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## DETERMINATION OF OPTIMAL GAS PIPELINE ROUTE BASED ON COST MAPS OF INFLUENCE FACTORS

The mathematical statement of the problem of optimal gas pipeline route selection using multi-criteria optimization is considered. Methods of optimal pipeline route search using weighting coefficients of cost maps are proposed. The problem of cost surfaces weighting using expert and adaptive methods is solved.

**Keywords:** gas pipeline route, optimal route.

## Introduction

The selection of gas pipeline route is the selection of optimized connection between two or more points. Route optimization is the iterative process involving weighting and balancing of different influence factors which result in gas pipeline route deviation from the route being chosen initially [1]. Height drop, availability, roads, environment, natural and geological criteria are the factors influencing the gas pipeline route.

The aim of gas pipeline route optimization is to determine the route with the lowest cost estimated by resultant cost surface. Objective function has the form

$$C = \sum_i \sum_j w_j V_{ij}\,, \tag{1}$$

where $w_j$ is the weighting coefficient of $j$ factor map; $V_{ij}$ is the value of $i$ spatial element on $j$ map of influence factors; $i$ takes the value of spatial element indices which form the route.

To construct resultant cost surface on the base of which the calculation of the route will be carried out it is necessary to determine influence factors and weighing coefficients of the factors $w_j$ which determine the degree of influence of each factor on the route. To determine the optimal ratio of weighing coefficients of the factors can significantly affect the calculation of resultant cost surface and final gas pipeline route. Using data on influence factors it is essential to construct cost surface for each factor (Fig. 1).

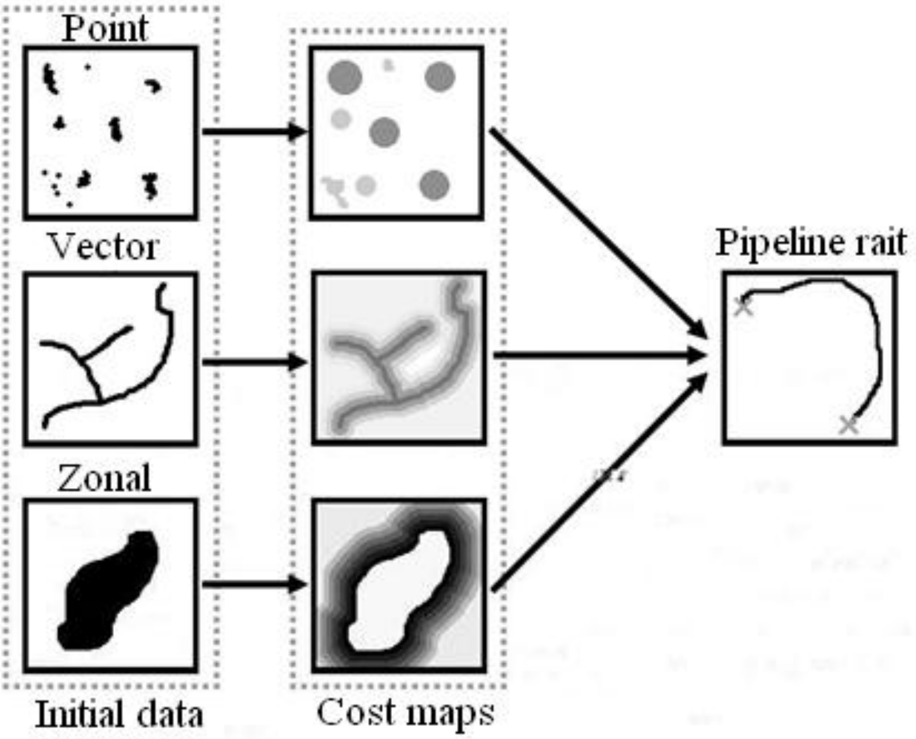


**Fig. 1.** Cost maps corresponding to the factors of different types

The examples of point data on the base of which cost surfaces are constructed are engineering structures, hard rock yields, the examples of vector data are roads and rivers; the examples of zone data are settlements, marshland, and soil corrosion resistance.

Besides weighing coefficients of influence factors the way of cost map integration in final cost map influences the resultant cost surface. The empirical determination of the coefficients is inefficient, since no one can assess objectively the relative importance of influence factors. In order to determine the weighing coefficients it is proposed to use data obtained with the help of the methods based both on public knowledge and data available. The judgment method is proposed to be used as the method based on public knowledge. Then factor importance measurements involve two parameterization categories, namely, calibration and weighing.

The calibration involves development of value scale to estimate each cost map corresponding to influence factors The Delphi technique is proposed to be used for calibration [2]. The subjects of the technique are expert and organizational group. The technique is inherently iterative; the assessment occurs in no less than three stages:

1. Members give their view on calibration of particular map of influence factors;
2. Members fill the questionnaire and thus assess the criteria;
3. Members reassess the criteria based on statistical summary of the questionnaires. Atypical opinions are discussed, consensus is pursued.

A key moment of Delphi technique is questionnaire making. The experts are asked to specify the range of values of the element of map corresponding to each value of the scale, for the maps with continuous values. For the maps with discrete values, each possible value of the map is assigned a value from rating scale.

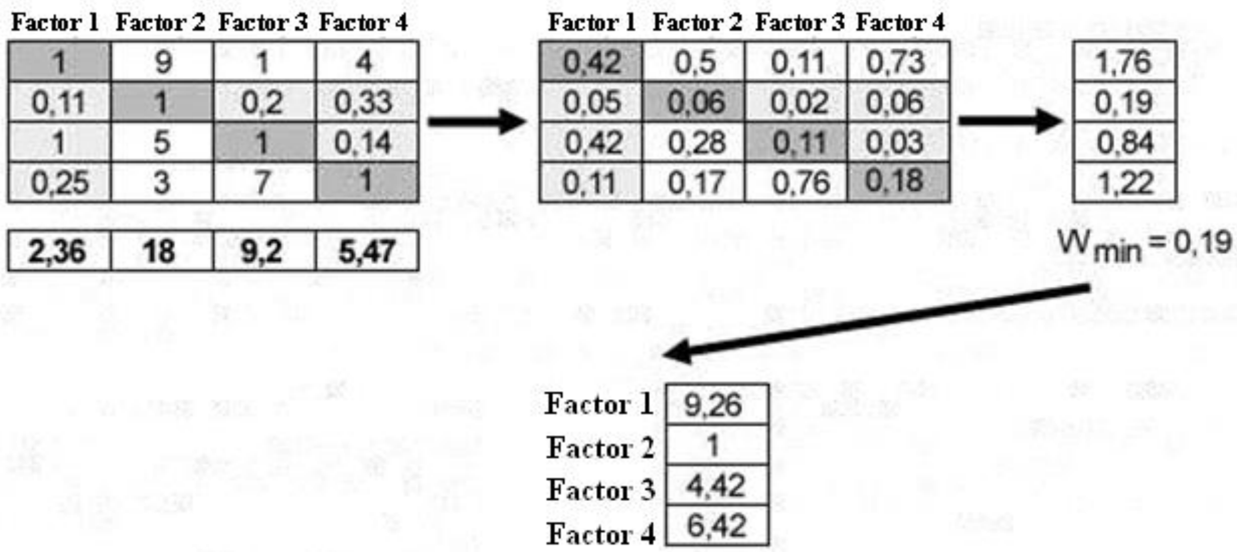
The same value of rating scale can be assigned to the different values of the map, but minimum and maximum values of the scale must necessarily be assigned. In the case of both continuous and discrete map, median, mean value and standard deviation are calculated for each question. Calculated values are used to assess group consensus and to determine the course of subsequent discussion.

Weighing of factor maps is supposed to be performed using analytical hierarchy technique, which is the system method of comparison of criteria for decision-making. Paired-comparison summarization of relative importance of criteria map is performed resulting in set of weighing coefficients for factor maps affecting gas pipeline routing. For instance, four maps of influence factors are compared, five direct comparisons being performed.

The experts independently of one another rank the statements in order of truth, then, each statement is assigned a relative level of importance. 1 is taken for the minimum value of importance, 9 is taken for the maximum one. Data obtained are entered in matrix of importance. Thereafter weights of factor maps are calculated (Fig. 2).

Weights of factor maps are determined by normalization of the values of the matrix. The normalization is performed dividing each element of the matrix by the sum of values of the column this element enters. Relative weighting coefficients are derived from line-by-line sum of normalized answers. The coefficients derived are divided by the least one to obtain the scale. Relative weighting coefficients for the group of participants are adjusted to the total scale and are averaged.

The method involving logarithmical form of Bayesian model of probability is proposed to be used as the method based on analysis of available data. The method finds use in calculation of weighting coefficients of maps of influence factors and in compilation of a posteriori map of probabilities. The weighting coefficients accounting for the importance of each map of influence factors are obtained using correlation between maps of influence factors and available gas pipeline route.



| Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|
| 1 | 9 | 1 | 4 |
| 0,11 | 1 | 0,2 | 0,33 |
| 1 | 5 | 1 | 0,14 |
| 0,25 | 3 | 7 | 1 |
| 2,36 | 18 | 9,2 | 5,47 |

| Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|
| 0,42 | 0,5 | 0,11 | 0,73 |
| 0,05 | 0,06 | 0,02 | 0,06 |
| 0,42 | 0,28 | 0,11 | 0,03 |
| 0,11 | 0,17 | 0,76 | 0,18 |

| |
|---|
| 1,76 |
| 0,19 |
| 0,84 |
| 1,22 |

| | |
|---|---|
| Factor 1 | 9,26 |
| Factor 2 | 1 |
| Factor 3 | 4,42 |
| Factor 4 | 6,42 |

**Fig. 2.** Paired comparison of the factors for weighting coefficients determination in analytical hierarchy technique

If factor with index *i* influences gas pipeline route, probability of gas pipeline routing can be expressed by conditional probability

$$P(D\,|\,B_i) = \frac{P(D \cap B_i)}{P(B_i)} = P(D)\frac{P(B_i \cap D)}{P(B_i)}, \tag{2}$$

where *D* is the available gas pipeline; $B_i$ is the zone of influence of *i* factor.

Inversely,

$$P(D\,|\,\overline{B}_i) = P(D)\frac{P(\overline{B}_i \cap D)}{P(\overline{B}_i)}, \tag{3}$$

where *D* is the available gas pipeline; $B_i$ is the additional zone of *i* factor.

Using

$$O(A)=\frac{P(A)}{1-P(A)}, \tag{4}$$

we obtain
$$O(D\,|\,B_i)=O(D)\frac{P(B_i\,|\,D)}{P(B_i\,|\,\overline{D})} \tag{5}$$

and
$$O(D\,|\,\overline{B}_i)=O(D)\frac{P(\overline{B}_i\,|\,D)}{P(\overline{B}_i\,|\,\overline{D})}. \tag{6}$$

By applying the Napierian logarithm for the both sides of Eq. (5) and (6), we obtain

$$\ln(O(D\,|\,B_i))=\ln(O(D))+W^{+} \tag{7}$$

and
$$\ln(O(D\,|\,\overline{B}_i))=\ln(O(D))+W^{-}, \tag{8}$$

where
$$W^{+}=\ln\left(\frac{P(B_i\,|\,D)}{P(B_i\,|\,\overline{D})}\right), \tag{9}$$

$$W^{-}=\ln\left(\frac{P(\overline{B}_i\,|\,D)}{P(\overline{B}_i\,|\,\overline{D})}\right), \tag{10}$$

$W^{+}$ и $W^{-}$ are the positive and negative weighting coefficients, respectively.

For the purpose of compiling the probability map it is necessary to calculate the parameters for each spatial element of outlet map.

Ratio

$$\frac{P(B_i\,|\,D)}{P(B_i\,|\,\overline{D})}$$

is the necessity parameter, and ratio

$$\frac{P(\overline{B}_i\,|\,D)}{P(\overline{B}_i\,|\,\overline{D})}$$

is the sufficiency parameter.

The essence of necessity and sufficiency parameters is the correspondence between available gas pipeline and effective and complementary zones of factors influencing gas pipeline routing.

In the end the value of dependence is determined:

$$C = | W^{+} - W^{-} |. \tag{11}$$

Value *C* shows correlation between each criterion influencing the gas pipeline routing available gas pipeline. Subsequently weighting coefficients of factor maps are calculated on the base of the value. When applying this method it is necessary to take into account that the factors influencing the gas pipeline routing should be independent.

For integration of spatial data and factor maps different model were used. Let us consider some of them.

**1. Boolean model.** In Boolean model inlet maps are integrated using logical operators, such as AND, OR, Xor and NOT. In spite of the fact that Boolean operators are simple there are problems when using this model. Since all inlet maps of factors have the same weight, it is impossible to enter different priorities for different points on map. The model can be applied for the maps of constraints marked by severe specification of trafficability, but it is inapplicable for influence factor maps with different weighting coefficients.

**2. Weighted model.** In this model maps of factors are integrated with the use of the equation

$$V_j = \frac{\sum_i V_{ij} w_i}{\sum_i w_i}, \tag{12}$$

where $w_i$ is the weighting coefficient of *i* map of factors; $V_{ij}$ is the value of j spatial element on *i* map of influence factors; $V_j$ is the short of *j* spatial element on outlet map.

When comparing weighted and Boolean model it can be noted that the former is more flexible and accounts for weighting coefficients of influence factor maps and value of each spatial element on these maps. The model was used for comparison and assessment of integration models when calculating cost surface.

3. **Fuzzy logic model.** Fuzzy map are compiled to integrate factor maps.

The value of each element of fuzzy map involves relative importance of the factors and values of spatial elements of factor maps. The value of element of fuzzy map is the value from fuzzy set [3]. The value from fuzzy set should fall in the range between 0 and 1.

However, the value has not other constraints. The values represent grade of membership on the base of subjective opinions; i. e., each value is the suitability of spatial element for gas pipeline routing determined on the base of selected criteria.

For the purpose of factor maps integration such operations as “Fuzzy And”, “Fuzzy OR”, fuzzy product, fuzzy sum and fuzzy $\gamma$.

“Fuzzy And” is similar to usual operations in classic set theory:

$$\mu_{A\cap B}(x)=\min(\mu_A(x),\mu_B(x)). \tag{13}$$

“Fuzzy And” separates out minimum value in one unit of outlet map and create the map of conservative assessment of efficient criteria.

The operation is used in the case when there are two or more factors which can be of help when solving the problem. However, the operation has such disadvantages as impossibility to use all efficient factors.

“Fuzzy OR” is also similar to usual operations in classic set theory:

$$\mu_{A\cup B}(x)=\max(\mu_A(x),\mu_B(x)). \tag{14}$$

“Fuzzy OR” separates out maximum value in one unit of outlet map and creates the optimistic map of assessment of efficient criteria. “Fuzzy OR” is used if there is a sufficient number of positive factors in the field under consideration.

When using “Fuzzy OR”, as well as when using “Fuzzy OR”, only one influence factor are used to determine summarized value, which is unacceptable.

The operator of fuzzy product multiplies values of membership of influence factor map. Thus, it has reducing impact on the results and is used if inlet factor maps reduce influence of each other.

$$\mu=\prod_{i=1}^{n}\mu_i\,, \tag{15}$$

where $\mu$ is the value of the element of outlet map; $\mu_i$ is the weight of $i$ map of factors.

When using fuzzy sum operation the values of membership tend to 1, and influence of maps of factors on each other increases. Owing to these properties, the operator was used for integration influence factors maps and compared with other fuzzy operators.

$$\mu=1-\prod_{i=1}^{n}(1-\mu_i). \tag{16}$$

Fuzzy $\gamma$ is determined as the product of fuzzy sum and fuzzy product:

$$\mu=\left(1-\prod_{i=1}^{n}(1-\mu_i)\right)^{\gamma}\left(\prod_{i=1}^{n}\mu_i\right)^{1-\gamma}. \tag{17}$$

In Eq. (17) the value of $\gamma$ is restricted by the range [0...1]. Determination of appropriate value of $\gamma$ results in outlet map which reflects scope of increasing and decreasing tendencies in operations of fuzzy sum and fuzzy product.

By varying the values of $\gamma$ in (17) and using Eq. (15), (16), it is possible to obtain high flexibility when integrating cost maps and to take into account individual characteristic of influence factors.

As a rule, the methods based upon data analysis have higher accuracy than judgment methods. However, since model learning is performed on the base of available gas pipeline the design errors can be repeated if any.

The resultant cost surface is constructed using proposed models of weighting and integration of influence factor maps. The search of gas pipeline optimal route is carried out using cost surface obtained. Dijkstra's algorithm was used to find optimal route [4]. Since cost surface was calculated in discrete form, the connectivity of meshes was determined in the form of queen pattern, which makes it possible to minimize objective function.

## Summary

For the first time generalization of mathematical statement of the problem of optimal gas pipeline route selection using multi-criteria optimization was performed.

The methods providing required detailedness and accuracy of optimal route selection in conditions of heterogeneity of influence factors were developed.

The problem of cost surface weighting was solved with the use of expert and adaptive methods.

The application of modern mathematical methods made it possible to solve the problem of optimization of gas pipeline route when limited in resources.

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