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Decision support system for refinery site selection

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A B S T R A C T

Considering the importance and extensive range of decision-making, scientists from various fields have had many discussions on this issue. Various models have been proposed to facilitate decision-making and have had much utilization. In many site selection problems, multiple objectives must be obtained, simultaneously. This study uses a mathematical model to select a suitable location for the refinery in the multi attribute environment. The proposed model uses a large amount of qualitative and quantitative information in the frame of multi objective functions for the first time in the refinery site selection and is flexible enough to use decision makers' opinions in order to achieve goals. For this reason, after a brief overview of the selected area characteristics, using analytic hierarchy process (AHP) for weighting the criteria, a mathematical operation research model is proposed to determine the best alternatives.

1. Introduction

The purpose of this paper is to explain the activities of selecting the location of a refinery site. We discuss not only the characteristic of each alternative in different aspects such as construction cost, passive defense, etc., but also we consider some other important elements of site selection such as surrounding seismic faults, evaluation of criteria regarding technical and economical optimization in order to meet decision maker's perspective and responding to the demands. The process of decision-making consists of two phases: the first phase, after criteria selection, weights each criterion using Analytic hierarchy process (AHP) method. During the second states of the mathematical model, objective functions are converted into single objective by assigning weights. In recent years, there are numerous site selection optimization models. Zaghian and Shahanaghy (2009) integrated AHP method and VIKOR in order to select the best site for a crude oil refinery. Karbasian and Abedi (2011) used a multi objective non-linear model considering passive defense principles. Yang and Jones (2007) proposed a method based on a combination of a fuzzy multi-objective programming and a genetic algorithm. The original fuzzy multiple objectives were converted into a single unified 'min–max' goal, which makes it easy to apply a genetic algorithm for the problem solving.

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Akbari and Rajabi (2008) integrated GIS and fuzzy multi criteria decision analysis (FMCDA) to solve the landfill site selection problem and to develop a ranking of the potential landfill areas based on a variety of criteria. Zhou and Li (2013) proposed a multi-objective goal-programming model, taking both service quality, setup costs, and operating costs into consideration in the uncertain environment.

2. The proposed model

2.1. Assumptions of the model

- The stage of feasibility study has fulfilled for every alternative before site selection considering required area for construction.
- Surrounding faults means faults within a radius of 150-kilometer of each alternative.
- Surrounding inhabited areas means inhabited areas within the radius of 12-kilometer of each alternative.
- Pipe material has been considered carbon steel.
- Sulfur has been considered granule, packed and rail transported connecting to the existing trans-railways.

2.2. Methodology

2.2.1. Phase 1: criteria selection and using AHP method

In order to identify site selection effective factors, we used relevant expert's opinion in accordance with internationally acceptable standards/codes e.g. IPS (Iranian Petroleum Standards). One of the main factors affecting construction costs is length of pipelines; shorter refinery distance to wells is an advantage of each alternative from a technical and operational point of view. It is also very important to investigate the effect of earthquake ground motions potential and surrounding seismic faults based on relevant data and drawings. Environmental reviews are considered as well. Amount of pollutant dispersion is related to direction and velocity of prevailing wind. Refer to environmental and establishment industries criteria, production process and series of profiles approved by ministers, (Environmental and establishment industries criteria, 2000) minimum distance of some industries from some critical centers is described in Table 1 as follows,

Table 1
Minimum required distance from critical centers

Item	Critical center	Distance(m)
1	Inhabited areas	1500
2	Educational centers	100
3	Main roads	150
4	International park	1000
5	Protected areas /major rivers/canals	300

Risk assessment is required in every stage of the project. In this regard, probability estimation, measuring maximum concentration of pollutant must be carried out, maximum concentration of air pollutant must also be measured. In this level of the project, location and dimensions of equipment have not been determined. Thus, just the amount of air pollutant dispersion through flare and safe radius are measured by using PHAST software. (Safe radius: Within safe radius, concentration of toxic gas is less than quantity mentioned in standards to be safe) (e.g. less than 10 ppm for H_2S). (IPS-E-SF-860, 2010). Passive defense is a considered criterion. Vulnerability and threats of each type of attack e.g. high/low altitude aerial attack and risk factor are calculated.

Weighting techniques

Various methods can be used for weighting the criteria (e.g. decision maker's opinion or AHP based on pair wise comparison). In this paper, the second is used. (Momeni, 2010).

2.2.2. *Phase 2: Mathematical Model*

This developed mathematical model is inspired by general site selection model (Bashiri, 2009).

$$\text{Min } Z_1 = \sum_{i\in I} C_i Y_i + \sum_{k\in K} \sum_{i\in I} CR_{ki} dr_{ki} Y_i + \sum_{k\in K} \sum_{i\in I} CV_{ki} X_{ki} \tag{1}$$

This objective function seeks to minimize the costs of construction and sulfur transportation, where C_i is construction cost of the gas refinery if it is established in alternative *i* and defined as follows:

$$C_i = (C^1{}_i + C^2{}_i \times d_{IGAT\ i} + C^3{}_i \times d_{IGAT\ i} + C^4{}_i \times \sum_{j\in J} d_{ji} + C^5{}_i \times d_{gathering\ i} + C^6{}_i \times d_{hi} + C^7{}_i \times dw_i + C^8{}_i) \tag{2}$$

To calculate the cost of pipe, first we need to know their weight, wall thickness and size using formula below:

$$W_{pipe} = 0.02466\ t(d_0 - t) \text{ (McAllister, 2013)} \quad \text{kg/m} \tag{3}$$

where *t* is wall thickness (mm), d_0 is outside diameter, mm, and W_{total} is total weight.

$$W_{total} = W_{pipe} \times L \tag{4}$$

Where

L is length of the pipe, mm

Moreover, pipe wall thickness is as below:

$$t = \frac{Pd_0}{2SEFT} + C.A. \tag{5}$$

where

P, design pressure, psi

d_0, outside diameter, mm

S, Specified Minimum Yield Strength, psi

E, Longitudinal Joint Factor

F, Basic Design Factor

T, Temperature De-rating Factor

C.A., Corrosion Allowance (ASME B31.8, 2010, ASME B36.10, 2004),

For calculation of power supply, regardless of substation and demand costs, which are identical in all alternatives, just the execution cost of transmission line is calculated.

$$DL_i \times CE_i = C^8{}_i \tag{6}$$

where

DL_i, length of execution line for each alternative

CE_i, execution cost per kilometer

$C^8{}_i$, total execution cost

$$\text{Max } Z_2 = \sum_{i\in I} \sum_{e\in E} d_{ei} Y_i \quad (7)$$

Eq. (7) maximizes the sum of total surrounding fault distance of alternative.

$$\text{Max } Z_3 = \sum_{i\in I} \sum_{h\in H} (A_{hi} - I_i) Y_i \quad (8)$$

Eq. (8) maximizes the sum of total difference of inhabited areas of alternative and its safe radius.

$$\text{Max } Z_4 = \sum_{i\in I} \sum_{l\in l} (L_{li} - D) Y_i \quad (9)$$

Eq. (9) maximizes sum of total deference of minimum required distance between the refinery and protected areas and protected areas.

$$\text{max } Z_5 = \sum_{i\in I} E_i Y_i \quad (10)$$

$$\text{min } Z_6 = \sum_{i\in I} \sum_{m\in M} R_{mi} Y_i \quad (11)$$

Alternatives are evaluated from the perspective of passive defense. This function minimizes total calculated risk,

$$R = EC \times L \times C \quad (12)$$

where

EC, impact for each stage of the attack

L, probability of occurrence

C, cost reduction index (FEMA 452, 2005)

Considering the following restrictions:

$$\sum_{i\in I} Y_i = P \quad (13)$$

$$\sum_{k\in K} X_{ki} \leq MY_i \quad \forall i \in I \quad (14)$$

$$\sum_{k\in K} X_{ki} \leq S \quad \forall i \in I \quad (15)$$

$$\sum_{i\in I} C_i Y_i + \sum_{k\in K} \sum_{i\in I} CR_{ki} dr_{ki} Y_i \leq B \quad (16)$$

$$Y_i = 0 \text{ or } 1 \quad \forall i \in I \quad (17)$$

$$X_{ki} \geq 0 \quad \forall i \in I; \forall k \in K \quad (18)$$

Constraint (13) ensures that exactly *P* alternatives are selected. Constraint (14) ensures no sulfur is transported to export port unless the alternative is selected. Constraint (15) shows capacity limitation of sulfur produced per day. Constraint (16) limits the amount of budget for establishment. Constraint (17) means that Y_i is a binary variable, that is equal to 1 when alternative *i* is selected and equal to 0 otherwise. Constraint (18) means that X_{ki} is a positive variable.

2.3. Sets

I	set of all potential alternatives (or sites)
J	set of all wells
K	set of all ports to them the sulfur is transported for export
L	set of all protected areas
H	set of all surrounding inhabited areas

E set of all surrounding fault
M set of all type of enemy's attack

2.4. Parameters

P Number of selected alternative
B total budget
D Minimum required distance of the protected area from the refinery
S Production capacity of sulfur per day
E_i Environmental score for each alternative
A_{hi} Distance of inhabited area h from alternative i
d_{ei} Distance of fault e from alternative i
C_i Fixed construction cost of the alternative
C^1_i Earth working cost of each alternative (excavation and filling)
C^2_i Cost of fuel transferring pipeline from IGAT (trans-pipeline) to the refinery per unit
$d_{IGAT\ I}$ Trans-pipe line distance from the refinery if it's located in alternative i
C^3_i Construction cost of gas pipeline from refinery to IGAT per unit
C^4_i Construction cost of flow pipeline from well to gathering center alternative i per unit
d_{ji} Distance of well j from gathering center alternative i.
C^5_i Construction cost of pipeline from gathering center to alternative i per unit.
$D_{gathering\ i}$ Gathering center distance from the refinery established in alternative i
C^6_i Construction cost of condensate pipeline to export port
d_{hi} Distance of Established refinery in alternative i from export port
C^7_i Construction cost of road
dw_i Distance of the refinery established in alternative i from the existing road
C^8_i Power supply cost
CR_{ki} Railway construction cost connecting export port k to alternative i via trans-railway
dr_{ki} Distance of alternative i from trans-railway ends to export port k
CV_{ki} Variable cost of sulfur transportation from alternative i to export port k
L_{li} Distance from protected area l from alternative i
I_i Safe radius of alternative i
R_{mi} Risk factor attack type m for alternative i

2.5. Decision variables

Y_i =1 if the refinery is established in alternative i

or

=0 otherwise.

X_{ki} Quantity of sulfur transported to export port k from alternative i

3. Case study

The proposed study of this paper assigns appropriate weights to convert the multi objective problem into a single objective problem so that we could solve the resulted problem using a simple linear programming package (Asgharpour, 2012).

Table 2a
The summary of information associated with alternatives

alternative	1	2	3	4
N	3013407.11	3021995.87	2993589.52	3021872.34
E	364884.32	401128.77	383415.54	441232.99
Location	60 km from north west of Bandar Abbas	30 km from north west of Bandar Abbas	45 km from south west of Bandar Abbas	17 km from north east of Bandar Abbas

Table 2b
The summary of information associated with alternatives

S(ton)	D	B	P
1,000	300	1,800,000,000,000	1

Table 3 shows pair wise comparison of criteria. If more than one decision maker is needed based on a selection policy, GAHP can be used (Asgharpour, 2012). In addition, Table 4 shows the distances.

Table 3
Pairwise comparison of criteria

	Total cost	Sum of fault distance	Distance of inhabited area	Distance of protected area	effecting on environment Score	Passive defense	Relative weight
Total cost	1	3	5	8	6	4	0.473
Sum of fault distance	0.333	1	2	2	3	2	0.180
Distance of inhabited area	0.2	0.5	1	2	2	1	0.109
Distance of protected area	0.125	0.5	0.5	1	1	0.5	0.063
effecting on environment Score	0.167	0.333	0.5	1	1	0.5	0.062
Passive defense	0.250	0.5	1	2	2	1	0.113
total	2.075	5.833	10	14	17	9	IR=0.006

Table 4
Distances

Distances from(km)	Alternatives			
Trans-railway	43	5	24	18
Main road	1.7	2	1.5	1.5
Protected area	55	10	45	30

3.1. Calculations related to pollutant concentration

The aim is to calculate the maximum concentration of H_2S. Stack height and diameter are calculated (API521, 2007).
Stack height (m) H: = 92.94
Stack Diameter (m) D: = 0 .93

Table 5
H_2S concentration

alternative	Distance from the nearest inhabited area(km)	Safe radius(km)
1	5	4
2	4	5
3	7	8
4	5	7

Table 6
Sum of difference between safe radius and inhabited areas

Alternative	1	2	3	4
$\sum A(H,I)$	13,500	1,900	-1,000	35,000

3.2. Pipe cost & power supply calculation

Table 7
Pipe cost calculation (Exclusive unit price of oil and gas refineries establishment, 2013)

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
fuel transferring pipeline from IGAT-4”	Length (m) $d_{IGAT\ i}$	500	2,500	24,000	8,000
	Thickness based on ASME B36.10 (mm)	5,56			
	Weight (km/m)	14,91			
	Cost per unit C^2_i € *	25			
	Total cost €	191,000	955,000	9,168,000	3,056,000
gas pipeline to IGAT - 24”	Length (m) $d_{IGAT\ i}$	500	2,500	24,000	8,000
	Thickness based on ASME B36.10 (mm)	15,88			
	Weight (km/m)	232,67			
	Cost per unit C^3_i €	382			
	Total cost €	191,000	955,000	9,168,000	3,056,000
flow pipeline -6”	Length (m) $\sum d_{ji}$	55,000	32,000	32,000	32,000
	Thickness based on ASME B36.10 (mm)	7,11			
	Weight (km/m)	28,26			
	Cost per unit C^4_i €	47			
	Total cost €	2,585,000	1,504,000	1,504,000	1,504,000
gathering pipeline -20”	Length (m) $d_{gathering\ i}$	500	35,000	25,000	78,000
	Thickness based on ASME B36.10 (mm)	14,27			
	Weight (km/m)	173,75			
	Cost per unit C^5_i €	285			
	Total cost €	142,500	9,975,000	7,125,000	22,230,000
condensate pipeline -4”	Length (m) $\sum d_{ji}$	45,000	36,000	24,000	48,000
	Thickness based on ASME B36.10 (mm)	5,56			
	Weight (km/m)	14,91			
	Cost per unit C^6_i €	25			
	Total cost €	1,125,000	900,000	600,000	1,120,000

* pipe cost :1.64 € per km/ 1 € = 42,600 Rials

Table 8
Power supply cost of alternatives

Alternative	Length of execution line (m)	Power supply cost(million rial)
1	35,000	140,000
2	60,000	240,000
3	15,000	60,000
4	10,000	40,000

3.3. Volume of Earthwork and seismic faults

Table 9
Volume of earthwork(m^3)

Alternative	1	2	3	4
Filling	142,000	600,000	1,575,000	250,000
Excavation	1,820,000	5,850,000	525,000	3,500,000
Total cost(million rial)	31,740	101,090	170,620	60,090

Table 10
Siesmic fault info of alternative 1

Fault no.	Length(km)	Distance of established area(km)
1	27	25
2	40	7
3	140	20
4	35	35

Table 11
Siesmic fault info of alternative 2

Fault no.	Length(km)	Distance of established area(km)
1	27	0
2	3	1

Table 12
Siesmic fault info of alternative 3

Fault no.	Length(km)	Distance of established area(km)
1	150	10
2	140	15
3	15	20

Table 13
Siesmic fault info of alternative 4

Fault no.	Length(km)	Distance of established area(km)
1	20	20
2	150	5
3	15	17
4	27	20

3.4. Environmental score

Table 14
Final environmental score

	Scores			
	Water resources	Natural environment	Social environment/lands utilization	Total
Alt 1	13	15	8	36
Alt 2	13	13	9	35
Alt 3	10	12	7	29
Alt 4	13	9	12	34

(Land affair organization, 2004; The Environmental Protection organization, Environmental Criteria and Standards Regulations, 2004; Ziaee, 2009; Iskandar, 2009; The surface waters of Hormozgan province, 2012; The weather and climate of Hormozgan province, 2012; The underground waters of Hormozgan province, 2012; Mansoori, 2013; Monavari, 2007)

3.5. Passive defense data

Table 15
Cost reduction index

Attack Type	High altitude aerial	Low altitude aerial	Missile	Marine Artillery	Ground	partisan
Index	%72	83%	90%	95%	75%	85%

Table 16
Attack type probability (%)

alternative	Attack Type						
	High altitude aerial	Low altitude aerial	Missile	Marine Artillery	Ground	partisan	Mean
1	25	30	30	15	15	20	22.5
2	45	10	25	15	15	20	21.67
3	5	35	15	55	50	40	33.33
4	25	25	30	15	20	20	22.5

Table 17
Total calculated risk

Alternative	1	2	3	4
$\sum R(M,I)$	0.1705	0.1525	0.2512	0.1690

Table 18
Impact index for each stage of the attack

	Attack Stage				
Attack Type	Identity	Presence	Recognition	Target	damage
High Altitude Aerial	10	5	10	25	50
Low Altitude Aerial	10	10	10	20	50
Missile	10	5	15	20	50
Marine Artillery	20	15	15	25	25
Ground	5	35	5	-	40
Partisan	5	35	-	5	35

3.6. Software results

Table 19
Software results

Selected alternative	Alternative1
Optimal value of objective function	
Objective function 1	9.84226E+11
Objective function 2	87000.000
Objective function 3	13500.000
Objective function 4	54700.000
Objective function 5	43.000
Objective function 6	0.171
Construction cost	
Alternative1	3.82226E+11
Alternative2	1.01988E+12
Alternative3	1.21577E+12
Alternative4	1.36633E+12
Quantity of sulfur transported	200

4. Conclusion

In this paper, a unique model was presented, which could select the refinery site in order to consider every important site selection criterion specifically the effect of construction cost, earthquake ground motions potential, surrounding seismic faults in accordance with internationally acceptable standards and also passive defense in a manner that the possibility of damages by the enemy being reduced. In this developed mathematical model, technical terms met decision maker's perspective with the help of GAMS software. The model has been demonstrated through the case study in this paper. The case has shown how effectively this model could be applied in the process of selecting an alternative for establishing a refinery site. However, this model can be used to select the appropriate location for any other sites e.g. manufacturing plants, etc.

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