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Algorithms for choosing a design solution for transforming a relief

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Abstract. The article deals with the creation of algorithms for selecting a project of territory in the process of transforming a relief into a project surface. The selection function and the design problem are defined. Such tasks belong to the class of multicriteria optimization problems. At present, adaptive procedures based on a dialogue between a decision-maker and a computer is being successfully used. Such procedures are focused on the search for effective (Pareto optimal) alternatives. A modification of the "shifted ideal" method is proposed. Here, at the first stage, an "ideal" object is formed from the maximum utility values of the criteria. Also, the "worst" object is formed from the minimum criteria values in terms of utility. In the second stage, units of measurement are formed that allow us to estimate the distance of the object from the "ideal" object. At the next stage, the distance of each design solution to the ideal is calculated. Then design decisions are ranked by distance from the "ideal" project and are removed from the original set: the search for the optimal design solution continues until an option is found that is preferable for the decision-maker

1. Introduction

Adjustment of natural relief for functional purposes is one of the main tasks in the complex of tasks of engineering preparation of territories, industrial sites, reclamation of irrigated lands. Numerous methods of engineering training design are aimed at building algorithms that allow obtaining an optimal solution in automated mode [2, 4, 18, 19]

In the complex of tasks of engineering preparation of territories and industrial sites vertical planning is defined as 1) a complex of engineering measures aimed at adaptation of natural relief for the subsequent operation of the territory taking into account functional features [11, 13, 14].

At the reclamation of irrigated lands there are specific requirements to the project surface - maximum preservation of fertile soil layer [15].

It is necessary to note the following points in the development of the theory and methods of optimizing the design of vertical planning:

1) approaches to the analytical solution of the problems of vertical planning have not changed significantly for a long time - the introduction of modern super and microcomputers into the design practice allowed to get a large number of design solutions, to make some corrections in the project, to create more comfortable working conditions for the estimators, but the methods of solving the above-mentioned problems remained the same [16].

2) attempts made to solve several optimization tasks simultaneously using a special selection of the target function type and the system of restrictions do not lead to the desired result. An overcomplicated task with a large number of calculations requires the designer to have mathematical

knowledge in cases when it is necessary to make corrections to the project. In turn, reducing the planning task to the step-by-step optimization subtasks using iterative methods also does not always lead to the optimal solution [18].

In the conditions of the automated designing to models of the decision of engineering problems the system of requirements that can be broken down on 4 classes is shown to models of the decision of engineering problems [21].

1) geometrical, reflecting the quality of modeling of the geometrical object, absence of distortions introduced by the mathematical apparatus on the model

2) applied, characterizing convenience of implementations based on the constructed mathematical model of functional subsystems

3) system-technical evaluation of the model usability simplicity and stability of algorithms unification and standardization of the model

4) ergonomic, characterizing the convenience of using methods by a person (first of all, the possibility of choosing a criterion for completing the design process of operating with familiar concepts, the locality of operations performed on a model).

Modern systems of automated designing assume the presence of hierarchical structure of the system of designing, corresponding level decomposition of the object of designing, and a stage decomposition of the process of designing.

2. Methods

Introduction of the integrated CAD covering the basic stages of the life cycle of difficult technical systems is focused on the improvement of quality of design decisions and reduction of terms and cost of designing at the set quality. Total expenses for quality assurance, as it is known, reach 10-20 % of the cost of production. Thus 50-70% of the general reasons for defects of finished goods are connected with errors in design decisions, 20-30% - with lack of technological processes [1, 2, 8].

There is a problem of a choice of design decision among some set of alternatives.

Let's formulate this task. Let's assume that there are a lot of *{x}* design solutions of relief transformation into a design surface. For all sorts of pairs of alternatives from *X* let's define on the set *{x}* the binary ratio of comparative efficiency: alternative $xi \subset X$ is more effective than the alternative $xj \subset X$ if and only if $(xi, xj) \in F$. Let's denote through *C(X)* a subset of alternatives, which is singled out by the decision-maker *(DM)* from *X*. A display that matches the $x \subseteq A$ set of *C(x)* is called a selection function, *C(x)* is a choice in *X*.

Consider a pair *(X, R)* consisting of a set of x and a binary ratio *R* on it. Such a pair is a model of choice. The element $x \in X$ is called maximal in the model *(X, R)* if *uRx* attracts *xRu*. The set of all maximum in *(X, R)* elements is denoted by *max(X, R)*.

The subset of $u \subset x$ is externally stable in *(X, R)*, if for any $x \in X/Y$ is found $y \in Y$ such that *uRx*. If *max(X, R)* is externally stable in *(X, R)*, then *max(X, R)* is the nucleus of the ratio *R* and *x*.

The task of designing is understood as the task of selecting the kernel - the set of maximum elements of their *X* by the binary ratio *F*,

$$x+=Max\ (x, F) \qquad (1)$$

the solution is supposed to exist. Moreover, in the problems of designing put in the closed form, it is natural to consider that the decision - set *x+* - consists of one element. Formally, it means that the binary relation *F*, with which the DM operates, is such that |x+|=1, is often connected with the completeness of the relation *F*, i.e. with the fact that for any *x, $u \in X$* at least one of the following relations is executed: *xFu, uFx*.

However, in the real conditions of design, the practical implementation of the problem statement (1) with the full ratio of F is almost impossible. This fact is objectively connected with both the complexity of the design object itself and the design process [4].

Often the relation F is generated by the parametric family (system) of criteria of comparative efficiency

$$\varphi_A = (\varphi^{\alpha} : x \to E^+, \ \alpha \in A) \qquad (2)$$

The following binary relationships are possible:

$$x_1 F_1 x_2 \leftrightarrow W^i(x_1) \geq W^i(x_2),\ i=\overline{1,m}$$
$$x_1 F_2 x_2 \leftrightarrow W^i(x_1) \geq W^2(x_2),\ i=\overline{1,m}$$
$$W(x_1) \neq W(x_2) \tag{3}$$

where $W(x)=(\ W'(x) \ldots Wm(x))$ is a vector efficiency criterion.

The ratio F_1 is called the Pareto ratio, while the ratio F_2 is called the Slater ratio or the strict dominance ratio.

For the design task set as the task of finding the kernel: x→x*=Max(x, F)

models (x, F), where x is the set of competing variants of the project (alternatives) supposed to be final, F is the binary ratio of comparative efficiency on x, there are special methods of solution. [5, 6, 7, 8]

Methods based on the idea of sequential analysis of variants use the "rejection policy". In the j-th iteration, the available set of alternatives *xj-1* is narrowed to *xj=xj-1\Qj*.

Alternatives from *Qj* are discarded and are not considered further. The solution is the output, i.e. at each step of the procedure there is a lot of *xk*.

In other cases, the binary ratio on x is set by the system of preferences of the decision-maker (DM).

Such problems concern several weakly structured problems in which the center of gravity is displaced aside definition that it is necessary to consider as the best alternative in a problem with several target functions that reach a maximum in various points of the set of alternatives. At present, the most effective methods of solving multi-criteria problems are adaptive procedures based on the dialogue between DM and computer. The majority of works in this area are focused on the task of searching for effective (optimal according to Pareto) and weakly effective (optimal according to Slater) alternatives [10].

Let's stop on the specificity of the decision of a problem of a choice of a design surface in problems of a vertical layout. Let us note its peculiarities.

1) Number of performance criteria of course

$\{K_1, K_2, K_3, K_4\}$. K_1 is the total cost of construction works, K_2 is zero balance of construction works, K_3 is maximum approximation to the existing relief, K_4 is minimum transport costs.

2) The problem under consideration belongs to the class of discrete multi-criteria problems. In the space of criteria $K_1\ x\ K_2\ x\ K_3\ x\ K_4$ each design solution is displayed as a point, and the set of design solutions - as a final set of discrete points.

3) The solution to the problem requires the development of special algorithms focused on the application of human-machine (interactive) procedures.

We will proceed from the relative equality of all efficiency criteria.

In the general statement of the problem, there are N design solutions, evaluated by K_1, K_2, K_3, K_4 - criteria.

At the first stage, an ideal object $\{K_1+, K_2+, K_3+, K_4+\}$ is formed from the maximum utility values of the criteria achieved on the available set {x}, in this case $Kj+=min\ Kij$.

In addition to the ideal object, the "worst" object $\{K_1-, K_2-, K_3-, K_4-\}$ is formed from the minimum utility values of criteria achieved on the set {x}, in this case Kj+=max Kij

The second step is to form relative units of measurement to compare different criteria.

$$d_j^i = \frac{k_j^+ - k_j^i}{k_j^+ - k_j^-} \tag{4}$$

allows you to estimate the distance of the object on the criterion of Kj from the ideal object.

At the next stage, the DM sets the coefficients of relative importance (weight) of the criteria, based on its judgments about their importance, and introduces the metrics into the set of design solutions. The type of the given metrics depends on the DM.

Using the set metrics, calculate the distance of each project solution to the ideal

$$l_i^p = \sum_{j=1}^{4} \left\{ \left[\left(1 - d_j^i\right)^p \right] \right\}^{\frac{1}{p}} \tag{5}$$

where p is the metric parameter. At $p=2$, expression (5) turns to Euclidean distance in scaled coordinates. Theoretically, parameter p can take values from 1 to ∞, for practical purposes can be limited to the values of $\boldsymbol{p} = \overline{\boldsymbol{1, 5}}$.

At the final stage for each p-value design solutions are ranked by the distance from the ideal object.

The objects furthest from the "ideal" object with all p values are removed from the initial set *{x}*. For the new set *{x'}*, the "ideal variant" of the project is formed and the procedure of searching for the optimal project solution is repeated. DM dialogue with the computer stops when the agreement is reached that the project variant most preferable from the point of view of DM is found.

3. Results and Discussion

Table 1. Consider the following example. Suppose there are 10 vertical planning projects evaluated according to K_1, K_2, K_3, K_4 criteria

Projects	Criteria K_1	Criteria K_2	Criteria K_3	Criteria K_4
Project 1	$155000	$133000	0.84	$91000
Project 2	$157000	$149000	0.80	$95000
Project 3	$141000	$147000	0.72	$101000
Project 4	$129000	$126000	0.79	$106000
Project 5	$151000	$108000	0.89	$85000
Project 6	$168000	$105000	0.67	$94000
Project 7	$169000	$132000	0.75	$97000
Project 8	$168000	$142000	0.68	$106000
Project 9	$157000	$146000	0.65	$105000
Project 10	$147000	$136000	0.69	$105000

We formulate the ideal project "Project +" with the characteristics of {$126000, $105000, 0.9, $84000} and the worst project "Project -" with the characteristics of {$173000, $158000, 0.6, $107000}. Let's move on to relative units.

Table 2. Translation results in relative units of measurement of criteria values are as follows:

Projects	d_1	d_2	d_3	d_4
Project 1	0.62	0.545	0.2	0.31
Project 2	+0.66	0.84	0.3	0.45
Project 3	0.31	0.80	0.6	0.72
Project 4	0.06	0.4	0.36	0.95
Project 5	0.53	0.06	0.03	0.03
Project 6	0.89	0.002	0.76	0.41
Project 7	0.89	0.506	0.5	0.55
Project 8	0.88	0.70	0.73	0.94
Project 9	0.66	0.78	0.83	0.91
Project 10	0.44	0.58	0.7	0.91

We calculate the distance of each project to the ideal in various metrics.

Table 3. The results of the calculations are as follows

P	l_1p	l_2p	l_3p	l_4p	l_5p	l_6p	l_7p	l_8p	l_9p	$l_{10}p$
1	2.225	1.75	1.57	2.23	3.35	2.028	1.554	1.29	1.69	2.18
2	1.082	0.966	0.868	1.286	1.728	1.189	0.842	0.737	1.016	1.179
3	0.936	0.811	0.75	1.094	1.403	1.067	0.697	0.692	0.926	1.002
4	0.853	0.767	0.714	1.019	1.280	1.028	0.635	0.615	0.906	0.944
5	0.812	0.741	0.711	0.983	1.199	1.012	0.602	0.606	0.902	0.921

All projects are ordered for each p according to the distance from the ideal project.

p=1 $l_5 > l_4 > l_1 > l_{10} > l_6 > l_2 > l_9 > l_3 > l_7 > l_8$

p=2 $l_5 > l_4 > l_6 > l_{10} > l_1 > l_9 > l_2 > l_3 > l_7 > l_8$

p=3 $l_5 > l_4 > l_6 > l_{10} > l_1 > l_9 > l_2 > l_3 > l_7 > l_8$

p=4 $l_5 > l_6 > l_4 > l_{10} > l_9 > l_1 > l_2 > l_3 > l_7 > l_8$

p=5 $l_5 > l_6 > l_4 > l_{10} > l_9 > l_1 > l_2 > l_3 > l_8 > l_7$

For all values of the indicator p $(\overline{1,5})$ the best is "Project 5".

4. Conclusions

The algorithms considered above are embedded in computer programs (MathLab). They can be used in modern computer aided design systems (CAD). The advantage of the proposed methodology for choosing a design solution is its versatility and the ability to automatically select the optimal one according to various project criteria

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