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Research Article / Araştırma Makalesi

ESTIMATION OF TAXI FLEET SIZE: A GENERIC ALGORITHM

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ABSTRACT

Taxis play an important role in providing passenger mobility in many cities of the world. In a recent IRU/EU report taxis are considered as part of the collective public transport chain. The Land Transport Authority in Singapore states clearly in their website that while public transport is the most efficient means of travel, taxis bridge the gap between commuting and driving a car. In this context taxis can be considered as a complementary mobility option to public transport rather than as a competitive one. Currently many cities in the world have taxi fleets, where taxis are utilized by many local and foreign residences as well as by tourists and visitors. Riding a taxi should be a pleasant, comfortable, convenient and relatively affordable experience. In order for cities to continue providing acceptable taxi level of service the taxi fleet has to increase to meet the expected demand. The literature shows a limited number of taxi fleet prediction techniques. Towards this end this research identifies and reviews a number of taxi fleet prediction models, namely the model based on taxi availability indicator, the Hara model. The research further develops a generic algorithm of algebraic equations to estimate future taxi fleet requirements in cities of the world. This research demonstrates the utilization of the 3 models in estimating future taxi fleet requirement in a hypothetical city case study.
Keywords: Algorithm, estimation, models, prediction, taxis.

1. INTRODUCTION

Taxi services are among the most frequently used passenger transport services in many cities in the world. A review of literature issued by several countries and international organizations indicated that taxi service is not regarded as a competitor to mass transit systems but on the contrary can be considered as a supplement to assist in achieving an integrated mass transit system. A quotation from the cover page of a recent IRU report has iterated an EU statement, see [1] "Taxis Are Part of the Collective Public Transport Chain". Also it is vital to note that the policies and measures developed to minimize the use of cars often lead to a shift of car users from cars to taxis. This falls in line with what is reported by Singapore Land Transport Authority, see [2] "While Public Transport Is the Most Efficient Means of Travel, Taxis Bridge the Gap between Commuting and Driving a Car". Taxis can be also considered as one of the main Mobility Management Options as taxi occupancy in many cities averages between 1.5 to 2 passengers excluding drivers which assist in achieving the mobility notion of reducing Single Occupancy Vehicles (SOV) and increasing High Occupancy Vehicles (HOV).

However, in many cities, numerous complaints are voiced by taxi users concerning the difficulties of locating a taxi and the limited availability of taxis. Local transport authorities should exercise their

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regulatory role in terms of ensuring a balance between the taxi service providers i.e. taxi operators whether companies or individuals and between the taxi users (passengers). Such balance is achieved by predicting the right size of the taxi market via estimating the number of taxis needed in the future in accordance with the anticipated demand. Authorities should avoid the provision of taxis that are more than what is required as this will create unnecessary oversupply and hence pressure on taxi operators in terms of longer roaming periods and difficulty to find potential passengers. On the other hand, authorities should also avoid provision of taxis that are less than what is required as this will create unnecessary undersupply, hence pressure on taxi users in terms of longer periods and difficulty to locate taxis when needed. Accordingly, it is important to develop techniques, models & algorithms that can assist in assessing future needs of taxi fleet in cities of the world.

2. FACTORS AFFECTING REQUIRED NUMBER OF TAXI FLEET

It is important to conceptualise factors affecting demand for taxis. Such conceptualisation is depicted in Figure 1. The Figure shows in the center that taxi demand can be represented by number of taxi passengers, number of tax trips and hence number of taxi fleet required. Such demand is impacted by 2 main sets of factors namely demand based factors and supply based factors. Demand based factors namely include population, tourists, visitors, special needs population, income, transit taxi integrated trips, traffic congestion levels. On the other hand, supply based factors include taxi availability (represented by number and average waiting time to obtain a taxi), taxi fare, taxi reputation & branding (expressed in comfort, courtesy, convenience, safety, security), car availability, cost of owning and operating a car, and other competing modes such as limo service and mobility application companies such as Uber.

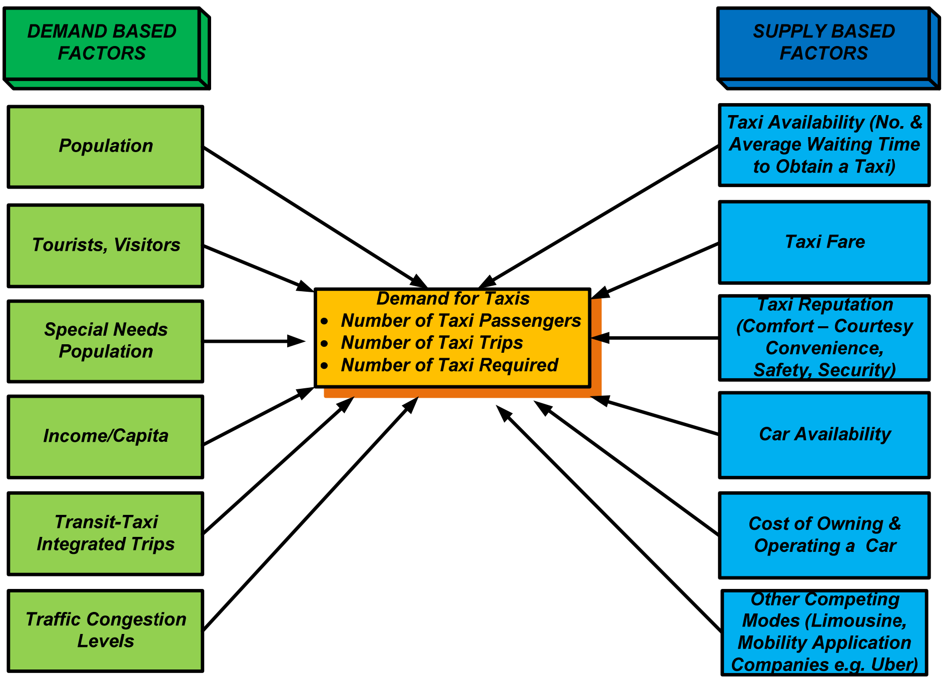

Figure 1. Demand and Supply Factors Affecting the Demand for Taxis

3. METHODS FOR ESTIMATING FUTURE TAXI REQUIREMENTS

Limited literature exists in the area of methods for estimating future taxi requirements. The paper identified 2 methods the first is based on taxi availability index and the second is based on HARA Associates' Taxi Demand Model. In both methods the expected number of future population is considered as the driving factor behind estimation of required number of taxis.

This research also develops a generic algorithm for estimation of taxi fleet requirements. This relies on several factors including population, average taxi occupancy, average taxi trip distance, average rate of taxi passengers per capita, the index comparing the number of revenue kilometers to number of total traveled kilometers. In the next sections the 3 methods are reported and applied to a hypothetical city to estimate the future taxi fleet requirement.

4. TAXI AVALIABILITY INDEX

Many world cities report a taxi indicator as the average number of taxis per 1000 population. In this research this indicator will be labelled as the Taxi Availability Index (TAI). The average availability index across 23 cities in the world is equal or higher than 3 taxis per 1000 population, see Figure 2 for a comparison between these cities. It is obvious that some cities such as London, Barcelona, Prague, Stockholm, Dublin and Washington are above this average, while on the other hand Melbourne, Vancouver, Brussels and Sydney are below such average. A similar comparison is conducted for North American cities, see Figure 3 where it is obvious that cities such as New Orleans and District of Columbia, and New York City have taxi availability index of more than 3 taxis per 1000 population. It is also worth mentioning that growing Asian cities like Singapore has a high taxi-to-population ratio of 5.2 taxis per 1000 persons compared to 2.6 in Hong Kong, while the city of Dubai is targeting to achieve taxi availability index of 4.09 taxis per 1000 population in the coming years.

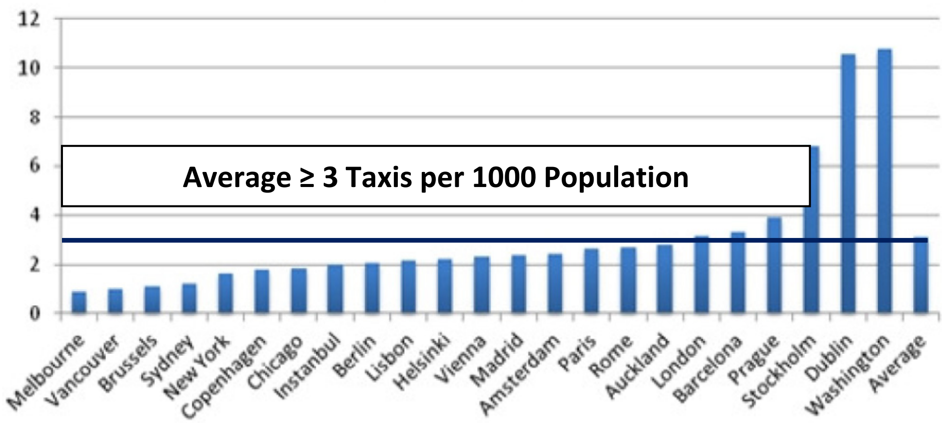

Figure 2. Comparison of Taxi Supply Among Selected European Cities (Source: Indecon–Various Sources Including Darbera 2010 [3]/Local Authorities websites)

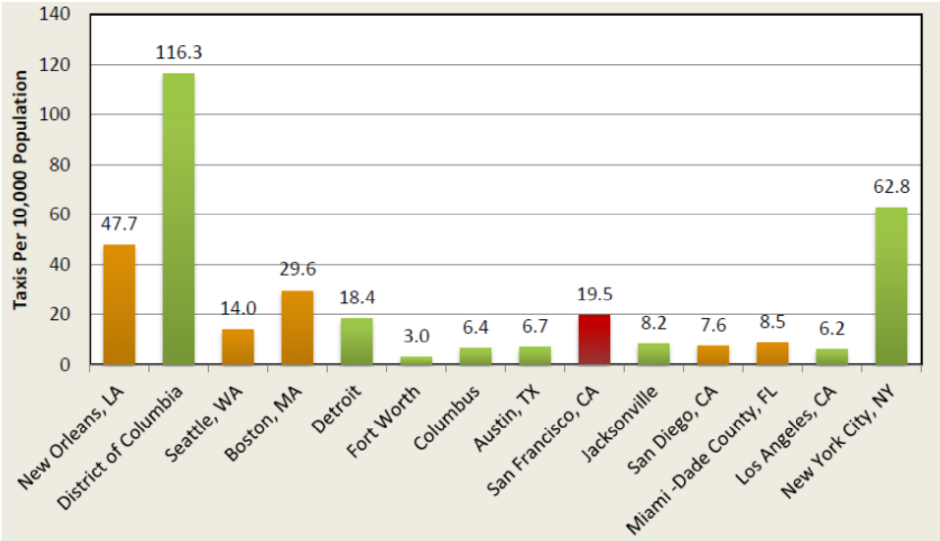

Figure 3. Comparison of Taxi Supply Among Selected North American Cities-Taxis per 10000 Population (Source: Based on US Bureau Census 2011, see [4])

Towards this end this research attempts to develop a taxi availability level of service categorisation from A to F and as shown in table 1 below. The table shows a 5 category LOS from A to F where LOS (A) demonstrates the highest taxi availability index ranging from 10 to 12 taxis per 1000 population as in Dublin –Washington – District of Colombia, and LOS (C) demonstrates an average taxi availability index ranging from 5 to 7 taxis per 1000 population as in Singapore - Stockholm –New York City, while most cities are lying in LOS (E) with taxi availability ratios ranging from 1 to 3 taxis per 1000 population as in Copenhagen – Chicago – Istanbul – Berlin – Lisbon etc..

Table 1. Level of Service Categorisation of Taxi Service Based on Taxi Avalaiability Index

Taxi Availability LOS Categories	Index (Taxis/1000 Population)	Cities
A	10 to 12	Dublin –Washington – District of Colombia
B	7 to 10	
C	5 to 7	Singapore - Stockholm –New York City
D	3 to 5	Prague–London– Barcelona–New Orleans-Dubai
E	1 to 3	Copenhagen – Chicago – Istanbul – Berlin – Lisbon– Helsinki – Madrid – Amsterdam – Paris – Rome – Auckland – Boston – San Francisco – Seattle – Hong Kong
F	Less than 1	Many Other Cities

5. FUTURE TAXI FLEET SIZE BASED ON TAXI AVALIABILITY INDEX

In this section the taxi availability index method will be utilized to demonstrate its applicability to estimate the future requirements of taxi fleet in a hypothetical city. The proposed methodology is depicted in Figure 4 where based on historical data of both population and taxi fleet estimations of taxis per 1000 population is done for each year, see Figure 5 for the years 2007 to 2015. This is followed by computing an average index of that city where in this case and as shown figure 5 it is around 2.71 taxis per 1000 population. For future estimation the local authority in this city has to make a decision either to relax the taxi availability index to go beyond 2.71 or to maintain the taxi availability index at 2.71 or to attain a higher taxi availability index say of 3.1 in an attempt to change their city status taxi availability LOS from E to D and as shown in table 1. For reasons of demonstration the average taxi availability will be retained with a population growth of 2% per year. Table 2 displays the results of the estimation throughout the years 2016 to 2020.

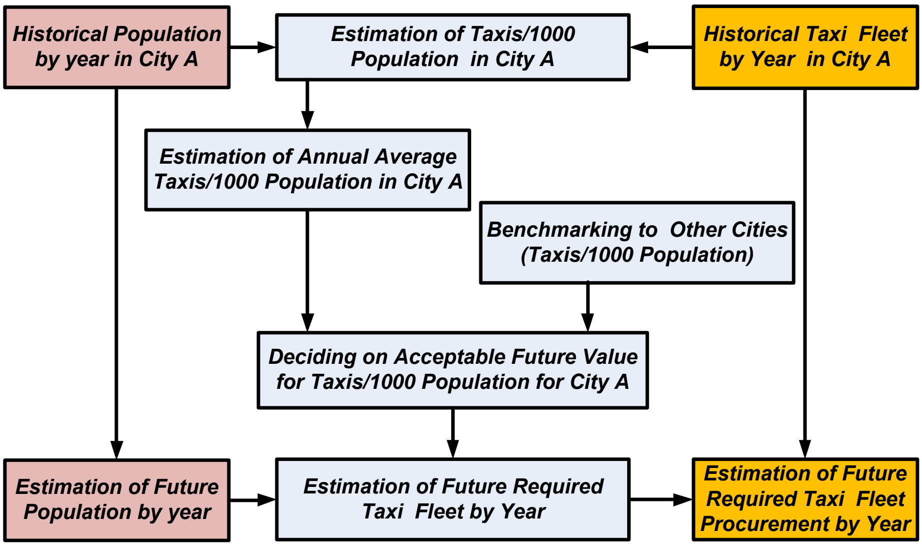

Figure 4. Methodology for Utilising Taxi Availability Index to Estimate Taxi Fleet Size

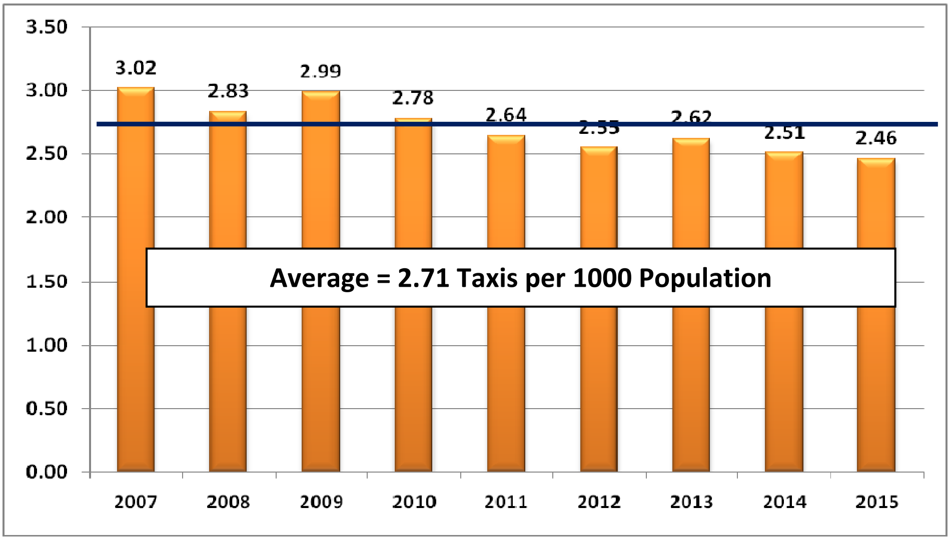

Figure 5. Taxi Availability Index 2007 to 2015 in a Hypothetical City

Table 2. Estimate of Future Requirements of Taxi Fleet in Hypothetical City Based on Retaining a Taxi Availability Index of 2.71

Year	2016	2017	2018	2019	2020
Forecasted Population	7468738	7618113	7770475	7925885	8084402
Targeted Taxi Availability Index	2.71	2.71	2.71	2.71	2.71
Required No of Taxis	20240	20645	21058	21479	21909

6. TAXI FLEET REQUIREMENTS BASED ON HARA TAXI DEMAND MODEL

In this section the Hara taxi demand model, see [5] will be utilized to demonstrate its applicability to estimate the future requirements of taxi fleet in a hypothetical city. The percentages below indicate the estimated average percentage change in taxi demand from a 1% change in each variable accounted for by the Hara model:

- Population. (1% increase in demand from a 1% increase in population).
- Low income population. (0.3% increase for every 1% increase in percentage of population that is low income).
- Cost to consumers (1.4% decrease in demand for every 1% increase in inflation adjusted meter rates).
- Proportion of commuters working in the city but living outside, to city population. (0.3% increase in demand for every 1% increase in the ratio of commuters entering city from outside the city to the city resident population)
- Cost of private vehicle ownership. (3.8% increase in taxi demand for every 1% increase in the local cost of owning and operating a personal vehicle).

For the sake of demonstration the Hara model will be used for the hypothetical city taking into account only that a 1% increase in taxi demand is generated from a 1% increase in population. Table 3 displays the results of the estimation throughout the years 2016 to 2020.

Table 3. Future Size of Taxi Fleet in Hypothetical City Based on Hara Taxi Model

Year	2015	2016	2017	2018	2019	2020
Forecasted Population	7322292	7468738	7618113	7770475	7925885	8084402
Population Percentage Increase		2%	2%	2%	2%	2%
Required No of Taxis	18024	18384	18752	19127	19510	19900

7. GENERIC ALGORITHM FOR ESTIMATION OF TAXI FLEET SIZE

In this section, a generic algorithm for estimation of taxi fleet requirements is developed and reported. This includes the computation of several algebraic equations forming an algorithm that is capable of computing the taxi future fleet requirements. Some of the equation inputs are related to demand factors such as population and others are related to supply factors such as average occupancy, average distance per taxi trip, etc… Towards this end the algorithm requires several items of data including historical trends of population, taxi fleet, taxi trips, revenue kilometers, total kilometers, average roaming time, taxi average occupancy etc… One of the most important inputs as well is the indicator comparing revenue kilometers to total travelled kilometers where this indicator aims to achieve a balance on the one hand between financial efficiency to taxi operators and on the other hand avoiding users' dis-satisfaction as a result of difficulties in locating taxis when needed. This indicator can range between 50% to 60 %. In this research, it is assumed at average target value of 55% to be used in the algorithm for estimating future needs of taxis. Equations used in algorithm are displayed below:

Applying the above algorithm for a hypothetical city and taking into account the following assumptions

- Annual Average Rate of Taxi Passengers per Capita = 51 passengers
- Annual Average Taxi Occupancy = 1.69 passengers
- Annual Average Kilometers Travelled for a Taxi Revenue Trip = 10 Km

Table 4 displays the results of the estimation throughout the years 2016 to 2020.

Table 4. Estimate of Future Requirements of Taxi Fleet in City A Based on Generic Equation Algorithm

Year	2016	2017	2018	2019	2020
Forecasted Population	7468738	7618113	7770475	7925885	8084402
Required No of Taxis	19061	19442	19831	20227	20632

Annual Average Rate of Taxi Passengers per Capita = Annual Average (No. of Taxi Passengers/Population)	***(1)***
Future Expected Taxi Passengers = Future Year Population * Annual Average Rate of Taxi Passengers per Capita	***(2)***
Annual Average Taxi Occupancy = Annual Average (Number of Taxi Passengers / Number of Taxi Trips)	***(3)***
Future Number of Taxi Revenue Trips = Future Expected Taxi Passengers /Average Taxi Occupancy	***(4)***
Annual Average Kilometers Travelled for a Taxi Revenue Trip = Annual Average (Total Revenue Kilometers Travelled/Number of Taxi Revenue Trips)	***(5)***
Total Future Expected Revenue Kilometers = Future Number of Taxi Revenue Trips * Annual Average Kilometers Travelled for a Taxi Revenue Trip	***(6)***
Annual Average Rate of Kilometers Travelled per Taxi (Roaming & Revenue) = Yearly Average (Total Kilometers Travelled /Number of Taxis)	***(7)***
Targeted Future Operator-User Kilometer Index = Rate of Total Revenue Kilometers to Total Travelled Kilometers (Roaming & Revenue)	***(8)***
Total Future Expected Travelled Kilometers (Roaming & Revenue) = Total Future Expected Revenue Kilometers / Operator-User Kilometer Index	***(9)***
Number of Future Required Taxis = Total Future Expected Total Travelled Kilometers/ Average Rate of Kilometers Travelled per Taxi	***(10)***
Required Number of Taxis in Future Year = ((((Future Year Population * Average Rate of Taxi Passengers per Capita)/Average Taxi Occupancy)*Average Km. of a Taxi Revenue Trip)/Target Rate of Revenue Kilometers to Total Kilometers)/Average Rate of Kilometers Travelled per Taxi	***All***

8. CONCLUSION

This research addressed one of the important topics as related to the taxi industry, namely the methods used to estimate future taxi requirements in cities of the World. The importance of the role played by taxis in the mobility of people is unquestionable. Taxis are part and parcel of the integrated passenger transport chain especially in urban cities. This paper provided a conceptualization of factors affecting the demand for taxis. Such demand is impacted by 2 main sets of factors namely demand based factors and supply based factors. Demand based factors include population, tourists, visitors, special needs population, income, transit taxi integrated trips, traffic congestion levels. Supply based factors include taxi availability (represented by number and average waiting time to obtain a taxi), taxi fare, taxi branding (expressed in comfort, courtesy, convenience, safety, security), car availability, cost of owning & operating a car, and other competing modes such as limo service and mobility application companies such as Uber. Limited literature exists in the area of methods for estimating future taxi fleet size. The paper identified 2 methods the first is based on taxi availability index and the second is based on HARA Associates' Taxi Demand Model. Both were used for a hypothetical city to demonstrate their applicability. In both methods expected number of future population is considered as the driving factor behind estimation of required number of taxis.

The average taxi availability index across 23 cities in the world was computed and reported as being ≥ 3 taxis per 1000 population, It is obvious that some cities such as London, Barcelona, Prague, Stockholm, Dublin and Washington are above this average, while Melbourne, Vancouver, Brussels are below such average. A similar comparison is conducted for North American cities, where it is obvious that cities such as New Orleans and District of Columbia, and New York City have taxi availability index of more than 3 taxis per 1000 population. It is also worth mentioning that growing Asian cities like Singapore has a high taxi-to-population ratio of 5.2 taxis per 1000 persons compared to 2.6 in Hong Kong, while the city of Dubai is targeting to achieve taxi availability index of 4.09 taxis per 1000 population. The research also developed a taxi availability level of service categorisation from A to F, where LOS (A) demonstrates the highest taxi availability index ranging from 10 to 12 taxis per 1000 population as in Dublin –Washington – District of Colombia, and LOS (C) demonstrates an average taxi availability index ranging from 5 to 7 taxis per 1000 population as in Singapore - Stockholm, while most cities are lying in LOS (E) with taxi availability ratios ranging from 1 to 3 taxis per 1000 population as in Copenhagen– Chicago– Istanbul etc.

Furthermore, the research developed a generic algorithm for estimation of taxi fleet requirements. This includes computation of several algebraic equations (10 equations) forming an algorithm that is capable of computing taxi future fleet requirements. Some equation inputs are related to demand factors such as population and others are related to supply factors such as average occupancy, average distance per taxi trip, etc. Towards this end the algorithm requires several items of data including historical trends of population, taxi fleet, taxi trips, revenue kilometers, total kilometers, average roaming time, taxi average occupancy etc. One of the most important inputs is the indicator comparing revenue kilometers to total kilometers where this indicator aims to achieve a balance on the one hand between financial efficiency to taxi operators and on the other hand avoiding users' dis-satisfaction as a result of difficulties in locating taxis when needed. This indicator can range between 50% to 60 %. The paper demonstrated applicability of this algorithm which is considered superior compared to the other 2 methods. However, the selection of one of the 3 methods of taxi fleet requirement estimation relies on the target LOS objective and the availability of data.

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