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ALGORITHMS FOR SOLUTION INFERENCE BASED ON UNIFIED LOGICAL CONTROL MODELS

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Abstract. *Unified forms of knowledge representation models in expert control systems are proposed. It is proved that at quantitative measurement of the characteristics of the state of the controlled object, the problem of deriving a managerial solution is reduced to the investigation of a combinatorial optimization problem with a linear structure and two-sided inequality constraints. An algorithm for solving such problems is given, which implements the idea of directional selection of variants.*

Keywords: *expert systems, control, logical models, algorithms, inference of decisions, optimization.*

INTRODUCTION

Increasing complexity of technical devices and technologies as well as speed-up of economic, social, and political processes have caused gradual transformation of modern information society into knowledge society. This transformation, in its turn, triggers the need for building various AI-driven information systems, including expert control systems. Mathematical basis for such systems in most cases represents logical knowledge representation models (control models) with corresponding algorithms for logical inference of managerial solutions [1–10].

Practice shows that when developing such systems, it is logical model building stage where major complications emerge, since there is no unified technique for their building at the moment. Diversity of control model forms leads to additional difficulties due to the need to develop new algorithms of logical inference, geared towards specific models or their adaptation to the known method structure. As for the latter ones, the most widely used method is a cumbersome and informatively excessive J. Robinson's resolution method, initially intended for automatic theorem proving [10].

At the same time, comparative analysis of logical models being used in various expert control systems permits building certain mathematical constructions that can be considered as unified forms of knowledge representation for a wide range of practical tasks. Such forms allow for systematization of expert polling procedure, automation of knowledge base building, selection (or development) of simple but efficient algorithms for logical inference of managerial solutions.

PRIMITIVE MODELS AND ALGORITHMS

Most primitive logical control models are built according to "situation" $\to$ "action" scheme. As such, situation usually refers to "a set of indicators, describing status of the controlled object (CO) at a certain moment of time," [11], i.e., situation is associated with CO status. This definition limits applicability of such models because control action selection is based not only on the CO status but also on the resources available to the control system at the moment of decision making. Thus, a more functional scheme is "resource" & "action" $\to$ "result," where "action" refers to execution of one or several control operations, "resource" refers to means required for execution of each such operation, and the required "result" is defined depending on the CO status.

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Let $z = (z_i \mid i = \overline{1, m})$ be a vector of CO status parameters.

A logical control model, built according to this scheme, can be represented by the following formula:

$$(\forall\, i = \overline{1, m})\ (\forall\, j \in J_i)\ [M_j^P \to D(z_i, a_{ij})], \tag{1}$$

where $M_j^P = R^P(r_j^P, s_j^P) \,\&\, X(u_j, r_j^P)$; $R^P(r_j^P, s_j^P) = \bigwedge_{p \in P_j} R(r_{jp}, s_{jp})$; J_i is a set of control operation numbers, execution of which causes the ith parameter of CO status to change; u_j is the identifier of jth control operation; P_j is a set of resource types, needed for implementation of jth control operation; r_{jp} is the identifier of p type resource, needed for implementation of jth control operation; s_{jp} is the status indicator of the resource r_{jp} (its availability or quantity); a_{ij} is the indicator of z_i parameter change in response to the jth control operation; $R(r_{jp}, s_{jp})$ is the predicate that, after the model is adjusted to the situation, corresponds to availability (if $R(r_{jp}, s_{jp}) = 1$) or lack (if $R(r_{jp}, s_{jp}) = 0$) of the p type resource, needed for implementation of the control operation u_j; $X(u_j, r_j^P)$ is the predicate defining execution (if $X(u_j, r_j^P) = 1$) of the control operation u_j using all required resources r_{jp}, $p \in P_j$; $D(z_i, a_{ij})$ is the predicate that shows change (at $D(z_i, a_{ij}) = 1$) of the value of the ith parameter of CO status, resulting from implementation of the control operation u_j.

Let $(z_i^{(1)}, z_i^{(2)})$ be the range of acceptable values of the parameter z_i, $i = \overline{1, m}$, and z_{i^*} is a value of a CO status parameter outside the acceptable range $z_{i^*} \notin (z_{i^*}^{(1)}, z_{i^*}^{(2)})$, $1 \le i^* \le m$.

An algorithm of searching control operation capable of bringing the value of parameter z_{i^*} to the acceptable range provides performing the following actions.

1. Forming a set of control operation numbers, capable of bringing the value of this parameter to the acceptable range: $J_{i^*}^D = \{ j \in J_{i^*} : z_{i^*}^{(1)} \le z_{i^*} + a_{i^*, j} \le z_{i^*}^{(2)} \}$. If $J_{i^*}^D = \varnothing$, then computation stops, otherwise Item 2 of this algorithm is executed.

2. Forming a subset of control operation numbers within the set $J_{i^*}^D$ that the required resources for their implementation are available: $J_{i^*}^R = \{ j \in J_{i^*}^D : R^P(r_j^P, s_j^P) = 1 \}$. If $J_{i^*}^R = \varnothing$, then computation stops, otherwise Item 3 of this algorithm is executed.

3. Selecting control operation u_{j^*}, $j^* \in J_{i^*}^R$, to be implemented.

If the subset $J_{i^*}^R$ consists of a single element j^*, then this element defines the control operation u_{j^*} to be implemented. When $|J_{i^*}^R| > 1$, then the selected control operation is the most preferable (upon the specified criterion) operation u_{j^*}, $j^* \in J_{i^*}^R$.

If $J_{i^*}^D = \varnothing$, then model (1) does not provide any control operation that can (without invocation of other operations) bring the value of parameter z_{i^*} to the acceptable range. In this case, it makes sense to consider simultaneous implementation of several control operations u_j, $j \in J_{i^*}$, that cause the parameter in question to change.

If $J_{i^*}^R = \varnothing$, then none of control operations, capable of bringing the value of parameter z_{i^*} to the acceptable range, has required resources available. In this situation, the problem has no solution.

DEFINING A COMBINATION OF CONTROL OPERATIONS FOR A SINGLE PARAMETER

A logical control model for simultaneous execution of multiple operations, aimed at changing a single CO status parameter value, is built according to the following formula:

$$(\forall\, i = \overline{1, m}) \left[\bigvee_{j \in J_i} M_j^P \to D(z_i, a_{ij}) \right]. \tag{2}$$

A search algorithm for combination of control operations to bring the value of a single CO status parameter to the acceptable range provides sequential performing of the following actions.

1. Forming a set of control operation numbers, capable of changing (increasing or decreasing) the value of OC status parameter z_{i^*} that the required resources for their implementation are available $J_{i^*}^R = \{j \in J_{i^*} : R^P(r_j^P, s_j^P) = 1\}$. If $J_{i^*}^R = \varnothing$, then model (2) does not enable necessary change of the parameter value z_{i^*} in the current situation due to the lack of required resources. In this case, computation stops. If $J_{i^*}^R \neq \varnothing$, then Item 2 of this algorithm is executed.

2. Detecting a combination of control operations, implementation of which can bring the value of CO status parameter z_{i^*} to the acceptable range.

This is a combinatorial problem. So its solution is based on algebraic model, adequate to logical model (2) with regard to the contents of the subset $J_{i^*}^R$ of control operations intended for value change of the CO status parameter z_{i^*} that have the required resources available.

To build such an algebraic model, each predicate $X(u_j; r_j^P)$ is assigned a boolean variable $x_j \in \{0, 1\}$, $j \in J_{i^*}^R$, and the following two-sided inequality is formed:

$$z_{i^*}^{(1)} \le z_{i^*} + \sum_{j \in J_{i^*}^R} a_{i^*, j} \; x_j \le z_{i^*}^{(2)}. \tag{3}$$

The intention behind these boolean variable is as follows: if solving inequality (3) results in a certain variable $x_{j'} = 1$, then the control operation $u_{j'}$ is to be implemented; if $x_{j'} = 0$, then this assertion is false, $j' = J_{i^*}^R$. The following algorithm that implements the idea of directional selection of variants can be used to solve two-sided inequality (3).

SIDE EFFECT

A side effect can manifest itself as the fact that control operations $j \in J_{i^*}^R$, implemented in order to bring the value of any parameter z_{i^*} to the acceptable range, can cause unacceptable changes in value of other CO status parameters z_i, $i \in I_1^E(i^*)$, where $I_1^E(i^*) = \{i \in \{1, \ldots, m\} \setminus \{i^*\} : J_{i^*}^R \cap J_i^R \neq \varnothing\}$. To prevent this, inequality (3) should be supplemented by similar expressions, relevant to each of the parameters z_i, $i \in I_1^E(i^*)$, separately.

In its turn, implementation of control operations that compensate negative changes of parameter values z_i, $i \in I_1^E(i^*)$, can cause unacceptable deviations of another group of CO status parameters z_i, $i \in I_2^E(i^*)$, that are not connected with the parameter z_{i^*} by common control operations, etc.

To define the full set $I^E(i^*)$ of CO status parameters, subject to possible value changes due to implementation of the control operations, intended to bring the value of parameter z_{i^*} to the acceptable range, the following step-by-step procedure is used.

First, accept that $I_0^E(i^*) = \{i^*\}$; $J_0^E(i^*) = J_{i^*}^R$. Then, at each lth step, sequentially define the sets

$$I_l^E(i^*) = \{i \in \{1, \ldots, m\} : J_i^R \cap J_{l-1}^R(i^*) \neq \varnothing\};$$

$$J_l^R(i^*) = \bigcup_{i \in I_l^E(i^*)} J_i^R, \; l = 1, 2, \ldots \; .$$

The procedure is complete if $J_l^R(i^*) = J_{l-1}^R(i^*)$ or (as an equivalent) $I_l^E(i^*) = I_{l-1}^E(i^*)$.

The set $I^E(i^*) = I_l^E(i^*)$, formed using the method discussed, contains numbers of all CO status parameters (including z_{i^*}), whose values can change due to implementation of control operations, intended to bring the value of parameter z_{i^*} to the acceptable range.

In view of this side effect, the logical control model changes to

$$(\forall i^* = \overline{1, m}) \left[\bigvee_{j \in J_{i^*}} M_j^P \to \bigwedge_{i \in I^E(i^*)} D(z_i, a_{ij}) \right]. \tag{4}$$

This logical model corresponds to the two-sided inequality system that include expressions, similar to (3) in terms of their structure, but formulated for all values $i \in I^E(i^*)$. To solve this system and define a combination of control operations, capable of bringing the value of parameter z_{i^*} to the acceptable range, the following algorithm that implements the idea of directional selection of variants can be used.

DEFINING A COMBINATION OF CONTROL OPERATIONS FOR MULTIPLE PARAMETERS

Let I^* be the set of CO status parameters, whose values are outside the acceptable range. The logical control model can be represented as (2) without the side effect, or as (4) where the side effect exists. Corresponding systems of inequalities are developed on expressions in the form of (3), laid down separately for each $i \in I^*$ in the former case and for each $i \in I^E(I^*)$ in the latter case, where $I^E(I^*)$ is a set of numbers of all CO status parameters, whose values can change as a result of control operations, implemented for bring the collection of parameter values z_i, $i \in I^*$, to the acceptable range.

To define the set $I^E(I^*)$, the above-mentioned step-by-step procedure is used, starting with assumption that $I_0^E(I^*) = I^*$; $J_0^E(I^*) = \bigcup_{i \in I^*} J_{i^*}^R$. Then, at each *l*th step, sequentially define the sets

$$I_l^E(I^*) = \{i \in \{1, \dots, m\} : J_i^R \cap J_{l-1}^R(I^*) \neq \varnothing\};$$

$$J_l^R(I^*) = \bigcup_{i \in I_l^E(I^*)} J_i^R, \; l = 1, 2, \dots \, .$$

The procedure completes with finding the set $I_l^E(I^*) = I_{l-1}^E(I^*) = I^E(I^*)$.

Finding a combination of control operations, capable of normalizing the CO status, is a multi-variant and, therefore, an optimization problem. Thus, apart from two-sided inequality system (3), mathematical model of this problem should include criterion function

$$f(x) = \sum_{j \in J^X} c_j x_j, \tag{5}$$

where J^X is a set of identifiers for the discussed control operations, $J^X = \bigcup_{i \in I^X} J_i^R$; I^X is the set of CO status parameters, such that $I^X = I^*$ with no side effect, and $I^X = I^E(I^*)$ where the side effect exists; c_j, $j \in J^X$, are coefficients showing preference levels for specific control operations (e.g., implementation costs, technological benefits, etc.); x is a vector of independent boolean variables: $x = (x_j \mid j \in J^X)$, $x_j \in \{0, 1\}$, $j \in J^X$. Whereas minimum of the function $f(x)$ is reached at the same argument values as maximum of the function opposite in sign, without loss of generality we may proceed with assumption that criterion function (5) requires maximizing.

It makes sense to represent the system of two-sided inequality constraints in a more compact form

$$b_i^{(1)} \le \sum_{j \in J_i^R} a_{ij} x_j \le b_i^{(2)}, \ i \in I^X, \tag{6}$$

where $b_i^{(1)} = z_i^{(1)} - z_i$ and $b_i^{(2)} = z_i^{(2)} - z_i$, $i \in I^X$.

Formal statement of the problem is reduced to finding the vector of boolean variable values $x = (x_j \mid j \in J^X)$ that maximize criterion function (5) with respect for the system of inequality constraints (6).

The problem discussed is a combinatorial optimization problem with linear structure. It can be solved using an algorithm that implements the idea of directional selection of variants, adapted to the structure of two-sided inequality constraints [9]. This directional selection method provides for sequential fragmentation of full set G of solution variants, performed until an optimal plan or inconsistency of the constraint system is established. New subsets of variants, acquired as a result of such fragmentation, are subject to formal analysis, aimed at processed data reduction, cutting down the number of algorithm steps leading to the desired result, and, consequently, minimizing duration of solution process. This effect can be achieved by means of excluding subsets containing no acceptable plans from further treatment, removal of constraints that have rendered inactive regardsing the plans of the subset of variants from the mathematical model as well as by means of establishing single-option variables and assigning them the only acceptable values.

Suppose that at a certain stage of solving problem (5), (6), in a full set of variants G, λ disjoint subsets G_k, $k = \overline{1, \lambda}$, that contain acceptable plans are extracted.

Let $J_k^1 \subseteq J^X$ be a set of numbers of independent variables that in the plans of the kth subset have gained the value 1 and $J_k \subseteq J^X$ is a set of numbers of variables that have no fixed values within G_k. Similar sets, related to criterion function (5) and each constraint of system (6), are defined by the formulas

$$J_{0k}^1 = J^X \cap J_k^1; \ J_{0k} = J^X \cap J_k; \ J_{ik}^1 = J_i^R \cap J_k^1; \ J_{ik} = J_i^R \cap J_k, \ i \in I^X.$$

Model (5), (6) brought into correspondence with the kth subset of variants is of the following form:

$$f_k(x) = \sum_{j \in J_{0k}^1} c_j + \sum_{j \in J_{0k}} c_j x_j \to \max, \tag{7}$$

$$b_{ik}^{(1)} \le \sum_{j \in J_{ik}} a_{ij} x_j \le b_{ik}^{(2)}, \ i \in I_k, \tag{8}$$

where $x = (x_j \mid j \in J_k)$, $x_j \in \{0,1\}$, $j \in J_k$; $b_{ik}^{(p)} = b_i^{(p)} - \sum_{j \in J_{ik}^1} a_{ij}$, $p \in \{1,2\}$, $i \in I_k$; I_k is the set of system (8) constraint numbers that are active with respect to the plans within the variant subset G_k.

To analyze model (7), (8) on the sets J_{0k} and J_{ik}, $i \in I_k$, the following subsets are extracted: a set of numbers of independent variables $J_{0k}^3 = \{j \in J_{0k} : c_j > 0\}$, included into criterion function (7) with positive coefficients; sets of numbers of independent variables $J_{ik}^2 = \{j \in J_{ik} : a_{ij} < 0\}$ and $J_{ik}^3 = \{j \in J_{ik} : a_{ij} > 0\}$, included into the ith constraint of system (8) with positive and negative coefficients, respectively; a set of numbers of independent variables $J_{ik}^2(j') = \{j'\} \cup \{j \in J_{ik}^2 : a_{ij} \le a_{ij'}\}$, included into the ith constraint of system (8) with negative coefficients that do not exceed the value of $a_{ij'}$; a set of numbers of independent variables $J_{ik}^3(j'') = \{j''\} \cup \{j \in J_{ik}^3 : a_{ij} \ge a_{ij''}\}$, included into the ith constraint of system (8) with positive coefficients no less than $a_{ij''}$.

Let $\sigma_{ik}^{(2)}$ and $\sigma_{ik}^{(3)}$ be sums of negative and positive coefficients of the ith constraint of system (8), hence, $\sigma_{ik}^{(p)} = \sum_{j \in J_{ik}^p} a_{ij}$, $p \in \{2,3\}$, $i \in I_k$.

It is supposed that $\sigma_{ik}^{(p)} = 0$ if $J_{ik}^{p} = \varnothing,\ p \in \{2, 3\}$.

Properties of the kth ($k = \overline{1, \lambda}$) subset of solution variants to problem (5), (6) can be expressed as the following statements.

Statement 1. Subset G_k contains no acceptable plans if for a certain constraint $i \in I_k$ the following condition is satisfied: $(\sigma_{ik}^{(3)} < b_{ik}^{(1)}) \vee (\sigma_{ik}^{(2)} > b_{ik}^{(2)})$.

Statement 2. Constraint $i \in I_k$ is not active with respect to the plans within the subset G_k if the following condition is satisfied: $(\sigma_{ik}^{(2)} \geq b_{ik}^{(1)}) \vee\ (\sigma_{ik}^{(3)} \leq b_{ik}^{(2)})$.

Statement 3. If $J_{ik}^{3} \neq \varnothing$ and a certain $j'' \in J_{ik}^{3}$ satisfies the condition $\sigma_{ik}^{(3)} \geq b_{ik}^{(1)} > \sigma_{ik}^{(3)} - a_{ij''}$, then only those of complementary plans within the subset G_k can be acceptable, where $[\forall\, j \in J_{ik}^{3}(j'')](x_j = 1)$.

Statement 4. If $J_{ik}^{2} \neq \varnothing$ and a certain $j' \in J_{jk}^{2}$ satisfies the condition $\sigma_{ik}^{(2)} \leq b_{ik}^{(2)} < \sigma_{ik}^{(2)} - a_{ij'}$, then only those of complementary plans within the subset G_k can be acceptable, where $[\forall\, j \in J_{ik}^{2}(j')](x_j = 1)$.

Statement 5. If $J_{ik}^{2} \neq \varnothing$ and a certain $j' \in J_{jk}^{2}$ satisfies the condition $\sigma_{ik}^{(3)} \geq b_{ik}^{(1)} > \sigma_{ik}^{(3)} + a_{ij'}$, then only those of complementary plans within the subset G_k can be acceptable, where $[\forall\, j \in J_{ik}^{2}(j')](x_j = 0)$.

Statement 6. If $J_{ik}^{3} \neq \varnothing$ and a certain $j'' \in J_{ik}^{3}$ satisfies the condition $\sigma_{ik}^{(2)} \leq b_{ik}^{(2)} < \sigma_{ik}^{(2)} + a_{ij''}$, then only those of complementary plans within the subset G_k can be acceptable, where $[\forall\, j \in J_{ik}^{3}(j'')](x_j = 0)$.

The algorithm of directional selection of variants provides the execution of the following sequence at each stage of solution process for problem (5), (6).

1. Selecting a subset of variants to be fragmented, for which purpose we select subset G_{k^*}, corresponding to the maximum estimate of the criterion function $\xi(G_{k^*}) = \max\{\xi(G_k),\, k = \overline{1, \lambda}\}$, where $\xi(G_k) = \sum\limits_{j \in J_{0k}^{1}} c_j + \sum\limits_{j \in J_{0k}^{3}} c_j$.

2. Selecting a variable x_{j^*}, $j^* \in J_{0k^*}$, whose values are to be fixed, included in the criterion function $f_{k^*}(x)$ with the maximal coefficient $c_{j^*} = \max\{c_j;\, j \in J_{0k^*}\}$.

3. Fragmenting the subset of variants into two disjoint subsets. By fixing values of the selected variable x_{j^*} subset G_{k^*} is fragmented into two disjoint subsets $G_{k^*}^{0}$ and $G_{k^*}^{1}$. Plans of the former have $x_{j^*} = 0$, and plans of the latter have $x_{j^*} = 1$.

4. Analyzing subsets of variants $G_{k^*}^{0}$ and $G_{k^*}^{1}$. Analysis procedure for any kth subset of solution variants for a combinatorial optimization problem involves sequential checking whether conditions of each formulated statement are satisfied for all the constraints of system (8). Depending on the results of this check, specific sequence of actions is performed in the analysis cycle.

If a certain constraint $i \in I_k$ satisfies the condition of Statement 1, then subset G_k is excluded from further treatment.

Constraints $i \in I_k$ that satisfy the condition of Statement 2 are deleted from system (8) and their numbers from the subset I_k. Thus, corrected set of constraint numbers that are active with respect to the complementary plans within the variant subset G_k are referred to as I'_k.

If the ith constraint ($i \in I'_k$) satisfies the condition of any Statement 3–6, then the single-option variables, specified therein, are assigned the only acceptable values. These values are substituted into all constraints $i \in I'_k$ and after that analysis cycle is repeated for the subset G_k.

It is recommended to start checking fulfilment of conditions of Statements 3–6 for the next ith constraint ($i \in I'_k$) with typifying as $a_{ij'}$ and $a_{ij''}$ the minimal (negative) and the maximal (positive) coefficients of, respectively, $a_{ij'} = \min\{a_{ij},\, j \in J_{ik}^{2}\}$ and $a_{ij''} = \max\{a_{ij},\, j \in J_{ik}^{3}\}$. Afterwards, if this choice of $a_{ij'}$ and $a_{ij''}$ enables the conditions of the mentioned statements to be satisfied, then it is feasible to use the following as these parameters, respectively:

$$a_{ij''} = \min \{a_{ij},\ j \in J_{ik}^{3} : \sigma_{ik}^{(3)} - a_{ij''} \geq b_{ik}^{(1)}\},$$

$$a_{ij'} = \max \{a_{ij},\ j \in J_{ik}^{2} : \sigma_{ik}^{(2)} - a_{ij'} \leq b_{ik}^{(2)}\},$$

$$a_{ij'} = \max \{a_{ij},\ j \in J_{ik}^{2} : \sigma_{ik}^{(2)} - a_{ij'} \geq b_{ik}^{(1)}\},$$

$$a_{ij''} = \min \{a_{ij},\ j \in J_{ik}^{3} : \sigma_{ik}^{(3)} - a_{ij''} \leq b_{ik}^{(2)}\}.$$

Such choice of parameters $a_{ji'}$ and $a_{ji''}$ ensures that the subsets of variants with the greatest cardinality containing no acceptable plans are cut off from G_k.

Procedure of analyzing the variant subset G_k completes if proven that it contains no acceptable plans; constraint system (8) contains no active constraints ($I'_k = \varnothing$); a full acceptable plan x is formed by assigning values to single-choice variables; none of the single-choice variables has been assigned a specific value at the final analysis cycle of this subset.

After completing the analysis procedure for subsets $G_{k^*}^{0}$ and $G_{k^*}^{1}$, the remaining subsets are numbered anew with positive integers from 1 to λ'. It is obvious that $\lambda' = \lambda - 1$ if both subsets $G_{k^*}^{0}$ and $G_{k^*}^{1}$ turn out to contain no acceptable plans; $\lambda' = \lambda$ if only one of them contains no acceptable plans; $\lambda' = \lambda + 1$ if absence of acceptable plans has not been proved for both variant subsets being considered.

Computation process is completed in the following two cases: inconsistency of constraint system (6) is established as shown by the equation $\lambda' = 0$; a vector x^* of variable values is found that sets criterion function (5) at a value of no less than possible, $f(x^*) \geq \max \{\xi(G_k),\ k = \overline{1, \lambda'}\}$.

It is feasible to start solving with analyzing the full set G of variants. In certain cases, it allows us to establish inconsistency of constraint system (7) a priori or cut off a subset containing no acceptable plans from G.

CONCLUSIONS

The discussed unified forms of logical models allow us to reduce decision-making tasks in expert control systems to researching mathematical models of combinatorial optimization problems. Such problems are NP-class problems. It means that theoretical estimate of solution process duration exponentially depends on dimensionality of the mathematical model. However, variant subset analysis, based on formulated statements, substantially cuts down the number of algorithm steps leading to the end result, thus reducing required computer time. Practice shows that by means of detecting and excluding subsets that contain no acceptable plans from further consideration, removal of constraints that have rendered inactive as regards plans of the currently treated subset of variants from the mathematical model as well as by means of establishing single-option variables and assigning them the only acceptable values, one can ensure highly targeted search and find the desired managerial solution within acceptable time.

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