$ and $S_j$ in solution $S$ (the same type of interval multiset estimates is used for the elements and for their compatibility). Then, the problem is:

$$\max e(S) = M^* = \arg \min_{M \in D} \sum_{i=1}^{m} | \delta(M, e(S_i)) | + \sum_{(i,j) \in S} | \delta(M, w(i, j)) |,$$

s.t. $w(S) = w(i, j) \geq w_0, \ \forall (i, j) \in S.$

Here $w_0$ is a constraint (a bottom bound) for compatibility. Evidently, enumeration methods or heuristics can be used here as well.

### 3.2. Example of Composite Strategy

The four-stage (four-part) morphological scheme of solving strategy for multicriteria ranking (sorting) to obtain the layered structure $B$ is presented in Fig. 24: $S = H \ast T \ast U \ast X$. Generally, design alternatives (local techniques, DAs) are evaluated upon six criteria \cite{99} and the vector estimates are transformed into interval multiset estimates. In the example, expert judgment was used and illustrative estimates are presented in Table 4 (Fig. 27). Note, the estimates of DAs correspond to a certain applied situation, e.g., professional level of expert(s).

Here the design of series solving strategy is based on the compressed morphology (without aggregation, i.e., without local techniques $X_1$ and $X_2$) (Fig. 27). Table 5 contains estimates of compatibility.

Finally, the following composite Pareto-efficient DAs are obtained:

(i) $S_1 = H_1 \ast T_0 \ast U_2 \ast X_0$, $N(S_1) = (2; 4, 0, 0)$; (ii) $S_2 = H_2 \ast T_0 \ast U_2 \ast X_0$, $N(S_2) = (3; 3, 1, 0)$; (iii) $S_3 = H_3 \ast T_0 \ast U_2 \ast X_0$, $N(S_3) = (3; 3, 1, 0)$; (iv) $S_4 = H_4 \ast T_0 \ast U_5 \ast X_0$, $N(S_4) = (3; 3, 1, 0)$.

Fig. 28 illustrates a space of quality for the obtained solutions.

### Table 4. DAs and estimates

| DAs   | Description                  | Interval multiset estimate |
|-------|------------------------------|---------------------------|
| $H_0$ | Absence                      | -                         |
| $H_1$ | Pairwise comparison          | (4, 0, 0)                 |
| $H_2$ | Dominance by Pareto-rule     | (3, 1, 0)                 |
| $H_3$ | Outranking technique         | (3, 1, 0)                 |
| $T_0$ | Absence                      | -                         |
| $T_1$ | Line elements sum of preference matrix | (1, 2, 1) |
| $T_2$ | Additive utility function    | (2, 2, 0)                 |
| $U_0$ | Absence                      | -                         |
| $U_1$ | Step-by-step revelation of maximal elements | (2, 2, 0) |
| $U_2$ | Step-by-step revelation of Pareto efficient elements | (4, 0, 0) |
| $U_3$ | Dividing the linear ranking  | (0, 1, 3)                 |
| $U_4$ | Expert procedure for ranking | (2, 2, 0)                 |
| $U_5$ | Direct logical method for ranking | (3, 1, 0) |
| $X_0$ | Absence                      | (0, 4, 0)                 |
| $X_1$ | Expert procedure for ranking | (3, 1, 0)                 |
| $X_2$ | Direct logical method for ranking | (4, 0, 0) |

Fig. 27. Morphology of series strategy
### Table 5. Compatibility of DAs

|   | $T_0$ | $T_1$ | $T_2$ | $U_1$ | $U_2$ | $U_3$ | $U_4$ | $U_5$ | $X_0$ |
|---|---|---|---|---|---|---|---|---|---|
| $H_0$ | 3 | 3 | 0 | 0 | 0 | 3 | 3 | 0 |   |
| $H_1$ | 0 | 1 | 0 | 2 | 2 | 0 | 0 | 0 | 3 |
| $H_2$ | 0 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 3 |
| $H_3$ | 0 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 3 |
| $T_0$ |   |   |   |   |   |   |   |   | 0   |
| $T_1$ |   |   |   |   |   |   |   |   | 0   |
| $T_2$ |   |   |   |   |   |   |   |   | 0   |
| $U_1$ | 3 |   |   |   |   |   |   |   |   |
| $U_2$ |   | 3 |   |   |   |   |   |   |   |
| $U_3$ |   |   | 3 |   |   |   |   |   |   |
| $U_4$ |   |   |   | 3 |   |   |   |   |   |
| $U_5$ |   |   |   |   | 3 |   |   |   |   |

4. CONCLUSION

In the paper, a modular approach to solving strategies in DSS for multicriteria ranking (sorting) has been described. First, methodological issues in architectural design of DSS are examined (decision making framework, typical problems, approaches to configuration of solving strategies). Second, combinatorial synthesis for design of series composite strategy for multicriteria ranking (sorting)) is presented. The study is based on DSS COMBI for multicriteria ranking (1984...1991). Evidently, an important and prospective direction consists in aggregation (fusion) of preference relations which are obtained from different sources (experts, algorithm / procedures). This leads to series-parallel solving strategies (e.g., [99]). Here it may be reasonable to take into account the following two research directions: (1) routing in And-Or graphs (e.g., [1],[34]); (2) activity nets [40]). In addition, it is reasonable to point out the significance of an extended composite solving framework that involves a preliminary stage for problem formulation, a final stage for analysis of results, and on-line monitoring of the solving process (Fig. 28). Here, the same design approaches may be applied.
Finally, it is reasonable to emphasize the significance of our approach for teaching of multicriteria analysis and system design (techniques, case studies, applied examples, projects) (e.g., [95], [100], [103], [104]).

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