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DEVELOPMENT OF A METHODOLOGY FOR DETERMINING THE BEST OPTION FOR THE ROUTE OF THE HEAT NETWORK AT THE INITIAL DESIGN STAGE

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Statement of the problem. Choosing the best option for the route of the thermal network at the initial stage of design is a complex multifactorial task, in addition, due to the lack of a number of necessary design calculations, its solution is accompanied by a limited set of initial data. Thus, it becomes relevant to develop a new methodology for designing the optimal route of the heat supply system considering the qualitative and quantitative characteristics of the discussed object.

Results. A mathematical model of a generalized additive vector optimality criterion has been developed, taking into account the material consumption of the heat network, its reliability, construction time, annual thermal losses, heat turnover and temperature dispersion at the consumer. A method is proposed for determining the best option for the route of a thermal network at the initial design stage by jointly solving the optimization problem using vector optimization and matrix generalization methods. The expediency of the joint application of the methods of pairwise comparison and vector optimization in solving the problem under consideration is noted.

Conclusions. An important characteristic of the developed mathematical model of the generalized criterion is the possibility of obtaining a more accurate solution to the optimization problem under consideration with an uneven distribution of the heat load by means of a biased estimate of the temperature variance among consumers. A combination of the methods of matrix generalization, pairwise comparison and vector optimization can improve the accuracy of the calculation while solving the optimization problem of choosing the best route of the thermal network.

Keywords: thermal networks, normalized optimality criteria, the best route option, multi-criteria optimization, pairwise comparison.

Introduction. In [7, 11, 12] it was noted that the choice of the best one or a few equivalent options for tracing the heating network is a special case of a multi-criteria optimization problem. The solution to this problem involves having to identify a certain number of criteria for comparing the options under consideration. An error in the selection of these criteria might cause a wrong solution. Through the course of research, the results of which were presented in [11,

13, 14], the use of enlarged parameters of the material characteristic M , the actual heat turnover Z_f , construction time T_{str} , annual heat losses $Q_{t.p.}$ was justified, reliability R_{syst} and temperature dispersion at the consumer σ as comparison criteria. This makes it possible to obtain a more accurate solution of the optimization problem under discussion at the initial design stage when there is lack of initial data for the calculation.

There are presently lots of methods for solving optimization problems. Hence, in [7] the method of the generalized additive vector criterion of optimality is examined, the method based on the matrix generalization in [12]. The disadvantage of the first method is a high degree of subjectivity of the resulting solution associated with assigning weights to the selected particular optimality criteria, which is commonly performed by means of expert assessments. The disadvantage of the second method is that when it is applied (in the case of a large number of comparison criteria), it is only possible to obtain a limited set of options without highlighting the best one. Therefore it becomes urgent to develop a methodology for choosing the best option for a heating network route having none of the above disadvantages.

1. Normalizing particular criteria for choosing the best solution. As the aggregated parameters selected as optimality criteria have different dimensions, and their values can equal one, dozens, hundreds, and even thousands, for the correct application of the criteria it is essential to normalize and reduce them to a dimensionless form. There are a few ways to do this [10], we are going to consider the most common ones.

Directive value of the particular criteria. This value is recommended to be used as a normalizing divisor, it is set by an expert. In this case, the transformed criterion will be given by the formula

$$f_i(x) = \frac{F_i(x)}{F_i^{hopm}(x)}, \quad (1)$$

where $F_i(x)$ is the optimality criterion prior to rationing; $F_i^{hopm}(x)$ is the i -th normalized divider; $f_i(x)$ is the normalized value of the optimality criterion.

This method can be used, e.g., for the indicator of the actual heat turnover. The theoretical turnover Z_T , which is an indicator of the inevitable transit of thermal energy and the minimum possible value, can serve as a standardized divider. With the same location of the source and consumers for all schemes, this indicator will be the same, which is convenient while standardizing the criterion. The main disadvantage of this option is the assumption that the specified value of the divisor will be exemplary, i.e., the choice of this value is not always possible, particularly in problems like the one we are dealing with.

Maximum value of the particular criteria. As a normalizing divisor, it is suggested that the maximum value of the value that is achieved in the field of existence of design solutions is used. Then the transformed criterion will be given by the formula

$$f_i(x) = \frac{F_i(x)}{F^{\max}(x)}, \quad (2)$$

where $F^{\max}(x)$ is the maximum value of the optimality criterion. A similar option was considered in [7] for the convenience of presenting the criteria in graphical form.

Difference between the maximum and minimum values of the particular criterion in the area of compromise. Then the transformed optimality criterion will be defined as

$$f_i(x) = 1 - \frac{F_i(x) - F^{\max}(x)}{F^{\min}(x) - F^{\max}(x)}, \quad (3)$$

where $F^{\min}(x)$ is the minimum value of a particular criterion of optimality. In [9], this method is called the most convenient one.

The choice of one of the methods is daunting and affects the outcome of the calculation. E.g., the first method is less suitable for the reliability indicator, as it is difficult to identify the required reliability in each specific case. Thus it is advisable to apply the third method. As at the moment it is generally accepted that, depending on the reliability indicator, heat supply systems are divided into several groups: systems with a high reliability (or highly reliable ones) — R_{syst} is more than 0.9; reliable systems — R_{syst} is from 0.89 to 0.75; unreliable systems — R_{syst} is from 0.5 to 0.75; unreliable systems — R_{syst} is less than 0.5, then 0.5 can be taken as the minimum value, and 0.9 as the maximum one. It is also advisable that dependence (3) is applied for the remaining particular criteria of optimality of the problem. As $F_{\max}(x)$ it is essential to take the maximum value of the particular criterion in the area of the discussed solutions, and as $F^{\min}(x)$ the minimum value.

2. Developing a methodology for choosing the best option for a heating network route.

As noted above, there are lots of methods for addressing optimization problems, their choice can have a major influence on the outcome. The models previously discussed in [7, 11, 12] designed based on the method of folding particular criteria, relied on the condition of the availability of qualitative information about a set of the particular criteria [1, 2] in the form of a series of priorities of one criterion over another.

There are lots of ways to account for the importance of the particular criteria, e.g., [1, 12]:

- a) *the method of sequential optimization* of the criteria considering rigid prioritization which is characterized by the fact that the minimization of the n -th criterion is per-

formed only after obtaining the minimum value of all the previous $(n - 1)$ -th criteria. The disadvantage of this method is the possibility of degeneration into a point of the region of satisfactory solutions R ;

- b) *the method of successive concessions* is a modification of the method of successive optimization: at each optimization step, a concession ΔF_{n-1} is sequentially introduced, which characterizes the permissible deviation of the $(n - 1)$ -th criterion;
- c) *the method for identifying the main criterion* is search for the minimum of the most important or main optimality criterion $F_1(x)$ is performed and the values of other criteria are $F_2(x)$, $F_3(x)$, etc. must not exceed certain thresholds:

$$\min_{x \in R'} F_1(x), \quad (4)$$

$$R' = R \cap R_0; R_0 = \{x \mid g_i(x) \leq g_i^0, i = \overline{2, N}\}; \quad (5)$$

- d) *the method of guaranteed result* is when the worst criterion is modified to fit to the level of the main criteria, as a result, this task is equivalent to the one solved using concessions;
- e) *the method of the ideal point* is when extra information is presented in the form of an ideal solution, and the initial problem is solved by constructing a generalized criterion and a one-criterion optimization problem;
- f) *the method of equality of the particular criteria* is when there is an equivalence of the importance of the criteria:

$$\min_{x \in R} F_k(x), \quad (6)$$

$$R_1(x) = R_2(x) = \dots = R_k(x); \quad (7)$$

- g) *the method of folding the vector criterion* is the most common one for the problem. The unification of particular criteria into one integral criterion is performed. In this case, the importance of the criterion is considered due to the function S :

$$\min_{(x \in R)} S(p, F(x)), \quad (8)$$

where p is the weight of the criteria.

In this method, the folding of the generalized criterion can be performed by means of various methods, depending on which their mathematical notation changes, e.g.:

- the logical criterion is written in the form

$$S_{\max}(p, F(x)) = \max_{1 \leq i \leq N} \{p_i F_i(x)\}; \quad (9)$$

- average criterion is written as

$$S_d(p, F(x)) = \left(\frac{1}{N} \sum_{i=1}^N p_i F_i^d(x) \right)^{1/d}, \quad d > 0, \quad (10)$$

$$S_{\min}(p, F(x)) = \max_{1 \leq i \leq N} \{p_i F_i(x)\}; \quad (11)$$

- multiplicative is correctly written as

$$S_{\Sigma}(p, F(x)) = \prod_{i=1}^N p_i F_i(x); \quad (12)$$

- the additive criterion is written as

$$S_{\Sigma}(p, F(x)) = \sum_{i=1}^N p_i F_i(x). \quad (13)$$

For the problem in question, the absolute values of the criteria are of extreme importance, it is thus necessary to choose the additive method of folding the generalized criterion.

Considering the performed analysis for the previously discussed selected aggregated parameters, the mathematical model of the generalized additive vector optimality criterion will take the form:

$$\begin{aligned} S = & p_M \cdot \left(1 - \frac{M_i - M^{\max}}{M^{\min} - M^{\max}} \right) + p_{Z_{\phi}} \cdot \left(1 - \frac{Z_{\phi i} - Z_{\phi}^{\max}}{Z_{\phi i}^{\min} - Z_{\phi}^{\max}} \right) + p_{T_{cmpi}} \cdot \left(1 - \frac{T_{cmpi} - T_{cmp}^{\max}}{T_{cmp}^{\min} - T_{cmp}^{\max}} \right) + \\ & + p_{Q_{m,n}} \cdot \left(1 - \frac{Q_{m,ni} - Q_{m,n}^{\max}}{Q_{m,n}^{\min} - Q_{m,n}^{\max}} \right) + p_{R_{cucm}^{opr}} \cdot \left(1 - \frac{R_{cucmi}^{opr} - R_{cucm}^{opr, \max}}{R_{cucm}^{opr, \min} - R_{cucm}^{opr, \max}} \right) + p_{\sigma} \cdot \left(1 - \frac{\sigma_i - \sigma^{\max}}{\sigma^{\min} - \sigma^{\max}} \right), \end{aligned} \quad (14)$$

where p_M is the weight value of material characteristics; $p_{Z_{\phi}}$ is the weight value of the actual heat turnover; $p_{T_{cmpi}}$ is the construction time weight value; $p_{Q_{m,n}}$ is the weight value of annual heat losses; $p_{R_{cucm}^{opr}}$ is the value of the weight of the reciprocal of the reliability parameter; p_{σ} is the value of the weight of the temperature dispersion at the consumer's end.

It should be noted that due to the need to set the priority of one criterion over another, the degree of subjectivity of the desired solution associated with the involvement of expert analysis to obtain the weight of a specific criterion rises. However, there are also methods based on ordering criteria or designing tables based on pairwise comparison of criteria. This information is commonly more objective than the assigned weights. Application of the method of pairwise comparison was considered, e.g., in [4—6, 8].

Fig. Methods for choosing the best option for routing a heating network based on matrix generalization and vector optimization according to the generalized additive optimality criterion

A similar calculation principle was examined in [12] where the best tracing option was chosen based on the matrix generalization. As noted in the paper, the meaning of this generalization (considering minimization rather than maximization) is to sequentially account for all the possible pairs of rows from the reduced matrix. If all the positions in one of two such lines contain values which are strictly larger than the corresponding ones of the second line from the discussed pair (the first line dominates the second which is its majorant), the first line can be excluded from searching for optimal options. The disadvantage of this method is the limitation of the number of options with a large number of criteria, and not search for one or a small number of the best ones. It thus seems more appropriate to make use of a combination of the two methods. The technique of their joint application is shown in Figure.

Conclusions

1. A mathematical model has been developed for a generalized additive vector criterion for optimality of a pipeline route of a heating network, which is different from the existing ones in that it is possible to account for a biased estimate of the temperature dispersion among subscribers. This makes it possible to obtain a more accurate solution of the above optimization problem for heat supply systems with an uneven distribution of the heat load.
2. An algorithm for the system analysis of possible options for tracing a pipeline network has been developed using the joint application of matrix generalization and vector optimization methods according to the generalized additive criterion, which increases the reliability of the resulting solution.

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