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CHOOSING A MATHEMATICAL MODEL OF HEAT SUPPLY NETWORK ROUTE

Problem statement. Modern computational technologies allow to develop mathematical models for choosing optimal topology and construction routes of heat supply networks taking into account a large amount of influencing factors. Important pivots when developing a mathematical model are the choice of source data representation, of the model of choosing the optimal topology and route and the computational algorithms for model implementation at computing facilities. The difficulty of choosing a computational method, aside from the nature of topological models, is complicated by a large amount of limiting factors. This is the reason why the choice of forms of representation of mathematical models and the efficiency of computational methods of their solution is actual when used in practical applications.

Results. A mathematical model of the cost of construction of heat supply networks has been developed which, as opposed to traditional models, leaves the necessary degrees of freedom for determining acceptable and optimal topology and construction route for account of using multicriterion optimization. A method of weighted summation has been proposed for usage for combining raster maps corresponding to different routing criteria.

Conclusions. The considered method allows to take account of the whole system of factors influencing the construction route of heat supply network and to conduct route optimization based on several criteria, which allows to choose the optimal topology and construction route under the influence of multiple external and internal factors.

Keywords: heat networks, routing, dynamic programming, optimal topology, optimal routes of heat networks.

Introduction

The major problem to be addressed in the planning of the structure of a heating network is how to achieve its long-run efficiency. Planning, construction and operation of pipeline systems is performed against ever changing heat loads, parameters and operation modes as deeply influenced by a multitude of factors, both inside and outside. A lot of various infrastructure objects have to be affected in the process of the planning and construction of a heating network. Choosing a topology and a network's route is the first step to be taken in the planning and construction of heating networks. It is generally crucial to the construction and operation of heat networks. Optimizing the process of choosing a topology and a network route is essential in order to lower financial and material construction costs and all further operation costs.

Therefore, defining an optimal topology and heat network routes is a pressing scientific and technical issue.

It is advisable that a problem of multi-criteria heat network optimization using the dynamic programming methods is addressed while providing heat to new areas in search of heat network routes.

1. Formulating a dynamic programming problem

Let us formulate a dynamic programming problem. Let us assume we have a set of vertices numbered arbitrarily from 1 to N. Each pair of vertices are joint together. A price of repositioning from a vortex i to a vortex j is assumed to be positive and independent directly of a distance between the vertices i and j. We obtain a non-symmetric matrix $T = (t_{ij})$ with its each element being a price of repositioning. Let us set a task of seeking a set of vertices whose repositioning from vortex 1 to vortex N has the smallest price.

Let us give a general outline of the problem.

Let f_i be a cost of repositioning from a vortex i to a vortex N, $i = 1, 2, \ldots, N\text{-}1$, using an optimal movement strategy and $f_N = 0$.

f_i is to meet the following non-linear system of equations:

$$f_i = \min_{j \neq i}(t_{ij} + f_i),\ i = 1, 2, \ldots, N\text{-}1, \tag{1}$$

$$f_N = 0.$$

We obtain a solution of this system of equations using the method of successive approximations. Let us choose an initial succession $\{f_i^{(0)}\}$ and continue in an iterative manner.

Assumingly

$$f_i^{(k+1)} = \min_{j \neq i}(t_{ij} + f_i^k),\ i = 1, 2, \ldots, N\text{-}1, \tag{2}$$

$$f_N^{(k+1)} = 0,$$

where $k = 1, 2, \ldots$.

We choose $\{f_i^{(0)}\}$:

$$f_i^{(0)} = t_{iN},\ i = 1, 2, \ldots, N. \tag{3}$$

It can be shown that a succession $\{f_i^{(k)}\}$ is monotonously declining:

$$f_i^{(k+1)} \leq f_i^{(k)},\ i = 1, 2, \ldots, N,\ k = 0, 1, 2, \ldots. \tag{4}$$

Thus

$$\lim_{k \to \infty} f_i^{(k)} = f_i,\ i = 1, 2, \ldots, N. \tag{5}$$

Obviously, in order to attain the consistency of a succession $\{f_i^{(k)}\}$, we need a maximum N-1 iteration.

Let us supplement the algorithm by remembering in each iteration p_i, $i = 1 \ldots N$ which equals a previous vortex in a route with a minimum cost of repositioning. In order to find a heat network route using the method of dynamic programming, we need to define vertices and edges of a graph according to which an optimal route will be sought [1, 2]. It is most natural to depict areas of a heat network as straight lines. Each area is an edge of the graph that joins two vertices together. An area invariably has two technological elements as its end vertices [3, 4]. Elements of a heat network are described based on their technological classification. Generally in a heat network there may the following types of elements: heat sources, users, heat chambers, heating circuits.

2. Choosing the way the data is presented

This technique relates to a vector data presentation. An example of it used in the planning an inner-block heat network is given in Fig. 1. A significant advantage of this data presentation is that no great memory capacity is needed to store data. Also, a more accurate data positioning is provided. The objects with a linear structure are presented clearly with no disruptions. Much of the data (e. g., a heat network topology) are most naturally presented in the vector form. The use this form of data storage allows one to perform operations that require topological information (e. g., a network analysis).

It is disadvantageous though that data manipulation in vector presentation calls for complex algorithms and it is costly in terms of how much times it takes to do calculations. Other than that, the data positioned densely from a spatial standpoint is not efficiently stored.

Much of the data that requires that a heat network is sought (e. g., topological conditions of the area, type of planning and building of urban areas, positioning of aboveground and underground structures and communications, properties of subgrades and bedding depth as well as mode and physical and chemical properties of groundwater) is continuously presented and cannot be efficiently converted into the vector form.

In order to utilize this data in defining a heat network route, it is necessary that all the objects under study are depicted on a structured grid that makes up a graph. A graph of this kind is exemplified in Fig. 2.

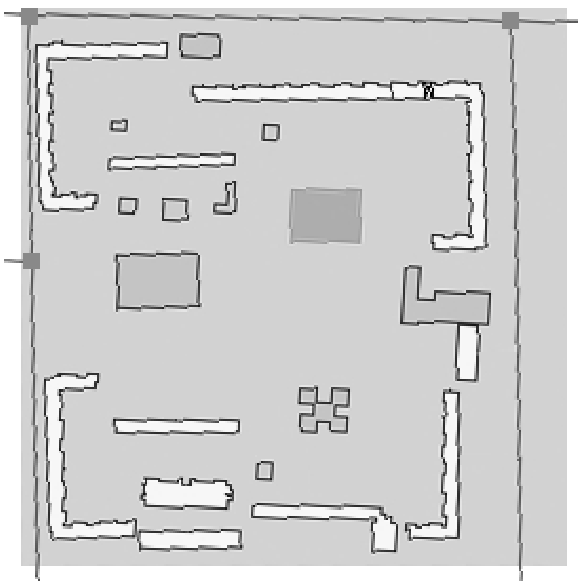

Fig. 1. Vector presentation of a heat network data (the lines are the edges of the graph and the squares are vertices)

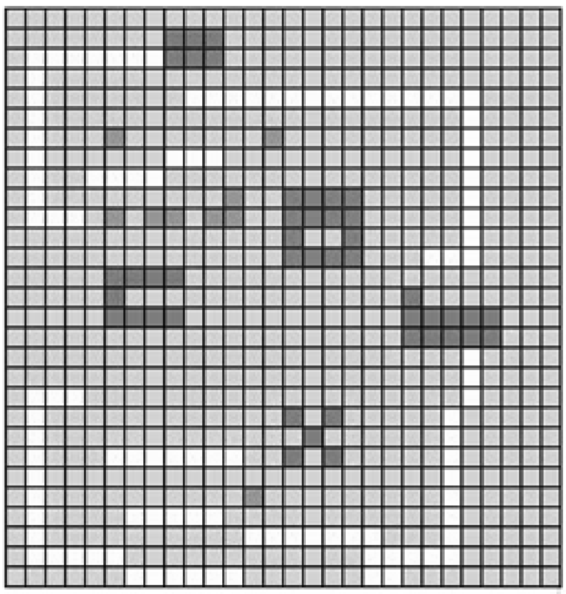

Fig. 2. A structured grid

Each cell of the grid relates to an area of an object being depicted which is the same in size but has varying characteristics. Each cell is joint to the edges with eight neighboring cells. A big downside of this technique is that data storage requires a great memory capacity which is particularly inefficient with data considerably scattered in space.

In order to define a heat network route using the methods of dynamic programming, we need a weighted graph. Each edge of the graph has to be opposed to a non-negative numeric value. This value is to correspond to a cost of repositioning from one edge to another.

When seeking a heat network route, there are usually several things a careful consideration is given to. They are the shortest heat network length, a minimum amount of construction work, reliability of heat supply [5], a speedy removal of failures and emergencies, safety of the maintenance staff. An optimal option is chosen from a range of viable options by comparing technical and economic and other indicators [6]. Thus, a heat network route is affected by a variety of factors, some of which can be raster data layers and some can calculated only using a network route at hand. The data that can be raster maps is used to establish the weight of the edges of a graph. For that, one rater map with numeric values is to be obtained from several raster maps with heterogeneous data [7, 8]. An approach that allows one to obtain one raster map with the weight of a graph is weighted summation. It allows one to establish a coefficient for each map that reflects its relative effect on the resulting heat network route.

A numeric value of each cell of the resulting map is calculated using the following formula:

$$b_{ij} = \frac{1}{\sum_{k=1}^{N} w_k} \sum_{k=1}^{N} w_k a_{ijl} , \tag{6}$$

where b_{ij} is a resulting value of the cell with the indices i, j; a_{ijl} is a value of the cell with the indices i, j on a map with the index l; w_k is the weight of a map with the index k.

Fig. 3 gives an example of weighted summation of two maps 3×3 cells in size. The first map is given a standard weight coefficient $w_1 = 0.2$, and the second map with $w_2 = 0.8$. The fact that there is one raster map with numeric values that reflect a cost of repositioning from one cell to another allows us to establish the weight of the edges of the resulting graph. Thus, it becomes possible to use the above method of dynamic programming. Fig. 4 presents a scheme of a route of inner block heat networks that was chosen using the developed technique.

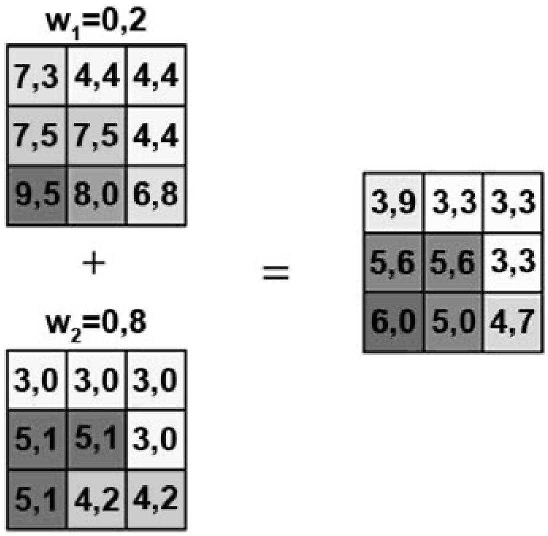

Fig. 3. Weighted summation of two raster maps

Fig. 4. Route of inner block heat networks

Conclusions

The formalization is suggested of a model of the construction cost of heat network routes which, unlike the conventional models, leaves us at some liberty to seek acceptable and optimal topologies and routes owing to the use of multi-criteria optimization by means of the methods of dynamic programming.

A new approach to choosing an optimal heat network route which gives a chance for simultaneous route optimization based on several criteria. The method discussed allows for a fuller insight into a variety of factors affecting the construction of a heat network route.

In order to combine raster maps that correspond to different criterion of the route construction, it was suggested that the method of weighted summation be used.

The method used allows one to choose an optimal topology and route of heat networks affected by a variety of inside and outside factors.

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