HEAT AND GAS SUPPLY, SEWERAGE, BUILDING CONSTRUCTION OF WATER RESOURCES PROTECTION

UDC 711.4:697.3:711.8

V. N. Mel'kumov[1], S. V. Chujkin[2], A. M. Papshickij[3], K. A. Sklyarov[4]

MODELLING OF STRUCTURE OF ENGINEERING NETWORKS IN TERRITORIAL PLANNING OF THE CITY

Voronezh State University of Architecture and Civil Engineering
Russia, Voronezh, tel.: (473)271-53-21, e-mail: teplosnab_kaf@vgasu.vrn.ru
[1]D. Sc. in Engineering, Prof., Head of Dept. of Heat and Gas Supply and Oil and Gas Business
Russia, Voronezh, tel.: (473)271-53-21, e-mail: ser.chu@mail.ru
[2]PhD in Engineering, Assoc. Prof. of Dept. of Heat and Gas Supply and Oil and Gas Business
Russia, Voronezh, tel.: (473)271-53-21, e-mail: teplosnab_kaf@vgasu.vrn.ru
[3]PhD student of Dept. of Heat and Gas Supply and Oil and Gas Business
Russia, Voronezh, tel.: (473)271-53-21, e-mail: u00078@vgasu.vrn.ru
[4]PhD in Engineering, Assoc. Prof. of Dept. of Fire and Industrial Safety

Statement of the problem. One of the defining factors influencing development of the modern cities is existence of engineering infrastructure and possibility of its reorganization taking into account the changing needs for this or that resource. In this regard the problem of preliminary design and modeling of structure of urban engineering networks, territorial planning of the city based on analytical methods is very urgent.

Results and conclusions. During the analysis the main stages of the solution of a problem of optimization of networks which include creating a surface of cost and a choice of the optimum route between a source and the consumer of a resource were revealed. Basic provisions of the existing models of optimization based on genetic algorithms and Steiner's task are noted and also their most essential shortcomings come to light. It is revealed that the priority by drawing up models of optimization of city engineering networks consists of the development of new and corrections of the existing methods of calculation of weight coefficients of maps of cost of the area of construction of the projected network.

Keywords: territorial planning, heat supply, town planning, city engineering networks, gas supply, mathematical modeling, genetic algorithms.

Introduction

Territorial planning of modern cities necessarily involves consideration of a myriad of factors that impact their development.

One of the crucial factors to consider is an engineering infrastructure of a city that can be transformed and tailored to the changing needs of the population. One of the pressing issues is how heat, gas and water supply, drainage are to be addressed in construction.

Therefore, decisions have to be made as to whether an individual user should access a central or a local heat supply system. A wrong decision may cause increasing construction and operational costs and thus less revenue.

Structural planning of engineering networks has several major goals [13, 14, 24]. Firstly, users that are likely to bring in the maximum revenue must be identified out of the total number of users of a particular resource (heating, gas, electric energy, etc.). Secondly, distances between supply and demand points should be minimum. For that, the major factors influencing the cost of laying engineering networks should be identified. These are infrastructure and communication structures, various natural obstacles such as rivers, forests, changes in altitude as well as the cost of a construction site land.

In order to address all of these, a lot of construction and building companies are embracing geoinformation technology and digital schemes of engineering networks for the optimization of their route [1, 13, 14, 16, 24, 25] and identification of their structure. The objective of this kind of optimization is to identify the route for laying a network at minimum costs.

There are several methods for doing that. The choice of a particular one might be crucial to the ultimate result. Hence, e.g., the paper [3] points out that a choice of a method is dependent on the type of the original variables of a mathematical model, type of the original data as well as the number of optimization criteria which are defined as numbers used to evaluate a particular solution.

Depending on a connection between variables in a mathematical model, it can be dealt with using linear, non-linear, integer, discrete, stochastic programming. However, these models normally only account of one optimization criterion. Since a construction solution is in fact affected by a number of factors, it can be a multi-criteria optimization [3] where all of the criteria should be taken on board.

For that it is necessary that a validity coefficient of each criterion is determined and ultimately the solution is actually the optimization using a common (new) criterion including all of the criteria considering their validity coefficients [3].

Therefore search for the best route for laying engineering networks is essentially comprised of two major stages [7], i.e. design of a cost surface and selection of an optimal route between the supply and demand points.

1. Designing a cost map of a construction area

The initial stage of optimization particularly in laying urban engineering networks is to design a final cost surface [6, 15] which accounts not only for the effects of some constant factors but also their mutual dependence on the cost of laying a network. The final function in determining routes at the smallest cost is the following according to

$$H = \sum_i \sum_j \mu_j \varepsilon_{ij}, \tag{1}$$

where μ_j is a validity coefficient of a specific factor map; ε_{ij} is the i-th element in the j-th factor map.

According to [15], the initial data for designing cost surfaces can be specified as point and vector data as well as those specified as areas. The first ones are engineering buildings and structures, the second ones are rivers, highways and railways, the third ones are areas of cities with varying prices, swamp land, health and safety areas, etc.

In construction of a final cost map considering the major factors, a few maps of certain factors should be possible to be joined. Validity coefficients of cost surfaces of different influencing factors necessary to design a final cost map can be determined in a number of ways.

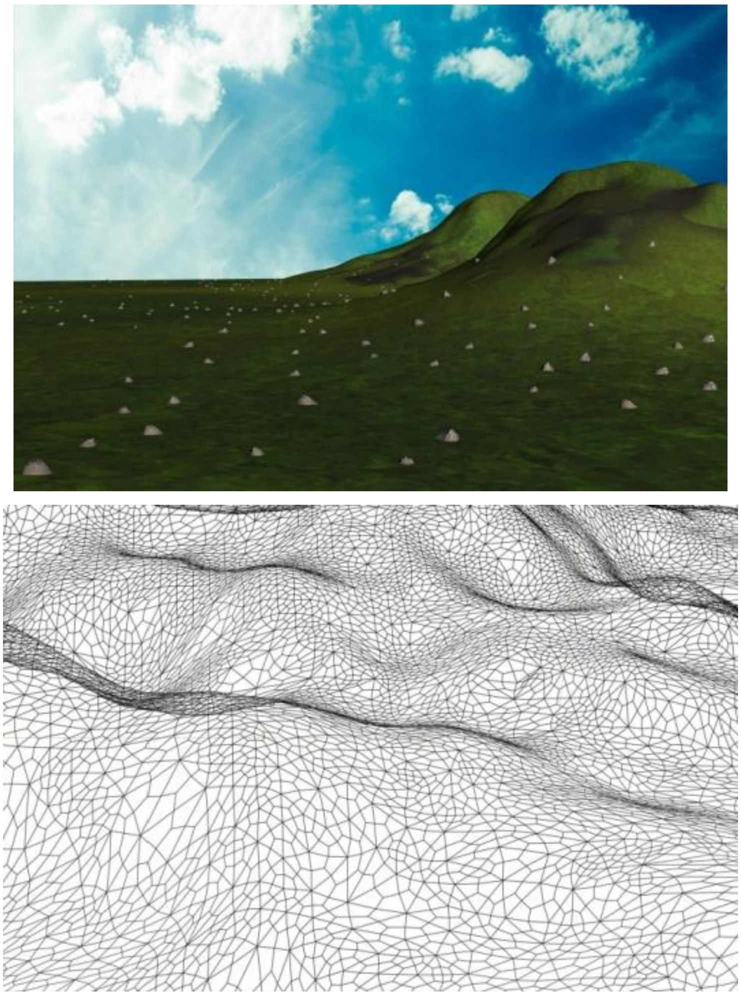
Expert evaluation is the most important and based on the analysis of the available data (e.g., designing probability maps) and a combined method.

More details on determining validity coefficients are in [15] where the method based on the analysis of the available data, e.g., current projects of engineering networks is described as having the least error compared to the other ones. However, on the other hand, there is a high likelihood of an error provided there is one in a model project. Therefore, the most daunting thing about designing cost maps is determining validity coefficients of different factors influencing the final surface.

Generally a cost map is a regular grid (Fig. 1) with its cells being a total cumulative cost [5, 7, 21—23] which corresponds with the construction costs of engineering networks in this cell.

The use of a raster cost map requires determining a method of designing a graph between the cells of the cost map [7] which is designed with the following in mind: a cent of each cell of this cost map is a junction or a node of a graph and connections between the cells are ribs or arc of a graph. In [5] there are three major models of optimization, i.e. models with an oriented, non-oriented and combined graph.

After designing the final cost map [8, 12, 17—19] the best route for laying an engineering network is searched for.



1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	25	24	25

Fig. 1. Maps of a construction site of an engineering network

2. Choosing an optimal route between the supply and demand points

An optimal route for an engineering network can be identified in a number of ways. One of the most common methods is based on genetic algorithms [5, 15]. These algorithms are stochastic methods of optimization that mimic natural selection [8].

In this particular regular grid of the final cost map each cell in the theory of genetic algorithms represents a gene in a chromosome which is in its turn a route for an engineering network. More on this method is in [5, 8].

One of the disadvantages of genetic algorithms is no intervention into a search of an optimal solution, i.e. the only way to manipulate it is by specifying the initial parameters. Besides, it takes professional expertise to formulate tasks such as entering a code and other parameters and the use of genetic algorithm terms makes it impossible to analyze a statistical significance of a resulting solution. Modeling might involve automatic ruling out of solutions that are deemed confusing or not promising. Hence the resulting final solution cannot be guaranteed to be optimal.

Along with the above methods, a method based on the solution of Steiner's problem, which is a type of a transportation problem [2], is worth our attention. It requires that the shortest network joining the final number of points on a plane is identified. Steiner's problem is discussed in detail for the optimization of engineering networks in [9—11] where modeling of a "tree" (a graph with no looms and isolated contours, Fig. 2) of a network is considered.

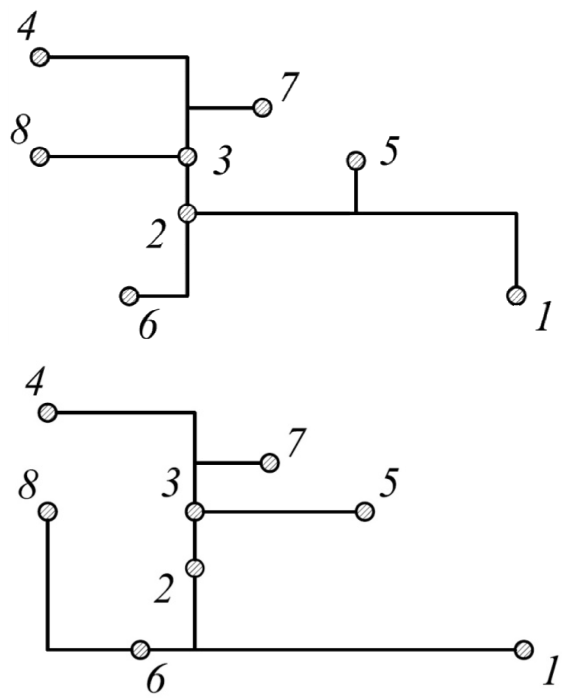


Fig. 2. Ways of routing a designed network

It is also noted that geometric modeling of an engineering network requires that a connection (adding extra tops) is designed so that a total distance between the tops being connected is given by the expression

$$h = \sum_i \sum_j m_{ij} e_{ij}, \quad (2)$$

where m_{ij} is a validity coefficient that depends on a construction cost of a route; e_{ij} is a distance between the points being connected.

It is worth noting that in designing shortest lines joining the original number of points it is important that the following is considered [11]:

– a minimum line joining the original tops is a graph with no looms and isolated contours;

– angles between the lines coming out of one of the graph junctions should be no less than 120°;

– each top should join no less than three lines;

– a minimum line joining the original graph junctions should have a limited number of Steiner points.

Additionally, it should be borne in mind that the coefficient m_{ij} in the expression (2) also depends on a distance between the points being connected [11]. A designing method and a model of an optimized routing in a network in space using Euclidean metrics are scrutinized in [9—11]. It should be noticed that the Steiner problem considered in this model is not generally solved and an extreme combinatory task of discrete optimization. This in fact restrains the use of the method. Therefore the number of original junctions (tops) is restrained as well and the number of possible planning options for routes with lots of users of a particular resource thus decreases, which makes choosing original boundary conditions a lot more daunting. An increase in the number of original tops leads to slower calculation rates of models and thereby impacts their effects.

The equations (1) and (2) suggest that determining an optimal route between these junctions depends on validity coefficients indicating the influencing factors on the construction costs and further operation of the network. Therefore in both the first and second case an error in determining these coefficients leads to wrong optimization solutions.

Conclusions

Therefore searching for the best route for laying engineering networks essentially involves two major stages: designing a cost surface and choosing an optimal route between the supply and demand points. The major issue in designing cost surfaces is choosing validity coefficients, which is not yet consistent and the existing methods of determining it have a number of disadvantages.

For example, the method based on the analysis of available data is flawed if there are errors in a model project.

Choice of an optimal route for an engineering network that commonly relies on genetic algorithms also has a few disadvantages such as:

– no intervention into an optimal solution search;

– difficulty in correcting the formulation of tasks which essentially requires professional expertise;

– a task using genetic algorithm terminology makes the analysis of statistical significance of a resulting solution impossible, etc.

The methods based on the Steiner problem can particularly be used for optimization. However, in this case just like in the one above, determining an optimal route of a network between these junctions depends on validity coefficients indicating the influencing factors on the construction cost and further operation. An error in determining these coefficients leads to wrong optimization solutions.

Hence the major concern in the optimization of engineering networks is developing new and correcting existing calculation methods of calculating validity coefficients of cost maps of a construction area of a network.

References

1. Zhatikova M. S. Uchet faktora nalichiya istoriko-kul'turnogo naslediya i osobo okhranyaemykh territoriy pri kompleksnom ekologicheskom kartografirovanii trassy magistral'nogo gazoprovoda [Based on the availability of historical and cultural heritage and protected areas in the complex ecological mapping of main gas pipeline route]. *Vestnik Volgograd. gos. arkh.-stroit. un-ta. Stroitel'stvo i arkhitektura*, 2014, no. 35 (54), pp. 196—198.

2. Ivanov A. O., Tuzhilin A. A. Zadacha Shteynera na ploskosti ili ploskie minimal'nye seti [The Steiner problem in the plane or in plane minimal nets]. *Matematicheskiy sbornik*, 1991, no. 12, pp. 1813—1844.

3. Kostin V. N. *Optimizatsionnye zadachi elektroenergetiki* [Optimization problems of power industry]. St. Petersburg, SZTU Publ., 2003. 120 p.

4. Kuznetsov I. S., Kuznetsov R. N., Gorskikh A. A. Variantnoe proektirovanie pri prokladke trass inzhenernykh setey [Variant design for laying tracks utilities]. *Inzhenernye sistemy i sooruzheniya*, 2009, no. 1, pp. 159—163.

5. Kuznetsov I. S., Mkrtchyan A. G. Vybor optimal'noy trassy prokladki avtomobil'noy dorogi s ispol'zovaniem geneticheskikh algoritmov [Selection of the optimal route lining the road using genetic algorithms]. *Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arxitektura*, 2014, no. 1, pp. 123—130.

6. Kuznetsov I. S., Mkrtchyan A. G. Integrirovannye karty vliyayushchikh faktorov dlya vybora optimal'noy trassy avtomobil'noy dorogi [Integrated card influencing factors for the selection of the optimal route of the road]. *Inzhenernye sistemy i sooruzheniya*, 2014, no. 2, pp. 67—72.

7. Kuznetsov I. S., Kuznetsov R. N., Gorskikh A. A. Poisk marshruta prokladki inzhenernykh setey s naimen'shey stoimost'yu [Directions laying of utilities with the lowest cost]. *Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arxitektura*, 2009, no. 4, pp. 33—39.

8. Kuznetsov S. N., Kobelev V. N. Povyshenie effektivnosti vybora trass inzhenernykh setey [Improving the efficiency of selecting tracks utilities]. *Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arxitektura*, 2011, no. 4, pp. 45—51.

9. Kuspekov K. A. Algoritm postroeniya optimal'noy konfiguratsii gazoraspredelitel'noy seti na ploskosti s ortogonal'noy metrikoy [An algorithm for constructing the optimal configuration of the gas distribution network on the plane orthogonal to the metric]. *Omskiy nauchnyy vestnik*, 2012, no. 107, pp. 14—16.
10. Kuspekov K. A. Geometricheskie metody trassirovki trekhmernykh inzhenernykh setey [Geometric methods of three-dimensional trace utilities]. *Sovremennaya nauka: aktual'nye problemy teorii i praktiki. Estestvennye i tekhnicheskie nauki*, 2013, no. 7—8, pp. 7—10.
11. Kuspekov K. A. Modelirovanie transportnykh setey na kar'erakh [Modelling of transport networks in the quarries]. *Sovremennaya nauka: aktual'nye problemy teorii i praktiki. Estestvennye i tekhnicheskie nauki*, 2013, no. 3—6, pp. 7—10.
12. Lovyagin V. F., Pankrushin V. K. Ierarkhicheskaya sistema protsessa proektirovaniya optimal'nykh trass inzhenernykh sooruzheniy [Hierarchical system design process of optimal routes of engineering structures]. *Vestnik Sibirskoy gos. geodezich. akad*., 2001, no. 6, pp. 45—51.
13. Medvedeva O. N. Modelirovanie i optimizatsiya mezhposelkovykh sistem gazoraspredeleniya [Modelling and optimization of inter-settlement gas distribution systems]. *Vestnik Volgograd. gos. arkh.-stroit. un-ta. Stroitel'stvo i arkhitektura*, 2012, no. 28, pp. 135—142.
14. Mel'kumov V. N., Kuznetsov I. S., Kobelev V. N. Zadacha poiska optimal'noy struktury teplovykh setey [The problem of finding the optimal structure of heating networks]. *Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arxitektura*, 2011, no. 2, pp. 37—42.
15. Mel'kumov V. N., Kuznetsov I. S., Kuznetsov R. N. Opredelenie optimal'nogo marshruta trassy gazoprovoda na osnove kart stoimosti vliyayushchikh faktorov [Determination of the optimal route of the gas pipeline on the basis of the factors affecting the value of cards]. *Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arxitektura*, 2009, no. 1, pp. 21—27.
16. Peters E. V. *Gradostroitel'stvo i planirovanie naselennykh mest* [Urban planning and development of residential areas]. Kemerovo, KuzGTU Publ., 2005. 163 p.
17. Rogozhkin V. M., Kiselev V. V. Vybor optimal'noy trassy stroitel'stva magistral'nykh sooruzheniy metodom dinamicheskogo programmirovaniya [Selection of the optimal route of the main building structures by dynamic programming]. *Mekhanizatsiya stroitel'stva*, 2009, no. 3, pp. 6—8.
18. Sachivka V. D. Metodika vybora optimal'nogo sposoba prokladki podzemnykh inzhenernykh kommunikatsiy v usloviyakh gorodskoy zastroyki [Method of selection of the optimal method of installing underground utilities in urban areas]. *Nauchnyy vestnik Moskovskogo gos. gornogo un-ta*, 2011, no. 3, pp. 88—99.
19. Sachivka V. D. Modeli i metody vybora optimal'nogo sposoba prokladki podzemnykh inzhenernykh kommunikatsiy v usloviyakh gorodskoy zastroyki [Models and methods of choosing the optimal method of installing underground utilities in urban areas]. *Gornyy informatsionno-analiticheskiy byulleten'*, 2011, no. 12, pp. 359—360.
20. Sokolov V. G., Razov I. O. Parametricheskie kolebaniya i dinamicheskaya ustoychivost' magistral'nykh gazoprovodov pri nazemnoy prokladke [Parametric oscillations and dynamic stability of main gas pipelines in the above-ground laying]. *Vestnik grazhdanskikh inzhenerov*, 2014, no. 2 (43), pp. 65—68.
21. Medvedeva O. N. The Selection of Gas Pipeline Route on the Plan of Gas Supplied Area. *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture*, 2011, no. 3, pp. 26—35.
22. Melkumov V. N., Kuznetsov I. S., Kobelev V. N. Choosing a Mathematical Model of Heat Supply Network Route. *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture*, 2012, no. 1, pp. 17—23.
23. Melkumov V. N., Kuznetsov I. S., Mkrtchan A. G. Development of a Mathematical Model of the Ground Surface to Select the Optimal Route of the Highway. *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture*, 2014, no. 2, pp. 34—42.
24. Melkumov V. N., Kuznetsov S. N. Dynamics of Formation of Air Streams and Temperatures Fields in Premise. *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture*, 2009, no. 1, pp. 25—34.
25. Podborniy E. E., Chikharev V. A. Analysis of Gas Pipeline Geotechnical Systems Interaction with the Environment. *Tyumen State University Herald*, 2013, no. 4, pp. 141—148.