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March 2020

CRPASE

Computational Research Progress in Applied Science & Engineering

ISSN 2423-4591

CRPASE Vol. 06(01), 52-59, March 2020

Performance Analysis of Fixed Route Shared Taxi Services (Jitney) - Case Study of Tehran, Iran

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Keywords

Fixed Route Shared Taxi,
Jitney,
Paratransit,
Performance Analysis,
Performance Index,
Decision Criteria.

Abstract

The fixed route shared taxi, known as Jitney, is one of the common modes in paratransit services and covers a significant proportion of daily trips in some developing countries, including Iran. Such system, despite its disadvantages to transportation networks, has always been the most feasible solution to overcome the shortcoming in public transit supply. As a result, it has formed users' travel habits over the decades. Therefore, it is not possible to remove or replace Jitney lines with standard services suddenly but gradually. Unfortunately, there is a distinct lack of a comprehensive method to analyze and evaluate Jitney lines neither in the literature nor in practice. In this paper, first, to fill the gap in the literature, we develop a coherent framework to analyze the performance of fixed route shared taxi lines. This framework includes several indices that make it possible to rank and classify Jitney lines from different aspects. Second, to examine the applicability of the proposed framework, we apply it to the network of taxi lines in the metropolis of Tehran. The results prove that the framework is not only applicable in measuring the system performance, but it also provides decision-makers with decision criteria to choose improvement plans or alternatives.

1. Introduction

Paratransit systems aim to fill the gap between public transit systems and personal vehicles [1]. Lack of suitable travel options leads passengers to use private vehicles, in the result of which cities are faced with several challenges such as traffic congestion, decrease in transit network efficiency, and increase in air and sound pollution [2], [3]. Fixed route shared taxi is one of the attractive modes of transportation in Iran, and its operation is similar to Jitney service, that is widely used in many developing counties such as Brazil, Argentina, Egypt, Hong Kong, Indonesia, Mexico, Turkey, and South Africa. However, Jitneys are outdated and prohibited in many developed countries such as the US. The fixed route shared taxi, like jitney, has one route and two fixed stations, one at both ends of the route. Their function is not based on a predefined timetable, and generally, vehicles serving at shared taxi lines depart when they are full. The passengers also can board and alight at any point of the route. Shuttle services mostly use four-door sedans with the capacity of four passengers; however, jitney services use vans or minibuses with a capacity of 5 to 15 seats [4].

From another point of view, the shared taxi can be considered as shared riding systems (carpooling) that let passengers share their demanded vehicle at a specific time and location. This system is preferred by the local government as a tool for preventing single-rider trips in suburban areas that mass transit facilities are insufficient [1]. In African countries such as Nigeria, insufficiency in public transit supply, the increase in urbanization, and new demand for transportation systems have led to significant growth in taxi demand, especially shared taxis, since these systems offer a more flexible service that could partially meet the urban demand [5]. Shared taxis in Ghana is a prevalent transportation mode, inasmuch as it covers 70 to 80 percent of inter-cities, inner-city, and suburban or rural trip demands [6].

In developed countries, jitneys, despite their illegal activity in some cities, do not have a significant role in urban transportation. While in developing countries, shared taxi services sometimes include more than 25% of total urban trips (e.g. in Tehran and other metropolises in Iran). Therefore, the sudden elimination of such system, despite its defects and disadvantages, can challenge the urban

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Received: 22 February 2020; Accepted: 21 March 2020

transportation management in these countries since passengers' behavior in mode-choice has been formed over many years, and more importantly, there are no alternative systems in the urban network [4]. On one hand, their high modal share and on the other hand, users' dependency on the shared taxi system, highlight the importance of studying the system performance. Performance evaluation not only helps to recognize weak and strong, but it also facilitates decision-making about the elimination or improvement of weak lines, upgrading efficient lines to bus or minibus lines [4], or periodic maintenance scheduling [7]. Thus, the urban network can be gradually led to a state where jitney services are replaced with sustainable either standard or public services.

In this study, as the first step, a comprehensive framework for evaluating the performance of the fixed route shared taxi is presented; then, the proposed framework is implemented on a real-world case by collecting data from Tehran's taxi network. Using the results, the problems of each line are identified, and corresponding executive solutions are proposed. The proposed solutions can include line elimination, line replacement with public transit lines, route modification, as well as the fleet size and type modification. The remainder of this study is classified as follows: Section two carries out a review on the literature in this area. Section three presents the methodology of the research which includes the steps of developing the performance evaluation framework for taxi lines in detail. In section four, the presented framework is implemented on Tehran's taxi network and finally, section five includes the results and conclusions.

2. Literature Review

There are few studies on the analysis and evaluation of shared taxi or jitneys. Gholami et al. proposed an economic model that allows for evaluating taxi lines in comparison to alternative modes. This study shows that the shared taxi application is very limited, and this is a fundamental challenge for cities that widely use this mode. Their model considers the possibility of replacing taxi lines with van or bus lines based on the cost indicators and route topography [4]. Wright and Nelson studied the feasibility of offering shared taxi services for train stops in terms of income for taxi operators and in terms of trip costs for users. In this study, it is argued that with focusing on shared taxi services, a commercially stable service can be offered. Parking limitations, high prices of standard taxi service (solo-taxi), and fleet shortages at peak hours for standard taxis make the option of using shared taxis more attractive for both passengers and operators [8]. Ma et al. used the accessibility data of John F. Kennedy airport in New York in a study to compare and evaluate current status, solo-taxis, with two policies for shared taxis. These two policies include 1) shared taxis for passengers that have the same route and do not have a waiting time limitation and 2) shared taxis for passengers that have different routes but do not have time to wait. The results of their model indicate that the first policy is suitable for the densely populated part of the city, i.e. Manhattan, and the second policy for other parts of the city [9]. Domarchi et al. designed an interview with the users of the shared taxi network in Santiago, Chile, to study this network and developed a mode choice model. The results of their study show that the users' main reason for selecting the shared taxi service instead of the public transit system can be listed as having "on-seat" trips, experiencing no transfers, and less walking or waiting time. They claim that the results of their research will be efficient for the regulation and modernization of shared taxi services in the future [10]. In Iran, shared taxis have a significant role in urban transportation. However, their operation in the urban network for picking up and dropping off passengers along their route can cause disruption in traffic flow [11]. Zefreh and Török used traffic simulation software to study these maneuvers and sudden lane changes. The results of their simulation in Isfahan's network in Iran indicates that shared taxi service directly increases other users' travel time [12].

3. Methodology

The performance analysis is a process that illustrates the current status of a system and shows if the system is successful in delivering its duties and satisfying the object of planners through data collection, evaluation, and results presentation. The performance of a transportation system can be assessed using various measurements and indices from different perspectives. For instance, travel time, reliability, travel comfort, and out-of-pock costs are user-oriented indices, but other measures as load factor or operational cost are operator-oriented indices. There are also planner-oriented indices including modal share and intermodal connectivity [13]. To develop a thorough and skeletal framework for analyzing fixed route share taxi services, it is vitally important to take all these aspects into consideration. The proposed framework should enjoy two main characteristics: 1) considering all the performance aspects of the system; 2) defining a clear method to capture each index and its required data and information. Not only would this framework analyze the performance of the system, that is fixed route shared taxi lines, but also it makes it possible to carry out comparative studies on the system and other competitors or alternative systems [14]. It is noteworthy that performance indicators should not be selected based on our ability to quantify them, but rather, they should include qualitative criteria, such as social justice and user satisfaction, despite the difficulties in calculations [15]. To develop this framework, we follow five main steps that are presented in the flowchart.

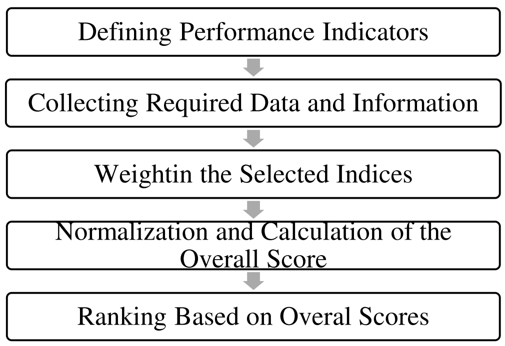

Figure 1. The methodology steps

3.1. Selecting the Performance Indicators

According to the general classification presented in [14], all factors that need to be entered in the performance analysis of a transportation system are as:

- Modal share
- Availability
- Accessibility
- Reliability
- Safety and Security
- Equity
- Affordability
- Inter-modal connectivity
- Operational features
- Environmental indices
- Economic indices
- Long-term policies

Considering the abovementioned classification, we present a set of the selected performance indicators for fixed route shared taxi and determine the necessary data for capturing them in the following sections. Note that the terms “taxi line” and “Jitney line” in this section refer to a fixed route share taxi serving between the specific stations that are the origin and destination of that line.

3.1.1. The Selected Indicators in the Modal Share Class

The modal share indicators have to do with the percentage of transported passengers by a transportation mode (personal car, taxi, bus, or subway). The indicators defined in this class are as:

- Modal share (M_m): That is equal to total passenger-travels in mode *m* over the total passenger-travels of the network in the same time interval. In fact, this type of indices is used when the taxi system is compared with other systems as bus or subway.
- Line share (ζ_l): Line share represents the percentage of passenger-travels in taxi line *l*.

3.1.2. Indicators in the Service Availability Class

These indicators check whether a transportation service is available for residence of an area, and they include:

- The ratio of active fleet to organizational fleet (η_l): That is equal to the number of active fleets (f^{act}) of Line *l* divided by the number of organizational fleets (f^{org}) allocated to that line.

$$\eta_l = \frac{f_l^{act}}{f_l^{org}} \tag{1}$$

3.1.3. Indicators in the Service Accessibility Class

The goal of this class of indices is to assure that all potential users of a transportation system have acceptable access to the system.

- Walking distance to stations (ω_l): The walking distance to transit stations is usually considered constant. However, thanks to spatial analysis, several methods have been proposed for quantifying such index [16], [17]. Foda and Osman [18] calculated the Ideal Station Accessibility Index (ISAI) and the Actual Station Accessibility Index (ASAI) for each station using the ArcGIS software. In this study, the ISAI is used for estimating the accessibility index of taxi stations. For this purpose, first all the streets ending at a station, within a buffer of 400 m on the station, were identified, and then, ISAI was defined as the summation of the intersected lengths divided by the area of a circle with radius of 400 m, the buffering area.

$$\omega_l = \frac{\sum \delta_{i,l}}{A_{bf}} \tag{2}$$

where $\delta_{i,l}$ length is the length of the ith streets ending at the station taxi line *l* and A_{bf} is the area of the peripheral circle with a 400m radius.

3.1.4. Indicators in the Reliability Class

Such indicators are mostly defined for public transit systems to control how much the system operates based on its schedule. But in Jitney services where taxies start a trip when they have all seats occupied, we cannot quantify the reliability of the system. Thus, we define the following indices to show if the presented supply meets the demand of a taxi line.

- The ratio of required fleets to active fleets (θ_l): that is the number of required fleets over active fleets:

$$\theta_l = \frac{f_l^{req}}{f_l^{act}} \tag{3}$$

To calculate this index, we need to obtain the number of required fleets (f^{req}) for each taxi line which is equal to the cycle time (Cyc_l) divided by the minimum required headway (h^{min}) as presented in Eq. (4)

$$f_l^{req} = \frac{Cyc_l}{h_l^{min}} \tag{4}$$

where h^{min} is the minimum of required headway to serve all passengers and is estimated by the number of entering passengers to the stop in each period. Thus, the minimum required headway can be calculated by Eq. (5)

$$h_l^{min} = \frac{\text{fleet capacity}}{\text{the number of entering passengers}} \tag{5}$$

3.1.5. Indicators in the Safety and Security Class

Generally, the safety of a transportation system is represented by the number of accidents or exposure indices. The increasing number of fatal accidents in recent years in Iran forces decision-makers in urban planning to take the right actions to improve the safety of transportation systems [12].

- Probability of accidents in each day (φ_l): In order to estimate this indicator, first, the probability of accidents in the mode of taxi is estimated using Eq. (6). Then, using Eq. (7), the probability of accidents in a day for one line can be calculated.

$$p_{taxi}^{acc} = \frac{\text{total number of accident in one year}}{\text{vehicle kilometer traveled in one year}} \tag{6}$$

$$\varphi_l = p_{taxi}^{acc}.freq_l.l_l \tag{7}$$

where p_{taxi}^{acc} is the probability of a taxi accident per VKT, $freq_l$ is the number of departures in line *l*, and l_l is the length of line *l*.

3.1.6. Indicator in Affordability Class

These indices have to with the out-of-pocket costs of a transportation mode, and thus users' affordability affects their mode choice, especially for those users who do not have personal cars. Considering the fact that public transit users usually are from groups with low or moderate-income [19], we can use this group of indicators to decide what is the best alternative for share taxi services from the users' viewpoint. Thus, we define the following index in this class:

- The ratio of fare to passenger income (λ_l): This indicator is one of the most decisive criteria for evaluating the affordability of the dwellers in a region for using a service. This indicator is defined as the division of line fare and the average of passengers' income. In order to calculate the average passenger income, the information from the population and housing census can be used.

3.1.7. Indicators in Intermodal Connectivity Class

This class of indicators aims to evaluate the taxi lines role as a feeder of mass transit systems like subway and bus. More importantly, in public transit-oriented design, the first pillar is designing multimodal stations [20]. The introduced indicators in this class are as follows:

- the number of mass transit stations at both ends and along the line (ι_l): For one taxi line, this indicator shows the possibility of intermodal interactions with subway and bus lines. As it is calculated in Eq. (8), higher values of this indicator show a taxi line provides more accessibility to mass transit systems.

$$\iota_l = \beta_s[1 - \varepsilon_l^s](\alpha_e.n_l^{s,e} + \alpha_p.n_l^{s,p}) + \beta_b[1 - \varepsilon_l^b](\alpha_e.n_l^{b,e} + \alpha_p.n_l^{b,p}) \tag{8}$$

where $n_l^{s,e}$ is the number of subway stations at both ends of line l, $n_l^{s,p}$ is the number of metro stations along line l, $n_l^{b,e}$ is the number of bus stations at both ends of line l, $n_l^{b,p}$ is the number of bus stations along line l, α_e is the coefficient of being a station at both ends, α_p is the coefficient of being a station along the taxi lines, β_s is the weight of subway stations, β_b is the weight of bus stations, ε_l^s is a 0/1 variable to show if taxi line l is parallel with a subway line, and ε_l^b is a 0/1 variable to show if taxi line l is parallel with a bus line.

- The index of working parallel with mass transit systems (ν_l): This index indicates whether the route of a taxi line is parallel with either metro or BRT lines. If a taxi line is parallel with other mass transit lines, it could compete with those modes, that is against the fact that jitneys are developed as the feeder of an upstream system. This index can be estimated using the ArcGIS software and Eq. (9).

$$\nu_l = [\beta_s.\varepsilon_l^s] + [\beta_b.\varepsilon_l^b] \tag{9}$$

3.1.8. Indicators in Equity Class

Transportation plans by providing dwellers with access to work, education, or shopping can directly affect the distribution of equity in societies [21]. In order to implement a sustainable transportation system, it is crucial to meet the demand of all groups of people at a desirable level of service [22]. In Jitney services, we define equity as providing such services to those users who have fewer options for traveling. Thus, we ended up with the following index:

- The length of taxi lines in suburbs divided by the total length of taxi lines (τ_l): this index tries to quantify the equity in the availability of taxi services for both urban and suburban dwellers. As it is presented in Eq. (10), the index of suburb accessibility in taxi line l (τ_l) is equal to the length of line l in suburb area (l_l^{sub}) to the total length of line l (l_l).

$$\tau_l = \frac{l_l^{sub}}{l_l} \tag{10}$$

3.1.9. Operational Indicators

We define a set of indices to analyze the operation of taxi lines as follows:

- Average waiting time (μ_l): The average waiting time for each passenger at stations is usually equal to half the headway in each period. This concept is used when all the entering passengers to a stop in a period are transported by the dispatched vehicles. But if there is a queue, the waiting time in the queue should be added as well. Therefore, if the number of arrival passengers between two consecutive departures is more than the number of dispatched passengers, the traveled passengers experience half of the headway as waiting time, but the remaining passengers must wait for another departure. Thus, the average of waiting times in time interval t would be calculated using Eq. (11).

$$\mu_l = \frac{n_l^{load}.\frac{\square_l}{2} + n_l^{que}.\square_l}{n_l^{arrival}} \tag{11}$$

where n_l^{load} number of loader passengers in line l, n_l^{que} number of passengers in queue in line l, and $n_l^{arrival}$ number of arrival passengers at origin in line l.

- Maximum passenger queue length (q_l^{max}): The maximum queue length at stations indicates the severity of passengers' waiting time for service.
- Average operational speed (υ_l): This indicator is equal to the length of taxi line l divided by travel time in each direction (t_l).

$$\upsilon_l = \frac{l_l}{t_l} \tag{12}$$

- Average age of active fleets (σ_l): This indicator represents the quality of supply and is equal to the weighted average of fleets age, in which the number of departures by each fleet is considered as its weight (Eq. (13)).

$$\sigma_l = \frac{\Sigma freq_l^f.age_f}{freq_l} \tag{13}$$

where $freq_l^f$ is the number of departures by fleet f on line l and age_f is the age of fleet f in year.

3.1.10. Indicators of Environmental Impacts

- The cost of emitted gas per passenger (ξ_l): For each line, this indicator can be estimated as the summation of pollutants' cost divided by the number of transported passengers. For this purpose, the cost of the pollutants of each fleet in one kilometer should be multiplied by its traversed distance [23]. Therefore, the pollutant indicator of line l can be defined as Eq. (13).

$$\xi_l = \frac{\sum Em_f^{cost}.freq_l^f.l_l}{n_l^{load}} \tag{13}$$

where Em_f^{cost} is the emission cost for fleet f

- Fuel consumption cost per passenger (ρ_l): Fuel consumption is another indicator of environmental impacts, for estimation of which there are different functions in European standards [23]. As the standard of the Iranian vehicles used on taxi lines is Euro II, the respective values were calculated for the taxi fleet and fuel consumption per kilometer was estimated using the density of each kind of fuel including petroleum, diesel, or CNG. Since fuel consumption shows an increase of 20-45 percent when there is heavy traffic [24], a coefficient of 1.4 for personal cars and vans and 1.2 for minibuses and buses were considered. Therefore, the cost of the consumed fuel per passenger on each line can be calculated by Eq. (14), depending on the type of active fleet:

$$\rho_l = \frac{\sum Fuel_f^{cn}.Fuel_f^{cost}.freq_l^f.l_l.\alpha_f^{traffic}}{n_l^{load}} \tag{14}$$

where $Fuel_f^{cn}$ is the fuel consumption of fuel f per kilometer, $Fuel_f^{cost}$ is the fuel price of fleet f per kilometer, and $\alpha_f^{traffic}$ is coefficient of fuel consumption in heavy traffic condition.

- The percentage of fresh fleets (ς_l): This indicator is defined as the ratio of fresh fleets to the number (f_l^{fress}) of active fleets of line l where the fresh fleet consists of vehicles younger than two years old.

$$\varsigma_l = \frac{f_l^{fress}}{f_l^{act}} \tag{15}$$

3.1.11. Economic Indicators

- Capital Cost (χ_l): Capital cost includes the cost of buying fresh fleet in a system. In order to calculate this cost, the latest prices by the producers in the current year and methodology presented in [19] were used. This indicator aims to determine the lines which would need investment and new fleets for their future operations.

$$\chi_l = \sum Cost_f^{cap}.freq_l^f.l_l \tag{16}$$

where $Cost_f^{cap}$ is the capital cost of fleet f per kilometer.

- Drivers' daily income (o_l): This indicator evaluates if the service is profitable for drivers. For this purpose, the direct costs of the service and the benefits of each system are calculated.

$$o_l = \frac{\sum fare_l^f.n_{l,f}^{load} - \sum Cost_f^{opr}.freq_l^f.l_l}{f_l^{act}} \tag{17}$$

where $fare_l^f$ is the fare defined for fleet f in line l and $Cost_f^{opr}$ is the operational cost of fleet f per kilometer

3.1.12 Indicators of Long-Term Policies

In this category, only the indicator of modal share in the future planning horizon (P_m) is taken into consideration, and it aims to lead the service to the defined vision in the long-term plans.

3.2. Collecting the required data and information

In this step, we try to collect data to quantify all performance indicators determined in the previous step. To do so, we categorized the required data into four groups as follows:

- Operational data of taxi lines:
  This data are collected at both end stations of each taxi line at different time intervals and includes a number of distinct plate number (active fleets), number of departures done by each fleet, number of arrival passengers, number of loaded passengers, number of passengers in queue, travel time for one way and round trips, etc.
- Fleet database:
  This database contains all vehicle registered for jitney services and has attributes as plate number, model, make, age, capacity, and fuel type.
- General features of taxi lines:
  This information is provided by operators of taxi services and covers all features of a taxi line such as origin and destination, path, number of fleets organized for that line by fleet type, fare.
- Geographical information of transportation networks:
  That includes GIS layer of taxi lines and stations, GIS layer of subway and bus, GIS layer of streets network
- Current and long-term plans and policies:
  It is related to long-term policies about jitney services.
- Other information like accidents annual reports, dwellers' income, capital costs of different vehicles, fuel price, modal share different modes, and so forth.

3.3. Weighting the Defined Indicators

After defining performance indicators and required data to calculate them, the third step is to determine the weight or impact factor of each indicator based on its importance. To do so, we design a survey based on simple weighting and ask planners, operators, drivers, and passengers to determine the value of each index out of 100. In this questionnaire, we stated the relation between each index and taxi lines performance with + and – signs. Using the questioners' responses, we calculated the average of weights of the indicators and scaled them in such a way that the summation of all weights gets equal to 1. Table 1 presents this information.

3.4. Normalization and Calculating Overall Score

The next step is to normalize the indicators during which each indicator is fitted into 0 to 1 depending on its relation to the final score. Eqs. (18) and (19) show the normalization and revers-normalization functions, respectively. At the end, the overall score of each taxi line is formulated as the linear combination of the normalized indices and their weights. The lines with no passenger or active vehicles are considered as inactive lines and are removed from the set of taxi lines. Since the existence of zero indicators would cause problems in the normalization process and might lead us to wrong results.

$$i_{norm} = \frac{i}{\max i} \tag{18}$$

$$i_{norm} = \frac{\max i - i}{\max i - \min i} \tag{19}$$

Table 1. Summary of indicators and their weights

Title	Index	Unit	Relation	Weight
Modal share	M_m	%	+	0.3
Line share	ζ_l	%	+	1.1
active fleet to organizational fleet	η_l	ratio	+	12.3
Walking distance to stations	ω_l	1/km	+	8.2
required fleets to active fleets	θ_l	ratio	–	11.0
Probability of accidents	φ_l	#	–	4.1
fare to passenger income	λ_l	ratio	–	5.5
mass transit stations	ι_l	#	+	5.5
working parallel with mass transit	ν_l	0/1	–	5.5
taxi lines in suburbs	τ_l	ratio	+	6.8
Average waiting time	μ_l	hr	–	2.0
Maximum queue length	q_l^{max}	#	–	1.4
Average operational speed	υ_l	km/hr	+	2.1
Average age of active fleets	σ_l	year	–	2.7
The cost of emitted gas	ξ_l	$	–	1.5
Fuel consumption cost	ρ_l	$	–	1.5
share of fresh fleets	ς_l	%	+	2.1
Capital Cost	χ_l	$	–	9.6
Drivers' daily income	o_l	$	+	13.7
modal share in the future	P_m	%	+	3.1
Sum				100.0

3.5. Classification and Ranking

Afterward, the lines are ranked and classified according to their overall score. The classification demonstrated the performance of the line and is defined as illustrated in Table 2 where μ is the average score of all lines, and σ is the standard deviation of the scores.

Table 2. Classification of taxi lines performance

The Score Range	Performance Class
$[\mu + 1.96\sigma, \dots)$	Excellent (E)
$[\mu + \sigma, \mu + 1.96\sigma)$	Acceptable (A)
$[\mu - \sigma, \mu + \sigma)$	Medium (M)
$[\mu - 1.96\sigma, \mu - \sigma)$	Unacceptable (U)
$[\dots, \mu - 1.96\sigma)$	Critical (C)

Be a powerful tool for decision-makers and operators to find "Critical" lines, they need to find the reason of reduction in the performance of those lines for making the best choice. To address this issue, we used the same classification for each index to show the level of taxi lines from different aspects.

4. Case Study

As a real-world case, we gather data and information of taxi lines in the metropolis of Tehran. Tehran is the capital of Iran, with a population of 8.6 million persons and an area of 750 km^2. In Tehran, over 18 million trips are made every day, and the share of taxi services, in which fix route shared taxi lines are the most common service, is 22 percent. Over 40 percent of daily trips are done by personal vehicles, and after taxi services, Bus and subway take the third and fourth place with 20 and 18 percent, respectively. This city consists of 22 districts, and overall, has 678 taxi lines with over 34 thousand organized fleets in 6.2 million kilometers.

We collected the operational data of the taxi network in one day and at three periods of morning peak hours, afternoon peak hours, and off-peak hours. In this process, two or more persons are assigned to both ends of a taxi line based on the line demand. They were asked to write down the plate number, the number of loaded passengers, and departure time of each taxi in one table, and record the number of arrival passenger at the station every 15 minutes in the second table.

In order to calculate the average passenger income, the information from the population and housing census was used. As we cloud not access this information by each district, it was assumed that the average income per family, GDP per capita, in different districts of Tehran is distributed according to the housing price in that area. The estimated GDP is illustrated in Figure 2.Since taxi lines operate in an origin-destination manner, the income of a line passengers is supposed to be equal to the average of dwellers' income in the origin's region and the dwellers' income in the destination region.

The other source of data we used was the database of fleets in taxi services in Tehran. We took the GIS data of Tehran's subway system, called Metro, and Bus Rapid Transit (BRT) are used as mass transit systems. Other required information as accident data, fuel and vehicle price, operational costs, and long-term plans are collected. As it was impossible to show the results of all districts of Tehran in this paper, we decided to present the obtained results for district 2 of Tehran. All taxi and BRT and Metro lines in district number 2 of Tehran are mapped in figures 3 and 4.

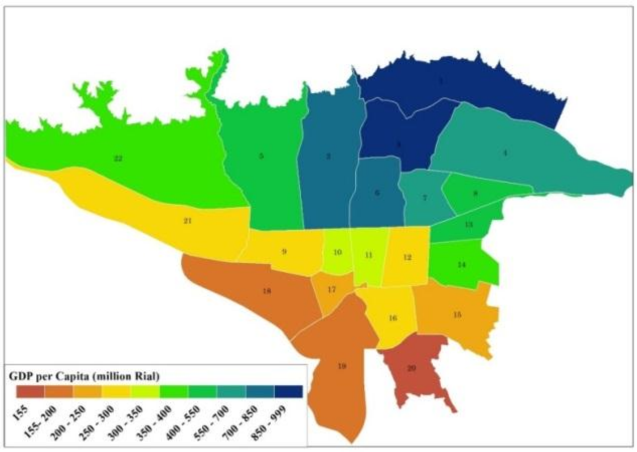

Figure 2. Distribution of GDP per family in Tehran

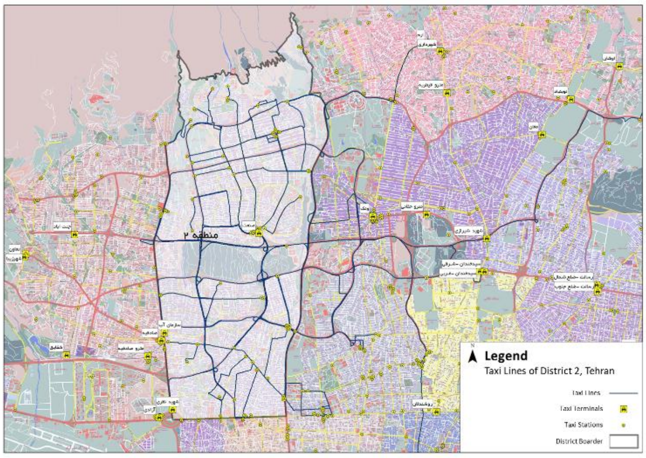

Figure 3. All taxi lines in district 2 of Tehran

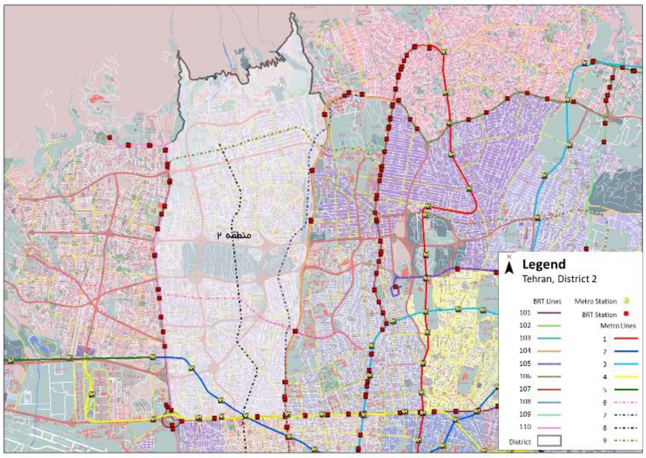

Figure 4. Accessibility of district 2 dwellers to Metro and BRT

According to the database of Municipality of Tehran, 74 lines are designed for district number 2, but our results show that 14 lines are now inactive. The primary analysis determined 7 % of active lines as Critical and 26 % as Unacceptable lines. Figure 5 represents the percentage of other classes.

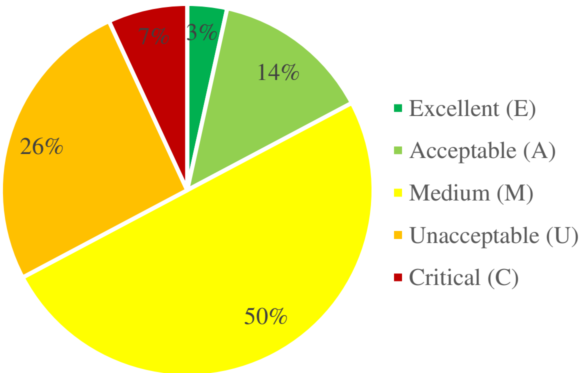

Figure 5. Classification of district 2 taxi lines

As it was mentioned before, our framework makes it possible to find major defects leading a taxi line to a critical or unacceptable overall score. To reach this goal, we define a heat-map plot where each row shows one taxi line, and columns are representing the performance indicators. The color of each cell states the category of the related index for that taxi line. Take the first line in figure 6, for instance. It presents the result for line 235 that is classified as an excellent line. Accordingly, most of the indices in this line are Medium, and its strengths are share of fresh fleets, average age of active fleets, the cost of emitted gas, fuel consumption cost, and drivers' daily income; while its active fleet to organizational fleet and operation speed indices are unacceptable.

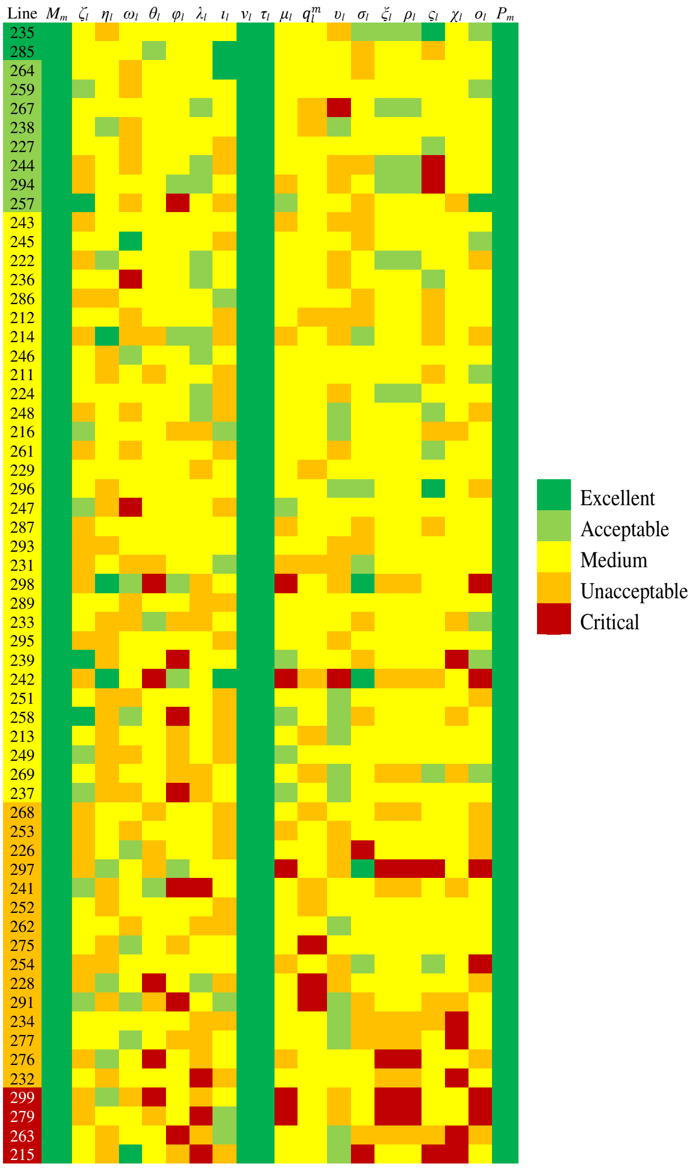

Figure 6. Performance analysis of district 2 taxi lines

5. Conclusion

In this study, a procedure for ranking the performance of taxi lines was introduced, and the most important results and solutions are as follows:

- Study and evaluation of taxi lines in District 2, Tehran shows that most of the lines in this region have a medium, unacceptable, or critical performance. 7% of the lines in this region can be eliminated, and the lines with medium and unacceptable performance need revision or improvement.
- The indicators of capital cost, drivers' daily incomes, average age of active fleets, the cost of emitted gas, fuel consumption cost, and share of fresh fleets are the most important defects for most of the Critical lines and some

of the Unacceptable lines. Thus, for improvement plans, we can prioritize lines with lower capital costs.

- The indicators of being parallel with mass transit and suburban accessibility are not useful in district two because there was no parallel line or line in suburban areas. But it does not mean that they are useless because they may be meaningful in other districts.
- Unlike the common perspective of organizational managers, a taxi line's efficiency cannot be judged merely based on its high demand or the drivers' income. It is necessary to calculate other operational indicators and take them into consideration.
- Considering the validity period and time-constrained value of the collected data from Tehran's taxi lines (in the second half of 2017), an annual data collection and performance evaluation of the lines is recommended in order to update the study and include the changes in economic parameters and the developments in metro lines.
- It is recommended to use mechanized systems to decrease human errors while collecting and recording data.
- Calculating the number of daily accidents with better accuracy is possible if there is a database of taxi accidents by line number or license plate.

Acknowledgments

This study is part of the 'Studies of Organizing Tehran's Taxi System' by the Rahan Sazeh Consulting Engineers from 2017 to 2019.

References

[1] A. Kalpakcı, N. Karataş Ünverdi, Integration of paratransit systems with inner-city bus transport: the case of Izmir, Public Transport 8 (2016) 405–426.
[2] I. Bargegol, M. Nikookar, R. V. Nezafat, J. Lashkami, A. M. Roshandeh, Timing Optimization of Signalized Intersections Using Shockwave Theory by Genetic Algorithm, Computational Research Progress in Applied Science & Engineering 01 (2015) 160–167.
[3] Y. Hatamzadeh, A. Hosseinzadeh, Toward a deeper understanding of elderly walking mode choice behavior : An analysis across genders in a case study of Iran, In: Proceedings of the 15th World Conference on Transport Research, (2019).
[4] A. Gholami, Y. Taghizadeh, Z. Tian, Classification of taxi khattee (jitney) lines based on topography and line cost indices, Transportation Research Part A: Policy and Practice 59 (2014) 239–249.
[5] Y. U. Madugu, Filling the mobility gaps: The shared taxi industry in Kano, Nigeria, Journal of Transport History 39, (2018) 41–54.
[6] S. Agyeman, R. A. Kwarteng, S. Zurkalnaine, Principal component analysis of driver challenges in the shared taxi market in Ghana, Case Studies on Transport Policy 7, (2019) 73–86.
[7] B. Rahimikelarijani, A. Mohassel, M. Hamidi, Railroad Track Geometric Degradation Analysis: A BNSF Case Study, Journal of Transportation Engineering, Part A: Systems 146 (2020) 04019068.
[8] S. Wright, J. D. Nelson, An investigation into the feasibility and potential benefits of shared taxi services to commuter stations, Urban, Planning and Transport Research 2 (2014) 147–161.
[9] Z. Ma, M. Urbanek, M. A. Pardo, J. Y. J. Chow, X. Lai, Spatial welfare effects of shared taxi operating policies for first mile airport access, International Journal of Transportation Science and Technology 6, (2017) 301–315.
[10] C. Domarchi, J. E. Coeymans, J. de D. Ortúzar, Shared taxis: modelling the choice of a paratransit mode in Santiago de Chile, Transportation 46, (2019) 2243–2268.
[11] M. Habibian, Z. Avaz, A. Hosseinzadeh, Sociological Study of Influence of Citizen's Traffic Ethics on Driving Violations: Case Study of Tehran, Iran, In: Proceedings of Transportation Research Board 94th Annual Meeting, (2015) 15–6029.
[12] M. M. Zefreh, Á. Török, Improving traffic flow characteristics by suppressing shared taxis maneuvers, Periodica Polytechnica Transportation Engineering 44 (2016) 69–74.
[13] J. Aarhaug, Taxis as a Part of Public Transport Sustainable Urban Transport Technical Document #16, Germany, 2016.
[14] C. Dhingra, Measuring Public Transport Performance: Lessons for Developing Cities, Sustainable Urban Transport Technical Document 9 (2011) 11.
[15] J. Parks et al., TCRP Report 141: A Methodology for Performance Measurement and Peer Comparison in the Public Transportation Industry. Washington, D.C.: National Academies Press, 2010.
[16] R. Daniels, C. Mulley, Explaining walking distance to public transport: The dominance of public transport supply, Journal of Transport and Land Use 6, (2013) 5–20.
[17] M. Habibian, A. Hosseinzadeh, Walkability index across trip purposes, Sustainable Cities and Society 42 (2018) 216–225.
[18] M. Foda, A. Osman, Using GIS for Measuring Transit Stop Accessibility Considering Actual Pedestrian Road Network, Journal of Public Transportation 13 (2010) 23–40.
[19] M. Jafari Kang, M. Khodadadifard, S. Afandizadeh, Providing a Decision-Making Method for Evaluation of Exclusive BRT lanes Implementation Using Benefit-Cost Analysis – Case Study: Tehran BRT line 4, Journal of Civil Engineering and Materials Application 1 (2017) 8–15.
[20] P. Pezeshknejad, S. Monajem, H. Mozafari, Evaluating sustainability and land use integration of BRT stations via extended node place model, an application on BRT stations of Tehran, Journal of Transport Geography 82 (2020).
[21] H. Behbahani, S. Nazari, M. Jafari Kang, T. Litman, A conceptual framework to formulate transportation network design problem considering social equity criteria, Transportation Research Part A: Policy and Practice, (2018).
[22] H. Behbahani, S. Nazari, H. Partovifar, M. J. Kang, Designing a Road Network Using John Rawls's Social Justice Approach, Journal of Urban Planning and Development 145 (2019) 05019002.
[23] EMEP/EEA air pollutant emission inventory guidebook 2019: Technical guidance to prepare national emission inventories (3.B Manure Management), 2019.
[24] I. De Vlieger, Influence of traffic conditions on fuel consumption and emissions - Brussels as a case study, Transactions on the Built Environment 30 (1997) 1–3.