UDC 622.692.4

ROUTES OF LAYING GAS SUPPLY SYSTEM PIPELINE

Oksana N. Medvedeva[1],
medvedeva-on@mail.ru

Valeriya D. Penenko[2],
isabel16122012@gmail.com

[1] Yuri Gagarin State Technical University of Saratov,
77, Politekhnicheskaya street, Saratov, 410054, Russia.

[2] AO «Giproniigaz» (Joint Stock Company),
54, Kirov S.M. avenue, Saratov, 410012, Russia.

Relevance. *Designing a gas pipeline route is an important step in planning and building gas pipeline. There are various methods, dependencies and algorithms characterizing the functional component of the gas pipelines, various methods of laying. The most important part in the design process is the choice of an optimal route, which application effectiveness will be high and at the same time the project will have minimal capital investments in construction. Despite many proposed approaches, at present there is no a uniform method for determining the optimal costs for construction and reconstruction of the gas distribution networks.*
The aim *of the research is to study assumes solution of the problem of choosing the optimal pipeline route.*
Methods. *Our program is based on wave algorithms, or search by width. It means the search strategy, used in solving the problem, does not use additional information, but only that presented in the definition. The essence of this method is development successors and distinguish between a target and a non-target state.*
Results and conclusions. *Submitted description of a software package allows calculating the position of a linear structure on the area, based on a one-factor approach, linking the cost criterion to the complexity of developing different groups of soil.*

Key words:
Gas supply, optimal route, route design, wave algorithm, main gas pipeline, average method, digital terrain model.

Introduction

Currently, gas supply systems are changing priorities, primarily due to the use of:

- the low-pressure gas transfer technologies;
- the high-performance devices for compression;
- an improved internal coating of pipes, which allows reducing roughness and increasing productivity up to 8…10 %.

At the same time, reconstruction of the existing gas transmission system should be directed to decrease energy costs and the cost of transporting gas, in particular. Forecasting and planning of increasing economic efficiency are the priority tasks of the gas supplying industry. Strategic planning helps use resources efficiently, focusing on the need to continuously reduction of production costs by increasing the reliability and the safety of equipment and improving technological processes. The use of innovative technologies, materials and equipment is capable to improve reliability and safety indicators, therefore long-term planning directed to the efficient use of resources is one of the most important functions of the gas transmission system. The design of gas pipelines should be a complex of optimal solutions, ranging from the choice of route, method of installation, materials and insulation, to the technology of making welded joints.

Gas networks are capital-intensive projects. However, comparing possible types of transportation of energy carriers (automobile, railway, shipping and gas pipelines) on the main parameters (capital costs, operational costs, carrying capacity, season restrictions, transportation in adverse conditions, etc.), it can be concluded that the use of the gas pipelines is economically beneficial.

Shortcomings of the gas transportation are the high cost of the gas pipelines construction (gas pipeline fittings, transitions, pipes, shutoff valves), the complexity of laying in the difficult areas, environmental hazards, especially at operation of underwater transitions (pipe canal). Advantages of using gas pipelines are:

- the possibility of laying gas networks in any direction at any distance;
- all-season work, regardless of natural influences;
- reliability and simplicity of operation;
- low shipping cost;
- safety of the product due to sealing the pipe;
- less material and capital intensity;
- full automation of transportation operations.

The main project document for construction of facilities is a feasibility study for construction, on its basis project documentation is developed. The design target must specify the source and end points of the pipeline, which are outlined in the initial stages of design. Designing the laying route is the first significant step in planning and construction of the gas pipeline, which affects the gas distribution system operation and, undoubtedly, streamlining the process will minimize economic losses and reduce the consumption of material and monetary resources [1–6].

For the effective choice of a gas pipeline route, it is necessary to predict the development of already existing gas networks, to develop improved methods and algorithms using geoinformation technologies [6–15].

Methods

It is possible to use various criteria for optimization of the pipeline route. The optimal route is the gas pipeline

DOI 10.18799/24131830/2021/1/3008

rout, the construction of which allows obtaining the maximum or minimum value of the evaluation criterion. The general, universal criterion is the minimum of reduced (integral) costs in the construction and operation of the gas distribution system.

The major factors affecting the cost of construction are:

- diameter of the pipeline (the metal consumption grows with increasing diameter);
- gas pressure (higher the pressure in the pipeline, thicker the pipe wall, which leads to an increase in cost);
- natural conditions;
- economic and geographical conditions.

In the course of the analysis, the authors have considered the methods currently used for determining the optimal route of the gas pipeline:

- the method of the average coefficient [6];
- advanced average coefficient method [7];
- selection of the optimal route and multiple routes on the grid between two points [2, 16];
- selection of the optimal route of the pipeline with the use of value maps of determining factors [17];
- model for optimizing gas pipeline routing using genetic algorithms;
- and others [17–31].

When using the method of the average coefficient of the pipeline development (on condition the coefficient of development of the line K_p is set), the length of the route can be calculated from the expression:

$$L \le K_p \cdot \ell, \qquad (1)$$

where L is the maximum path length; K_p is the coefficient of development of the gas pipeline line; ℓ is the length along the geodetic line.

The line bounding the area of the possible position of the pipeline has to be determined so condition (1) is fulfilled. This line represents a curve (or an ellipse), which each point is removed from the source and end point of the pipeline route by a distance, giving in total $K_p \cdot \ell$. Thus, the search area is the area of the territory bounded by an ellipse, the small axis of which b is calculated by the formula (2) [6]

$$b = \ell\sqrt{\left(K_p^2 - 1\right)}. \qquad (2)$$

The result of using the method of an average data is presented in Fig. 1.

Optimal functioning issues of the inter-settlement gas supply systems are widely covered in the studies of domestic and foreign scientists. For example, in study [6], the author proposes to take into account criteria characterizing the elevation differences on the ground, along with the choice of a route variant with the minimal cost expenditure in a specified time interval. The research of P.P. Borodavkin is very useful for studying the theory of design and construction of the gas pipelines. The authors of this paper have analyzed the main design targets in theoretical terms, showed a large number of conditions for designing a digital model, which allows evaluating the construction conditions in the different climatic and geographical areas, using computer search. Construction complexity of the gas pipeline lies mainly in the fact that different sections of the route require different design schemes; in addition, a number of factors, such as:

- environmental protection;
- river cross or other water barriers;
- approach to highways, settlements, must be taken into account.

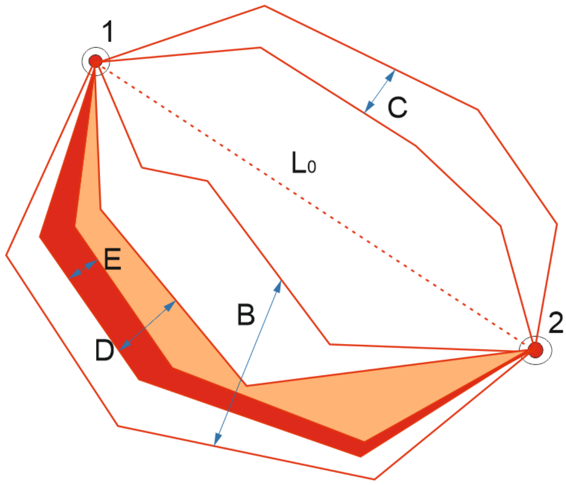
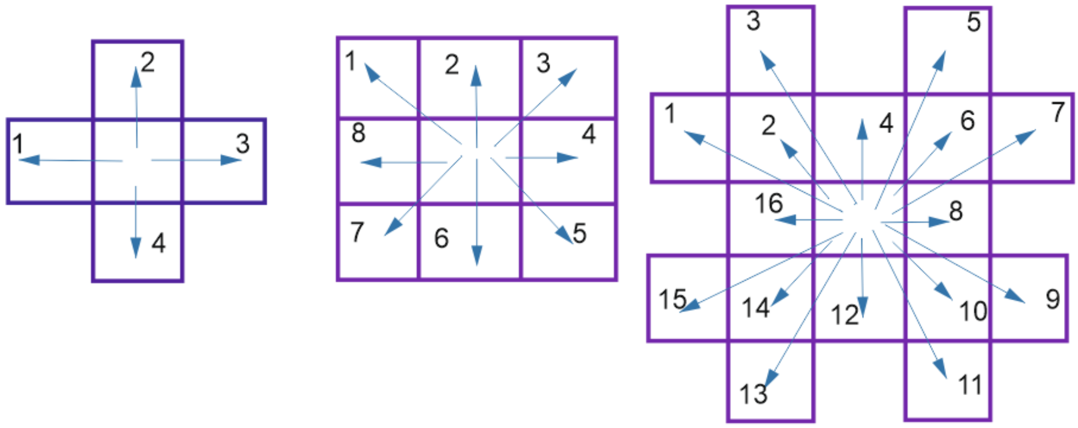


Fig. 1. *Graphical interpretation of route optimization: 1, 2 are the starting and ending points of the pipeline route; L_0 is the distance between the starting and ending points along the geodesic line, km; B, C, D, E are the track search areas*

Рис. 1. *Графическая интерпретация процесса оптимизации трассы: 1, 2 – начальная и конечная точки трассы газопровода; L_0 – расстояние между начальной и конечной точками по геодезической прямой, км; B, C, D, E – области поиска трассы*

In the 1980-s and 1990-s, subjective factors were required to create high-quality gas pipeline projects, for instance – designer experience and qualification. At present, for effective selection of the gas pipeline route, forecasting the development of already existing gas networks and improved methods and algorithms the geoinformation technologies (GIS) should be used. GIS allows minimizing the costs and time at the stage of choosing gas pipeline route, modifying the route, making adjustments when the source data changes.

Most of these methods are based on the average coefficient method. The disadvantage of this method is the use of the average coefficient, since the data on the construction conditions may differ from the actual conditions of the new gas pipeline construction. The improved method corrects the errors of the averaged coefficient method by using cost cards, while initially taking into account the cost in actual conditions, and then – the average construction cost. For considerable acceleration of the search process and the amount of information processed, it is necessary to remove the areas unsuitable for construction. Basically, the existing methods for optimizing the laying route use the same methodology with small additions. For example, the method described by R.N. Kuznetsov uses cost cards [17]. To construct the surface of the accumulated value the factors influencing the route of the gas pipeline are determined and choose significant weight coefficients. Subsequently, cost cards corresponding to the influencing factors are combined into a single cost card, taking into account their relative importance. The differences of the methods are reduced to the choice of the connectivity graph pattern: «rook pattern» (Fig. 2, *a*); «queen pattern» (Fig. 2, *b*); «horse pattern» (Fig. 2, *c*).



a/*a* *b*/*б* *c*/*c*

Fig. 2. *Templates of connectivity graphs of the next cells: a) «rook pattern»; b) «queen pattern»; c) «horse pattern»;* → *1, 2, …., 16 – connecting the neighboring cells by arcs of the graph*

Рис. 2. *Шаблоны графов связности соседних ячеек: а) «шаблон ладьи»; б) «шаблон ферзя»; с) «шаблон коня»;* → *1, 2, …., 16 – соединения соседних ячеек дугами графа*

The connectivity graph is constructed by connecting the neighboring cells by arcs of the graph. The «rook pattern» is the simplest for implementation, but its use is not the most universal. The use of the «horse pattern» is more universal, but at the same time, construction of a graph from this pattern requires more resources [17].

At present, the methods of the optimal gas pipeline routing (at the stage of design engineering) are developed rather well. The authors researched the main design tasks in theoretical terms, showed a large number of conditions for creating a digital model, which allows evaluating the conditions of construction in different climatic and geographical areas, using computer search. However, according to the proposed solutions, the pipeline route cannot lay beyond the corridor, chosen at the feasibility study stage of the project.

The complexity of the gas pipeline construction lies mainly in the fact that different sections of the route require the use of various constructive schemes, in addition, it is necessary to consider a number of factors, such as: environmental protection; crossing rivers or other obstructions; approximation to highways, settlements, prospects for the development of gas supply facilities to maintain system performance, etc.

It should be noted, that the solutions obtained by the authors are based on a number of assumptions which existence significantly affects the accuracy of the final results.

The route, calculated by the method of the average coefficient, is not always economically beneficial, due to the fact that there are no restrictions on the angles of slopes and heights of the relief, ecological zones, water barriers and the inability to lay the route directly from point *I* to point *B*. After determining the area of the gas pipeline routing, the territory where the construction of gas pipelines is prohibited is excluded from it. Then there is an adjustment up to the moment when the track will not meet the standards. In the developed program, we will try to get away from some recalculations in order to immediately mark the territories unsuitable for the construction of the main line.

Using only one criterion for estimating the route shows a one-sided point of view, since the optimal route will be beneficial only for this criterion and will not be the best solution from the influence of other possible criteria.

The main criterion for construction of any engineering networks are the reduced costs, it is a universal criterion for achieving the economic effect

$$C = K \cdot Ie + E,$$

where K is the investments; Ie is the investment efficiency ratio; E is the expenses on operation of an object.

Investments in the construction of the pipeline include the cost of building the linear part of compressor stations, gas distribution stations and other related facilities.

Among the programs for the construction of the gas pipelines we could find independent programs and, in the form of modules (additions), popular design programs, such as AutoCAD. Our task is to develop a program for building the gas pipeline with the possibility to use it for training purposes and at the stage of pre-design calculations [32].

Initially, it is necessary to create a digital terrain model. To do this, let us use the map of the future location of the route and the grid applied on it. Depending on the method of placing the source data, the existing terrain models are divided into: regular (start and final points have known coordinates and are replaced at the nodal points of the geometric grid), irregular (points are uneven on the ground, but with a certain density) and structural (reference points of known coordinates are located at the turning points of the terrain). The simplest type is rectangular, such grid depends on the search area and is constructed without taking into account topographic conditions and is preferably used for flat terrain.

The currently used algorithms for finding the optimal trace can be divided into three groups:

- wave algorithms based on Li ideas. Widely used in CAD, and allow you to build a route for the existing path;
- high-speed orthogonal algorithms;
- heuristic-type algorithms based on the method of finding a path in a maze.

Our program is based on wave algorithms, or search by width. The algorithm is a uniform search algorithm. It means the search strategy, used in solving the problem, does not use additional information, but only that presented in the definition. The essence of this method is in development of successors and distinguishing between a target and a non-target state.

Width search can be represented as a hierarchical tree (Fig. 3), in which the root node or vertex first develops, then the lower levels of the root node, then the successors are revealed, etc. At the same time, before deploying any nodes at the next level, all nodes at a given depth are revealed.

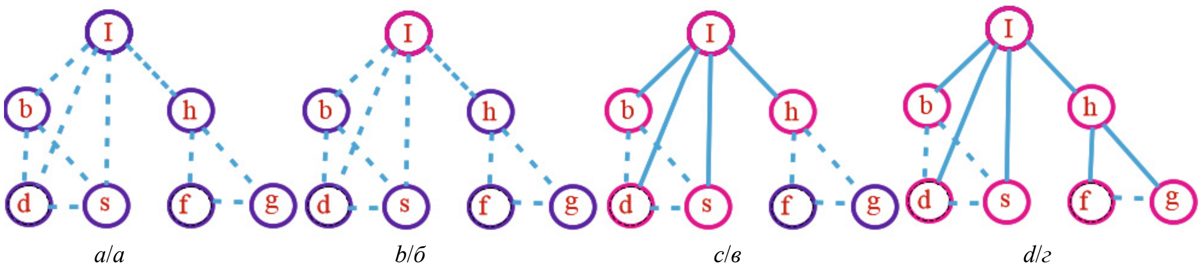


Fig. 3. *Image of the hierarchical structure of the wave algorithm: a) hierarchical tree; b) start of the search; c, d) development of the root node, lower levels of the root node, the disclosure of successors; I – the root node; b, h – the lower levels of the root node; d, s, f, g – the successors*

Рис. 3. *Изображение иерархичной структуры волнового алгоритма: а) иерархическое дерево; б) начало поиска; в, г) развитие корневого узла, нижних уровней корневого узла, раскрытие преемников; I – корневой узеле; b, h – нижние уровни корневого узла; d, s, f, g – преемники*

The wide search functions were selected by sequential viewing of individual levels of the graph, starting from the top. If the considered node is finite, then the search for the optimal variant is completed; otherwise, the node is added to the queue. As a result, after checking all the edges that go out of the vertex, the next node is extracted from the queue and the process repeats.

The description of a similar search looks as follows:

1. An empty queue is placed at the node where the search begins.
2. The node «X» is extracted from the beginning of the queue and marked as expanded, if the node «X» is final (target), then the search is completed. Otherwise, the search continues and successors of node «X» are added to the queue.
3. If there is no queue, all nodes are scanned and the target node is unreachable. As a result, the search fails.
4. Return to paragraph 2.

This structure has a large range of data to check. This is directly proportional to the speed of processing the source data and issuing a response. According to the speed of computation, the program executed by the means of the width search will somewhat lose to other algorithms that are not considered in this study, since there are studies on the basis of these algorithms describing the speed of their action – Dijkstra and A* algorithm. The developed program does not have such a large field of information which can strongly affect the speed of the solution.

To design a program, the programming language GML (GameMakerLanguage) was chosen as intuitive and easy to use. This programming language provides much more control, than standard actions, contains an extensive library of built-in functions to provide basic functionality. It is possible to create your own scripts that are called in the same way as functions. GML's drawing functions use the Direct3D API. If it is necessary, GML also allows you to call native platform code via extensions (DLL on Windows, Java on Android, JS on HTML5, etc.).

The study field of the program is geographically limited, the Saratov region was chosen as an example of scientific research. Such main gas pipelines pass through the region: Saratov–Moscow, Saratov–Cherepovets and others, and the transcontinental gas pipeline Central Asia – Center with two powerful gas compressor stations: in Aleksandrov Gai and Petrovsk.

The territorial limitation allows reducing the number of soil types for calculations, taken according to «Federal unit prices for general construction work 2001, Earthworks». For example, the surveyed area has a flat character, relatively small fluctuations in the heights of the earth's surface at significant distances and smooth transitions from lows to highs. Flat slopes do not exceed 8–10°. After analyzing the geological map of the area, we get the predominance of sands, sandstones, clay, silt, a small presence of chalk, limestone, which will correspond to groups of soil 1–5. The fifth group of soil (limestone, flask, etc.) will not be taken into account in the program, since the program is calculated for one type of equipment, and the fifth group of soils is not developed by excavators, other development methods are used for it (drilling and blasting operations, rock cutting).

The most common is underground laying, although in this case there are some problems that increase the unprofitability of the system – for example, laying gas pipelines in mountainous areas, with frequent elevation changes and the possibility of landslides and mudflows, areas with unstable erosional river beds, in permafrost soils with an active upper layer subject to annual freeze and thaw, and a high level of groundwater. This work considers only the underground method.

The choice of the gas pipeline route is based on assessment of a variant of economic feasibility and environmental acceptability from several possible options, taking into account the natural characteristics of the territory, the location of settlements, the occurrence of peatlands, as well as transport routes and communications that may have a negative impact on the main gas pipeline.

Operation principle of the program

The settings window allows setting the grid size (the smaller the set value, the smaller the grid size and the more accurate the calculation and the drawing smoothness), selecting the map scale (1 pixel=N m), setting the distance between compressor stations (from 90 to 125 km), soil cost coefficients, choosing the soil type (initially 1 type was selected, but there are 5 ones in the program). When start and final points of the track are placed, the program starts searching for the shortest path between these points using the algorithm. The entire grid on the desktop is represented as a graph, with vertices at the points of intersection of the grid lines. An array is created that reads the number of graph edges passed. In order to update the array on the *i*-th iteration, the program traverses each edge, trying to optimize the distance to the vertices it connects. After finding the shortest path in the graph, the program uses the shortest path by pixels to the input, which allows you to find the path more accurately than when using a single algorithm. Then the program begins to calculate the route and immediately lay it. Every 0,03 seconds, the program checks the new ability to build a shorter path and accurately takes into account the distance traveled by the marker, draws the path and sets the markers of the compressor (gas distribution) stations. After completion of the analysis, the program calculates the distance, counts the cost and builds graphs.

As an example of the program's efficiency, the construction of a gas-main pipeline from Atkarsk to Volsk, the Saratov Region, is considered. Using the visibility coefficients obtained from the local estimate for the construction of a gas pipeline, we enter values for each soil group. Further, according to the map color on the substrate of the program, we mark the groups of soils and designate insurmountable barriers and conservation zones (Fig. 4).

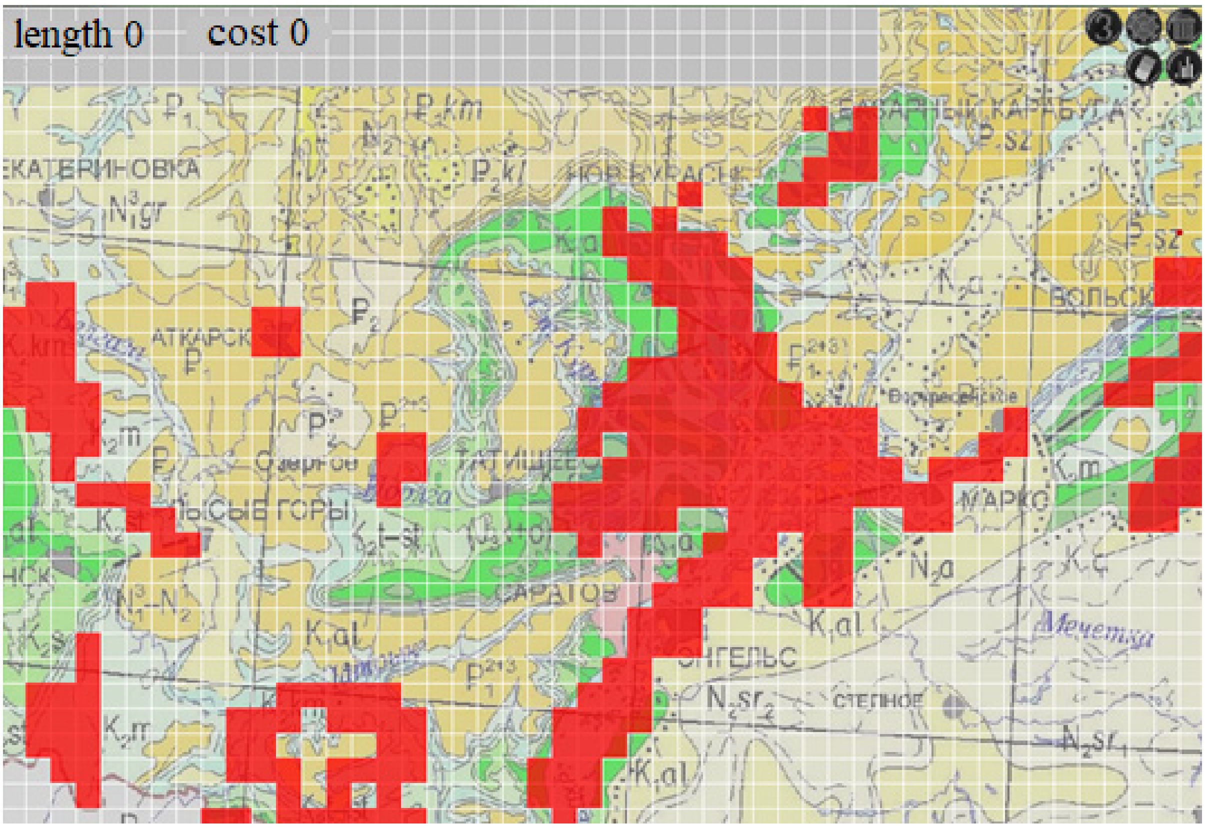


Fig. 4. *Program map with the marked «red» type of soil*

Рис. 4. *Карта программы с отмеченным на ней «красным» типом грунта*

Fig. 5 shows the possibility of changing the cost of construction of the gas pipeline due to the changes in the soil type. Next, the program selects the start and final points of the path, as soon as the final point is set, the program will begin making a path.

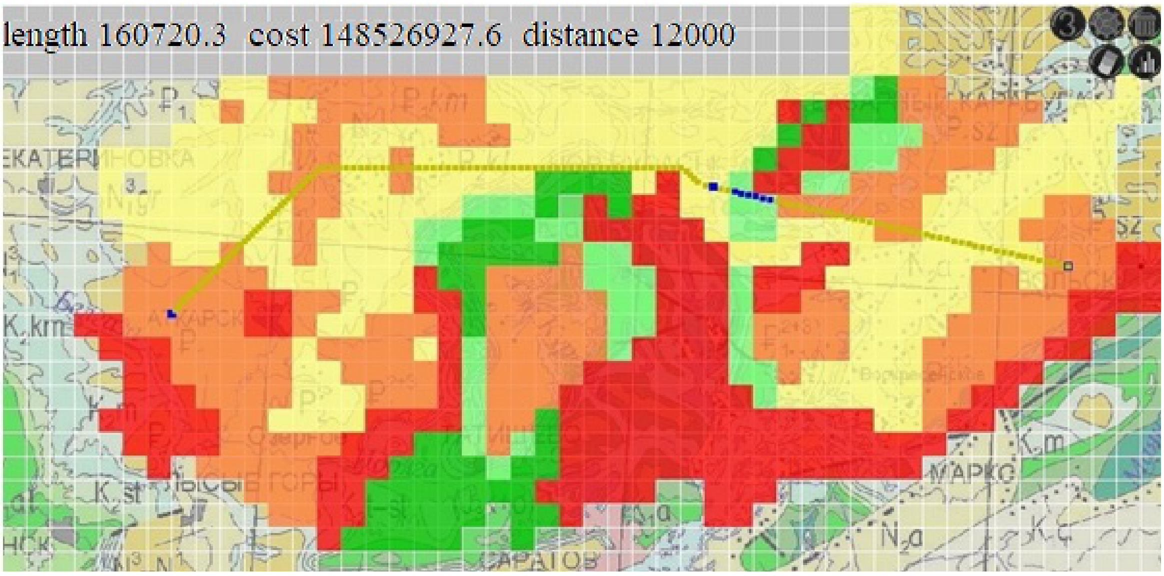


Fig. 5. *Calculation in the program (first example) [32]*
Рис. 5. *Расчет в программе (первый пример) [32]*

The first result: the soils are displayed according to the actual data of the map. The scale was taken approximately. It was laid for 4 km in the direction of the square. The automatic calculation of the route showed the following results (Fig. 5): the distance of the route of the main gas pipeline is 160,720 km, and the cost is 148,53 million rubles.

The second result (Fig. 6): the route was extended to 166,586 km, and the cost increased to 183,44 million rubles with randomly generated terrain.

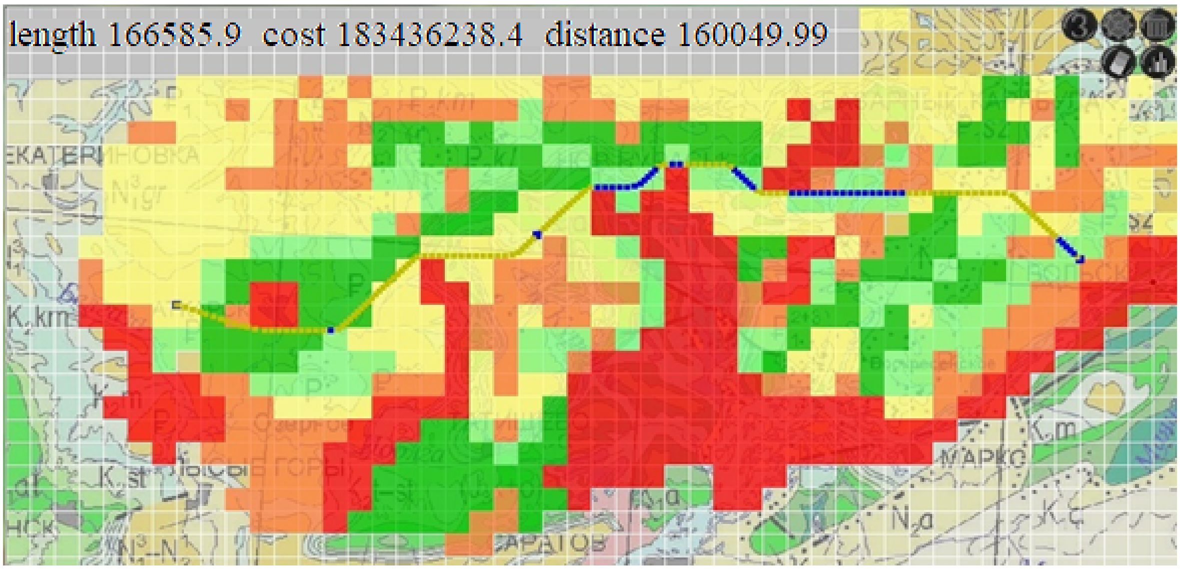


Fig. 6. *Calculation in the program (second examples) [32]*
Рис. 6. *Расчет в программе (второй пример) [32]*

The total cost of the route includes the total cost of laying the pipeline in various soils and the cost of compression stations.

Results and discussion

Let us consider the operation of the program in comparison with the actually existing object with the following characteristics: the high-pressure polyethylene gas pipeline of 0,6 MPa from the gas-distribution substation in the Kharitonovka village to the Tselinny village of the Perelyubsky district of the Saratov region (Fig. 7).

The diameter of the pipeline is 225 mm, the length is 3575 m. The cost of construction in terms of current prices was 1,130 million rubles. According to the geological structure, in the area from the gas-distribution substation in the Kharitonovka village to the Tselinny village, the soils are represented by dark brown soft plastic (humified) loams and covered with a slight soil layers to 0,1–0,2 m.

To use the program, you need to find the soil cost coefficients, for which it is necessary to calculate the estimated cost per 1 km of a 225 mm polyethylene pipeline. As a result, the following coefficients were obtained:

$к_1$=51, $к_2$=46, $к_3$=43, $к_4$=39. We set the scale and size of the grid. To obtain the actual distance according to the calculations, we should use the grid size of 16 and a scale of 7. We mark the area with the color marks (Fig. 8). We put points *I* and *B* according to the real object and observe the result (Fig. 8, 9).

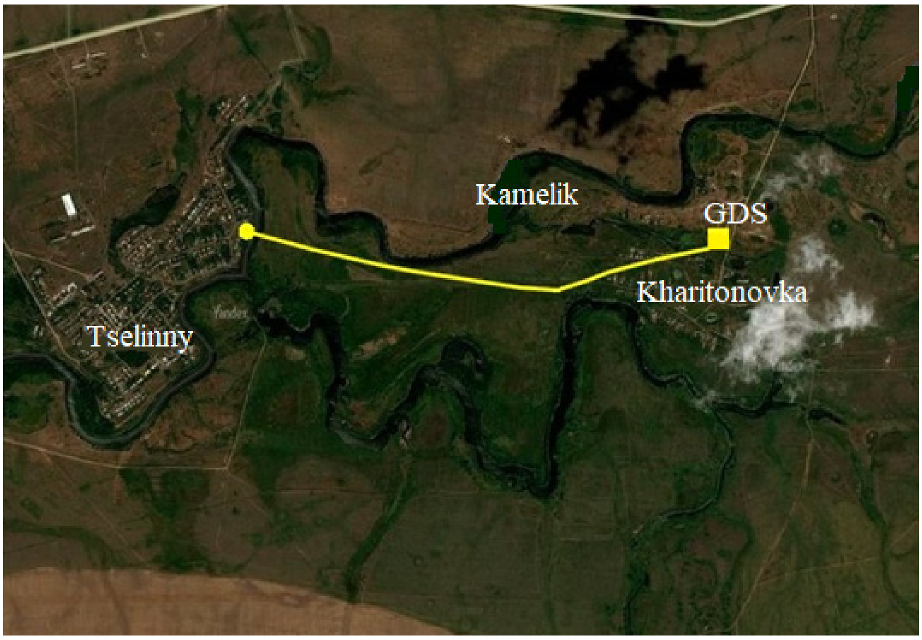


Fig. 7. *Polyethylene gas pipeline from the gas-distribution substation in the Kharitonovka village to the Tselinny village*
Рис. 7. *Полиэтиленовый газопровод от АГРС с. Харитоновка до п. Целинный*

We obtained the following results: the route constructed by the program turned out to be shorter than the actual route, with the lengths being 3212 and 3575, respectively, m; and the laying cost 1,264 million and 1,130 million rubles.

To calculate the soil permeability coefficient, it is necessary to carry out an estimate calculation (per kilometer of gas pipeline, taking into account the work, depending on the soil group).

Fig. 8. *Area marking*
Рис. 8. *Разметка местности*

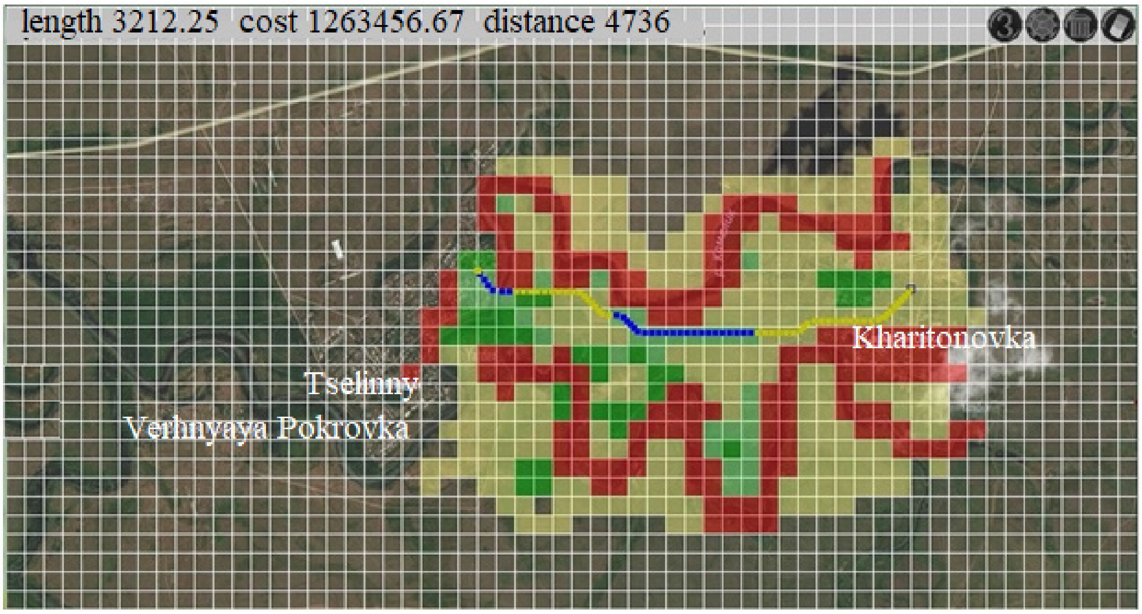


Fig. 9. *Route constructed by the program [32]*
Рис. 9. *Трасса, построенная с помощью программы [32]*

After calculating the estimate, we find the visibility factor of the increased cost of construction in different soil groups, obtained by converting a series of values in relation to one of them (baseline), taken as 1; 100; 1000, etc.

So, for the considered case, taking a line from the estimated calculation with the values «Total estimated cost» we find that the construction costs of 1 km of the pipeline are:

- in the 1st soil group – 1067278,79 rubles, visibility factor H_1 – 1,37;
- in the 2nd soil group – 948324,82 rubles, visibility factor H_2 – 1,22;
- in the 3rd soil group – 881826,68 rubles, visibility factor H_3 – 1,13;
- in the 4th soil group – 777832,79 rubles, the visibility factor H_4 – 1,00.

The program introduced five groups of soils with appropriate coefficients. As a result, five areas of color selection were taken:

- 1 – marked in green – zone with the 1st soil group;
- 2 – marked in bright green color – zone with the 2nd soil group (type of soil);
- 3 – marked in yellow – zone with the 3rd soil group (type of soil);
- 4 – marked in orange – zone with the 4th soil group (type of soil);
- 5 – marked in red – insurmountable barriers (residential areas, ecological zone, water protection zone, not included 5 soil group, etc.).

Conclusion

Continuous supply of the fuel and energy resources to the Russian regions largely depends on the reliability of the gas transmission system. Fundamental knowledge, experience in the construction and operation of the gas supply systems, development of applied sciences allow us to simulate efficient energy supply systems of a new level, endowed with a high degree of reliability, safety and environmental friendliness.

After analyzing the modern methods of laying the main and linear gas networks, we come to the conclusion that the existing practice of designing gas pipelines (in a straight line from the initial to the final reference point) is not always optimal and economical. The cost of construction of a small length of the pipeline, which is difficult in terms of construction, installation and special works, often turns out to be higher than the cost of constructing a multi-kilometer bypass on the site with normal laying conditions. Therefore, at the choice of the pipeline route, it is necessary to take into account all factors affecting the cost of installation. At the same time for the effective functioning of the gas transmission system the strategic planning and preliminary technical and economic assessment of construction works are of great importance. The proposed method for software construction of the gas pipeline route has informational character. The program can be used in the design of engineering networks for various purposes, for educational purposes and, with appropriate revision, for implementation in the practice of design. As a mathematical basis for creating a model, the theory of wave algorithms is used. It allows determining the spatial location of various engineering networks.

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Received: 23 December 2020.

Information about the authors

Oksana N. Medvedeva, Dr. Sc., professor, Yuri Gagarin State Technical University of Saratov.
Valeriya D. Penenko, master, engineer, AO «Giproniigaz» (Joint Stock Company).

УДК 622.692.4

МАРШРУТЫ ПРОКЛАДКИ ТРУБОПРОВОДНЫХ СИСТЕМ ГАЗОСНАБЖЕНИЯ

Медведева Оксана Николаевна[1],
medvedeva-on@mail.ru

Пененко Валерия Дмитриевна[2],
isabel16122012@gmail.com

[1] Саратовский государственный технический университет им. Гагарина Ю.А.,
Россия, 410054, г. Саратов, ул. Политехническая, 77.

[2] АО «Гипрониигаз»,
Россия, 410012, г. Саратов, пр. им. Кирова С.М., 54.

Актуальность. *Проектирование маршрута прокладки газопровода является важным этапом процесса планирования и строительства газопровода. Существуют различные методы, зависимости и алгоритмы, характеризующие функциональную составляющую газопроводов, различные способы прокладки. Самым важным в процессе проектирования является выбор такого оптимального маршрута, при котором эффективность применения будет высокой и при этом проект будет иметь минимальные капитальные вложения в строительство. Несмотря на множество предлагаемых подходов, в настоящее время единой методики по определению оптимальных затрат на строительство и реконструкцию газораспределительных сетей не существует.*

Цель: *провести сравнительный анализ существующих алгоритмов построения оптимального трубопроводного пути, разработать программы моделирования и обоснования рациональных маршрутов прокладки трубопроводных систем газоснабжения на основе однокритериального подхода.*

Методы. *В основу разработанной программы заложены волновые алгоритмы, или поиск в ширину, являющийся одним из методов обхода графа. Это означает, что в стратегии поиска при решении задачи не используется дополнительная информация, а только та, что представлена в определении. Суть этого метода – вырабатывать преемников и различать целевое и нецелевое состояние узла.*

Результаты и выводы. *Рассмотрев и проанализировав современные способы прокладки магистральных газовых сетей и способы прокладки линейной части, можно сделать вывод, что существующая практика трассировки магистральных газопроводов не всегда предлагает к использованию оптимальный вариант. Стоимость сооружения небольшого по протяженности, но сложного с точки зрения проведения строительно-монтажных и специальных работ, участка газопровода зачастую оказывается выше стоимости сооружения многокилометрового обхода на участке с нормальными условиями прокладки. Поэтому при выборе трассы магистрального газопровода необходимо учитываться все факторы, влияющие на стоимость прокладки. Предложенная методика носит ознакомительный характер программного построения трассы газопровода. Представленное описание программного комплекса позволяет рассчитать положение линейного сооружения на местности на основе однофакторного подхода – привязки критерия стоимости к сложности разработки разных групп грунта.*

Ключевые слова:
Газоснабжение, оптимальная трасса, проектирование маршрута, волновой алгоритм, магистральный газопровод, среднестатистический метод, цифровая модель местности.

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Поступила 23.12.2020 г.

Информация об авторах

Медведева О.Н., доктор технических наук, доцент, профессор кафедры теплогазоснабжения, вентиляции, водообеспечения и прикладной гидрогазодинамики Института Урбанистики, архитектуры и строительства Саратовского государственного технического университета им. Гагарина Ю.А.

Пененко В.Д., магистр техники и технологий, инженер, АО «Гипрониигаз».