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A Non-Radial Model in Data Envelopment Analysis (DEA) for Ranking of Fire Station Candidate in District Ten of Tehran Municipality

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Abstract
Ranking of fire stations is one of the most important issues in urban planning and crisis management. Because ranking increases the speed of service in crises. In the real world, the value of some attributes is non-controllable, so planners and decision makers can't change the values in the ranking process and it must be considered in the ranking. The aim of this study is ranking of fire stations candidates in district ten of Tehran municipality and for this, has used non-radial DEA model. The decision matrix consists of eleven alternatives and twelve attributes. The attributes are controllable (that the decision makers able to change values) and non-controllable (that the decision makers unable to change the values). The results show that station 5 is prioritized among the stations and has higher non-controllable attribute values in decision matrix than the others, and it validates the results.

Keywords: Non-Radial Model, DEA, Ranking, Fire Stations

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1. Introduction

Fire stations are one of the most important service centers in cities. Those has important role in the safety of citizens and the development of cities. Obviously, timely service of fire stations required an optimal location whit consider limitations of the urban environment and loss reduction on residents [1]. Research on fire station site selection and spatial optimization has a long history. For example, Hogg noted that the key to fire system analysis is to first determine the optimal number of stations and their most effective locations in order to reduce losses. Helly argued that the most important attribute of fire station location should be the minimum emergency response time [2]. This factor was used as the foundation of a fire station site selection model that was subsequently developed by Plane and Hendrick [3], who utilized response time as the coverage criterion to apply the location set covering problem (LSCP) theory to the issue of site selection. Memarzadeh et al. define 12 attributes for locating of fire stations in District Ten of Tehran Municipality. Also, they presented a new ranking method named “Fibonacci Sequence Technique” [4]. Reilly and Mirchandani considered the dual criteria of maximum and fastest response to potential demand points as key to fire station site selection, building the use of the p-median problem into their analysis [2]. Habibi et al., Erden et al. and Pandav et al. conducted site selection and optimization analyses in different regions and cities via the successive use of the analytic hierarchy process (AHP) and geographic information system (GIS) [2]. The location of fire stations is an important factor in the ability of fire management. locating of fire stations and number of stations of areas is very important for decision makers and crisis management [5]. Locating is an analysis about capabilities of an area in terms of the existence of suitable and sufficient land for a special land use. Locating It takes a lot of time because a lot of the available attributes must be assessed [3]. Also, ranking a finite set of actions evaluated on a finite set of criteria is a problem of uttermost importance in many real-world areas of decision-making [6]. In most of the countries, the overall layout of firefighting facilities is an important part of fire control planning in the cities. Reasonable construction of fire facilities and layout of fire stations can improve governments’ ability to reduce or prevent fire disasters in cities considerably [7].

2. Data Envelopment Analysis (DEA)

In urban management, resource limitations have made the managers find a method for optimum use of available factors. One of the important factors is efficiency assessment, the production function is required. DEA is a nonparametric method which identifies an envelope approach using some observation. The shape of this approach is named experimental production function and this envelopment approach is named efficient frontier. DEA was first based in the article CCR by Charnes-Cooper and Roads.

They generalized Farrels primary analysis, which was in one output-multi input mode to multi input-multi output mode. Then Charnes- Cooper and Banker were able to establish the model BCC by recognizing the return to scale method and modifying the CCR model.

As stated, resource limitations and unlimited needs and wills have made a human being plan and manage resources in order to succeed in affairs; since human beings want to assure that they achieve their maximum results and goals of available resources. There is at least one efficient unit among the units and its efficiency score by data envelopment analysis equals 1. Now this question is raised that if there are several DMUs whose efficiencies are 1 (100% efficient), which unit performs better? In other words, which unit is better among the efficient units and how can the efficient units be ranked [8]?

An important aspect of DEA efficiency assessment is the correct selection of set of input/output that an inefficient DMU is efficient. Therefore, selection of appropriate benchmark for evaluating of an inefficient DMU is favorable for us [9].

2.1 Non-Radial Model

There are two categories of indicators: cost (Negative) and benefit (Positive). The cost attributes are inputs and the benefit attributes are outputs. Also, some of the attributes are controllable, some of them non-controllable and some others up to percentage controllable. assume that $X=\begin{pmatrix} x^D \\ x^{ND} \end{pmatrix}$ and $Y=\begin{pmatrix} y^D \\ y^{ND} \end{pmatrix}$ be inputs and outputs vectors.

D= controllable variables

ND= non-controllable variables

Now, non-radial model is formulated as follows:

$$Min \ \frac{1-\frac{1}{|I|}\sum_{i\in I}\frac{s_i^{-D}}{x_{ip}^D}}{1+\frac{1}{|o|}\sum_{r\in o}\frac{s_i^{+D}}{y_{rp}^D}} \qquad (1)$$

$$
\begin{aligned}
& s.t. \\
& \sum_{j=1}^{n}\lambda_j x_{ij}^D = x_{ip}^D - s_i^{-D},\ i\in I \\
& \sum_{j=1}^{n}\lambda_j x_{ij}^{ND} = x_{ip}^{ND} - s_i^{-ND},\ i\in I' \\
& \sum_{j=1}^{n}\lambda_j y_{rj}^D = y_{rp}^D + s_r^{+D},\ r\in o \\
& \sum_{j=1}^{n}\lambda_j y_{rj}^{ND} = y_{rp}^{ND} + s_r^{+ND},\ r\in o' \\
& \lambda\geq 0,\ s^{-o}\geq 0, s^{+D}\geq 0, s^{-ND}\geq 0, s^{+ND}\geq 0
\end{aligned}
$$

2.1.1 Linearization process

For the linearization process, assume that

$$\frac{1}{1+\frac{1}{|o|}\sum_{r\in o}\frac{s_r^{+D}}{y_{rp}^D}} = q \qquad (2)$$

So, the formulation of Model (1) formulated as follows:

$$Min \quad q-\frac{1}{|I|}\sum_{i\in I}\frac{q.s_i^{-D}}{x_{ip}^D} \qquad (3)$$

$$
\begin{aligned}
& s.t. \\
& \sum_{j=1}^{n}\lambda_j x_{ij}^D = x_{ip}^D - s_i^{-D} \quad ,\quad i\in I \\
& \sum_{j=1}^{n}\lambda_j x_{ij}^{ND} = x_{ip}^{ND} - s_i^{-ND}, i\in I' \\
& \sum_{j=1}^{n}\lambda_j y_{rj}^D = y_{rp}^D + s_r^{+D}, r\in o \\
& \sum_{j=1}^{n}\lambda_j y_{rj}^{ND} = y_{rp}^{ND} + s_r^{+ND}, r\in o' \\
& q+\frac{1}{|o|}\sum_{r\in o}\frac{q.s_r^{+D}}{y_{rp}^D}=1 \\
& \lambda\geq 0,\ s^{-o}\geq 0, s^{+D}\geq 0, s^{-ND}\geq 0, s^{+ND}\geq 0, q\geq\varepsilon
\end{aligned}
$$

For linearization changed of the variables as following:

$$
\begin{aligned}
& q.s_i^{-D}\rightarrow s_i^{-D} \quad ,\quad i\in I \qquad (4) \\
& q.s_i^{-ND}\rightarrow s_i^{-ND} \quad ,\quad i\in I' \\
& q.\lambda_j\rightarrow\lambda_j \quad ,\quad j=1,\ldots,n \\
& q.s_r^{+D}\rightarrow s_r^{+D} \quad ,\quad r\in o \\
& q.s_r^{+ND}\rightarrow s_r^{+ND} \quad ,\quad r\in o'
\end{aligned}
$$

So, the final model for efficiency of DMU_p is as follows:

$$Min\, Z_p = q - \frac{1}{|I|}\sum_{i\in I}\frac{s_i^{-D}}{x_{ip}^D} \qquad (5)$$

$$s.t.$$

$$\sum_{j=1}^{n}\lambda_j x_{ij}^D = q.x_{ip}^D - s_i^{-D} \quad , \quad i \in I$$

$$\sum_{j=1}^{n}\lambda_j x_{ij}^{ND} = q.x_{ip}^{ND} - s_i^{-ND} \quad , \quad i \in I'$$

$$\sum_{j=1}^{n}\lambda_j y_{rj}^D = q.y_{rp}^D + s_r^{+D} \quad , \quad r \in o$$

$$\sum_{j=1}^{n}\lambda_j y_{rj}^{ND} = q.y_{rp}^{ND} + s_r^{+ND} \quad , \quad r \in o'$$

$$q + \frac{1}{|o|}\sum_{r\in o}\frac{s_r^{+D}}{y_{rp}^D} = 1$$

$$\lambda \ge 0,\, s^{-D} \ge 0, s^{+D} \ge 0, s^{-ND} \ge 0, s^{+ND} \ge 0, q \ge \varepsilon$$

For the ranking, DMUs in model (5) convert to model (6). Assume that DMUs efficient in model (5).

$$Max\ Z_p' = q - \frac{1}{|I|}\sum_{i\in I}\frac{s_i^{-D}}{x_{ip}^D} \qquad (6)$$

$$s.t.$$

$$\sum_{\substack{j=1\\ j\ne p}}^{n}\lambda_j x_{ij}^D = q.x_{ip}^D + s_i^{-D} \quad , \quad i \in I$$

$$\sum_{\substack{j=1\\ j\ne p}}^{n}\lambda_j x_{ij}^{ND} = q.x_{ip}^{ND} + s_i^{-ND} \quad , \quad i \in I'$$

$$\sum_{\substack{j=1\\ j\ne p}}^{n}\lambda_j y_{rj}^D = q.y_{rp}^D - s_r^{+D} \quad , \quad r \in o$$

$$\sum_{\substack{j=1\\ j\ne p}}^{n}\lambda_j y_{rj}^{ND} = q.y_{rp}^{ND} - s_r^{+ND} \quad , \quad r \in o'$$

$$q + \frac{1}{|o|}\sum_{r\in o}\frac{s_r^{+D}}{y_{rp}^D} = 1$$

$$\lambda \ge 0,\, s^{-D} \ge 0, s^{+D} \ge 0, s^{-ND} \ge 0, s^{+ND} \ge 0, q \ge \varepsilon$$

If Z_p' is optimal value of objective function in model (6), so, increasing the value of Z_p' will improve the rank of DMU_p.

3. Materials

This research has used the attributes from standard No. 6430 (Locating Urban Fire Stations Agenda) and the attributes that has defined in Memarzadeh et al. (2022) research. These attributes are: geotechnical items, width of street, useful performance radius, population, neighborhood, land area, land price, number of past fires, traffic, costs of station construction, density, urban decay [4].

In this research, will use non-radial model of DEA for ranking. Attributes containing controllable and non-controllable data. Controllable (D) are attributes that the decision makers able to change values, such as width of street, useful performance radius, land area, costs of station construction. Non-controllable (ND) are attributes that the decision makers unable to change the values, such as geotechnical items, population, neighborhood, land price, number of past fires, traffic, density, urban decay. Also, some of the attributes were negative (Cost attributes) and some of them positive (Benefit attributes). Land price, traffic and cost of station construction are cost attributes and geotechnical items, width of street, useful performance radius, population, neighborhood, land area, number of past fires, density, urban decay are benefit attributes. Therefore, decision matrix is as follows (Table 1).

The geotechnical items and traffic attributes are qualitative. The table below shows the equivalent values of qualitative to quantitative variables.

Table 1. Decision matrix

Attribute	Geotechnical Items	Width of Street	Useful Performance	Population	Neighborhood	Land Area	Land Price	Number of Past Fires	Traffic	Costs of Station Construction	Density	Urban Decay
Status	+	+	+	+	+	+	-	+	-	-	+	+
	ND	D	D	ND	ND	D	ND	ND	ND	D	ND	ND
Station 1	Good	20	800	64908	163	700	11000000	411.236	Heavy	2000000	0.0397	0.004866
Station 2	Good	20	800	41263	140	2200	11500000	295.0819	Heavy	2000000	0.035	0.004274
Station 3	Good	16	800	93015	48	4700	11300000	548.5123	Heavy	2000000	0.0469	0.00684
Station 4	Good	20	800	89579	35	1100	10800000	519.0982	Heavy	2000000	0.05	0.006871
Station 5	Good	30	800	96990	64	6000	10250000	640.3766	Heavy	2000000	0.049	0.01211
Station 6	Good	45	800	79374	546	2000	10200000	549.482	Too heavy	2000000	0.044	0.010264
Station 7	Good	16	800	98958	350	1400	10000000	669.5706	Too heavy	2000000	0.0492	0.01345
Station 8	Good	45	800	41076	63	6800	9500000	343.4163	Heavy	2000000	0.0427	0.008901
Station 9	Good	45	800	49482	62	2800	9500000	444.3293	Heavy	2000000	0.0412	0.014653
Station 10	Good	45	800	31465	100	2900	9500000	432.3067	Heavy	2000000	0.0329	0.016122
Station 11	Good	10	800	28521	93	980	Municipal Ownership	346.5901	Light	2000000	0.0379	0.012512

Table 2- Convert qualitative variables to quantitative

Attribute	Geotechnical Items	Width of Street	Useful Performance radius	Population	Neighborhood	Land Area	Land Price	Number of Past Fires	Traffic	Costs of Station Construction	Density	Urban Decay
Status	+	+	+	+	+	+	-	+	-	-	+	+
	ND	D	D	ND	ND	D	ND	ND	ND	D	ND	ND
Station 1	3	20	800	64908	163	700	11000000	411.236	4	2000000	0.0397	0.004866
Station 2	3	20	800	41263	140	2200	11500000	295.0819	4	2000000	0.035	0.004274
Station 3	3	16	800	93015	48	4700	11300000	548.5123	4	2000000	0.0469	0.00684
Station 4	3	20	800	89579	35	1100	10800000	519.0982	4	2000000	0.05	0.006871
Station 5	3	30	800	96990	64	6000	10250000	640.3766	4	2000000	0.049	0.01211
Station 6	3	45	800	79374	546	2000	10200000	549.482	5	2000000	0.044	0.010264
Station 7	3	16	800	98958	350	1400	10000000	669.5706	5	2000000	0.0492	0.01345
Station 8	3	45	800	41076	63	6800	9500000	343.4163	4	2000000	0.0427	0.008901
Station 9	3	45	800	49482	62	2800	9500000	444.3293	4	2000000	0.0412	0.014653
Station 10	3	45	800	31465	100	2900	9500000	432.3067	4	2000000	0.0329	0.016122
Station 11	3	10	800	28521	93	980	Municipal Ownership	346.5901	2	2000000	0.0379	0.012512

4. Results

In this research for solving non-radial model use gams. The ranking results as follows:

The results show that station 5 is prioritized among the stations and has higher non-controllable attribute values in population, land area, number of past fires and density attributes in decision matrix than the others. So, it validates the results.

Results

Station No.	Rank Result from Gams	Ranking
1	0.18365501	6
2	0.685722803	2
3	0.126057516	8
4	0.485294128	3
5	0.984348482	1
6	0.058210732	10
7	0.245085426	5
8	0.068256735	9
9	0.024219297	11
10	0.143498564	7
11	0.432352951	4

5. Conclusion

In this research ranked the fire stations candidate in district ten of Tehran municipality via non-radial model. The characteristic of this model was using controllable and non-controllable data. It was important because the results were closer to reality. In fact, in the real world some of the attributes are non-controllable, so the ranking is more realistic. Therefore, decision makers in fire stations can start construction based on the obtained rank of candidates of fire stations. It can optimize the quality and increase speed of service. Using the DEA models in decision making increases the possibility of foresight and reduces risks in management. Mistakes that can cause financial and human losses.

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