Method for route selection of transcontinental natural gas pipelines

Fotios G. Thomaidis[1]

National and Kapodistrian University of Athens
Department of Informatics and Telecommunications
fthom@kepa.uoa.gr

Abstract. The route of transcontinental natural gas pipelines is characterized by complexity, compared to national and cross-border pipelines, since their large magnitude results in the examination of parameters that do not exist or are considered negligible for pipelines of smaller scale and that require management of more information. The aim of the present dissertation is the development of a route selection method, able to deal with the aforementioned complexity of transcontinental pipelines. The developed algorithm examines the validity of the conditions for economic viability of the pipeline, defines the alternative routes, selects the weights of criteria that affect the pipeline design and compares the routes, taking into consideration the available data, the experience and knowledge of the decision maker. The consistency and sensitivity of the results is examined. The method is applied in the case of a transcontinental pipeline transporting gas from the broader Caspian Region to Western Europe. Different scenarios of criteria weights are used and discussed at the results of the application. The software tool Gas-PRS, allows quick application of the method and facilitates the decision maker in examining the consequences of different choices.

Keywords: Optimum route method, natural gas, transcontinental pipelines, Caspian Region – E.U. energy corridor

1. Introduction

Route selection of transcontinental natural gas pipelines is characterized by complexity compared to the cases of national and cross-border pipelines. This complexity arises from their large magnitude, which results in the examination of parameters that do not exist or are considered negligible for pipelines of smaller scale and that require processing of more information. Large volumes of natural gas need to be transported for long time periods, of 15 – 20 years, so that the transcontinental pipeline is economically viable; thus construction of such a project can only proceed if long-term gas supplies from large fields are secured and final markets with adequate demand to buy all the transported volumes are selected. The large pipeline

[1] Dissertation Advisor: Dimitrios Mavrakis, Assoc. Professor

length also affects the complexity of route selection, as it results in passing through territories with different political, economic, institutional and environmental characteristics. Additional issues concerning transcontinental pipelines are the prospects of supplying gas to the intermediate markets and the high costs, that depend on the geological characteristics of the crossed terrain and the transit fees paid to third countries. The need to examine large amounts of information regarding the pipeline route increases the complexity of the problem.

Several methods have been developed to select the optimum route of national and cross-border hydrocarbon pipelines, using the Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT) and Verbal Decision Analysis (VDA) and Geographic Information Systems (GIS) [1 – 11]. These methods can be applied effectively to small scale projects, but fail to meet the complexity of transcontinental pipelines. None of the existing methods examines the natural gas supply and demand and evaluates issues related to the intermediate regions, such as the political, economic and institutional conditions of the transit countries, the payment of transit fees and the prospects of supplying gas to third markets. The present dissertation aims to develop an optimum route selection method, able to address the aforementioned complexity of transcontinental pipelines.

2 Optimum route selection method

The route selection method for transcontinental natural gas pipelines results in the selection of the optimum route, after examining a group of alternative solutions which are defined by the decision maker. The method combines the selections of the decision maker, regarding the importance of the route parameters, with the available information and his ability to evaluate them. From this point of view, the selected optimum route reflects the choices of the decision maker.

The algorithm of the method is divided into three phases (Figure 1), which include validation of the conditions for economic viability of the pipeline, definition of the alternative routes, selection of criteria weights, comparison of the alternative routes, taking into consideration the available data, the experience and expertise of the decision maker, test of the comparisons' consistency and sensitivity analysis of the results.

Phase 1: Examination of natural gas supply and demand

In the first phase of the method, the two main conditions for economic viability of the pipeline are validated; the necessity to secure sufficient gas supplies at the entrance of the pipeline and demand at the targeted markets. In this respect, the supply potential of the pipeline is assessed and the demand of the final markets is examined.

The supply potential of countries that constitute possible suppliers for the pipeline is assessed by examining the countries' availability of gas, large gas fields that have adequate production to supply the pipeline, infrastructure that can transport gas from the fields to the pipeline entrance, political and financial stability. Gas demand of the final markets is investigated by examining the countries' projections of future consumption that cannot be covered by indigenous production or existing gas supply contracts, import infrastructure that is competitive to the studied transcontinental pipeline, political and financial stability.

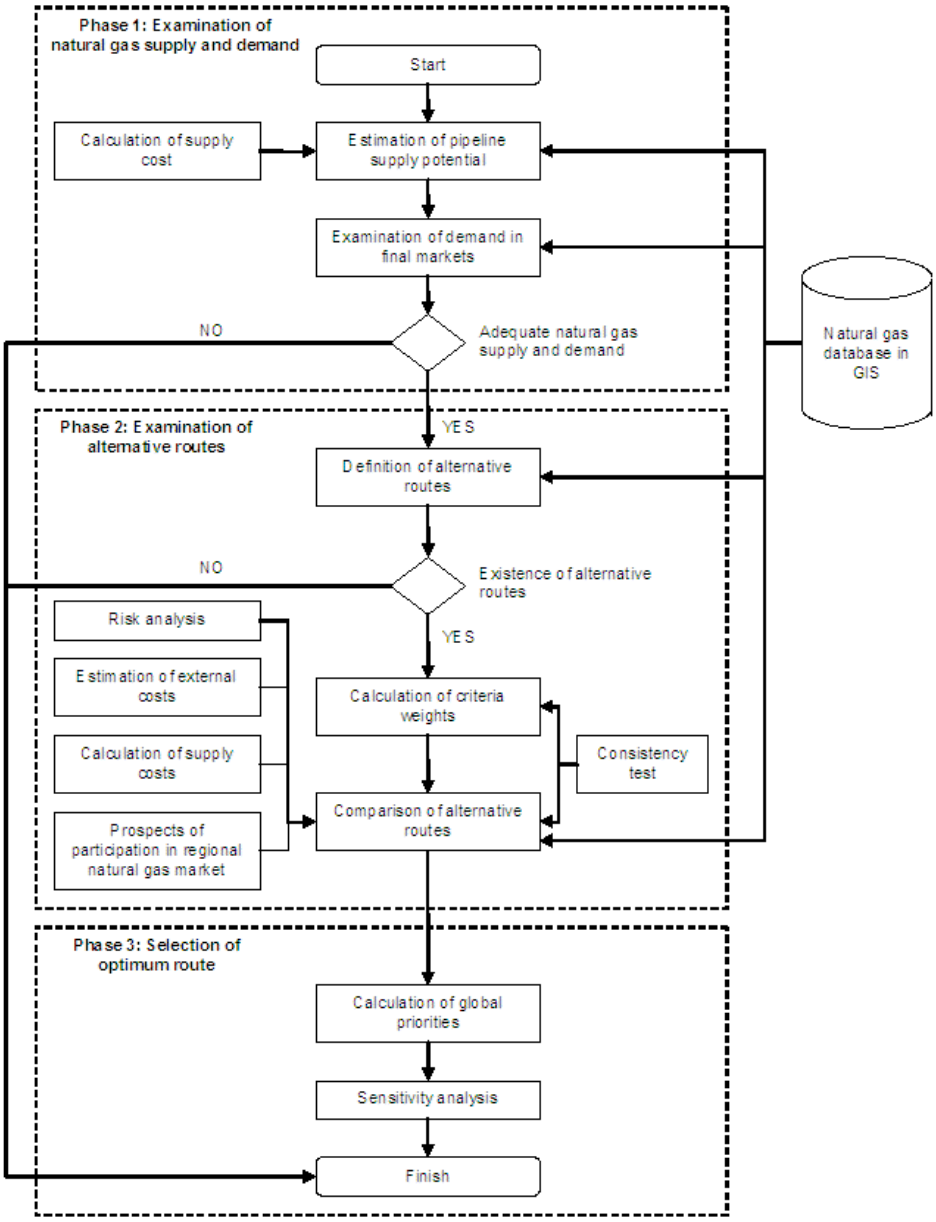

Figure 1: Flowchart of optimum route selection method.

If the supply potential is limited, or the demand at the final markets cannot justify transportation of large gas volumes, then construction of the pipeline is not economically viable, thus the method is terminated.

Phase 2: Examination of alternative routes

In the second phase the decision maker selects the group of alternative routes. The alternative routes are then compared using the hierarchic structure of Figure 2 [12].

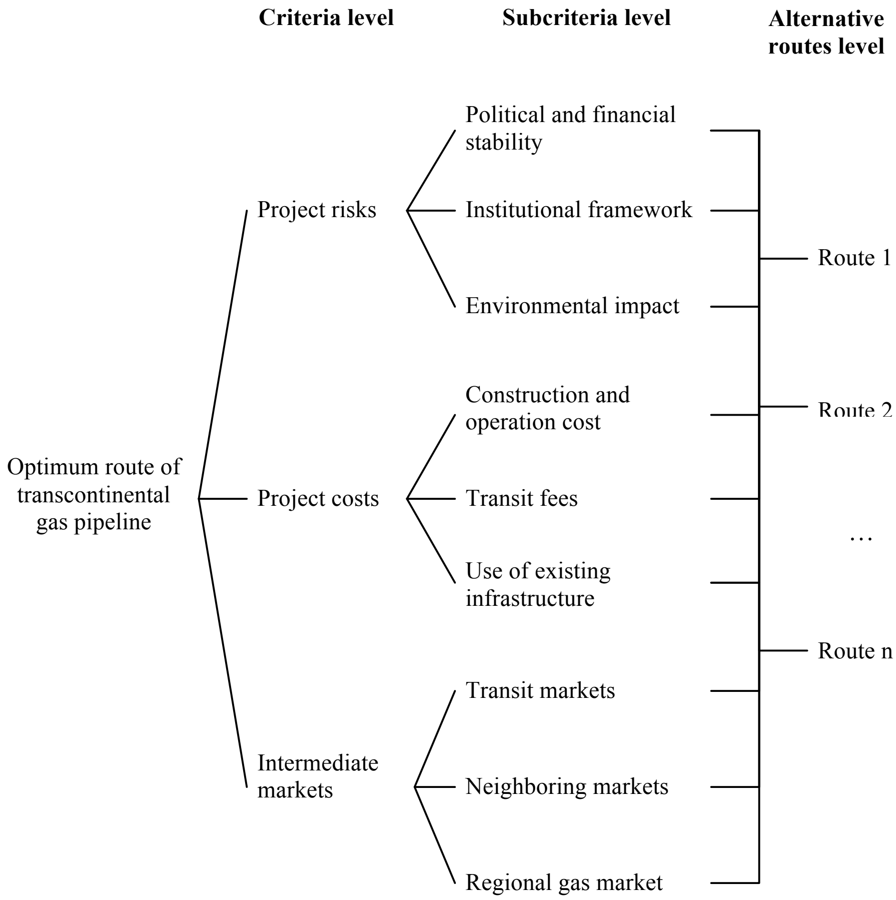

Figure 2: Hierarchic structure for comparison of alternative pipeline routes.

The **project risks** criterion reflects the characteristics of the transit regions that influence the construction and operation of the pipeline. In includes examination of the political and financial stability of the transit markets, the homogeneity of institutional frameworks along the pipeline and the potential environmental impact of the pipeline. The **project costs** criterion includes the pipeline construction and operation cost, the transit fees paid to third countries and the potential use of existing infrastructure to transport gas to other markets. The **intermediate markets** criterion concerns the prospects of supplying gas to the transit markets, neighboring markets and to regional gas markets.

Calculation of the criteria weights and the performance of the alternative routes on the criteria is carried out using the AHP method. This method is selected because it allows examination of both quantitative and qualitative criteria and takes advantage of the available data on the alternative routes and the experience and expertise of the decision maker [12]. Comparison matrices are constructed for the criteria, subcriteria and alternative routes. The elements of each matrix are compared in pairs and graded using a numeric scale 1 – 9. The primary right eigenvector of each matrix is then calculated, to define the local priorities [13]. The uncertainty of the comparison matrices is examined by performing consistency tests. Two methods are used, the consistency ratio of Saaty (eq. 1) and the method of Alonso – Lamata (eq. 2) [12].

$$CR = \frac{CI}{RI}, \qquad CI = \frac{\lambda_{max} - n}{n - 1} \qquad (1)$$

where CR is the consistency ratio, RI the random consistency index, CI the consistency index, λ_{max} the maximum eigenvalue of the comparison matrix and n its size.

$$\lambda_{max} < n + \alpha\,(1{,}7699\,n - 4{,}3513) \qquad (2)$$

where α the consistency limit, defined by the decision maker.

Comparison of the alternative routes requires the examination of large amounts of information regarding the routes. The method applies methodological tools that support the decision maker, by facilitating the management of all this information. These tools are:

- Natural gas database, developed on the GIS, which includes worldwide information regarding the natural gas markets, fields and infrastructure.
- Risk analysis, using country risk and regulatory risk indicators of each route's transit countries. The routes are classified into risk groups according to their minimum risk indicator and for each route the mean, coefficient of variance and coefficient of semivariance are calculated.
- Estimation of external costs, which reflect the environmental and social impact of the pipeline. To assess these costs for each route, the environmental sensitivity and population density of the transit regions are taken into consideration.
- Calculation of supply costs, which reflect the total cost for transportation of gas from the production field to the final market. The supply costs include the gas production cost at the field, the transport cost, which corresponds to the minimum gas price at the final market resulting in depreciation of the project investment after a given period of time and the transit fee, which depends on negotiations between the transit country and the company that transports the gas. If not all the required economic information of the pipeline are available, the transport cost can be

calculated by applying a learning curve linear function, that uses data from projects that have already been completed [14].

- Method that assesses the prospects of the transit countries for integration in a regional natural gas market. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is used with criteria regarding the country's network characteristics, natural gas regulatory framework and gas market functioning [15].

Phase 3: Selection of optimum route

In the third phase, the local priorities of the second phase are used to calculate the global priorities of the alternative routes (eq. 3), which define the ranking of the alternatives. The route with the highest global priority is considered the most preferred.

$$P_{tot,i} = \sum_{j=1}^{m} w_j p_{ij} \qquad (3)$$

where $P_{tot,i}$ the global priority of route i, w_j the weight of subcriterion j (calculated by multiplying the weight at criteria level with the weight at subcriteria level) and p_{ij} the performance of route i at the subcriterion j.

The ranking of the routes depends on the selections of the decision maker, concerning the importance of the criteria. Sensitivity analysis is performed to examine the connection between the final results and the initial conditions of the problem. The method is concluded with the selection of the optimum route.

3 Method application

The method is applied in the case of a transcontinental pipeline that belongs to the energy corridor connecting the broader Caspian Region to the European Union [12, 14].

Phase 1: Examination of natural gas supply and demand

Assessment of the supply potential of the region (Azerbaijan, Egypt, Iran, Iraq, Kazakhstan, Turkmenistan, Uzbekistan) shows that the examined countries have abundant available natural gas volumes however transportation of the produced gas from the large fields to the entrance of the transcontinental pipeline is hindered due to the lack of sufficient export infrastructures. The final markets of the application (Austria, France, Germany, Italy) have increasing gas demand and high dependency on imports, thus flow of Caspian gas to these markets would allow them to cover part of the future consumption and to diversify their supply sources.

Phase 2: Examination of alternative routes

Four alternative routes are examined, with starting point the town of Erzurum at eastern Turkey and ending point the Austrian gas system (Figure 3); the older route of the Nabucco pipeline (route 1), the current route of Nabucco (route 2), the trans-Balkan pipeline (route 3) and a route suggested by KEPA, passes through northern Greece, embodying part of the Greece – Italy interconnection (route 4).

Figure 3: Alternative routes of transcontinental pipeline.

Since the application was carried out without the participation of a decision maker who would proceed to the final decision for construction of the pipeline, three scenarios of criteria importance are examined:

- Scenario 1 (S_1): Project risks are the most important criterion.
- Scenario 2 (S_2): Project risks and costs have equal importance.
- Scenario 3 (S_3): Prospects of supplying gas to the intermediate markets is more important than the other criteria.

The local priorities of the hierarchic structure are calculated using the AHP method. The weights of the criteria and subcriteria levels for the three scenarios and the performance of the alternative routes are presented in Figure 4.

Phase 3: Selection of optimum route

Table 1: Global priorities of alternative routes.

	S_1	S_2	S_3
Route 1	0.217	0.220	0.246
Route 2	0.316	0.285	0.251
Route 3	0.096	0.130	0.089
Route 4	0.371	0.365	0.414

Equation 3 is used to calculate the global priorities of the alternative routes. Route 4 has the highest global priority for all three scenarios (Table 1), while sensitivity analysis shows that this route remains better than the other alternatives, regardless of the selected weights. Thus route 4 is selected as optimum.

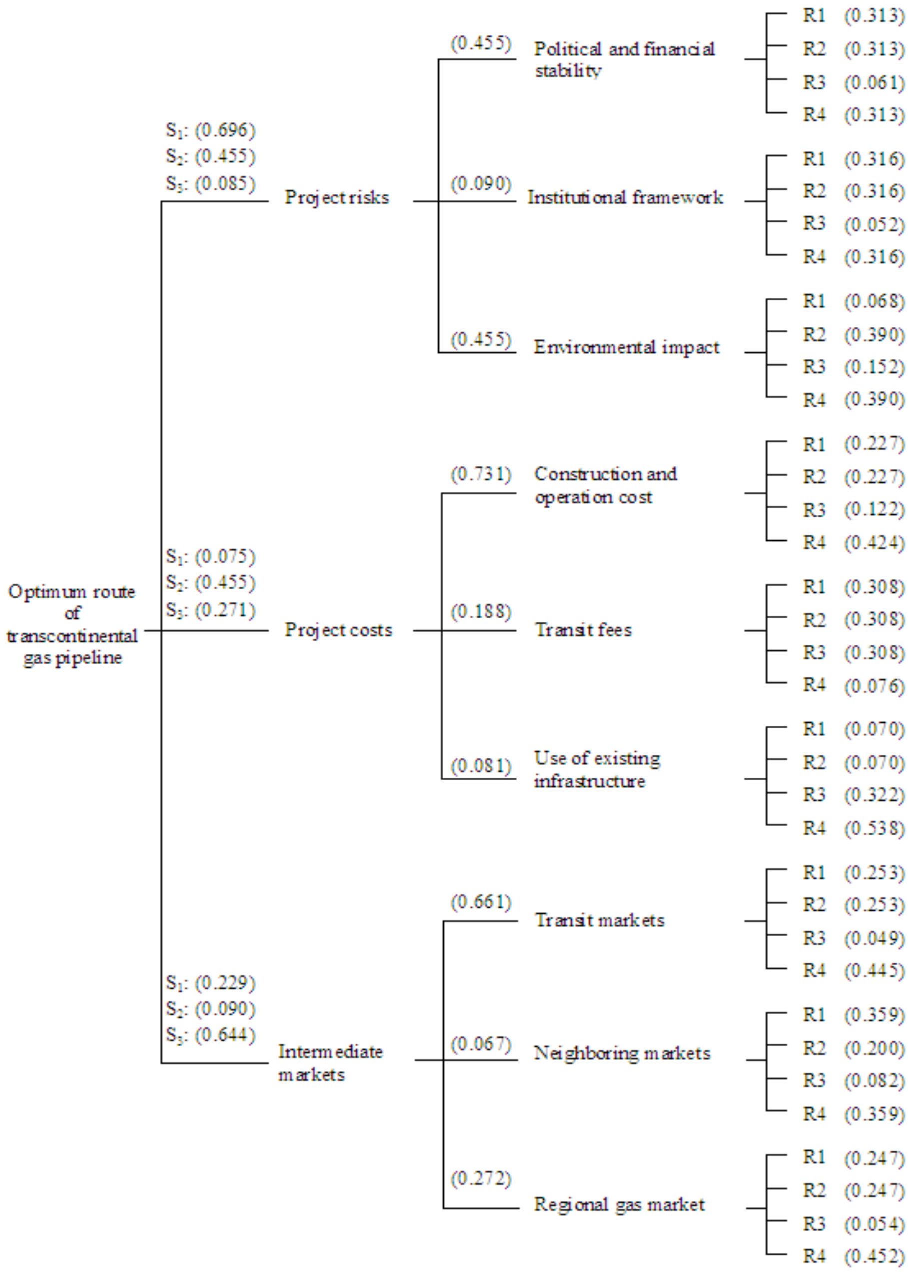

Figure 4: Local priorities of the hierarchic structure.

4 Gas-PRS software tool

The software tool Gas-PRS (Gas Pipeline Route Selector) has been developed with a view to facilitate the decision maker in applying the route selection method [16]. The software has the following characteristics:

- It allows quick implementation of the method.
- It is easy to use and includes step-by-step instructions.
- It facilitates the decision maker in studying the results of different initial conditions.
- It is connected to a natural gas database and to GIS maps, which can be easily updated.
- It automatically tests the consistency of the comparison matrices.

5 Conclusions

The method presented in this dissertation has been designed to select the optimum route of a transcontinental natural gas pipeline from a group of proposed alternatives. It addresses the complexity of the problem by examining the two main conditions for economic viability of the pipeline, assessing all the parameters that determine the pipeline route though a suitable hierarchic structure and facilitating the management of the required large amounts of information with a set of appropriate methodological tools. The final results of the method depend on the selections of the decision maker regarding the criteria weights and the availability and reliability of information for the alternative routes.

The method can be used by consortia constructing transcontinental pipelines, Governments of countries that aim to export, import or transit natural gas, International Organizations, such as the European Commission and international funding organizations such as World Bank and European Bank for Reconstruction and Development.

The method is applied in the case of a transcontinental pipeline of the south energy corridor, connecting the broader Caspian Region and Egypt with the E.U. The application has shown that despite the large natural gas resources of the Caspian Region, the pipeline cannot be filled, due to the lack of export infrastructure. Four alternative pipelines starting in Erzurum and ending in the Austrian borders are compared. The three examined scenarios and the sensitivity analysis lead to the conclusion that the optimum is the route which travels through northern Greece, embodying part of the Greece – Italy interconnection, and then branched north to Bulgaria. This route is a "win – win" option as it transits only through European member states, thus ensuring a level of political, financial and regulatory stability, it has decreased construction and operation costs due to the use of the Greece – Italy interconnection, it crosses large (Hungary, Romania) and emerging (Greece) natural gas markets, its location in the center of S.E. Europe allows connection of the pipeline to the Western Balkan gas systems.

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