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Location of compressed natural gas stations using multi-objective flow refueling location model in the two-way highways: A case study in Iran

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Abstract

Increasing the use of fossil fuels is with severe environmental and economic problems, bringing more attention to alternative fuels. The compressed natural gas (CNG), as an alternative fuel, offers many more benefits than gasoline or diesel fuel such as cost-effectiveness, lower pollution, better performance, and lower maintenance costs. Gas stations location and the number of gas stations are the pivotal factors, influencing the less using of CNG in comparison with other fuels. In this regard, this paper unveils a two-step phase method to locate the CNG stations in the two-way highways. In the first phase, an optimized Data Envelopment Analysis (DEA) model is deployed to determine the best candidate location for gas fuel stations. Concerning the selected candidate locations, the second stage devises a multi-objective flow refueling location model with the aim of maximizing the traffic flow of the vehicles in the two-way highways and reducing the cost of constructing fuel stations. Notably, fuel tanks capacity is considered to be hemmed in by uncertainty. The introduced method is evaluated and verified via investigating a three-part of Persian Gulf Highway. The results corroborate the effectiveness and usefulness of the model and can help researchers to set up their refueling location problems efficiently.

Keyword: Fuel station location, flow refueling, alternative-fuel vehicle, Data Envelopment Analysis (DEA), Compressed Natural Gas (CNG)

1- Introduction

The population growth in cities and a significant increase in the number of vehicles incur numerous urban and interurban travels. With the number of cars rising, the provision of their required fuel has become the government’s priority. Nowadays, 65% of global carbon dioxide emissions are generated by energy consumption, of which 21% is from fossil fuel-related transport. Likewise, greenhouse gas emissions are expected to increase in the coming years, especially in developing countries (Habibi et al., 2017). In as much as the importance of fossil fuels, special attention to compressed natural gas instead of gasoline worth trying. Petroleum problems, such as high prices, local air pollution, and greenhouse gas pollution have increased the focus on alternative fuel vehicles, including biodiesel, ethanol, hydrogen, electricity and natural gas (Wang et al., 2009). Compressed natural gas can be compared with gasoline from environmental, economic and technical points of view. This alternative fuel offers many more advantages than gasoline or diesel such as cost-effectiveness, lower pollution, better performance, and lower maintenance costs (Socalgas, 2018).

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These factors underscore the importance of paying attention to alternative fuels such as compressed natural gas. In Iran, there are 2,400 natural gas refueling stations; 2,350 of those were set up by government assistance and subsidies. Daily supply capacity of natural gas refueling stations is between 40 and 50 million cubic meters but last year, the stations with an average eight hours of operation, have consumed about 21 million cubic meters a day (Financial Tribune, 2018).

This amount of consumption is half the daily supply capacity. To give the importance of using compressed natural gas; it is incumbent upon to increase the exploiting of this alternative fuel. Decreasing natural gas consumption can be interrelated with to factors such as the low number of gas fuel stations in urban areas, long and slow queues at some stations, the high cost of installing a dual-fuel system for vehicles, and most importantly the inappropriate approach toward the distribution of natural gas refueling stations.

To date, a considerable deal of papers has been proposed in this filed. In this sense, Hodgson (1990) proposed a new type of location-allocation model as the flow-based model. They determined origin-destination flow in the shortest direction instead of the fixed points of the central location services. In flow-based models, the traffic flow is expressed as an origin-destination pattern that each component of which represents the number of vehicles moving from the origin to the destination. Therefore, the fuel stations should be located in a way that the flows are covered as much as probable. Kuby and Lim (2005) in view of the fact that the adaptability of natural gas into the environment and the need to replace it with fossil fuels, paid particular attention to the location of fuel stations. They afforded a complex integer programming formula for nodes as well as an algorithm for determining all combinations of nodes that can create a given path. For refueling, it may be necessary to stop in more than one installation in order to complete the entire route driving, depending on the range of the car, the length of the route. The refueling location model optimally maximizes the refueling stations so that the total flow rate is maximized. If only one refueling station is needed, this station should be within the scope of travel of both origin and destination. If a route requires multiple refueling, not only stations are required within the scope of origin and destination, but also, they should be more than the maximum range of vehicles. These factors create a more complex problem than the current refueling method. If the range of vehicles is longer than the distance between the origin and destination, the new constraints impose the same logic as the current refueling method. In this manner, it can be utilized as an integrated model for refueling both short and long trips. Kuby et al. (2007) devised three methods to add the candidate sites along arcs. One of the introduced methods applies the Added-Node Dispersion problem, where the results determine that this method provides better solutions than other methods. Kuby et al. (2009) developed a model that could locate hydrogen pumps for refueling the maximum coverage of the vehicle's flow. The proposed flow refueling location model maximizes the flow and measures the number of the vehicle. Lim and Kuby (2010) introduced three heuristic methods that determine the optimal locations for refueling stations for alternative fuel vehicles. These methods are confirmed to be effective and practical in solving flow-refueling location model problems. Capar et al. (2013) introduced a different formulation of the flow-refueling location model. The presented formulation is more effective than previous methods or heuristics, based on covering the arcs that include each path. MirHassani and Ebrazi (2012) reformulated the flow refueling location model and presented a compliant mixed-integer linear model that obtains an optimal solution so fast in a reasonable time. Upchurch et al. (2009) offered the capacitated flow refueling location model that defines the number of vehicles that are refueled at each fuel station. Meanwhile, their study introduces a qualified, objective function that maximizes vehicle-miles driven instead of trips. Huang et al. (2015) proposed a new alternative fueling station location model by analyzing the performances of alternative fuel vehicles users, who are ready to deviate from their routes. Yıldız et al. (2016) presented an enhanced compressed model based on a combination of existing methods. They showed that the proposed algorithm is very effective and useful. Hosseini et al. (2015) offered a stochastic refueling station location model. The model is implemented to an intercity network for Arizona, and the results confirm that the permanent stations are located in and around densely populated sites. Kim and Kuby (2012) explained and used a mixed-integer linear programming model by considering the limited driving range and the necessary deviations. Last but not least, Miralinaghi et al. (2017) presented a structure for the refueling demand uncertainty and the impact of deviation of drivers in the network. The proposed model is solved using an adequate genetic algorithm.

Concluding from literature, it is worthy to note none of the research has regarded a two-way road between origin and destination. More precisely, previous studies have considered the origin and destination as fixed locations, but each of the areas connected with a road can be an origin or a destination alternatively. Also, to discover the best fuel stations candidate location, none of the research has applied the linear programming methodologies such as Data Envelopment Analysis model. In an attempt to overcome the above-mentioned literature gaps, we propose a practical and convenient two-step phase method to locate the CNG stations in the two-way highways. In the first phase, an optimized Data Envelopment Analysis (DEA) model is extended to determine the best nominee locations for gas fuel stations. In the second phase, a multi-objective flow refueling location model with the aim of maximizing the traffic flow of the vehicles in the two-way highways and reducing the cost of building fuel stations is introduced. The recommended model locates the CNG stations separately on each side of two-way highways concerning the specified nominee locations in the first phase, combines the results and suggests a comprehensive, optimized solution for two-way highways. It should be explained that the traffic flow of the cars represents the cars that are on the move from the origin to the destination without fuel completion. Also, fuel tanks capacity is considered to be hemmed in by uncertainty and analyzed by stochastic programming.

The rest of this paper is structured as follows. In the next section, comprehensive details about the problem are provided. Sections 3 unveil the methodology used in this paper. Meanwhile, multi-objective flow refueling location model and optimized DEA model are explained. Section 4 elaborates the case study and discusses the considered criteria. Section 5 presents the results. Finally, conclusions and possible future researches are presented in section 6.

2- Problem Description

With regard to the literature review, the importance of using natural gas as an alternative fuel and the inappropriate approach at distributing fuel stations is defined. In this knowledge, this paper attempts to introduce a two-step phase method to locate the CNG stations in the two-way highways. In the first phase, an optimized Data Envelopment Analysis (DEA) model is used to determine the best candidate location for gas fuel stations. In the second phase, a multi-objective flow refueling location model with the purpose of maximizing the traffic flow of the vehicles in the two-way highways and reducing the cost of constructing fuel stations is presented. The suggested model locates the CNG stations separately on each side of two-way highways concerning the specified candidate locations in the first phase, combines the results and recommends a complete, optimized solution for two-way highways. As the capacity of fuel tanks in various cars is being considered to be imbued with uncertainty, stochastic programming is proposed as a modeling method. As such, some assumptions of the proposed model are as follows:

1- Vehicles have a limited driving range

2- The base vehicle is considered a Saipa Pride because it has the most critical and risky condition in terms of driving distance and fuel tank capacity in Iran

3- Car fuel consumption per kilometer is constant

4- All vehicles have the same tank capacity and consumption rate as Saipa Pride

5- The fuel consumption is measured in distance units, which show how far a car can drive with a full fuel tank. The Saipa pride, for example, can drive nearly 150 km with the full gas tank.

6- Vehicles start driving from origin and destination with a half-filling fuel tank

7- Vehicles refuel as a full fuel tank through the highway

8- The cost of building fuel stations is constant and the estimated cost range for gas stations, including engineering, equipment and installation costs, is almost half a million dollars (Gonzales, 2014).

As mention before, in this paper, the traffic flow of the vehicles is analyzed in two-way roads. A two-way road allows vehicles to travel in both directions. However, in one-way roads, the traffic moves in a single direction, and it can make some problems. Thus, we describe the importance of analyzing the problem in two ways road with a simple example.

Fig 1. An example of two-way road

Figure 1 displays a simple example two-way road with six nodes A, B, C, D, E, F. Nodes A, and F are the origin and destination. It is assumed that the vehicle driving range with the full filling fuel tank is 100 km. It will start the trip with a half filling fuel tank, so the driving range will be only 50 km when the vehicle starts the trip from A to F. But when the vehicle is refueling between origin and destination, the driving range will be 100 km again. With these assumptions, if we consider only the road A to F when the vehicle starts the trip from node A, there should be two fuel station in nodes B and D in the road. In this state, the vehicle finishes the trip without running out of fuel. Now imagine a vehicle starts the trip from F to A, it will run out of fuel with the fuel station in B and D. To solve this problem if we consider only the road F to A when the vehicle starts the trip, there should be two fuel station in nodes E and C in the road and the vehicle finishes the trip without running out of fuel again. So, we need four fuel stations at nodes B, C, D, E to cover this two-way road. However, it is clear that this answer is not optimal. By considering both roads together, there is only three fuel stations needed at nodes B, C, E.

3- Methodology

Locating the gas fuel stations to maximize the traffic flow of the vehicles in the two-way highways and reduce the cost of constructing fuel stations concerning the specified candidate locations and different fuel tanks capacity is the purpose of this paper. Achieving this goal is with the following methodology.

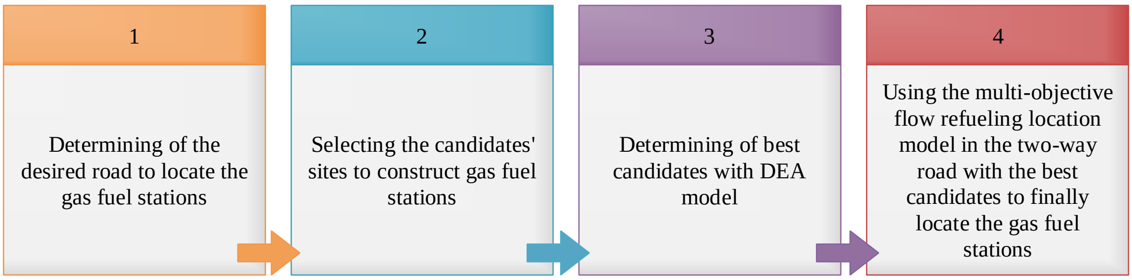

Fig 2. The methodology of this paper

As can be known from figure 2, in the first step the desired road should be determined to locate the gas fuel stations. Then some candidates' sites will be selected, and an optimized Data Envelopment Analysis (DEA) model will be used to define the best candidate locations among them. At last a multi-objective flow refueling location model with the goal of maximizing the traffic flow of the vehicles in the two-way highways and reducing the cost of building fuel stations will be applied. Concerning the specified candidate locations; as mentioned, the proposed model locates the CNG stations separately on each side of two-way highways, combines the results and suggests a complete, optimized solution for two-way highways.

3-1- Identifying candidate locations with DEA model

Data Envelopment Analysis or DEA is a non-parametric approach to evaluate the performance of similar decision-making units (DMUs) based on observed data (Cooper et al., 2004). This method is able to manage the complicated relations between the multiple inputs and outputs, while predetermined weights for inputs and output criteria are not required (Farrell, 1957; Charnes, Cooper and Rhodes, 1978). Thereinafter, Dehghani et al. (2018 b) recommended a DEA model applying the information of both efficient and anti-efficient frontiers that enhance the distinction of DEA analysis. Further, the application and utility of the suggested approach were verified. In this paper, we used an optimized DEA model that considers each candidate location as a DMU and improves distinction power in the analysis, using the distances to both efficient and the anti-efficient frontiers (Dehghani et al., 2018 a). The proposed method applies the standard DEA model, and the inverted DEA model to respectively determine the efficient and the anti-efficient frontiers.

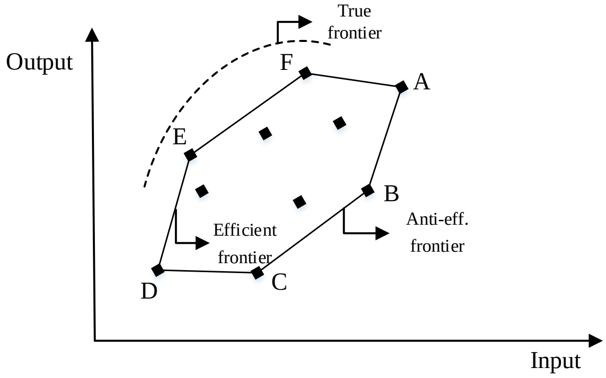

Fig 3. Representations of the efficient and anti-efficient frontiers

Figure 3 shows that the standard DEA model obtains the best practice DMU_S F, E, D, and A, whilst the inverted DEA model proposes the worst practice DMU_S D, C, B, and A. This paper introduces the planning criteria for the location of fuel stations. Locations with higher scores are more appropriate to choose.

The executed DEA model is directed as follow, and the index, parameters, and variables used in the model are first given.

indices	
c, l	Index of candidate locations for solar plant (DMUs) $c, l = 1, \ldots, n,$
d	Index of inputs $d = 1, \ldots, g,$
e	Index of outputs. $e = 1, \ldots, q,$
parameters	
x_{dc}	Amount of input *d* for DMU *c*
y_{ec}	Amount of output *e* for DMU *c*
Decision variables	
θ_l	The measure of the efficiency of DMU *l*
λ_c	The dual weight assigned to all inputs and outputs of DMU *c*

The standard DEA model that determines the efficient frontier is presented below:

$$Min\ h_{bl}^* = \theta_l \tag{1}$$

$$\sum_{c=1}^{n} x_{dc}\lambda_c \leq \theta_l x_{dl}, d = 1, \ldots, g, \tag{2}$$

$$\sum_{c=1}^{n} y_{ec}\lambda_c \geq y_{el}, e = 1, \ldots, q, \tag{3}$$

$$\lambda_c \geq 0, \qquad c = 1, \ldots, n,$$

$$\theta_l\ unconstrained \tag{4}$$

Also, the inverted DEA model that provides the anti-efficient frontiers is given below:

$$Min\ h_{wl}^{*} = \theta_l \quad (5)$$

$$\sum_{c=1}^{n} x_{dc}\lambda_c \geq \theta_l x_{dl}, d = 1,\ldots,g, \quad (6)$$

$$\sum_{c=1}^{n} y_{ec}\lambda_c \leq y_{el}, e = 1,\ldots,q, \quad (7)$$

$$\lambda_c \geq 0, \qquad c = 1,\ldots,n,$$

$$\theta_l\ unconstrained \quad (8)$$

The efficiency results in h_{bl}^{*} and h_{wl}^{*} are achieved by solving the standard DEA model and the reversed DEA model for the *l*th DMU. Moreover, the models should be solved n times to obtain efficiency scores for all DMU_s. Also, to calculate the distances to good and bad references concurrently and to combine information on both efficient and anti-efficient frontiers, an indicator is calculated as follows:

$$h_{il}^{*} = \frac{[h_{bl}^{*} + (1 - \frac{1}{h_{wl}^{*}})]}{2} \quad (9)$$

If DMU_l is only at the efficient frontier, h_{il}^{*} will be higher than $\frac{1}{2}$ and even if DMU_l is only on the anti-efficient frontier, $h_{wl}^{*} = 1$ and therefore $h_{il}^{*} \leq \frac{1}{2}$. Moreover, if DMU_l is at both efficient and anti-efficient frontiers$h_{bl}^{*}, h_{wl}^{*} = 1$, then $h_{il}^{*} = \frac{1}{2}$.

It should be pointed out that the criteria with an increasing trend are concerned as output criteria, and those with decreasing trend are realized as input criteria. The considered criteria are defined in details as follows:

- **Distance from the main road**

In accordance with the physical planning standards, to construct a fuel station, the distance from the road should not be less than 15 meters. Nonetheless, it is better if the fuel station has not been located far from the road. Thus, less distance is more convenient, and therefore it is as an input criterion.

- **Distance from hospitals and clinics**

The distance from the hospitals and clinics is critical when the accident occurs in a fuel station. So, it is an important criterion, and it is considered as an input indicator.

- **Distance from the fire station**

The distance from the fire stations is critical when the accident occurs in a fuel station. So, it is an important criterion, and it is considered as an input indicator.

- **Distance to the existing fuel station**

The more distance between stations in a road means the number of stations is reduced and as results, the total cost is reduced too. This criterion is recognized as an output indicator.

- **Distance from services and rest areas**

The rest areas can influence drivers to stop the car and get some rest and fill their fuel tank. So, it is considered as an input indicator.

3-2- Main model

The sets, parameters, and variables used in the optimization model are given below:
Nomenclature:

Sets	
i, j	Set of candidate sites to construct fuel station
parameters	
Q	Set of all candidate paths
$q_{(i,j)}$	the path between node i and j
D	set of the length of paths
$d_{(i,j)}$	the length of the path between node i and j
$\tilde{R}$	vehicle gas tank capacity
F	The traffic flow between origin and destination
C_i	The cost of building a station at node i
S	origin city
t	destination city
Decision variables	
$X_{i,j}$	1 if the arc of the path between i and j on the way from origin to destination is activated; otherwise 0
$X'_{i,j}$	1 if the arc of the path between i and j on the way from destination to the origin is activated; otherwise 0
Y_i	1 if a fuel station is located at node i; otherwise 0

The model presented in this paper aim at maximizing the traffic flow of the vehicles in the two-ways highways as well as reducing the cost of constructing fuel stations.
The model is formulated as follows:

$$MinZ_1 = \sum_i C_i Y_i \qquad (10)$$

$$MinZ_2 = \sum_i \sum_j F(X_{ij} + X'_{ij}) \qquad (11)$$

s.t.

$$\sum_{j/q_{(i,j)}} X_{i,j} - \sum_{j/q_{(i,j)}} X_{j,i} = \begin{cases} 1 & i = s \\ 0 & i \neq s,t \\ -1 & i = t \end{cases} \qquad \forall_i \qquad (12)$$

$$\sum_{j/q_{(i,j)}} X'_{i,j} - \sum_{j/q_{(i,j)}} X'_{j,i} = \begin{cases} 1 & i = s \\ 0 & i \neq s,t \\ -1 & i = t \end{cases} \qquad \forall_i \qquad (13)$$

$$X_{i,j} \leq Y_i \quad \forall_i \qquad (14)$$

$$X'_{i,j} \leq Y_i \quad \forall_i \qquad (15)$$

$$X_{i,j} = 0 \quad \forall_{i=j} \qquad (16)$$

$$X'_{i,j} = 0 \quad \forall_{i=j} \tag{17}$$

$$d_{ij}X_{ij} \leq \frac{\tilde{R}}{2} \quad i = s \quad \forall_{i,j} \tag{18}$$

$$d_{ij}X'_{ij} \leq \frac{\tilde{R}}{2} \quad i = s \quad \forall_{i,j} \tag{19}$$

$$d_{ij}X_{ij} \leq \tilde{R} \quad i \neq s \quad \forall_{i,j} \tag{20}$$

$$d_{ij}X'_{ij} \leq \tilde{R} \quad i \neq s \quad \forall_{i,j} \tag{21}$$

The objective functions	
(10)	*Minimizing the cost of refueling stations construction*
(11)	*Maximizing the traffic flow without running out of fuel*
Constraints	
(12) and (13)	*Mass balance constraints, the outflow minus inflow must equal the virtual supply and the demand of the node*
(14) and (15)	*Allow the flow pass through a node only when a fuel station is placed at that node*
(16) and (17)	*Do not allow that a node has a flow with itself*
(18) and (19)	*The fuel tank capacity constraint when the vehicle starts the trip from the first node*
(20) and (21)	*The fuel tank capacity constraint when the vehicle is in the middle of the highway*

4- Case study

Locating the fuel stations can be studied under two scenarios, one is the study of urban areas, and the other one is the study of interurban roads. Freeway 7 (Persian Gulf Highway) is one of the longest freeways in Iran that connects the Tehran city to Qum and Kashan and finally the Isfahan. Currently, in the light of the existing fuel station at the beginning and the end of highways, there are five natural gas fuel stations on the Tehran-Qum highway, five natural gas fuel stations on Qum-Kashan highway and six natural gas fuel stations on Kashan-Isfahan highway.

- **Tehran-Qum highway**

Tehran-Qum highway connects Tehran to Qum. This highway covers 135 *km* and has five CNG fuel stations. 12 candidate nodes are considered to locate CNG fuel stations. These nodes will be analyzed in order to select the best sites using the DEA model. Figure 4 indicates the existing gas fuel station and candidate location on the highway.

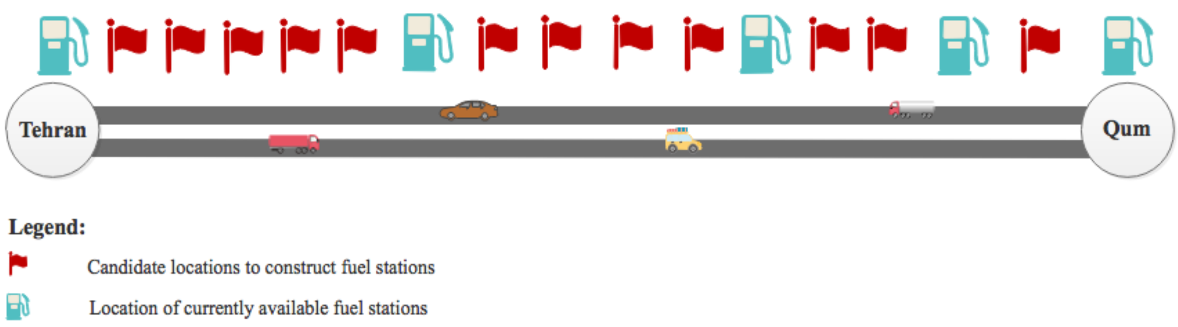

Fig 4. Tehran-Qum highway with the location of fuel stations

• **Qum-Kashan highway**

Qum-Kashan highway connects Qum to Kashan. This highway covers 100 *k*m and has five CNG fuel stations. 9 candidate nodes are considered to locate CNG fuel stations. These nodes will be analyzed in order to select the best sites using the DEA model. Figure 5 indicates the existing gas fuel station and candidate location on the highway.

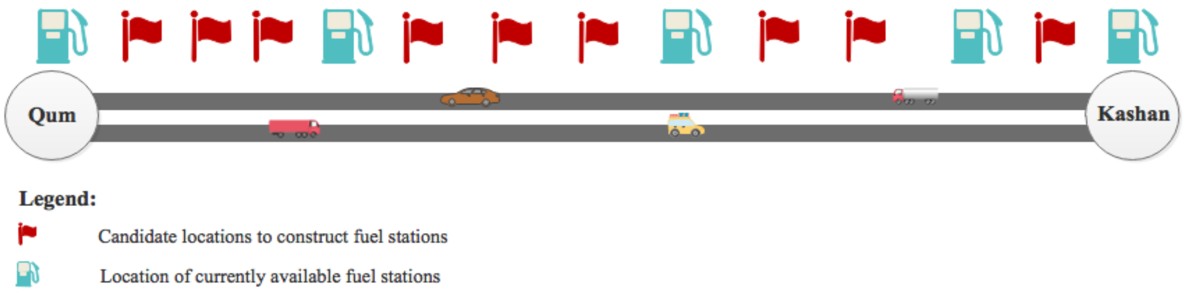

Fig 5. Qum-Kashan highway with the location of fuel stations

• **Kashan-Isfahan highway**

Kashan-Isfahan highway connects Kashan to Isfahan. This highway covers 200km and has eight CNG fuel stations. 15 candidate nodes are considered to locate CNG fuel stations. These nodes will be analyzed in order to select the best sites using the DEA model. Figure 6 indicates the existing gas fuel station and candidate location on the highway.

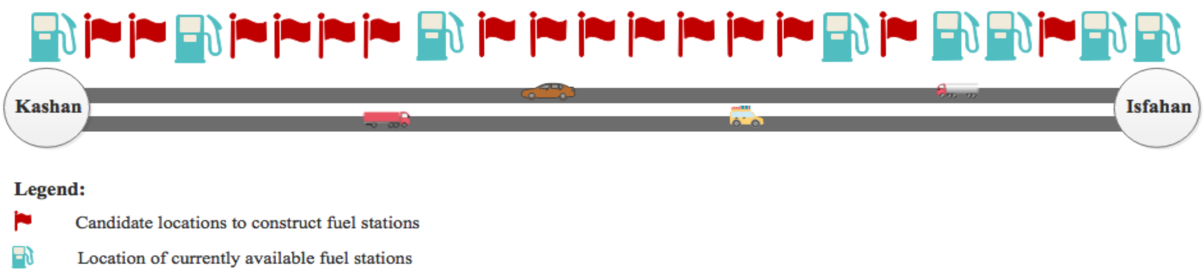

Fig 6. Qum-Kashan highway with the location of fuel stations

4-1- Data collection

The collection of parameter values is based on the actual data available. Responsible organization for criteria of the proposed DEA model including "Distance from the main road", "Distance from hospitals and clinics", "Distance from the fire station", "Distance to the existing fuel station" and "Distance from services and rest areas" is National Iranian Oil Products Distribution Company that is part of National Iranian Oil Refining and Distribution Company. National Iranian Oil Refining and Distribution Company was founded on 8 March 1991 and began to perform all operations associating with refining and distribution of oil products. Tables 1-3 describe the data collected in accordance with all DMUs criteria. It is worthy to note that the collected data is taken from Google maps service.

Table 1. Collected data based on the introduced criteria from Tehran-Qum highway

DMUs	Criteria				
	Distance from the main road (Km)	Distance from hospitals (Km)	Distance from the fire station (Km)	Distance from the existing fuel station (Km)	Distance from services and rest areas (Km)
DMU1	0.10	4	4	6	6
DMU2	0.15	6	3	10	10
DMU3	0.10	8	8	15	5
DMU4	0.13	10	7	10	0
DMU5	0.20	4	13	5	4
DMU6	0.30	2	6	8	8
DMU7	0.17	8	13	12	0
DMU8	0.15	14	24	23	11
DMU9	0.10	28	35	11	12
DMU10	0.20	17	23	9	9
DMU11	0.10	9	16	10	10
DMU12	0.16	2	7	12	0

Table 2. Collected data based on the introduced criteria from Qum-Kashan highway

DMUs	Criteria				
	Distance from the main road (Km)	Distance from hospitals (Km)	Distance from the fire station (Km)	Distance from the existing fuel station (Km)	Distance from services and rest areas (Km)
DMU1	0.10	6	2	6	6
DMU2	0.12	14	10	14	14
DMU3	0.17	19	15	9	9
DMU4	0.11	29	27	5	5
DMU5	0.30	25	23	9	9
DMU6	0.20	18	16	8	8
DMU7	0.23	3	2	8	0
DMU8	0.14	12	12	11	9
DMU9	0.10	6	7	4	4

Table 3. Collected data based on the introduced criteria from Kashan-Isfahan highway

DMUs	Criteria				
	Distance from the main road (Km)	Distance from hospitals (Km)	Distance from the fire station (Km)	Distance from the existing fuel station (Km)	Distance from services and rest areas (Km)
DMU1	0.10	13	14	12	12
DMU2	0.17	23	22	10	10
DMU3	0.20	25	23	12	11
DMU4	0.12	36	34	23	0
DMU5	0.23	22	23	22	15
DMU6	0.14	8	7	8	8
DMU7	0.27	24	22	8	8
DMU8	0.10	29	27	13	13
DMU9	0.10	36	33	20	9
DMU10	0.16	35	38	29	5
DMU11	0.22	30	33	25	13
DMU12	0.15	22	25	18	18
DMU13	0.10	15	18	11	11
DMU14	0.18	5	4	3	2
DMU15	0.20	6	7	3	3

5- Results and discussions

All proposed models have coded in General Algebraic Modeling System (GAMS) software. Furthermore, all practical experiments are carried out with a 2 GHz Intel Core i7 MacBook Pro with 4 GB of RAM. The recommended main model maximizes vehicle traffic flow on two-way highways and reduces the cost of building fuel stations. As already mentioned, the analysis of the gas tank capacity of the cars is subject to uncertainty. First, the DEA model results are represented, and then the results of the proposed multi-objective flow refueling location model are discussed. This paper reveals the results of the proposed model under the following two scenarios:
1- Considering the existing gas fuel stations as fixed and available locations
2- Considering the existing gas fuel stations as candidate locations

5-1- DEA model results

This paper is used an optimized Data Envelopment Analysis (DEA) model to determine the best location between all candidates for gas fuel stations.

• Tehran-Qum highway

Twelve candidate nodes are considered to locate a CNG fuel station, and after using the DEA model, table4 exhibits the DEA results and ranks. Notice that the top five best results of DEA model are chosen to be the final candidate locations to construct fuel station.

Table 4. DEA results of Tehran-Qom highway

Tehran -Qum	Candidate locations	**1**	**2**	**3**	**4**	**5**	6	7	8	9	10	11	12
	Model Score	**0/595**	**0/576**	**0/576**	**0/521**	**0/500**	0/491	0/480	0/480	0/480	0/437	0/434	0/434

• **Qum-Kashan highway**

Nine candidate nodes are considered to locate a CNG fuel station, and after using the DEA model, table5 exhibits the DEA results and ranks. Notice that the top five best results of DEA model are chosen to be the final candidate locations to construct fuel station.

Table 5. DEA results of Qum-Kashan highway

Qum-Kashan	Candidate locations	**1**	**2**	**3**	4	5	6	7	8	9
	Model Score	**0/709**	**0/500**	**0/500**	0/385	0/346	0/346	0/337	0/335	0/326

• **Kashan-Isfahan highway**

Fifteen candidate nodes are considered to locate a CNG fuel station, and after using the DEA model, Table6 exhibits the DEA results and ranks. Notice that the top five best results of DEA model are chosen to be the final candidate locations to construct fuel station.

Table 6. DEA results of Kashan-Isfahan highway

Kashan-Isfahan	Candidate locations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	11	12	13	14	15
	Model Score	**0/771**	**0/761**	**0/757**	**0/725**	**0/724**	**0/698**	**0/500**	**0/428**	**0/345**	**0/335**	0/329	0/303	0/262	0/238	0/221

To verify and confirm the obtained rankings by the proposed DEA models, a non-parametric test namely Spearman's rank correlation technique is used (Sheskin, 2003). This approach is a nonparametric measure of rank correlation that assesses the positive correlation among the proposed sets of ranks achieved by the standard DEA model and the introduced DEA model by implementing the following measure:

$$r = 1 - \frac{6\sum_i d_i}{n(n^2-1)} \quad (22)$$

Remark that n signifies the total number of DMU_s and the d_i describes the difference among ranks of the mentioned procedures for DMU_l. We examined the null hypothesis (H_0) and the alternative hypothesis (H_1) as follows:

H_0: There is no correlation between the ranks taken from the proposed DEA model and the standard DEA model.

H_1: There is a positive correlation between the ranks taken from the proposed DEA model and the standard DEA model.

It is considered that the confidence level is 0.95 $(1-\alpha)$. The Spearman's rank correlation coefficient and P-value results are individually obtained 0.913 and 0.000. Since P-value is smaller than the value of α, so the null hypothesis is refused and hence it can be assumed that there is a strong relationship between the ranks provided by the standard DEA model and the proposed DEA model. Additionally, the proposed DEA model ranks are compatible with the ones in the standard DEA model.

5-2- Main model results'

The results of the proposed multi-objective flow refueling location model are exposed under the following two scenarios:

1- Considering the existing gas fuel stations as fixed and available locations

2- Considering the existing gas fuel stations as candidate locations

5-2-1- First scenario results'

The first scenario is considering the existing gas fuel stations as fixed and available locations. Speaking intuitively, in this situation, the model determines if the current circumstance is suitable or not. Also, results expose that whether these highways need new fuel stations or not. After solving the introduced model, the following results underscore that the current situation is appropriate on all three highways and vehicles can travel between the cities without running out of fuel. In the knowledge of the existing fuel station at the beginning and the end of highways, there are five gas fuel stations on the Tehran-Qum highway, five gas fuel stations on the Qum-Kashan highway and six gas fuel stations on the Kashan-Esfahan highway. According to the results, the number of stations is enough, and the existing gas fuel stations can service the vehicles. So, there is not any need to construct new gas fuel stations. Figures 7-9 display the location of current gas fuel stations on all three highways.

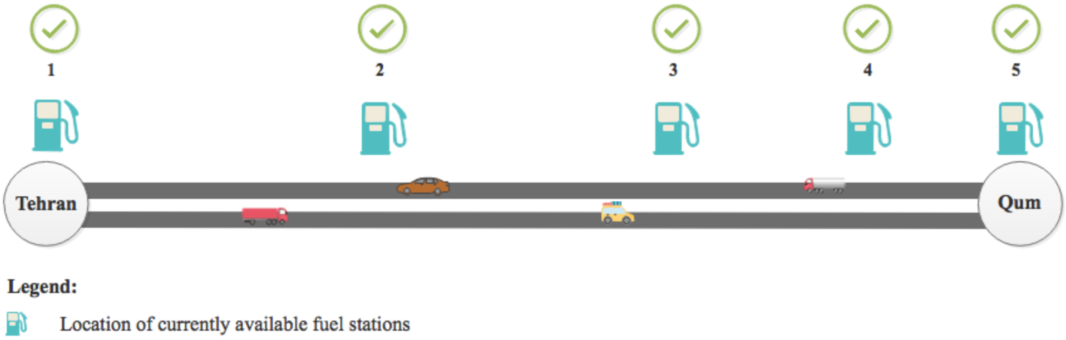

Fig 7. Tehran-Qum highway with the current location of fuel stations

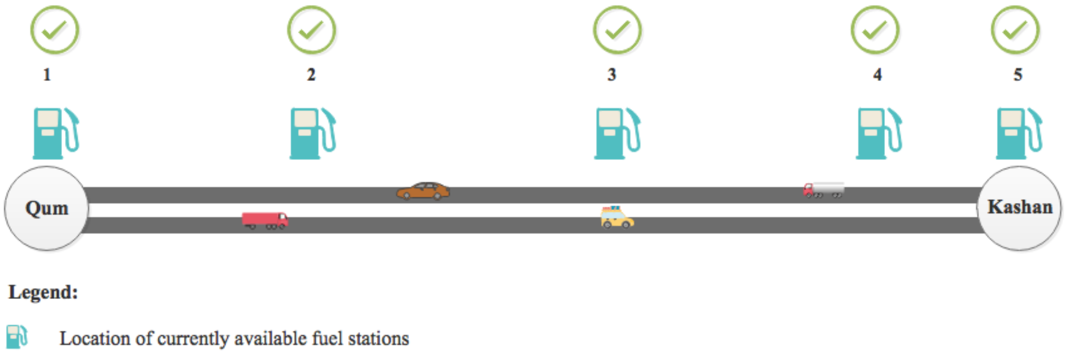

Fig 8. Qum-Kashan highway with the current location of fuel stations

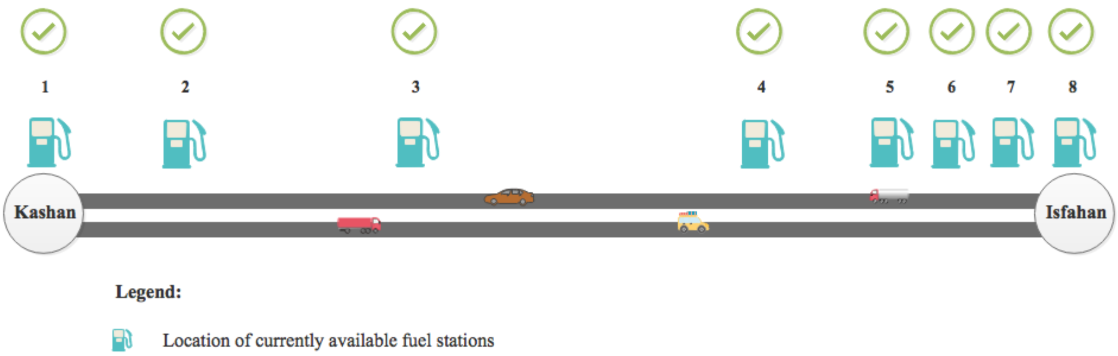

Fig 9. Qum-Kashan highway with the current location of fuel stations

5-2-2- Second Scenario Results'

In this scenario, the existing gas fuel stations are considered as candidate locations. Alternatively stated, it appears that we have a new highway and the main problem is to locate all fuel stations in the best system. After the proposed model has been solved, the following result is achieved. These results reveal the needed number of fuel stations and the number of extra fuel stations on the current situation on the highways. Also, the amount of cost saving and the final selected locations of the fuel stations is determined. Table 7 represents the results of the main model in this scenario. It shows the number of stations based on the current situation and the main model results. Moreover, the number of extra fuel stations in the current situation is determined.

Table 7. Results of the main model in the second scenario

	Tehran-Qum	**Qum-Kashan**	**Kashan-Isfahan**
Number of stations based on the current situation	5	5	8
Number of stations based on the main model results	4	3	4
Number of extra fuel stations in the current situation	**1**	**2**	**4**
Cost Savings	0/5 Million $	1 Million $	2 Million $
Selected Locations	1,4,9,10	1,6,8	1,5,10,18

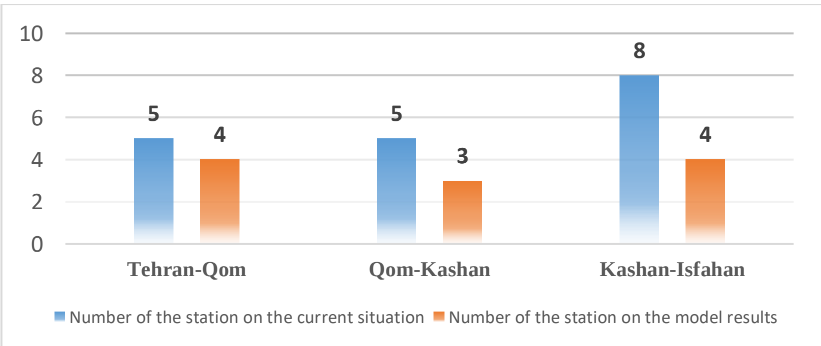

Fig 10. Results of the main model in the second scenario

What is apparent from the results is that the number of the gas fuel stations on the Tehran-Qum highway can be reduced to four without any problems, which will also reduce the costs. There is only one extra fuel station on this highway and the amounts of cost saving can be almost 0.5 Million Dollar. The results also manifest that the best location system on the Tehran-Qum highway is the gas fuel stations located on the numbered positions 1, 4,9,10. About the Qum-Kashan highway, the number of the gas fuel stations can be reduced to three, and there are two extra fuel stations on this highway. So, the amounts of cost saving can be almost 1Million Dollar. The best location system on this highway is the gas fuel stations located on the numbered positions 1,6,8. Eventually, the introduced model reveals great results on the highway between Kashan and Isfahan. It can reduce the number of gas fuel stations down to four. So, there are four extra fuel stations on this highway, and the amounts of cost saving can be almost 2 Million Dollar. Therefore, it is highly cost-effective and the best location system is the gas fuel stations located on the numbered positions 1,5,10,18.

Figure 11 represents the chosen locations of fuel stations on Tehran-Qum highway. None of the recommended locations are chosen and the location numbered 7 is not needed, so as it is explained before; the best location system on the Tehran-Qum highway is the gas fuel stations located on the numbered positions 1,4,9,10. Also, there is only one extra fuel station on this highway.

Fig 11. Tehran-Qum highway with the chosen locations of fuel stations

Figure 12 illustrates the chosen locations of fuel stations on Qum-Kashan highway. It is noted that one of the suggested locations is preferred, and the locations numbered 3,5 and 7 are not needed, so as it is defined before; the best location system on this highway is the gas fuel stations located on the numbered positions 1,6,8. Furthermore, there are two extra fuel stations on this highway.

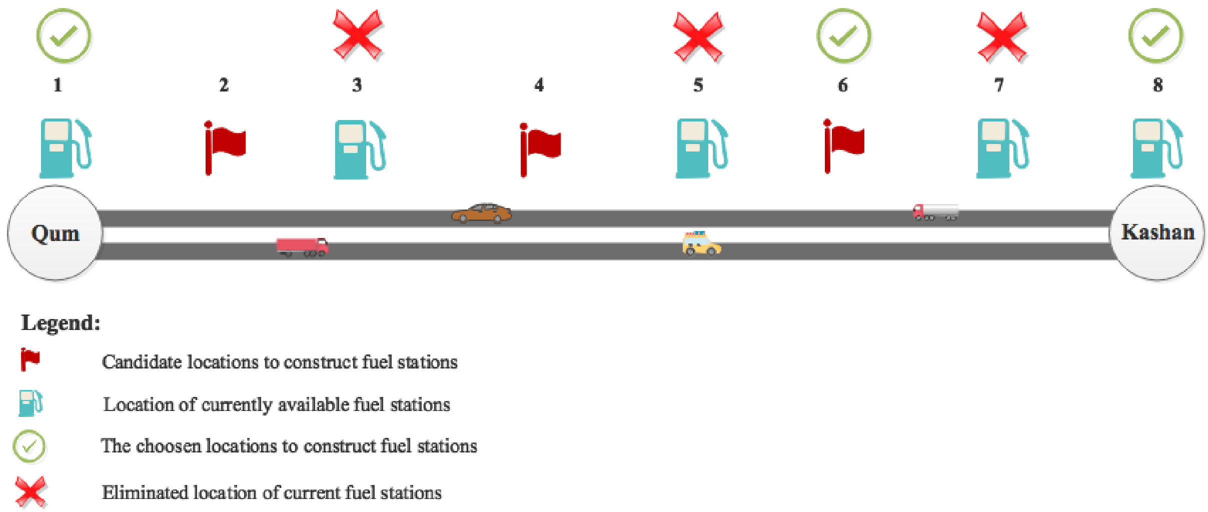

Fig 12. Qum-Kashan highway with the chosen locations of fuel stations

Finally, figure 13 shows the chosen locations of fuel stations on Kashan-Isfahan highway. Two of the recommended locations are chosen and the locations numbered 3,7,13,15,16 and 17 are not needed, so as it is revealed before; the best location system is the gas fuel stations located on the numbered positions 1,5,10,18. Additionally, there are four extra fuel stations on this highway.

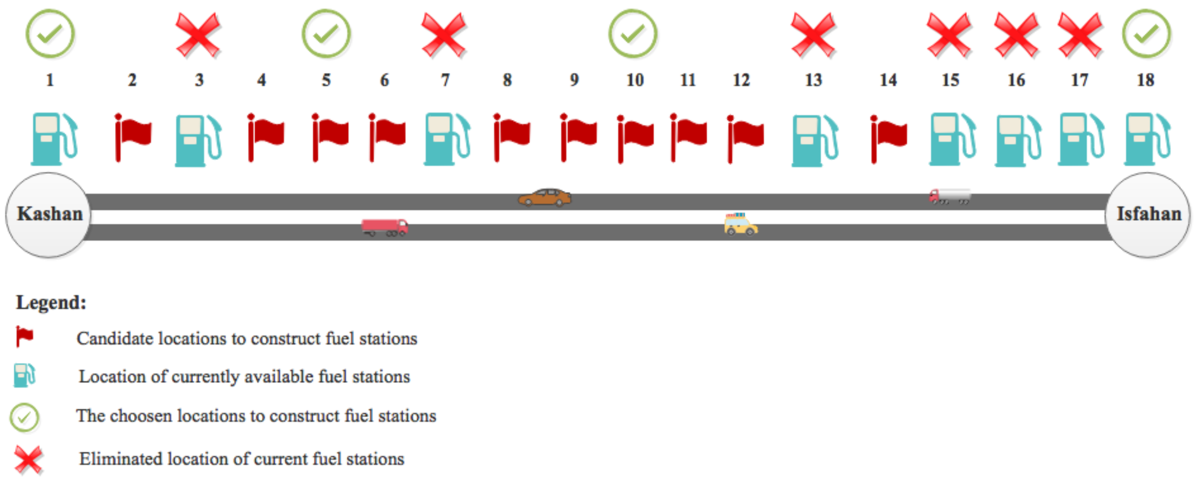

Fig 13. Kashan-Isfahan highway with the chosen locations of fuel stations

6- Conclusion and future research

Environmental concerns and economic motivations eventuate in more attention to alternative fuels such as compressed natural gas. Accordingly, locating the gas stations considering the number of them to cover the whole path is noticeable. The idea of the current research was to propose a model that locate the best sites to construct the gas fuel stations regarding maximize the traffic flow of the vehicles in the two-way highways and reduce the cost of constructing gas fuel stations with the help of mathematical and DEA models. One of the outstanding benefits of the proposed model is analyzing the traffic flow in two-way highways, gaining better results in location gas fuel stations.

The utilization and usefulness of the introduced method are studied in a real case study in Iran. Although the current location of gas fuel stations is acceptable and the number of current stations is enough. So, the existing gas fuel stations can service the vehicles and, there is not any need to construct new gas fuel stations. In the case where the existing gas fuel station is considered as candidate locations, results underscore the introduced model not only can locate fewer gas fuel stations that decreases the costs but also can cover the whole path. For example, the offered model can reduce the number of gas fuel stations on the Kashan-Isfahan highway to four while covering the whole path. So, the number of extra fuel stations on this highway is four, and it is incredibly cost-effective.

Many additions to this paper could be named for future research. Determining candidate location using Geographic Information System (GIS) can be recommended as an appealing direction with significant practical relevancies. As such, the proposed model can be developed by considering the supply capacity of the fuel stations, the queue system at fuel stations, and the different vehicles with the different fuel tank capacity.

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