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

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Keywords

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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 However, Jitneys are outdated and prohibited in many developed countries such as the US.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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transportation management in these countries since passen-
gers’ behavior in mode-choice has been formed over
many years, and more importantly, there are no alter-
native 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,
routing 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 el 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-taxi, 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-pocket 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:
- 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 ($\zeta$): 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 ($\eta_l$): That is equal to the number of active fleets ($f_{act}^l$) of Line $l$ divided by the number of organizational fleets ($f_{reg}^l$) allocated to that line.

\[ \eta_l = \frac{f_{act}^l}{f_{reg}^l} \]  
(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 ($\omega_l$): 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.

\[ \omega_l = \frac{\sum \delta_{i,l}}{A_{rf}} \]  
(2)

where $\delta_{i,l}$ length is the length of the $i$th streets ending at the station taxi line $l$ and $A_{rf}$ 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 ($\theta_l$): that is the number of required fleets over active fleets:

\[ \theta_l = \frac{f_{\text{req}}^l}{f_{\text{act}}^l} \]  
(3)

To calculate this index, we need to obtain the number of required fleets ($f_{\text{req}}^l$) for each taxi line which is equal to the cycle time ($C_{yc}$) divided by the minimum required headway ($h_{\text{min}}^l$) as presented in Eq. (4)

\[ f_{\text{req}}^l = \frac{C_{yc}}{h_{\text{min}}^l} \]  
(4)

where $h_{\text{min}}$ 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)

\[ h_{\text{min}}^l = \frac{\text{fleet capacity}}{\text{the number of entering passengers}} \]  
(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 ($\varphi_l$): 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.

\[ p_{\text{acc}} = \frac{\text{total number of accident in one year}}{\text{vehicle kilometer traveled in one year}} \]  
(6)

\[ \varphi_l = p_{\text{acc}} \times f_{\text{req}}^l \times l_i \]  
(7)

where $p_{\text{acc}}$ is the probability of a taxi accident per VKT, $f_{\text{req}}^l$ is the number of departures in line $l$, and $l_i$ 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 ($\lambda_i$): 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.

3.1.8. 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 ($t_i$): 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.

\[
t_i = \beta_a [1 - e^{\lambda_i}] (\alpha_e n_l^{s,e} + \alpha_p n_l^{b,p}) + \beta_b [1 - e^{\lambda_i}] (\alpha_e n_l^{b,e} + \alpha_p n_l^{b,p})
\]  

where $n_l^{s,e}$ is the number of subway stations at both ends of line $l$, $n_l^{b,p}$ 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 $l$, $\alpha_e$ is the coefficient of being a station at both ends, $\alpha_p$ is the coefficient of being a station along the taxi lines, $\beta_a$ is the weight of subway stations, $\beta_b$ is the weight of bus stations, $e^{\lambda_i}$ is a 0/1 variable to show if taxi line $l$ is parallel with a subway line, and $e^{\lambda_i}$ 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 (\(\nu_i\)): 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 considered as the feeder of an upstream system. This index can be estimated using the ArcGIS software and Eq. (9).

\[
\nu_i = [\beta_a, e^{\lambda_i}] + [\beta_b, e^{\lambda_i}]
\]  

3.1.9. Operational Indicators

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

- Average waiting time ($\mu_i$): 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).

\[
\mu_i = \frac{n_l^{load} + n_l^{que}}{n_l^{arrival}}
\]  

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 ($q_i^{max}$): The maximum queue length at stations indicates the severity of passengers’ waiting time for service.

- Average operational speed ($\nu$: This indicator is equal to the length of taxi line $l$ divided by travel time in each direction ($t_i$).

\[
\nu_i = \frac{l}{t_i}
\]  

- Average age of active fleets (\(\sigma_i\)): 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)).

\[
\sigma_i = \frac{\sum_{f} freq_f \cdot age_f}{freq_i}
\]  

where $freq_f$ 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 ($\zeta_f$): 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).

$$
\xi_l = \frac{\sum Em^\text{cost}_f \cdot freq^f \cdot l_l}{n^l_{\text{load}}}
$$

where $Em^\text{cost}_f$ is the emission cost for fleet $f$.

- Fuel consumption cost per passenger ($\rho_f$): 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:

$$
\rho_f = \frac{\sum Fuel^m_f \cdot Fuel^\text{cost}_f \cdot freq^f \cdot l_l \cdot a^\text{traffic}_f}{n^l_{\text{load}}}
$$

where $Fuel^m_f$ is the fuel consumption of fuel $f$ per kilometer, $Fuel^\text{cost}_f$ is the fuel price of fleet $f$ per kilometer, and $a^\text{traffic}_f$ is coefficient of fuel consumption in heavy traffic condition.

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

$$
\zeta_l = \frac{f^\text{fress}_l}{f^\text{act}_l}
$$

3.1.11. Economic Indicators

- Capital Cost ($\chi_f$): 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.

$$
\chi_f = \sum Cost^\text{cap}_f \cdot freq^f \cdot l_l
$$

where $Cost^\text{cap}_f$ 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.

$$
o_l = \frac{\sum fare^f_l \cdot n^l_{\text{load}} - \sum Cost^\text{opr}_f \cdot freq^f \cdot l_l}{f^\text{fleet}_l}
$$

where $fare^f_l$ is the fare defined for fleet $f$ in line $l$ and $Cost^\text{opr}_f$ 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 normalziation process and might lead us to wrong results.

\[ i_{\text{norm}} = \frac{i}{\max i} \qquad (18) \]

\[ i_{\text{norm}} = \frac{\max i - i}{\max i - \min i} \qquad (19) \]

Table 1. Summary of indicators and their weights

<table>
<thead>
<tr>
<th>Title</th>
<th>Index</th>
<th>Unit</th>
<th>Relation</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modal share</td>
<td>( M_a )</td>
<td>%</td>
<td>+</td>
<td>0.3</td>
</tr>
<tr>
<td>Line share</td>
<td>( \zeta )</td>
<td>%</td>
<td>+</td>
<td>1.1</td>
</tr>
<tr>
<td>active fleet to organizational</td>
<td>( \eta_l )</td>
<td>ratio</td>
<td>+</td>
<td>12.3</td>
</tr>
<tr>
<td>fleet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking distance to stations</td>
<td>( \omega_l )</td>
<td>1/km</td>
<td>+</td>
<td>8.2</td>
</tr>
<tr>
<td>required fleets to active fleets</td>
<td>( \theta_l )</td>
<td>ratio</td>
<td>+</td>
<td>11.0</td>
</tr>
<tr>
<td>Probability of accidents</td>
<td>( \varphi_l )</td>
<td>#</td>
<td>+</td>
<td>4.1</td>
</tr>
<tr>
<td>fare to passenger income</td>
<td>( \lambda_l )</td>
<td>ratio</td>
<td>+</td>
<td>5.5</td>
</tr>
<tr>
<td>mass transit stations</td>
<td>( \psi_l )</td>
<td>#</td>
<td>+</td>
<td>5.5</td>
</tr>
<tr>
<td>working parallel with mass transit</td>
<td>( v_l )</td>
<td>0/1</td>
<td>+</td>
<td>5.5</td>
</tr>
<tr>
<td>taxi lines in suburbs</td>
<td>( \tau_l )</td>
<td>ratio</td>
<td>+</td>
<td>6.8</td>
</tr>
<tr>
<td>Average waiting time</td>
<td>( \mu_{t, \text{hr}} )</td>
<td>hr</td>
<td>+</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum queue length</td>
<td>( q^{\text{max}}_l )</td>
<td>#</td>
<td>+</td>
<td>1.4</td>
</tr>
<tr>
<td>Average operational speed</td>
<td>( \nu_l )</td>
<td>km/hr</td>
<td>+</td>
<td>2.1</td>
</tr>
<tr>
<td>Average age of active fleets</td>
<td>( \sigma_l )</td>
<td>year</td>
<td>+</td>
<td>2.7</td>
</tr>
<tr>
<td>The cost of emitted gas</td>
<td>( \zeta_l )</td>
<td>$</td>
<td>+</td>
<td>1.5</td>
</tr>
<tr>
<td>Fuel consumption cost</td>
<td>( \rho_l )</td>
<td>$</td>
<td>+</td>
<td>1.5</td>
</tr>
<tr>
<td>share of fresh fleets</td>
<td>( \zeta_l )</td>
<td>%</td>
<td>+</td>
<td>2.1</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>( \xi_l )</td>
<td>$</td>
<td>+</td>
<td>9.6</td>
</tr>
<tr>
<td>Drivers’ daily income</td>
<td>( \alpha_l )</td>
<td>$</td>
<td>+</td>
<td>13.7</td>
</tr>
<tr>
<td>modal share in the future</td>
<td>( \rho_{\text{m}} )</td>
<td>%</td>
<td>+</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td><strong>Sum</strong></td>
<td><strong>100.0</strong></td>
<td>****</td>
<td>****</td>
</tr>
</tbody>
</table>

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 \( \mu \) is the average score of all lines, and \( \sigma \) is the standard deviation of the scores.

Table 2. Classification of taxi lines performance

<table>
<thead>
<tr>
<th>Score Range</th>
<th>Performance Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>([\mu + 1.96\sigma, \ldots])</td>
<td>Excellent (E)</td>
</tr>
<tr>
<td>([\mu + \sigma, \mu + 1.96\sigma])</td>
<td>Acceptable (A)</td>
</tr>
<tr>
<td>([\mu - \sigma, \mu + \sigma])</td>
<td>Medium (M)</td>
</tr>
<tr>
<td>([\mu - 1.96\sigma, \mu - \sigma])</td>
<td>Unacceptable (U)</td>
</tr>
<tr>
<td>([\ldots, \mu - 1.96\sigma])</td>
<td>Critical (C)</td>
</tr>
</tbody>
</table>

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 km². 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
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.

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.

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.

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References


