Optimization of Gas Pipeline Route Selection with Goal Programming Considering Environmental Aspects

Soufyan Maliki and Farizal
Department of Industrial Engineering
Universitas Indonesia
Depok – West Java, 16424, Indonesia
soufyan.maliki@ui.ac.id, farizal@eng.ui.ac.id

Abstract

Route selection is one of important activities when gas pipeline infrastructure wants to be built. When selecting any route many aspects are considered such as environment, social, economic and others. Peatland and conservation areas are two major environment aspects in Indonesia to be taken account. Besides, economical aspect and social return are also considered. A goal programming model is developed in order to reflect those aspects. To get the optimum solution when selecting a gas pipeline route, genetic algorithm is used. In this paper, gas pipeline infrastructure project in Kalimantan in Indonesia is selected to be studied since it is one of gas producer region and has special environmental condition such as peatland and conservation area. Data of geographical information is retrieved from the authorized institution website in Indonesia. In this study, it is found that the shortest route has length and cost estimation, 810 km and 760,789,510 USD respectively. By goal programming, the length and cost are proposed as 900 km and 892,904,583 USD, respectively. Estimated emission of CO_2 to atmosphere is, 55,917ton CO_2/year, which is 40% smaller than the shortest route. Impacted Conservation area is 0,64 km^2, which is 64% smaller than the shortest route.

Keywords
Genetic Algorithm, Geographic Information System, Goal Programming, Peat Land, and Pipeline Route

1. Introduction

Natural gas as one of energy source may have some means of transportation. It can be delivered as its natural form, as vapor. Another form of delivering natural gas is as liquid. When it is necessary to deliver gas from the source to the destination in the same land or island, pipeline is considered as the best option. Some papers mentioned studies in gas or oil pipeline route selection. Marcoulaki et al. (2012) did a study in optimization objectives which included capital cost, consumption of energy when the facility is operated, maintenance and reparation cost, and the risk of the facility to the environment. Simulated annealing was applied to solve the problem. Route Optimization of submarine pipeline were examined by Lucena et al (2014) using genetic algorithm, to solve multi objective case. Zhou et al (2016) assessed two phase flow fluid when optimizing pipeline route. General genetic algorithm (gGA) and steady state genetic algorithm were used to solve the automatic route model. Baeza et al (2017) did as study on pipeline route for ore concentrate which the fluid state is slurry. On the study, two algorithms were compared, Ant Colony optimization and Dijkstra algorithm. Kang and Lee (2017) compared two methods of pipeline route selection by using Dijkstra least cost path (LCP) and Laplacian smoothing algorithm. Yildrim et al (2016) used other types of method, they are simple additive weighting (SAW), analytic hierarchy process (AHP), and technique for order preference by similarity to ideal solution (TOPSIS) to solve spatial multicriteria decision making of gas pipeline routing.

When the pipeline route will be determined, many aspects should be considered (Mohitpour et al., 2000):

- Cost efficiency
- Pipeline integrity
- Impact to environment
- Public security
- Land use limitation
- Proximity to the facility

Every location where the pipeline will be installed has the different landscape and condition. It may relate to the climate of the location. The area near pole is different with the area in the equator. The area in the desert is different from the area in the tropical area which has heavy rainfall. Beside the difficulty of construction, the sustainability aspects should be in the mind of pipeline project decision maker. Decision maker should achieve minimum impact to environment whenever the impact cannot be avoided.

In this paper, we would like to include environmental factor which has major role in balance of ecosystem in the tropical land area, they are tropical peatland and conservation area. We found it is still rare, where a study includes these aspects. Why peatland is an important ecosystem has been analyzed in many papers. For only, 12% of peatland area globally, tropical peatland holds more than 20% of peatland carbon stock globally (Joosten, 2010). The contribution of CO_2 emission due to function degradation of peatland in South East Asia is about 1.3% to 3.1% of current global CO_2 emission from fossil fuel combustion (Hooijer et al., 2010). The effect of disturbing the peatland, some amount of CO_2 will be emitted to atmosphere. In tropical countries, many regions are now set as conservation zone by the government. The conservation areas conserve the local and special animals dan vegetations which are basically prohibited to disturb. Gas pipeline route selection in Kalimantan, Indonesia is focused as a case to be studied in this paper. Kalimantan has important tropical peatland and several conservation areas.

Since there are multi objectives want to be achieved, we should develop mathematical model which represents those purpose. One of model usually developed in this case is goal programming. Goal programming purpose is to find solution which is a tradeoff many objectives. There are many kinds of goal programming model. Two type are well known are pre-emptive (lexicographic) goal programming and weighting goal programming. Lexicographic goal programming will be used to find solution among several defined criterions in pipeline route selection.

The aim of this study is to understand the effect of two major environment aspects, i.e. total CO_2 emission due to peatland intervention and how much conservation area will be impacted in gas pipeline route selection. As per literature study, the use of goal programming in gas pipeline route selection still less. In this study, it is expected to have better understanding in using goal programming to solve the route selection case.

2. Methods

2.1 Data

Sources and demand of gas information in Kalimantan Island, as the object of this study, is referred to Indonesian government, Ministry of Energy and Mineral Resources report. According to the document, the gas flowrate, 300 MMscfd, will be used as basis for this study.

Geographical Information System provides data which are required in this study. Here are data were retrieved from some authorized websites, (i.e. http://tanahair.indonesia.go.id and http://geoportal.menlhk.go.id):

- Administrative regencies/districts/sub-districts
- Settlement of population
- River, lake, and other water appearance
- Peatland Areas
- Conservation Areas
- Contours
- Others

The raw data are processed by using Quantum GIS Software, version 3.6. Noussa. By using the software some information can be shown and interpreted easier.

2.2 Calculation

Isothermal fluid flow

Some formula is commonly used in oil and gas pipeline application when considering the flowing fluid is in Isothermal condition. Panhandle A formula is used for natural gas pipelines and it is applicable for partially turbulent (hydraulically smooth) flow. Panhandle B formula is used for long transmission lines and applicable for fully turbulent flow. Weymouth formula is used for sizing gas pipelines and applicable for fully turbulent flow (Crane, 2013). In this study, the pipe size is determined by calculation of Panhandle A formula, shown on equation below (Crane, 2013),

$$q'_h = 18.161E\left(\frac{T_b}{P'_b}\right)^{1.0788}\left[\frac{(P'_1)^2-(P'_1)^2}{L_m T_{avg} S_g^{0.8539}}\right]^{0.5} d^{2.6182} \quad (1)$$

where,
d = internal diameter (in)
E = efficiency factor (unitless)
L_m = length of pipe (ft)
P'_b = absolute pressure at standard conditions = 14.7 psia
q'_h = rate of flow at standard condition (14.7 psia and 60ºF) in millions of cubic feet perday (MMscfd)
S_g = specific gravity of gas relative to air = the ratio
T_{avg} = average temperature (ºR)
T_b = absolute temperature at standard condition = 520 ºR
Pressure drop is main concern in size selection, since the pressure should not drop drastically. As per calculation the size will be 32".

Cost estimation
For cost estimation, equation which consider inflation is used (Mc.Allister, 2009):

$$C(y) = DAme^{i(y-1980)} \quad (2)$$

where,
C(y) = cost of the pipe in year y
D = diameter pipeline in inch
A = average cost of pipeline construction per inch-diameter-mile
m = length of pipelines in miles
i = continuously compounded rate of inflation
y = year of which the cost estimate is desired

Year	Diameter of pipe, inches	Average cost US$ / (inch diameter × mile)	Range US$ / (in. dia. × mile) Low	high	Average % inflation since 1964*
1964**	10	2,059	—	—	—
	16	2,849	—	—	—
	20	2,632	—	—	—
	24	3,325	—	—	—
	30	4,085	—	—	—
	36	4,260	—	—	—
1980***	8	16,920	6,953	24,125	—
	12	18,446	13,882	16,644	—
	16	10,823	9,200	12,368	8.3
	20	14,226	12,039	16,698	10.5
	24	14,738	8,184	28,263	9.3
	30	16,730	13,100	28,756	8.8
	36	25,468	19,087	33,929	11.2

*Compounded continuously; from $100\% \times \left(\ln\left(\frac{A\ 1980}{A\ 1964}\right)\right) \div 16$.

**Source is *Pipeline Rules of Thumb Handbook*,[1] and these figures are based on 1964 data from the Federal Power Commission.
***Based on averages of costs for onshore projects from FERC Construction Permit applications as reported in the *International Petroleum Encyclopaedias*.[5]

Figure 1. Pipeline rule of thumb cost estimate, Cost = D x A x Miles of pipeline (McAllister, 2009)

Four cost components which commonly used are right of way (ROW), material, labor, and miscellaneous (McAllister, 2009). Other cost related items, can be categorized or included into one of those components. It is also necessary to consider location factor since many cost references are from USA. The location factor for South-East Asia is 0.8 of USA/Canada (IEA, 2002).

CO_2 emission
To estimate the amount of CO_2 emission to atmosphere, below equation is used (Hooijer, 2010):

$$CO_2 emission = LU_{Area} x\ D_{Area} x D_{Depth} x CO_{2_{1m}} [t/y] \quad (3)$$

Where,
LU_Area = peatland area with specific land use [ha]
D_Area = drained area within peatland area with specific land use [fraction]
D_Depth = average groundwater depth in drained peatland area with specific land use [m]
CO_2_1m = CO_2 emission at an average groundwater depth of 1m = 91 [t CO_2 $ha^{-1}y^{-1}$]

2.3 Mathematical Modelling

The mathematical model which contains variables in route selection are shown below:
Goal Constraints:
1. Total Pipeline Length, in km:
$$\sum_{i=1}^{m}\sum_{j=1}^{n} L_{ij}\, x_{ij} - d_1^+ = 1{,}210 \quad (2)$$
2. Total Pipeline Cost, in millions USD:
$$\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}\, x_{ij} - d_2^+ = 1{,}355 \quad (3)$$
3. Total CO_2 emission, in ton CO_2 per year:
$$\sum_{i=1}^{m}\sum_{j=1}^{n} E_{ij} x_{ij} - d_3^+ = 60{,}000 \quad (4)$$
4. Total Conservation Area, in km^2:
$$\sum_{i=1}^{m}\sum_{j=1}^{n} AV_{ij}\, x_{ij} - d_4^+ = 2 \quad (5)$$
5. Total Population, in peoples
$$\sum_{i=1}^{m}\sum_{j=1}^{n} N_{ij}\, x_{ij} + d_5^- = 1{,}000{,}000 \quad (6)$$

Hard Constraint:
6. Total Pressure Drop, in psi
$$\sum_{i=1}^{m}\sum_{j=1}^{n} PD_{ij} x_{ij} \le 500 \quad (7)$$

$x_{ij} = 1\ if\ the\ route\ is\ selected$
$x_{ij} = 0, if\ others$
$i = 1,2,3, \dots, m$
$j = 1,2,3, \dots, n$
$d_k^-, d_k^+ \geq 0$, $k = 1, 2, \dots, p$

Objective Functions with Preemptive Method
Priority 1: Minimize (d_3^+)
Priority 2: Minimize (d_4^+)
Priority 3: Minimize (d_2^+)
Priority 4: Minimize (d_1^+)
Priority 5: Maximize (d_5^-)

2.4 Algorithm for solving goal programming model

Several methods can be applied in solving goal programming model. In this study, genetic algorithm is selected since it has wide spectrum of application. Genetic algorithm is a search technique which is used in computing to find true or approximate solutions to optimization and search problems. This algorithm inspired by evolution theory in biology. Some terms are used in genetic algorithm, such as:

- Individual – any solution which is possible
- Population – individuals in group
- Fitness – target function for optimization (each individual has a fitness)
- Trait – possible aspects (features) of an individual
- Genome – collection of all chromosomes (traits) for an individual

3. Result and Discussion

It is found that the criteria of environment influenced the result of route selection. The shortest route has length and cost estimation, 810 km and 760,789,510 USD respectively. By goal programming, the length and cost are proposed as 900 km and 892,904,583 USD, respectively. Estimated emission of CO_2 to atmosphere is, 55,917ton CO_2/year, which is 40% smaller than the shortest route. Impacted Conservation area is 0,64 km^2, which is 64% smaller than the shortest route. Population near the pipeline route indicates one of social aspects. It is considered, that potentially the population will use gas as the main energy source. The government may decide to develop another project of gas city network to utilize the gas in the city or region. Population near the route of pipeline is 983,371 people, which is 32% higher than the shortest route. Total Pressure drop across the pipeline will be 322 psi. It higher 13% from the shortest route. It shows that the longer pipe will result the higher total pressure drop. But, since it is still lower the target, we can use this margin to get optimum result in overall aspects.

4. Conclusion

It will be much better to project decision maker or manager to use goal programming model to determine or select the best route of pipeline since multi criteria and objective are considered. We will get the optimum result from many possibilities of route. The prioritized criteria will govern the result of optimization.

Further study is required to set more points or nodes in order to get more data, hence more accurate result will be achieved. Other criteria and objective may be added according to the location's condition, climate, etc. Political and social aspect basically is quite hard to be quantified. But, by combining more than one method may be a good approach to be done. Comparing the genetic algorithm with another algorithm to solve this goal programming case seems necessary to have better view in optimization. Required time when the algorithm is running and the result itself can be analyzed.

Acknowledgements

This study has been supported partially by PITTA 2019 Grant funded by DRPM Universitas Indonesia under contract No.: NKB-0732/UN2.R3.1/HKP.05.00/2019.

References

Badan Informasi Geospasial, Peta per wilayah, *http://tanahair.indonesia.go.id*

Baeza, D., Ihle, C.F., and Ortiz, J.M., A comparison between ACO and Dijkstra algorithms for optimal ore concentrate pipeline routing, *Journal of Cleaner Production* 144, pp. 149-160. 2017

Crane, Flow of fluids through valves, fitting, and pipe, *Technical Paper No. 410*, pp. 1-9, 2013.

De Lucena, R,R, Baioco, J.S., de Lima, B.S.L.P., Albretch, C.H., and Jacob, B.P., Optimal design of submarine pipeline routes by genetic algorithm with different constraint handling techniques, *Advances in Engineering Software* 76, pp. 110-124, 2014.

Hooijer, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk, J., Wosten, H., and Jauhiainen, J., Current and future CO_2 emissions from drained peatlands in Southeast Asia, *Biogeosciences* 7, pp. 1505-1514, 2010.

IEA, Transmission of CO_2 and energy. *IEA Greenhouse Gas R&D Programme*, Report no. PH4/6, 2002.

Joosten, H., The global peatland CO_2 picture: peatland status and drainage related emissions in all countries of the world. *Wetlands International*, 2010.

Kang, J.Y. & Lee, B.S. Optimisation of pipeline route in the presence of obstacles based on a least cost path algorithm and laplacian smoothing. *International Journal of Naval Architecture and Ocean Engineering 9,* pp. 492-498, 2017.

Kementerian Energi dan Sumber Daya Mineral, *Neraca Gas Bumi Indonesia 2018-2027*, pp. 94-101, 2018.

Kementerian Lingkungan Hidup dan Kehutanan, Peta lahan gambut Indonesia, http://geoportal.menlhk.go.id

Marcoulaki, E.C., Papazoglu, I.A., and Pixopoulou, N., Integrated framework for the design of pipeline systems using stochastic optimisation and GIS tools, *Chemical Engineering Research and Design* 90, pp. 2209-2222, 2012.

Mohitpour, M., Szebo, J. and Hardeveld, T.V., *Pipeline Design and Construction*. ASME Press. New York., pp. 23, 2000

McAllister, E.W., *Pipeline Rules of Thumbs Handbook* 7th ed. (Gulf Professional Publishing), pp. 635-689, 2009.

Taha, H.A. *Operation Research an Introduction*, 8th ed. (Pearson Prentice Hall), pp. 329-344, 2007.

Yildrim, V., et al. A spatial multicriteria decision-making method for natural gas transmission pipeline routing. *Structure and Infrastructure Engineering*, 2016.

Zhou, J., Liang, G., Deng, T., and Gong, J., Route optimization of pipeline in gas-liquid two-phase flow based on genetic algorithm, *Hindawi International Journal of Chemical Engineering*, Article ID 1640303, 2017.

Biographies

Soufyan Maliki. He earned B.S. in Chemical Engineering from Bandung Institute of Technology, Indonesia. Soufyan has about 15 years of experience as Process Engineer. He has joined some local and international oil and gas facility projects with various scale of project, from small to mega project. He is a member of Indonesian Engineer Society PII). He is now a student of Graduate Program in Department of Industrial Engineering, Universitas Indonesia.

Farizal, PhD is Lector (comparable to Assistant Professor) at Department of Industrial Engineering, Universitas Indonesia. His research is on renewable energy planning and optimization. He has developed a model to select suitable energy sources among available renewable energy sources using quantitative and qualitative methods, conducted energy demand forecast and oil and gas forecast. Currently, his focus is on municipal solid waste (MSW) to energy. He has conducted a complete research on MSW utilization started from MSW potency research, MSW plant location determination, MSW collection routing determination, MSW plant financial model, and MSW plant business model. Currently he also serve as editorial board of Makara Journal of Technology (MJT).