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SUPPLY CHAIN MODEL FOR GAS PIPELINE

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ABSTRACT

Gas pipeline networks are widely used for gas transportation from gas sources to consumers. The main problem into the gas transfer is to accurately estimate the cost of transportation from production sites to the consumers. From the review of literatures is noted that the computation for optimization of the gas piping did not take into account the gas capacity allocated to each source, processing unit and distribution unit. Also the productive capacities of the different units are considered having the same and constant supply. The main objective of the study is to propose a linear integer programming model for gas distribution network from production sites to consumers for attainment the minimum cost of gas transportation. Incorporating variable capacity and supply of the units. Integer programming adopt the Zero-One approach for solving the model. This model simplify the analysis. The model was applied for analysis of north of Iran's gas. The result reveals that cost of transportation could be reduced approximately by 23 per cent of the transportation cost in comparison to current cost.

Keywords: supply chain model, linear programming, gas network optimization.

INTRODUCTION

In linear programming, several optimal design problems may be formulated using linear parameters. This work presents a new simplified approach by modeling the network to be a linear programming problem. Integer programming was used to solve the model of this problem. The model was used to analysis gas distribution network by using north of Iraniangas distribution network as the case study. In this world, the private and public organizations and companies are looking for earning more benefits. They are looking for decreasing the costs and increasing the benefits. For these reasons, the optimization in their current field is necessary. There are many optimization models for this kind of problem, Such as dynamic programming(Lall and Percell, 1990, Carter, 1998, Wu, Rios-Mercado *et al.*, 2000, Si, 2004), Ant Colony model (Mohajeri, Mahdavi *et al.*, 2012), Genetic algorithm (Djebedjian, El-Naggar *et al.*, Sidarto, Riza *et al.*), fuzzy algorithm (ŠINDEL and ˇR, 2003), minimum spanning tree model (Mahdavi, Mahdavi-Amiri *et al.*, 2010), mixed integer nonlinear programming (Hamedi, Farahani *et al.*, 2009, Saldarriaga, Hincapie *et al.*, 2013) andzero-one programming model (Pritsker, Waiters *et al.*, 1969, Toyoda, 1975, Doersch and Patterson, 1977, Sherali and Adams, 1990, Kuo, Glover *et al.*, 1993, Palubeckis, 1995, Golenko-Ginzburg and Gonik, 1997, Wei and Chang, 2008, Yahyazadeh and Abd Majid, 2015). With zero-one model we are able to show the active or non-active stations by considering the value one for active and the value zero for non-active stations. Also, it is simple to show the connection between centers with zero-one model. Means, if the connection value calculated is one, that connection is active in the optimum network for gas transportation. The model is for finding the optimum network with lowest cost for gas transportation. It means, the gas transportation network that is calculated from this model has optimum cost.

The cost of transportation of the model is based on distance between centers. Labor cost, facility cost for installation and gas pipe cost are considered for cost of each kilometer of distance between centers.

Mathematical model

The variables for the model are: (1) capacity of producing stations, (2) capacity of gas receiving and refining of refinery centers, (3) capacity of gas compressor stations, (4) amount of consumer demands, (5) transfer distances, (6) cost of transportation by the pipeline, and (7) active or inactive stations. For solving the proposed zero-one model, spreadsheet was used.

The aim of the proposed model is to find the optimum cost of gas transportation from sources to consumers. There are two parts for objective function as follows:

- Cost of transportation from gas production sites to refinery centers (Z_1). This is represented by Part (a) in Figure-1.
- Cost of transportation from refinery centers to consumers and compressor stations, and also from compressor stations to the consumers (Z_2). This is represented by Part (b) in Figure-1.

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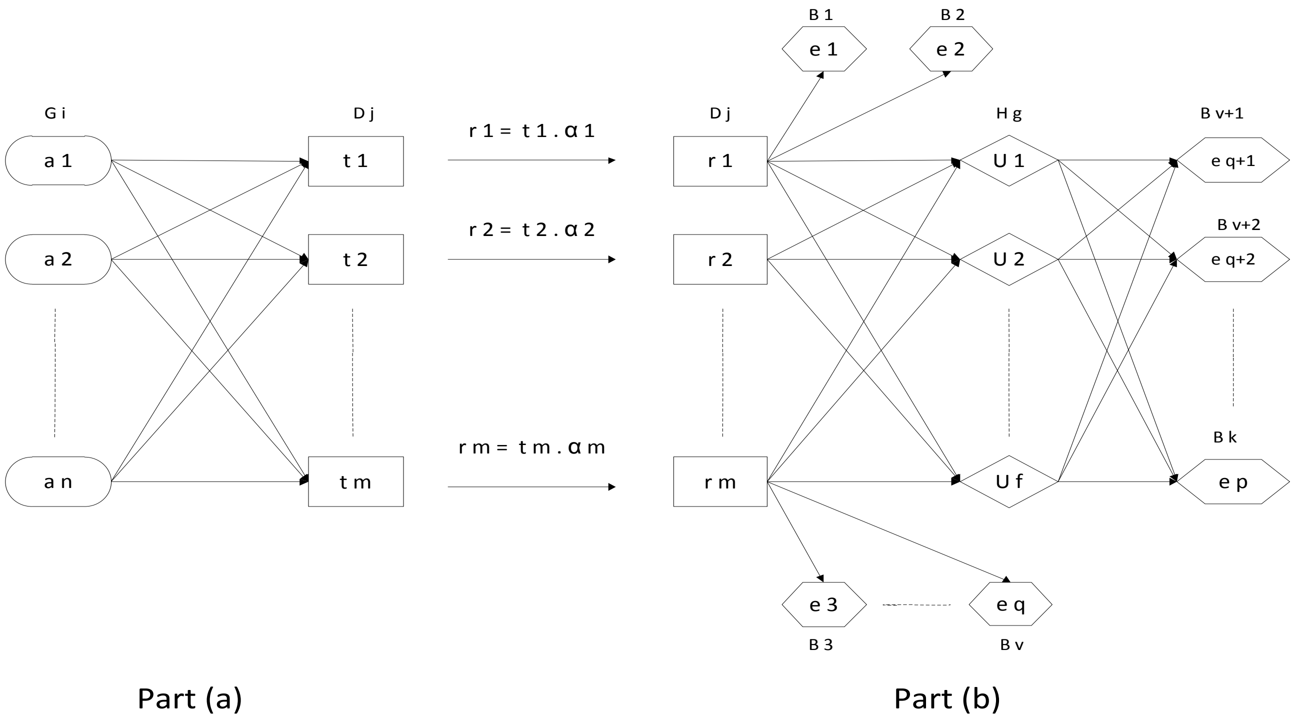

Figure-1. (a) Transportation model between production sites and distribution centers and (b) transportation model between distribution centers, consumers and compressor station.

The total cost is:

$$Z = Z_1 + Z_2 \tag{1}$$

The objective functions for Z_1 and Z_2 are represented by Equations (2) and (3) respectively;

$$Minimize\ Z_1 = cp * \sum_i^n \sum_j^m dp_{ij} * S_{ij} * x_{ij} \tag{2}$$

$$Minimize\ Z_2 = cd * \sum_v^q \sum_j^m dd_{jv} * B_{jv} * y_{jv} + ck * \sum_j^m \sum_g^f dk_{jg} * H_{jg} * l_{jg} + cc * \sum_g^f \sum_k^p dc_{gk} * W_{gk} * o_{gk} \tag{3}$$

$i = 1,2, \dots, n$
$j = 1,2, \dots, m$
$g = 1,2, \dots, f$
$v = 1,2, \dots, q$
$k = 1,2, \dots, p$
$S_{ij}, B_{jv}, H_{jg}, w_{gk} = 0\ or\ 1$
x_{ij} = quantity transported from i to j
l_{jg} = quantity transported from j to g
o_{gk} = quantity transported from g to k
y_{jv} = quantity transported from j to v

For first objective function (Z_1):

cp = unit cost of gas transportation from gas production sites to refinery centres for each kilometre.

dp_{ij} = distance between production sites$i$ and refinery centres*j*.

S_{ij} = connection between gas production sites *i*to the refinery centres *j*showing the active or non-active connections.

x_{ij} = amount of gas transported from gas production sites *i*to refinery centres*j*.

For second objective function, there are three parts.

First part is the cost of transportation between refining centres to consumers:

cd = unit cost of gas transportation from refinery centres to consumers for each kilometre.

dd_{jv} = distance between refinery centers$i$ and consumers*v*.

B_{jv} = connection between refining centers$i$ to consumers'*v* showing the active or non-active connections.

y_{jv} = amount of gas transported from refining centers*j*to consumers*v*.

Second part is the cost of transportation between refining centers to compressor stations:

ck = unit cost of gas transportation from refining centers to compressor stations for each kilometer.

dk_{jg} = distance between refinery *j*centers and compressor stations$g$.

H_{jg} = connection between refining centers j to compressor stations g showing the active or non-active connections.

l_{jg} = amount of gas transported from refining centers j to compressor stations g.

Third part is the cost of transportation between compressor stations to consumers:

cc = unit cost of gas transportation from compressor stations to consumers for each kilometer.

dc_{gk} = distance between compressor stations g and consumers k.

w_{gk} = connection between compressor stations g to consumers k showing the active or non-active connections.

o_{gk} = amount of gas transported from compressor stations g to consumers k.

Every refinery station has productivity factor (α). That means, the quantity of output in refining centres is less than or equal to quantity received. If one of these quantities was non-active value that is zero and gas will not be transported from these centres. S_{ij}, B_{jk}, H_{jg} are zero-one values.

There are two constraints for Part (a):

$$\sum_i^n \sum_j^m S_{ij} * x_{ij} \leq \sum_i^n a_i \quad (4)$$

Amount of gas production from every gas production sites (a_i) is different because some of these sources are very large and some of them are small. For exploitation of these sources, gas production sites (G_i) are installed at these sources. Capacities of production are high when gas stations are bigger and have better facilities. Hence the constraint of production capacity for every station must be considered. The amount of gas extractions from gas production sites that are sent to refining centres (D_j) should be less or equal to those production capacities.

$$\sum_j^m \sum_i^n S_{ij} * x_{ij} = \sum_j^m t_j \quad (5)$$

The natural gas is sent to refineries for refinement and distribution. Every refinery has limited capacity for receiving and refining the natural gas. The amount of extracted gas from sources is more than receiving capacity of refineries (t_j). On the other hand, to increase the production, maximum capacity of the refineries must be used.

There are five constraints for Part (b):

$$\sum_j^m \sum_v^q B_{jv} * y_{jv} + \sum_j^m \sum_g^f l_{jg} * H_{jg} \leq \sum_j^m r_j \quad (6)$$

The amount of gas transportation from refinery centres to the cities and to compressor stations must equal or lower than refining capacity. (r_j), which is the amount of gas refined from refineries.

$$\sum_g^f \sum_j^m l_{jg} * H_{jg} \leq \sum_g^f u_g \quad (7)$$

The amount of gas transportation from refinery centers to compressor stations must equal or lower than compressor stations capacity. (u_g), which is the amount of compressor capacity for compress the gas to the pipes.

$$\sum_k^p \sum_g^f \sum_j^m W_{gk} * o_{gk} \leq \sum_g^f \sum_j^m l_{jg} \quad (8)$$

The amount of gas transportation from compressor station to consumers must equal or lower than the amount of receiving gas from refinery stations to compressor stations.

$$\sum_v^q \sum_j^m B_{jv} * y_{jv} + \sum_k^p \sum_g^f W_{gk} * o_{gk} = \sum_k^p e_k \quad (9)$$

The aim of gas exploitation and transporting is to fulfill the consumer demand. The consumers can be houses, offices, companies, factories, vehicles and etc. The amount of gas demand for every city (e_k) is based on size of the population and industry. The gas network transportation must fulfill all consumer demands. Means the amount of gas transportation from refinery centers and compressor stations to the cities must equal to demands.

$$\sum_j^m \sum_k^p B_{jk} * dd_{jk} \leq 150 \quad (10)$$

After gas refined into the refinery centers, the gas pressure will drop. Because gas after going to the refinery station, gas will go to the refining process. This pressure is not enough to go far to the cities. The gas after refining is suitable to send around 150 kmfar than refinery centers. That means we have one constraint for transportation distance from refinery centers. (U_{jk}), which is the distance between refinery centers and cities.

Table-1. The information of gas production sites, gas distribution centres and cities.

Gas production sites			Gas distribution centers					Gas compressor stations			Cities		
Name	**Sign**	**Capacity of production**	**Name**	**Sign**	**Capacity of receiving**	**Productivity factor (α)**	**Capacity of refining**	**Name**	**sign**	**Capacity of receiving**	**Name**	**Sign**	**Amount of demand**
South pars	G_1	300	Fajr jam	D_1	175	%72	126	Shomal	H_1	123	Tabriz	B_1	64.7
North pars	G_2	102	Parsian	D_2	93	%87	80.9	Fars	H_2	334	Tehran	B_2	65
Homa&Shanul	G_3	35.6	Ilam	D_3	15	%86	12.9	Kerman	H_3	63.6	Mashhad	B_3	31.1
Veravy	G_4	5.8	Khangiran	D_4	98	%88	86.2	Hamedan	H_4	76	Zanjan	B_4	4.4
Sarkhun	G_5	2.15	Bidboland	D_5	40	%86	34.4				Semnan	B_5	24.6
Gorzin	G_6	1.2	Sarkhun-gheshm	D_6	22	%87	19.1				Ghazvin	B_6	10
South geshoy	G_7	14.1	South parth	D_7	321.5	%72	231.5				Sananaj	B_7	4
Arash	G_8	14.6									Sari	B_8	51.5
Salman	G_9	2.2											
Tangebijar	G_{10}	10											
Khangiran	G_{11}	60											
Dalan	G_{12}	20											
Aghar	G_{13}	95.22											
Madar	G_{14}	56.6											
Khayam	G_{15}	23.7											
Halkan	G_{16}	50											

Table-2. Connection between gas production sites $i$and refinery centers j (S_{ij}).

i \ j	1	2	3	4	5	6	7
1	1	0	0	0	0	0	1
2	0	0	1	0	1	0	1
3	0	1	0	0	0	0	0
4	0	1	0	0	0	1	0
5	0	0	0	0	0	1	0
6	0	0	0	0	0	1	0
7	0	0	0	0	0	1	0
8	0	0	0	0	0	0	1
9	0	0	0	0	0	0	1
10	0	0	1	0	0	0	0
11	0	0	0	1	0	0	0
12	1	0	0	0	0	0	0
13	1	0	0	1	0	0	0
14	1	1	0	0	0	0	0
15	1	0	0	0	0	0	0
16	0	0	0	0	0	0	1

Table-3. Connection between gas refinery centers j and consumers v (B_{jv}).

j \ v	1	5	7	9	10	13	15	20
4	0	0	1	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0

Table-4. Connection between gas compressor stations g and consumers k (W_{gk}).

g \ k	1	5	7	9	10	13	15	20
1	1	1	0	0	1	0	0	1
2	0	1	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	1	0	0	1	0	1	1	0

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Table-5. Connection between gas refinery centers *j* and compressor stations *g* (H_{jg}).

j \ g	1	2	3	4
4	1	0	0	0
5	1	0	0	0
6	0	0	0	0
7	0	1	0	1

Table-6. Amount of gas transportation from production sites *i* to refinery centers *j* (x_{ij}).

i \ j	1	2	3	4	5	6	7
1	73.63	0	0	0	0	0	226.37
2	0	0	5	0	40	0	28.33
3	0	35.6	0	0	0	0	0
4	0	1.25	0	0	0	4.55	0
5	0	0	0	0	0	2.15	0
6	0	0	0	0	0	1.2	0
7	0	0	0	0	0	14.1	0
8	0	0	0	0	0	0	14.6
9	0	0	0	0	0	0	2.2
10	0	0	10	0	0	0	0
11	0	0	0	60	0	0	0
12	20	0	0	0	0	0	0
13	57.22	0	0	38	0	0	0
14	0.45	56.15	0	0	0	0	0
15	23.7	0	0	0	0	0	0
16	0	0	0	0	0	0	50

Table-7. Amount of gas transportation from gas refinery centers *j* and consumers *v* (y_{jv}).

j \ v	1	5	7	9	10	13	15	20
4	0	0	31.1	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0

Table-8. Amount of gas transportation from gas compressor stations *g* and consumers *k* (o_{gk}).

g \ k	1	5	7	9	10	13	15	20
1	7.1	5.8	0	0	24.6	0	0	51.5
2	0	59.2	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	57.6	0	0	4.4	0	10	4	0

Table-9. Amount of gas transportation from gas refinery centers and compressor stations (l_{jg}).

j \ g	1	2	3	4
4	54.6	0	0	0
5	34.4	0	0	0
6	0	0	0	0
7	0	59.2	0	76

RESULTS AND DISCUSSIONS

The information of gas production sites, refinery centers, gas compressor stations and consumers are shown in the Table-1. The numbers are based on million cubic meters per day.

The results of zero-one variable are shown in Tables 2, 3, 4 and 5. Table-2 is for Part (a) and Tables 3, 4 and 5 are for Part (b) of Figure-1. Connectivity between the centers are shown in these tables. Value 1 means gas is transporting between the current centers and value 0 means there is no connection between the current centers for gas transporting.

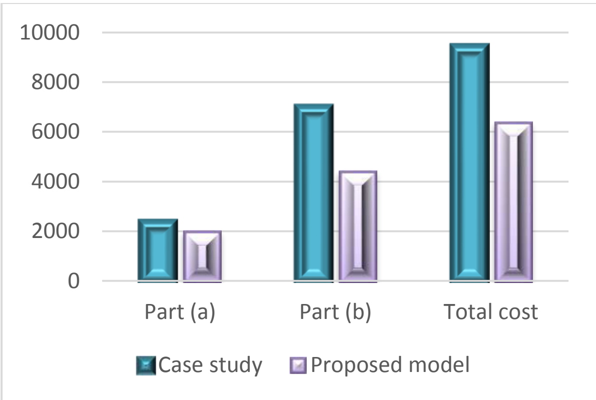

Figure-2. Comparison of model and case study.

The results of amount of gas transporting between the centers are shown in Tables 6, 7, 8 and 9. Table 6 is for Part (a) and Tables 7, 8 and 9 are for Part (b).

The results reveal that the gas compressor number 3 and the gas refinery center number 6 are not being used for gas transmission in optimum model. Excel software was used for solving the model.

Comparison of proposed model and case study is shown in Figure-2. In the Figure-2, the comparison of cost for Part (a), Part (b) and total transportation cost are shown. Costs of transportation for case study in Part (a) is 2422.7 (Million Dollars), Part (b) is 5857.2 (Million Dollars) and in total is 8279.9 (Million Dollars). Costs of transportation for proposed model in Part (a) is 1967.9 (Million Dollars), Part (b) is 4383.7 (Million Dollars) and in total is 6351.6 (Million Dollars). In comparison to the actual cost, the estimated transportation costs for Part (a), Part (b) and the total cost are reduced 19%, 25% and 23% respectively.

CONCLUSIONS

A linear integer programming model is presented in this study to determine optimal gas distribution network cost. Two parts are considered for the model. Part (a) is gas transportation between gas production sites and refinery centers. In this part, gas is transported to refinery station for refining before sending it to the consumers. Part (b) is gas transportation between refinery stations, compressor stations and consumers. After refining the gas, is transported to the consumers which are near to the refinery station. For the other consumers, gas is transported to the compressor station for increasing the gas pressure into the pipe. An optimum network presented by the proposed model for gas transporting between the centers. The proposed model resulted to saving of 1928.3 (Million Dollars) which is 23% lower than the actual cost. The model could be useful to make better decision for natural gas network due to it is capable to recognize the additional centers. For example in the result of the model is shown refinery number 6 is not active for sending gas. The new decision can be token for this center. This model also could be adapted for water and oil distribution network with minor adjustments.

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