International Journal of Railway Research, Vol. 11, No. 1, (2024), 59-68

Iran University of Science and Technology

International Journal of

Railway Research

ISSN: 2423-3838

Comparing safety efficiency of Tehran different regions and the impact of subway on it by using Data Envelopment Analysis

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ARTICLE INFO

Article history:

Received: 03.06.2024

Accepted: 01.09.2024

Published: 10.09.2024

Keywords:

Regions

Tehran

Subway

Efficiency analysis

Data envelopment analysis

A B S T R A C T

One of the most important issues in different systems is the evaluation of unit efficiency, which highly relates to its inputs and outputs. In order to compare the efficiency of different units, the inputs and outputs of those should be considered. Data envelopment analysis is a popular method for comparing the efficiency of different decision-making units, which is used in this paper.

The decision-making units of this paper are different regions of Tehran, which, by considering two inputs and two outputs in variable return to scale setting, have been used, and efficient and non-efficient regions are identified. The inputs of this model are trips that originated in the region and trips that ended in the region. The two outputs of the model are the number of accidents that led to injuries and the number of accidents that led to fatalities. In the end, the Tobit regression technique is used to identify whether the safety efficiency of regions as a dependent variable is related to the number of subway stations in that region as an independent variable.

1. Introduction

Traffic jams and accidents are problems for many metropolitan cities, and they cause various costs for cities and nations. Among all injuries, the rate of road accidents, especially urban road accidents, and efforts to reduce it are of great importance. In many cities around the world, including Tehran, traffic accidents continue to be a major cause of deaths and injuries. Therefore, the development of public transportation methods, increasing their efficiency as one of the effective methods of traffic management in metropolitan cities such as Tehran, and reducing the resulting damage, including urban road accidents, is discussed. One of the basic and desirable solutions is to use the urban train system or subway as a clean and high-capacity transportation method.

In this research, it is assumed that Tehran's regions with more subway stations should probably have higher safety efficiency than those with fewer subway stations. In fact, the main question of this research is, according to the available statistics on the number of urban road accidents in different regions of Tehran, if there is a significant relationship between the number of subway stations in different regions as a method of public transportation and the number of urban road accidents in those regions.
For this purpose, at first, the data envelopment analysis (DEA) method was used to obtain the safety efficiency of Tehran's different regions, and then the Tobit regression method was used to check the presence or absence of a significant relationship between the number of stations and the efficiency of each region.

The structure of this paper is as follows: Section 2 reviews previous studies in the field of

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[DOI: 10.22068/ijrare.348]

accidents with a special focus on DEA methods, along with identifying their inputs and outputs. In Section 3, an overview of DEA concepts and models is presented. The DEA model that is used in this paper is discussed in Section 4. The Tobit regression method is used in Section 5 to investigate whether or not the number of subway stations in each region affects accidents. Section 6 concludes the paper and includes suggestions for future research.

2. Literature review

Today, the rate of road accidents in most countries, especially in developing countries, is increasing rapidly due to the increase in the volume of road traffic. According to the reports published by the World Health Organization (WHO), more than 1.25 million people in the world die in road accidents every year, in which the share of countries with low and middle incomes is higher than other countries [6]. Therefore, considering the increasing level of motorization in developing countries, the issue of driving safety and addressing it in these countries is of particular importance [8]. Road traffic injuries cause great damage to individuals and societies and generate significant financial costs annually, especially in developing countries, to the extent that estimates show that this cost can be up to 4% of the gross domestic product of countries [10]. So, a number of papers have been published in various countries in the field of road safety [10, 12], and a framework has been created for the development of a comprehensive set of indicators for benchmarking among countries [14].

DEA models are recognized as suitable techniques to assess and analyze Road Safety Performance (RSP). Therefore, according to the advantages of using data envelopment analysis (DEA), many researchers have used this approach as a performance evaluation method in their studies in the field of road safety, and they are widely involved in policymaking by using decision-making techniques [16-18]. Moreover, previous research analyzed the strengths and weaknesses of five weighting methods, including DEA, in RSP based on the number of road accident fatalities per million population and found that there is a high correlation between DEA and road safety rank in EU countries [19]. The DEA method can also be used to evaluate road safety at micro levels (from a criterion for assessing road safety at the national level [20, 21] to a criterion for public transportation organizations [22].

Therefore, in some research, the DEA-based Malmquist productivity index approach has been used for road safety benchmarking in the United States [23] and for road safety risk evaluation and target setting in 27 EU countries. The main goal of the research conducted was to introduce a DEA-based road safety model (DEA-RS) as an extension of the basic DEA model [24]. Furthermore, investigating and comparing the level of safety in road traffic was considered an important issue in the research conducted in this field. Especially when there is a need to compare between different regions to better understand safety conditions at the local level and develop related actions. Therefore, some articles use traffic safety level calculation methods that rely on a single numerical value to evaluate it [25]. In some other research conducted in this field, different models based on DEA and other linear programming techniques have been used. The analysis of the obtained results showed that although the data used as input in the presented models are the same and independent from each other, each method provides a different set of results [26].

Therefore, the development of public transportation modes such as subways is one of the most effective methods of traffic management in the world. This transport mode is able to move travelers from private cars to a more efficient and less time-consuming solution. This shift determines lower traffic congestion rates, leading to reduced road traffic accidents [27, 28].

As it can be seen, due to the novelty of the subject under study, the comparison of statistics of urban road accidents and the impact of subways on them has not been studied so far, and not many studies have been done in this field. Therefore, this issue shows the importance of the subject of the current paper, which aims to investigate the impact of subways on road safety efficiency in different regions of Tehran by using DEA. *Table 1* shows some other papers related to the literature review in which data envelopment analysis (DEA) has been used.

[DOI: 10.22068/ijrare.348]

Table 1. Some other related articles that use data envelopment analysis.

Authors	DMU	Inputs	Outputs
[4]	19 Norwegian regions	No input (Constants)	Usage control, safety bel control, technical control
[5]	19 EU countries	Mean speed on (Urban roads/rural roads and motorways), speed limit violation, seatbelt usage, child restraint usage, helmet usage, fatalities caused by alcohol	(Fatalities/ serious injuries/ slight injuries) per million inhabitants, No. of crashes per million inhabitants
[7]	30 Iranian Provinces	3 principal components (PC): PC1 (road safety policies and fatalities), PC2 (“safety reformation”), PC3 (“safety instruction”)	1PC (no. of crashes and no. of causalities)
[9]	8 Urban Road networks in Italy	4 models were presented that used inputs/outputs from the following mix by taking account of minimum recommended DMUs:	
		“(number of vehicles registered in the metropolitan area)/ (length of metropolitan area network), number of major attractors within 300 m from the town hall, (€ spent by the Administration)/ (length metropolitan area network), number of public buses)/ (length metropolitan area network)”	“Level Of Service, (Rate of average time needed to reach the town hall)/ (number of main accesses), (number of fatal accidents)/ (length metropolitan area network), (number of passengers transported in a year)/ (length metropolitan area network)”
[11]	40 road intersections in Toronto	Cost of safety improvement project	Reduction of crashes resulting in fatalities/ injuries/ property damages
[13]	30 Provinces of Iran	Length of bright roads, degree of smart roads, number of police stations, number of emergency bases	Number of passengers. Freight, number of fatalities
[15]	31 Provinces of Iran	level of equipment at the disposal, level of approved provincial budget, level of manpower at the disposal	score of fatalities reduction, score of casualties reduction

3. Methodology

The data envelopment analysis method allows for the measurement and investigation of the relative efficiency of decision-making units (DMU). This method is a non-parametric linear programming method that penalizes the Pareto efficiency frontier for similar DMUs that have the same input and output variables [29]. In general, an objective function is used in parametric methods. The general data

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envelopment analysis model is as follows [29, 30]:

$$MaxE_j = \frac{\sum_{r=1}^{s} W_r O_{rj}}{\sum_{i=1}^{m} V_i I_{ij}} (j = 1, 2, ...n)$$

$$S.t:$$

$$\frac{\sum_{r=1}^{s} W_r O_{rj}}{\sum_{i=1}^{m} V_i I_{ij}} \leq 1 (j = 1, 2, 3, ...n)$$

$$W_r \geq 0 (r = 1, 2, 3, ..., s)$$

$$V_i \geq 0 (i = 1, 2, 3, ..., m)$$

This method evaluates the relative efficiency of decision-making units by placing at least one of the units on the border and the remaining units below it. For this reason, it is called Data Envelopment Analysis, and this name is derived from its enveloping feature. In DEA, assuming that a system (decision unit) converts a number of inputs to a number of outputs, efficiency is defined as the ratio of the total weighted outputs to the total weighted inputs. In other words, the relative efficiency of each DMU is measured based on its inputs and outputs.

As previously mentioned, the efficiency obtained in DEA is relative, and the convex combination of efficient units is considered the efficiency frontier. Therefore, the units that are on the border of efficiency are considered efficient units, and the rest of the units will be inefficient, and to make them efficient, changes must be made in the inputs and outputs of the units.

Two major decisions should be made for using DEA. In the first step, it should be identified whether the model is input-oriented or output-oriented. In input orientation, it is attempted to obtain technical inefficiency as a ratio that must be reduced at the inputs so that the output remains unchanged and the unit is on the efficiency frontier, while in output-oriented models, outputs should increase with the same inputs in order to reach the efficiency frontiers.

DEA has two general approaches: constant return to scale (CRS) and variable return to scale (VRS). In constant return to scale, it is assumed that there is no significant relationship between the operating scale and the efficiency of each of the decision-making units. As a result, larger and smaller units can have the same efficiency in converting inputs to outputs. Meanwhile, in variable return to scale, the increase in inputs does not lead to a proportional increase in outputs. This means that any input multiplier can produce the same, lower, or higher output multiplier [31]. In this paper, in order to calculate the efficiency of the twenty-two regions of Tehran, the Data Envelopment Analysis method with an output-oriented approach and variable return to scale has been used.

4. Model

In this paper and for the case study of Tehran, each of the 22 regions of the city is considered a

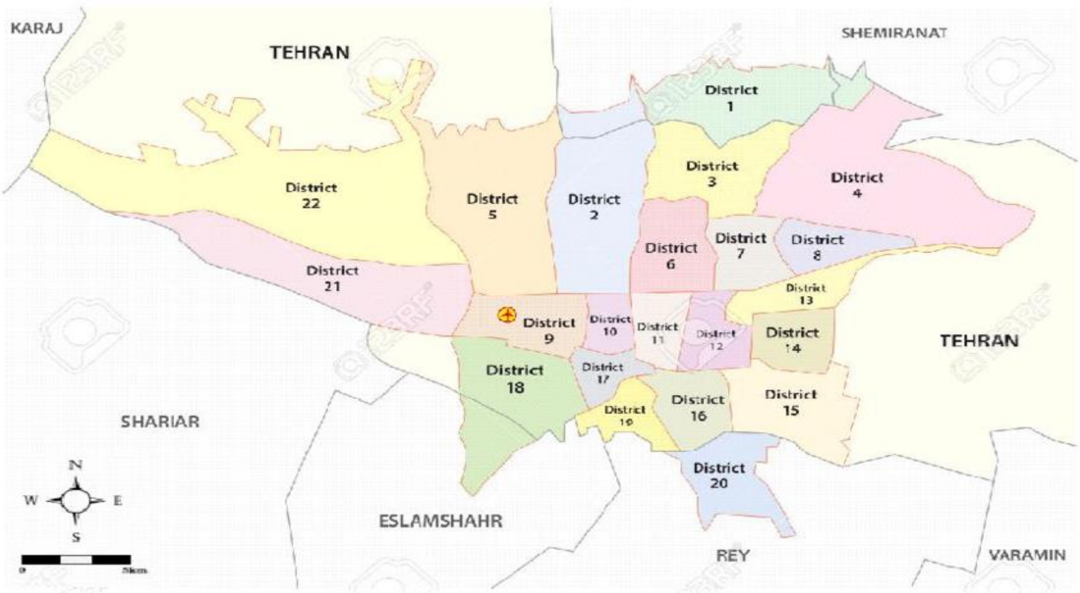

Figure 1. Map of twenty-two regions of Tehran [1].

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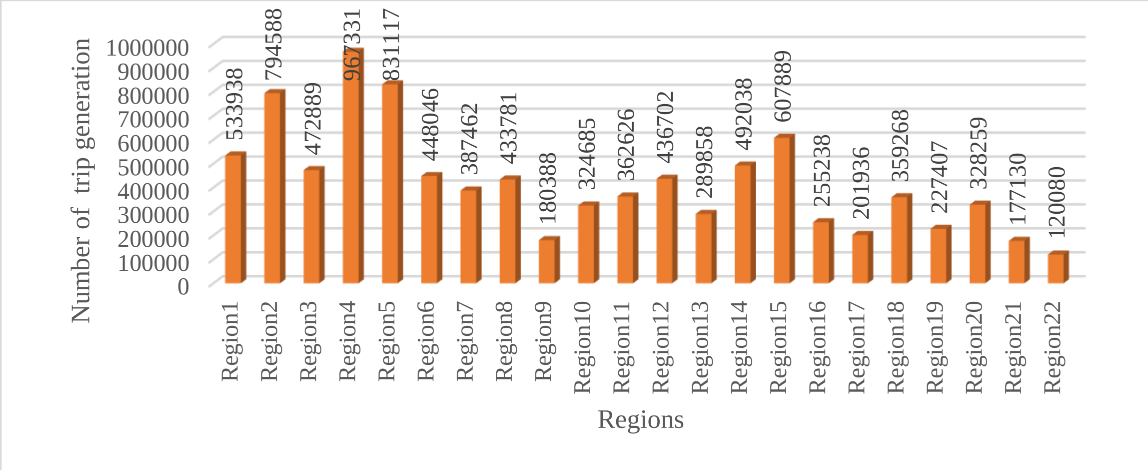

Figure 2. Trip generation in different regions of Tehran [3].

DMU, and *Figure 1* represents the regions of Tehran, Iran.

In this model, total trip generation and trip attractions are chosen as the two inputs of the model for regions, and the number of accidents leading to injury and accidents leading to fatality are chosen as the outputs of the model.

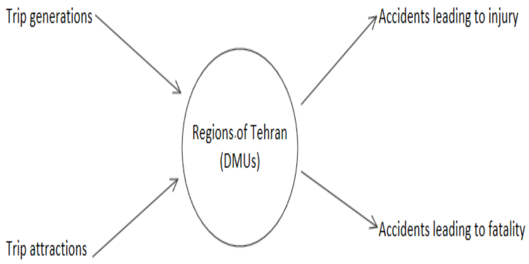

Figure 3. Inputs and outputs of DEA model.

After defining the model, data was collected for the year 2018. *Figure 2* shows that Region 4 has the highest trip generation by the number of 967,331, while Region 22 has the lowest trip generation by the number of 120,080.

Therefore, Regions 4, 5, and 2 are the top three regions for generating trips, with a share of 10.5, 9, and 8.61, respectively.

Figure 4 shows the number of trip attraction data for 22 regions of Tehran. Region 12 has the highest trip attraction by the number of 1,085,811, but region 22 has the lowest one with the number of 66,464. In fact, Region 12 that posts Tehran Grand Bazaar has the share of 11.7 percent of total trip attractions in the city, followed by Region 6 by 10.9 percent and Region 4 by 7.75 percent.

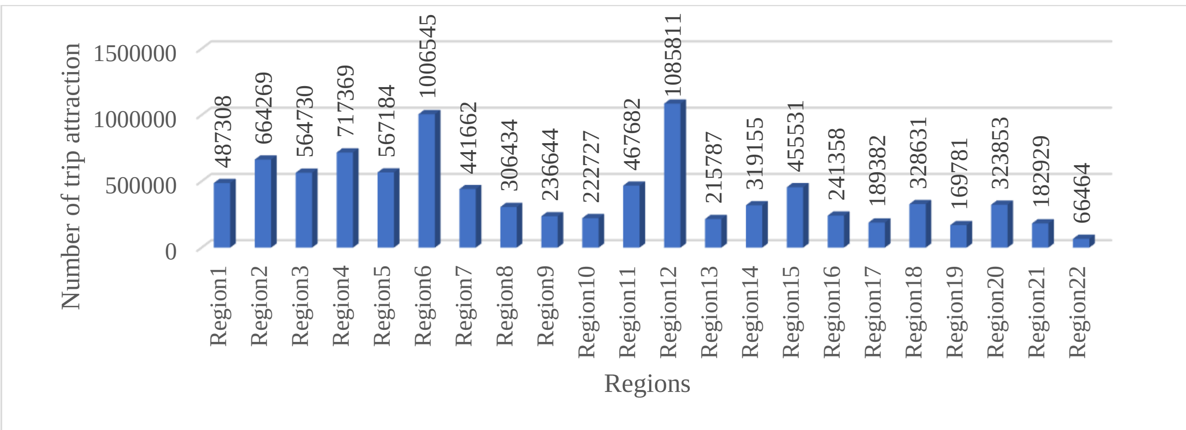

Figure 2. Trip attraction in different regions of Tehran [3].

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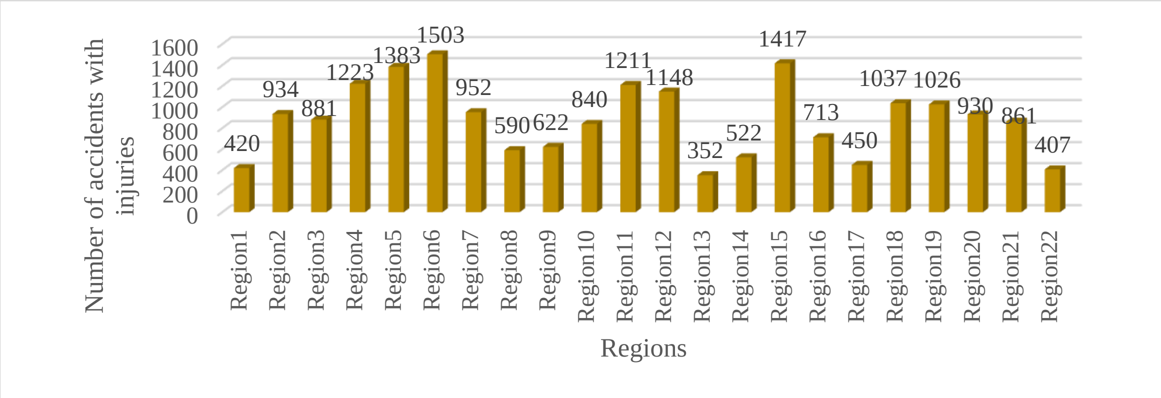

Figure 5. Accidents with the injuries in different regions of Tehran [3].

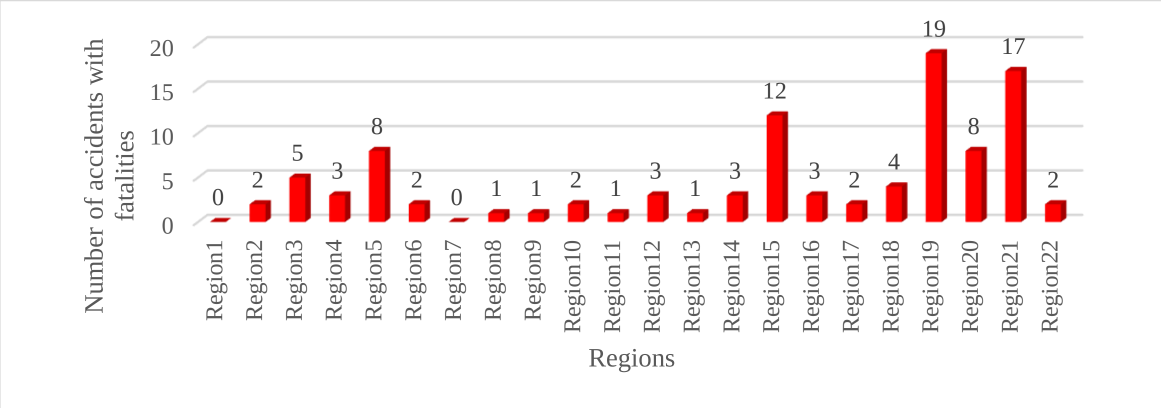

Figure 6. Accidents with fatalities in different regions of Tehran [3].

Figure 5 displays the total number of accidents with injuries for each region. Regarding the outputs, Region 6 has the most accidents, with the injuries amounting to 1,503 in 2018, and Region 13 had the best performance with 352 accidents that led to injuries. Overall, Regions 6, 15, and 5 had 7.74, 7.3, and 7.12 percent of total accidents with injuries, respectively.

Figure 6 shows that Region 19 had the highest number of accidents with fatalities (19), whereas Regions 1 and 7 had none in 2018. In fact, Regions 19, 21, and 15 had 19.19, 17.17, and 12.12 percent of total accidents with fatalities, respectively.

After collecting data, the model was solved, and the result is shown in *Table 2*.

Table 2. Efficiency score of regions of Tehran.

DMU	Efficiency	DMU	Efficiency
Region 1	1	Region 12	0.842
Region 2	0.895	Region 13	1
Region 3	0.737	Region 14	0.871
Region 4	0.842	Region 15	0.368
Region 5	0.579	Region 16	0.885
Region 6	0.895	Region 17	0.967
Region 7	1	Region 18	0.811
Region 8	0.979	Region 19	0.422
Region 9	1	Region 20	0.598
Region 10	0.943	Region 21	0.416
Region 11	0.953	Region 22	1

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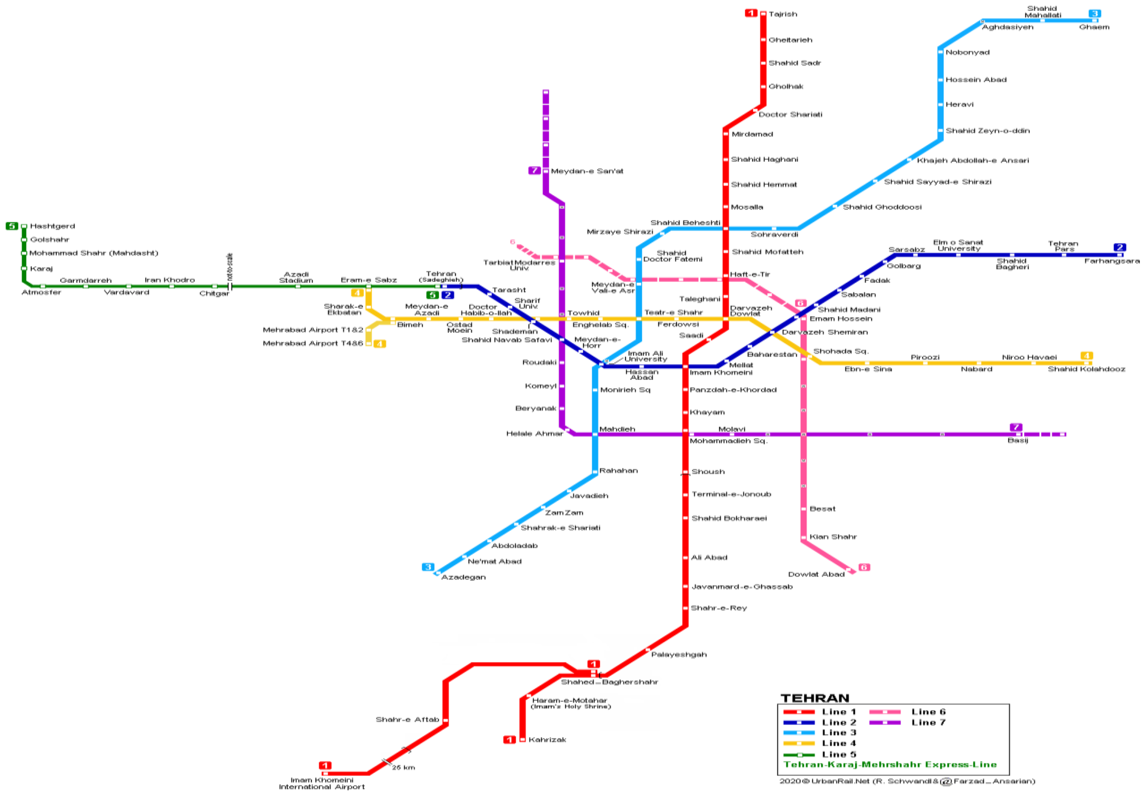

Figure 3. Map of Tehran subway lines [2].

Based on the results obtained from the implementation of the DEA model, taking into account the inputs and outputs mentioned in the previous section, Regions 1, 7, 9, 13, and 22 are the most efficient, with an efficiency score of 1. In contrast, Regions 21 and 15, respectively, with safety efficiency scores of 0.416 and 0.368, had the lowest efficiency among these regions. The reason for this issue can be related to the number of trip production and attraction and the number of accidents with injuries and fatalities for these regions, which were previously shown in the relevant figures (Figures 2, 4, 5, and 6). In the following section, the presence or absence of a significant relationship between these results and the number of subway stations in the regions will be further investigated using the Tobit regression model.

5. Tobit regression to analyze the impact of subway on safety efficiency of regions

In order to identify whether there is a meaningful relationship between efficiency scores of regions and subways, the Tobit regression technique was implemented in EViews software. Tobit models, sometimes called censored regressions, are used to examine linear relationships in situations where a critical limit is observed to the right or left of a dependent variable. Hence it also refers to this special type of censored regression prediction

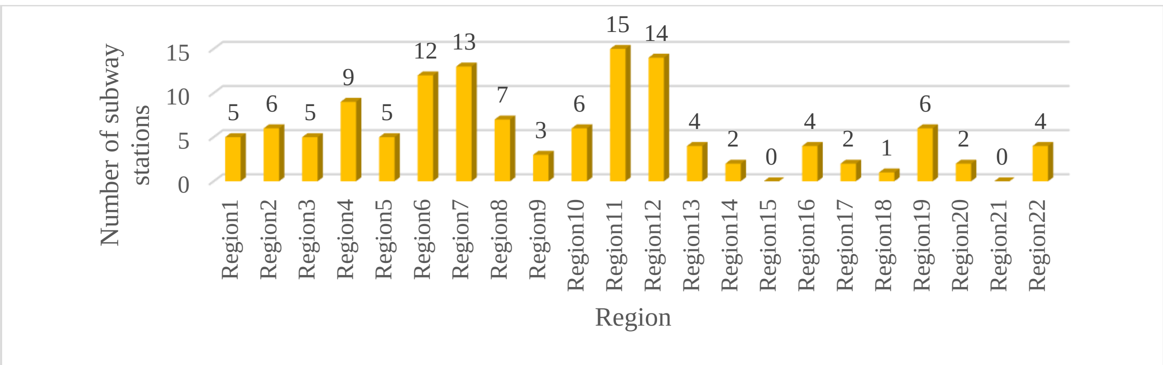

Figure 4. Number of subway stations in different regions of Tehran.

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functions. The presence of items above the critical limit or below the critical limit in the dependent variable indicates a serious and oblique problem in the regression equation and requires the use of Tobit regression.

In this research, the independent variable was the number of stations, and efficiency scores obtained from DEA was chosen as the dependent variable. This was to identify whether the number of stations in regions affects safety efficiency scores of the regions by using Tobit regression. A map of Tehran subway is shown in *Figure 7*. *Figure 8* presents the number of stations in different regions of Tehran.

Region 11 had 15 subway stations, which was the maximum number among other regions, whereas region 15 and 21 did not have any subway stations in 2018.

Table 3. Tobit regression results in EViews software.

INDEX = C (1) +C (2) *STATION

	Coefficient	Std. Error	z-Statistic	Prob
C (1)	0.736	0.063	11.712	0.000
C (2)	0.016	0.009	1.789	0.043
C (3)	0.178	0.027	6.633	0.000

In *Table3* the results of Tobit regression can be seen. P-value was calculated as 0.043 which is less than the threshold of 0.05 and is acceptable. Coefficient of C2 which equals to 0.016 shows that there is positive relationship between the number of subway stations in regions and efficiency scores of these regions. Although according to the obtained coefficient, maybe this relationship is not so strong.

Therefore, a more accurate analysis of the results obtained from the previous section can now be presented. For example, one of the main reasons that in the previous section, regions 15 and 21 had the lowest score of safety efficiency, could be related to the number of subway stations in these regions, which according to *Figure8*, there are no subway stations in these regions and in contrast, regions such as 2, 4, 6, 7, 8, 11 and 12 that have the greatest number of subway stations are among regions with highest score of safety efficiency.

6. Conclusion

In this paper, for the first time, the possibility of whether there is a relationship between the safety efficiency (as a dependent variable) of regions of a city and the number of their subway stations (as an independent variable) was studied using the Tobit regression technique. The case study of this paper was Tehran, which is the capital of Iran. The Data Envelopment Analysis (DEA) model was output-oriented and variable return to scale (VRS), and data was collected for 2018. The results reveal that five regions (1, 7, 9, 13, and 22) were the most efficient, and Region 15 had an efficiency score of 0.386, which was the least efficient region in this regard. The outputs of the model, i.e., the number of accidents with injuries and accidents with fatalities, were undesired outputs, which were converted by a conversion method.

The results of this paper can be used by policymakers to see which regions have the lowest safety efficiency and prioritize investment in these regions. The results of this research showed that there is a significant relationship between safety efficiency and the number of subway stations. Therefore, since the construction of subways is still continued in Tehran, regions that are inefficient and have fewer subway stations should be on the priority list for constructing subway stations.

Future research is suggested to develop DEA models to investigate the impact of bus stations on urban road accidents, conduct similar studies in other metropolitan cities of the world, and consider uncertainties of inputs and outputs by developing fuzzy DEA models.

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