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A Methodology of Evaluating Urban Parking System: Case Study of Delhi

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Abstract

A parking study is carried out in the NCT of Delhi to measure the parking system performance for different land-uses. Various parking statistics such as parking demand, demand-capacity (D/C) ratio, parking load, parking efficiency, and utilization are considered to demonstrate the parking conditions and problems at the selected parking locations. Further, four key-indicators viz., D/C ratio, search + park time, walk time and parking fees are chosen to develop parking performance index (PPI) which evaluate the parking facility from users' perspective. PPI is a single value index, which is estimated by combining the evaluation criteria of the four indicators using a radial coordinate system. PPI is classified into four categories: Excellent, Good, Fair and Poor using clustering analysis in order to define the thresholds for each category. The paper demonstrates the case study application, which describes the applicability of the developed PPI at three locations in Delhi. Lastly, a few parking strategies and guidelines are discussed based on the analysis, on-field survey observations, and past literature. The proposed method can be adopted globally with the required modifications. The study is helpful for the transport planners and policy-makers to quantify the quality of the existing parking system, and the improvement plans can be made accordingly.

Keywords: Parking Demand; Parking Performance Index; Clustering; Respondent Analysis; Level of Service

1. Introduction

As the accelerated industrialization throughout the world led to higher growth rates of urban economy, improving living standards of the inhabitants in count with a perennially burgeoning population, there is a continuous rise in the private vehicle ownership. Most of the Indian cities are facing rapid vehicular growth in conjunction with urbanization generating significant vehicular movement towards the potential zones of the city. Central Business District (CBD) is one of the attraction zones in the city given business and official activities. Besides, market and commercial areas attract a significant number of shopping trips creating huge parking demand in these areas. Metro cities like Delhi having

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a big challenge to reduce traffic congestion, environmental pollution, and the rate of accidents. Past trends of increasing motorized vehicles, particularly private cars in Delhi create the problems of parking. It has been surprisingly noted that in National Capital Territory (NCT) of Delhi, the growth rate of population is about 1%, but the increasing rate of motor vehicles is around 7% with private vehicle population of more than 100 million (Delhi Statistical Handbook, 2018). This increasing rate of private vehicle usage leads to mismanagement of a parking facility, which directly affects the utilization of the available parking resources (Litman, 2016). Parking system problems can be defined in terms of supply oriented, information-oriented, choice oriented, efficiency-oriented, and spill-over impacts (Parmar et al., 2019). As parking is an integral part of the urban transportation system, it is essential to evaluate the level of service (LOS) of the existing parking facilities to improve the parking design and operation planning. The parking cost, ease of finding a parking space, support for strategic transportation and land use objectives, and user satisfaction measured through surveys can be included as significant parameters for the evaluation as well as improvement.

This study emphasized on developing an efficient method to assess the service quality level of a parking lot from users' perception. This study identifies the locations within the boundary of Delhi, which are having different land-uses such as residential, office-business and market-commercial. Various parking statistics such as demand, demand-capacity ratio (D/C), parking load, parking duration, and parking efficiency are determined to assess existing parking situations at the selected locations. Further, based on the literature survey, parking LOS indicators like D/C ratio, search + park time, walking time, and parking fees are considered to estimate the LOS. Development of the level of service is a classification problem in the most general way. This study uses partitional clustering algorithms- K-means clustering and fuzzy c-means clustering to categorize the collected dataset. A four LOS classifications viz., Excellent, Good, Fair, and Poor are defined ranging from LOS A to LOS D. A single value index PPI is proposed which combines the thresholds of all four LOS indicators. This index can comprehensively evaluate the parking facility.

2. Past Studies

As with the rapid development of the economy, the level of living standard of the people improving continuously, and the car is becoming the primary mode of transportation, troubling for vehicle parking in urban areas. Car parking is one of the major issues in most of the urban areas, which appeals the attention of planners to consider the significance of it, both at a local and strategic level of planning (Young et al., 1991). Due to increasing parking demand, the overall parking capacity cannot satisfy it, which creates problems having a noticeable impact on traffic congestion. As noted by De Cerreño (2004), parking is one of the critical elements in forming transportation policy and management of traffic in large cities. Indeed, he found that many cities lack the necessary information about their parking resources. So, it becomes necessary to study the parking behaviour and performance of an existing facility in the direction of making a firm policy for parking. At a strategic level of planning, it is essential to evaluate the existing parking facilities to develop LOS to better plan and operation. This importance attracted many studies in the past. The previous study to establish the level of service (LOS) has been carried out by Yu and Lincoln (1973) to measure the efficiency of an individual parking facility. The study found parking availability and flow/capacity ratio to be significant variables. Smith (1996) studied the application of Crime Prevention through

Environmental Design concepts to parking facilities and defined the LOS approach based on safety and security. He proposed four categories of level of service A B C and D for lighting from best to worst conditions. The author explained various safety and security measures for the design of a suitable parking area. Another categorized level of service approach was introduced by Kay and Smith (2000) mainly in respect of how easy it is to find the parking space considering flow condition. Smith and Butcher (2008) developed a level of service of the parking facility as a measure of walking distance to the destination from parking for performance evaluation.

In China, the fuzzy model for evaluation of parking system performance has been used by Dong et al. (2009). Three aspects, namely safety, convenience and efficiency, have been considered based on expert's objective evaluation without conducting practical survey and analysis. Yang et al. (2010) conducted a study and did use parking inventory and customer preference survey to analyze the performance of parking facility using the multivariate logit model but the results obtained have large gap compared to the actual situation. Convenience (Ease of access & Searching time) is one of the main factors a driver would keep in mind while choosing a parking space (McGuiness and McNeil, 1991; Hensher and King, 2001) that also should be considered while defining LOS for the particular parking facility. Ye et al. (2013) estimated the level of service for curbside parking with consideration of parking accessibility. By conducting traffic survey and traffic conflict analysis technique, they defined the events of conflicts to describe the traffic block and conflict of parked vehicles caused by non-motorized vehicle flow. They established model to relate the events of conflicts with the velocity of non-motorized vehicles and parked cars, bicycles and e-bike volume, the width of bicycle lane- which designate the level of service of a curbside parking facility. Based on land use and parking inventory, Moeinaddinia et al. (2013) evaluated PILOS (Parking Inventory Level of Service) and PDLOS (Parking Demand Level of Service) through demand study and defined PALOS (Parking Area Level of Service) for university area. They considered space utilization, number of legal and illegal parking, parking shades, accessible walking routes and accessible transit station for evaluation of LOS. However, the applicability of this concept in parking lots other than university campus as well as in the context of Indian cities is limited. Cats et al. (2016) proposed a methodology to empirically measure the impact of on-street parking policies using automated parking transaction data. They analyzed the performance based on available data from ticket vending machines. Recently, Das and Ahmed (2018) conducted a study to develop a level of service for on-street parking facilities. They defined three categories- PC (Parking Characteristics), DC (Design Characteristics) and SC (Safety Characteristics) to classify different elements of parking and developed LOS equation whose coefficients are estimated using AHP process using user's perception data. The authors also carried out a K-Means clustering analysis to standardize the range of each variable.

It is seen that most studies in current literature focus on-street parking and related problems, however the off-street parking lots are less attended by the researchers, which in fact handle more parking demand in general case. Moreover, the studies lack in defining LOS method that can be implemented in the context of developing countries like India where smart parking systems are yet to be implemented at most of the places, and even a proper demarcation in the parking area is missing. In this study, the performance of the parking system has been measured from a quantitative approach, and PPI has been estimated using clustering technique. In addition, parking management strategies have been discussed, which can be useful while framing parking policy guidelines.

3. Research Frame Work

This paper comprises two analysis sections. The first discusses parking situations and problems at the selected parking lots in the National Capital Territory of Delhi. For that, four quantitative parameters: parking demand, D/C ratio, parking load, parking duration, and parking efficiency are considered. The first two parameters are self-explanatory. The parking load is the vehicle accumulation determined with respect to parking duration. It is the area under the accumulation curve and measured in terms of vehicle-hours. The parking efficiency, also called parking index is an aggregate measure of how effectually a parking lot is utilized. It is a ratio of number of bays occupied to the total capacity for a given time duration. A high parking load for a given parking demand suggests a lower efficiency since each unique vehicle park for a longer duration.

A later section describes a methodology to derive a PPI in the Indian context. Based on the literature survey, four most considered LOS indicators- D/C ratio, search + park time, walk time to destination from parking lot, and parking fees are used to develop an index. As stated earlier, two unsupervised clustering algorithms namely, k-means clustering (KM) and fuzzy c-means (FCM) clustering (Bezdek, 1981) algorithms are used for the classification problem. These both are considered as partitional clustering approaches. In this study, number of centroids are defined as four. K-means algorithm provides crisp and stabilized clusters. It identifies k numbers of centroids, and allocates every datapoints to the nearest cluster, keeping the centroids as small as possible. The fuzzy c-means algorithm is particularly utilized to find any overlapping between collected data-points, and between the clusters themselves. It can be considered as a crisp clustering if the membership function does not show any evidence of fuzziness in a cluster membership.

4. Estimation of Parking Performance Index (PPI)

The parking performance index is nothing but a parameter which is derived to assess the level of service of the parking lot. As this paper intends to develop a single value index which combines the developed evaluation criteria (i.e. thresholds) for the four parameters, it is essential to put these parameters on a common platform. It means that they should be dimensionless quantities so that they could be coalesced together. In this study, zero-dimension process is performed using min-max normalization to make the parameters unitless, which can be represented as Equation 1. It gives the values of each parameters in the range of [0, 1]. Now, to synthesize the normalized values, radial quartic equation is deployed for the first quadrant in the radial coordinate system. Equation 2 depicts the formula which integrate the four thresholds into one.

$$Normalized\ (z_i^*) = \frac{z_i - min(z)}{max(z) - min(z)};\quad z_i^* \in [0,1] \qquad \dots\dots\dots\dots (1)$$

$$(r) = \left(\sum_{i=1}^{4} (z_i)^2\right)^{\frac{1}{2}} \qquad \dots\dots\dots\dots (2)$$

The Equation 2 imparts the boundary condition for the PPI given a set of z = (z1, z2, z3, z4…), where z is the normalized threshold value obtained from Equation 3. The estimated r value is applied in defining the range for PPI for the four LOS categories- {A, B, C, D}.

5. Study Area and Data Collection

For this study, the National Capital Territory (NCT) of Delhi is considered. Delhi is ranked as one of the highest populous cities in the world having metropolitan population of 16.35 million (Census, 2011). As per Census 2011, 97.5% of the total population is urbanized. Even having a sound transit infrastructure (bus and metro), the share of it was roughly 50% in 2007 and likely to be increased by 1-2% in 2021 (Delhi Statistical Handbook, 2017). Burgeoning vehicle population in Delhi contributes to the enormous traffic jams, pollution, unauthorized parking on roads, and spill over in off-street parking lots. The selection of the survey locations is crucial while designing LOS. In this study, 12 parking lots from 6 different locations are selected for the survey. Table 1 shows the details of survey locations across the NCT of Delhi. These locations cover residential, shopping cum commercial shopping cum commercial, and office-business oriented land-use. These are some of the prime locations which attract huge number of trips through private vehicles from various parts of the Delhi as well as from the satellite towns around the city. They see heavy parking demand throughout the daytime. All of the selected parking lots are open-air, ground floor, paid parking lots and easily accessible from the main urban roads.

Table 1: Details of Parking Study Areas in Delhi-NCR

Land-Use Type	Locations		Raw Capacity	Parking Type
Residential	Sukhdev-Vihar, Pocket-A	RP1	408	Off-Street Surface Parking
	Dwarka Sector-14	RP2	509	
	Sukhdev-Vihar, Pocket-A	RP3	107	On-Street
Office & Business	Nehru Place (Car and Bike)	OBP1	98	Off-Street Surface Parking
		OBP2	212	
		OBP3	325	
	Bhikaji Cama Place	OBP4	899	Off-Street Surface Parking
	Bhikaji Cama Place	OBP5	132	On-Street
		OBP6	90	
Shopping/ Market	Atta Market	SM1	111	On-Street
		SM2	94	On-Street (Bike)
	Lajpat Nagar	SM3	124	Off-Street Surface Parking

For the data collection, firstly the parking inventory was carried out to estimate the capacity of each parking lot. The ECS (Equivalent Car Space) capacity was calculated based on the recommendations provided in the Indo-HCM 2017. The In-out license plate survey at each gate of the parking lot has been carried out for the 12 hrs. during weekdays, and also during weekends at market areas. In the In-Out survey, the data have been recorded as entry and exit time of each vehicle with license number plate. Based on the license plate number, the average parking duration for the selected parking lots is computed. In addition, a questionnaire survey was carried out to estimate the search + park time, walking time, and parking fees. Parking fees (per person) has been calculated based on the duration of parking of each respondent's vehicle, and fixed parking fees per hour. At each parking lot, 100 samples were collected resulting in a total of 1200 samples.

6. Analysis of Parking Statistics

This section is dedicated to the quantitative analysis and discussion of collected parking data for each selected parking lots. Five operational parking statistics are computed as stated in previous section. The capacity of parking lots is estimated considering the recommendations outlined in Indo-HCM 2017, that is the space required for a car is considered as (4.58 × 1.77) m. The following subsections discuss the land-use wise parking statistics evaluation.

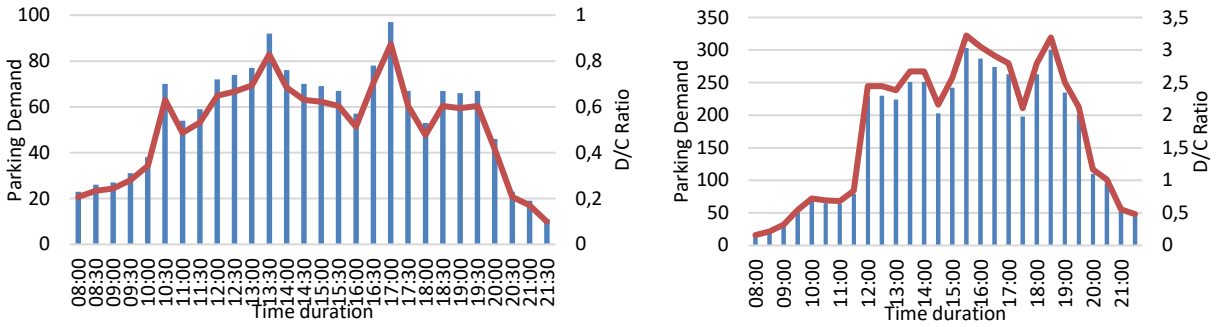
6.1 Shopping & Commercial Land-use

For the shopping-commercial land-use, two locations- Atta market and Lajpat Nagar are considered. They attract majority of visitors like consumers, self-employed vendors, marketing people and business fellows. The parking lots in these areas also hold a considerable extent of long-term parked cars by the shopkeepers. Figure 1 shows the demand of parking spaces for car parking lot (SC1) and bike parking lot (SC2) respectively at Atta market. Since it is a market area, the accumulation profiles consist more than one peak in a given time period. The parking statistics for both SC1 and SC2 is shown in Table 2. A peak occupancy for SC1 and SC2 is 0.87 and 3.2 respectively. For the SC1 lot, D/C ratio pass 0.85 only two times during the survey period, which depicts an underutilization of parking lot. While in case of bike parking, D/C ratio surpasses 1 at 12:00 noon and remains high for 8 hrs. after which it starts reducing. It creates a great spillover condition as peak reaches three times a capacity. The bikes are accommodated with no room for circulation.

Table 2: Parking Statistics at Shopping Areas

	Parking Demand	***D/C Ratio***	***Parking Load (veh-hr)***	***Parking Efficiency (%)***	***Avg. Parking Duration (min)***
			SC1		
Mean	59.96	0.54	30.77	67.01	79
Std. Deviation	20.92	0.188	2.03	9.42	48
			SC2		
Mean	45.27	0.48	83	64.08	82
Std. Deviation	25	0.266	9.47	13.3	63
			SC3		
Mean	89.84	0.72	22.46	28.11	183
Std. Deviation	44.91	0.36	11.23	9.055	67

At Lajpat Nagar market (SC3), majority of the shops open after 11:00 morning so that the survey was carried out from this time. It can be seen that accumulation has sharp increase of around 80 cars between 12:00 and 13:30. At the same time, demand also crosses the capacity of the parking lot as the D/C ratio passes the 1 and remains above 1 up to evening 5:00.



(a) Parking Demand Distribution at SC1 (b) Parking Demand Distribution at SC2

Figure 1: Parking Demand Distribution at Shopping & Commercial Land-use

It was observed during the survey that management authority forces the parkers to park a car in a circulation space between two parallel lines of 90° parking to accommodate extra incoming cars. Table 1 depicts low parking efficiency because of higher parking duration which reduces the parking utilization rate.

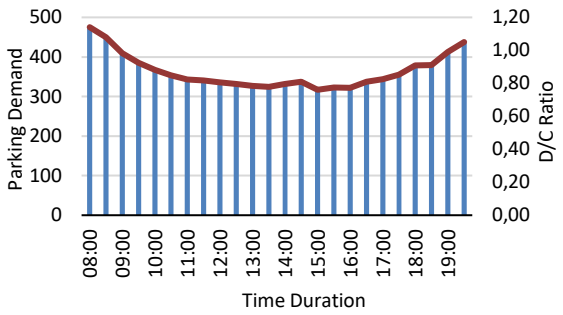
6.2 Residential Land-use

In this study, two locations- Sukhdev Vihar and Dwarka Sec. 14 are considered. The DDA (Delhi Development Authority) colonies at these locations were surveyed for the data collection. The car parking is provided at the boundary of these colonies which reflects a pattern of on-street parking. Two parking RP1 and RP2 at Sukhdev Vihar and one parking lot RP3 at Dwarka were selected. Parking demand distribution in Residential colonies have been shown in Figure 2. Since a type of land-use is residential, the peak accumulation occurs during the night time. In the three figures, either right or left most parking accumulation, whichever is higher express the peak demand which remains constant for a night time-cycle. For instance, RP1 has peak demand of 472 which is at 8:00 morning and before as well as after 19:30. All three accumulation profiles show that even during the daytime, the minimum accumulation is very high. It suggests that the people leave for the job or other purposes without their vehicles. It signifies that the cars parked for all the time only waste the valuable land resources, which should get serious attention by policymakers. Table 3 describes the parking statistics for RP1, RP2 and RP3 parking. The parking load is very high for RP1 and RP3 because they have high parking accumulation throughout the survey period with mean of 361 and 437 respectively.

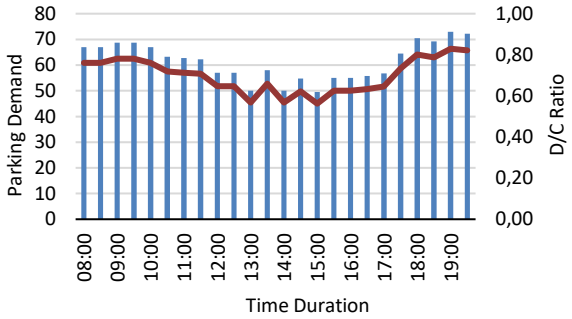
Table 3: Parking Statistics at Residence Area

	Parking Demand	***D/C Ratio***	***Parking Load (veh-hr)***	***Parking Efficiency (%)***	***Avg. Parking Duration (hrs.)***
			RP1		
Mean	361	0.87	180.51	44.24	18.3
Std. Deviation	43.94	0.11	21.97	5.38	1.12
			RP2		
Mean	62	0.70	30.73	34.92	16.7
Std. Deviation	7.36	0.08	3.68	4.18	2.31
			RP3		
Mean	437	1.11	218.79	42.98	16.4
Std. Deviation	34.81	0.08	17.41	3.42	1.73

At RP3, minimum and maximum D/C ratios are 0.78 and 1 which implies that about 22% of the total cars were used throughout the survey duration while 78% of the cars were stagnant. Even the average parking duration is 16.4 hrs. Similar conditions can be identified at RP1 and RP2 also, which suggests significant improvements required in parking and vehicle-ownership related policies. This paper discusses a few improvement strategies in the Section 8.



(a) Parking Demand Distribution at RP1

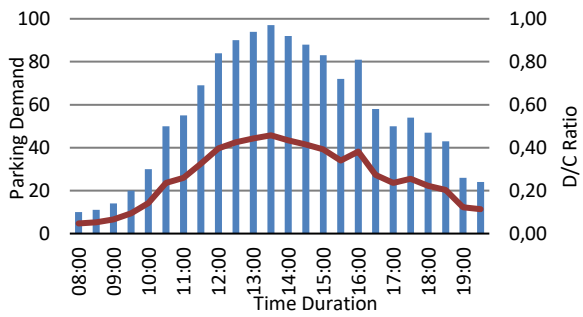


(b) Parking Demand Distribution at RP2

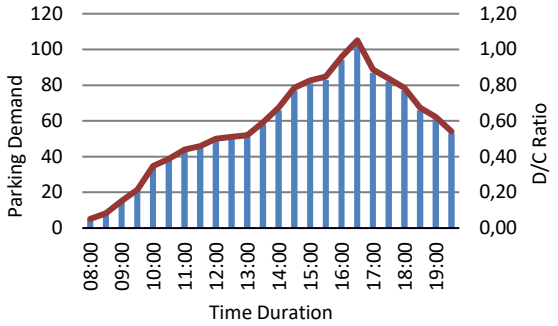
Figure 2: Parking Demand Distribution at Residential Land-us

6.3 Office-Business Land-use

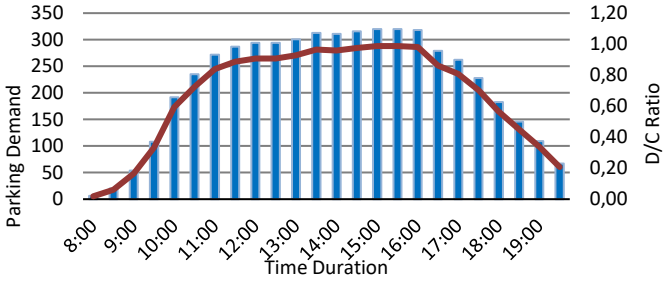
In Delhi, Nehru Place and Bhikaji Cama Place are considered as office-business oriented land-use. These both places comprise a great number of business offices which attract huge number of work trips through private vehicles. Nehru Place is one of the largest electronic and IT hubs in India, and the parking lots at this place handle more than 1500 cars a day as a whole. This study considers 3 parking lots- OB1, OB2 and OB3 dedicated for office buildings. Bhikaji Cama Place encompasses government as well as private company offices, and the parking lots here handle about 1000 cars a day as a whole.



a) Parking demand distribution at OB1



(b) Parking demand distribution at OB2



(c) Parking demand distribution at OB3

Figure 3: Parking demand distribution at Office-business land use

Table 4: Parking Statistics at Office-Business Areas

	Parking Demand	*D/C Ratio*	*Parking Load (veh-hr)*	*Parking Efficiency (%)*	*Avg. Parking Duration (hrs.)*
			OB1		
Mean	52.64	0.54	26.32	26.86	4.56
Std. Deviation	23.30	0.24	11.65	11.89	2.44
			OB2		
Mean	55.92	0.26	27.96	13.19	6.33
Std. Deviation	28.96	0.14	14.48	6.83	1.35
			OB3		
Mean	218.12	0.67	27.27	33.66	5.82
Std. Deviation	21.5	0.33	13.17	16.25	2.31
			OB4		
Mean	101.71	0.77	50.85	38.53	6.82
Std. Deviation	40.95	0.31	20.48	15.51	1.47
			OB5		
Mean	39.70	0.44	19.85	22.05	7.58
Std. Deviation	14.06	0.16	7.03	7.81	0.93
			OB6		
Mean	52.75	0.59	26.38	29.31	5.78
Std. Deviation	18.45	0.20	9.22	10.25	1.82

The parking statistics for three parking lots OB4, OB5, and OB6 are provided in Table 4. A peak demand is 149 cars for OB4 occurs at 1:30 afternoon, and D/C ratio at this time is 1.13. It can be seen that spillover occurs during 10:30 – 14:00 time period. Particularly at this place, it was noticed that these parking lots are lack in markings, signage, and

maintenance. Also, people have to spent more than 3 to 4 minutes to search for the space. For OB5 and OB6, it can be observed that the demand never reached up to the capacity throughout the survey time. The highest observed D/C ratio is 0.71 and 0.83 for OB5 and OB6 respectively while average is 0.44 and 0.59 respectively. The average D/C show the low utilization of these parking lots. As most trips attracted at these locations with work purpose, the average parking duration is high for all 6 parking lots (Table 4). For OB5, it is as high as 7.58 hrs., which depicts that cars are stagnant for much higher duration.

7. Development of Parking Performance Index (PPI)

As stated earlier, this study is intended to develop a methodology to assess the service quality level of parking facilities from users' perception. The four evaluation criteria-demand-capacity ratio, search + park time, walking time, and parking fees are considered to estimate the PPI. Both the temporal parameters are taken in a *minute* while the fees are considered in *INR (Indian Rupees)*. The performance (LOS) is classified into four categories viz., Excellent, Good, Fair, and Poor. The two clustering algorithms i.e., K-means clustering and Fuzzy C-means clustering were employed to classify the dataset into the four categories of PPI. The results of FCM revealed that there is no evidence of fuzziness and overlapping between the clustered data points as the membership values of all data points lie above 95% in a respective cluster. Hence, FCM results can be considered as a crisp cluster like KM. To check the performance of the clustering algorithms and validate the results, two indices namely, Silhouette index and Davies-Bouldin index are used. Higher SI value and lower DBI value indicates good clusters. For current work, KM imparts the same and therefore, it is taken for the further analysis. Further, the Kolmogorov-Smirnov test is applied to check the uniqueness of the clusters in terms of distribution of data. The results revealed that the distribution of each cluster vary significantly from each other at 99% confidence level. Table 5 illustrates the results of the KM clustering analysis that are the means of each cluster and number of cases in each cluster.

Table 5: Results of K-means Clustering Analysis

	Range		***Clusters***	
	Min	***Max***	***Cluster-centers***	***No. of Cases***
D/C Ratio	0	1.137	0.20, 0.51, 0.77, 1.01	144, 150, 190, 198
Search + Park Time	0	12.5	2.74, 4.81, 6.91, 9.99	316, 311, 289, 284
Walk Time	0	11	2.10, 3.59, 5.48, 8.59	327, 297, 275, 301
Parking Fees	0	100	20, 39.5, 60, 96.96	403, 199, 210, 388

Based on the cluster-centers, the threshold values are estimated. These thresholds define the ranges for the evaluation parameters for the four categories. For instance, the first category (i.e., Excellent) for the D/C ration can be computed as an average of first two cluster centers that are 0.20 and 0.51. It means, if the average D/C ratio for any parking lot lie below 0.35, then the condition would be defined as an Excellent from the user's point of view. Similarly, ranges for the all four categories for the four parameters are estimated and tabulated in Table 6.

Table 6: Classification of Evaluation Parameters

	Excellent	Good	Fair	Poor
D/C Ratio	< 0.35	0.35 - 0.63	0.63 - 0.88	> 0.88
Search + Park Time	< 3.75	3.75 – 5.75	5.75 – 8.25	> 8.25
Walk Time	< 2.75	2.75 – 4.55	4.55 – 7.04	> 7.04
Parking Fees	< 29.75	29.75 – 49.75	49.75 – 78.48	> 78.48

Now, to combine the four evaluation parameters in to single value PPI, it is essential to make them unitless (zero-dimension). For that, normalization is carried out with min-max normalization technique. The Equation 1 is used to carry out this process and to transform the values in Table 6 between 0 and 1. For example, the threshold value 0.63 for D/C would be 0.56 after the normalization. Table 7 illustrates the results of min-max normalization. Here, the normalized thresholds for each category is termed as z_i. The minimum possible value of the parameters is assumed as zero while normalizing the values.

Table 7: Thresholds

of Evaluation Parameters after Normalization

	Min	z_i^a	z_i^b	z_i^c	Max
D/C Ratio	0	0.31	0.56	0.78	1
Search + Park Time	0	0.30	0.46	0.66	1
Walk Time	0	0.25	0.41	0.64	1
Parking Fees	0	0.30	0.50	0.79	1

It can be interpreted that the normalized values between 0 and $\boldsymbol{z_i^a}$ for the four evaluation parameters signify the Excellent service level of a given parking lot. Now, it is possible to combine the four parameters in to single index since they are unitless and lie in the interval [0, 1]. To synthesize the normalized values, radial quartic equation is used as shown in the Equation 2. The individual formulas $\boldsymbol{z_i^a}$, z_i^b, and $\boldsymbol{z_i^c}$ are described in the Equations 3, 4, and 5 respectively, which are considered in the first quadrant of the radial coordinate system (Figure 4).

$$(r^a) = \left(\sum_{i=1}^{4} (z_i^a)^2\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (3)$$

$$(r^b) = \left(\sum_{i=1}^{4} \left(z_i^b\right)^2\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (4)$$

$$(r^c) = \left(\sum_{i=1}^{4} (z_i^c)^2\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (5)$$

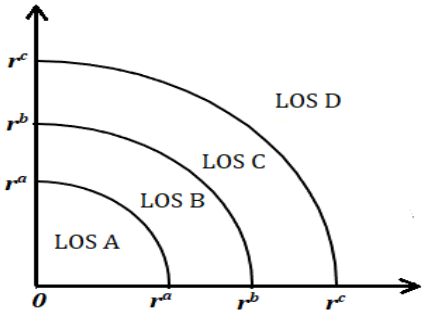


Figure 4: Illustration of PPI categories

Where: r represents boundary condition for the respective LOS categories corresponding to the z values. i is the number of parameters considered for the PPI development. Based on this approach, the estimated ranges for the PPI and respective LOS category is defined as demonstrated in Table 8. Here, r^a represents the boundary value for Excellent condition that is a combination of values of the four parameters. Subsequently, r^b and r^c denote the boundary values for Good and Fair conditions respectively.

Table 8: Level of Service (PPI) Definition

Boundary Condition	***Range of PPI***	***Classification***	***LOS Definition***
$\leq (r^a)$	< 0.58	Excellent	LOS A
$(r^a) \sim (r^b)$	0.58 – 0.97	Good	LOS B
$(r^b) \sim (r^c)$	0.97 – 1.44	Fair	LOS C
$\geq (r^c)$	> 1.44	Poor	LOS D

8. Case Study Application

In order to test the applicability of the PPI to the actual scenario, this section demonstrates the case study application of PPI. This section describes the process as well as results of applying the PPI to three different parking locations. It serves as an example of how to apply the PPI and recommendations on how to further improve the index. Three location within the boundary of Delhi are selected for the case study. Two of them are market areas and one is office-business oriented area. These locations were considered based on the shopping and work trips. Kamla nagar and Dwarka Sector 12 market are shopping places and Nehru place (parking lot other than used for developing PPI range) is office-business oriented area. These three locations were selected because they provide different types of samples from different municipalities, so a comparison can be done between types of parking scenarios.

The summary of the four parameters for three locations is given in Table 9. Based on the normalized values of the parameters, the PPI has been estimated for each conditions and LOS has been defined from Table 8. For instance, the normalized values of the four metrics for Kamla Nagar (Weekdays) is shown in the Table 9. Using Equation 2, PPI value has been calculated as 0.96. Further, Table 8 shows (r^a)=0.58 and (r^b)=0.97 between which the PPI=0.965 lies. Hence, by the definition outlined in the Table 8, the level of service for Kamla Nagar (Weekdays) is 'Good' (LOS B).

Table 9: PPI Application Results

Parameters		***Kamla Nagar***		***Dwarka Sec. 12***		***Nehru Place***
		WD	***WND***	***WD***	***WND***	***WD***
D/C Ratio	Actual	0.58	0.63	0.36	0.88	0.92
	Normalized	0.51	0.55	0.32	0.77	0.81
Search + Park Time	Actual	5.35	6.28	5.48	6.70	5.70
	Normalized	0.43	0.50	0.44	0.54	0.46
Walk Time	Actual	3.66	5.93	5.55	5.87	5.76
	Normalized	0.33	0.54	0.51	0.53	0.52
Parking Fees	Actual	61.48	56.67	60.87	76.62	67.75
	Normalized	0.62	0.57	0.61	0.77	0.68
PPI	-	0.97	1.08	0.96	1.33	1.26
LOS	-	B	C	B	C	C

Note: WD=Weekdays; WND=Weekend.

Most of the parking facilities in NCT of Delhi are on-ground, and it is obvious that there are limitations in terms of availability of parking berths. They cannot satisfy the parking demand particularly during holidays and weekend when traffic flow is higher mostly in commercial and shopping/market areas. Hence, it is important to improve the existing parking facilities as well as to promote the public transportation to reduce huge demand and spill-over of parking, particularly at office-business oriented area where average parking duration is much higher.

9. Parking Management Strategies

In a view of the foregoing analysis, field observations during the surveys, and literature survey, this section discusses the parking management strategies. The objective of these strategies is two-fold: 1. To make the parking system more efficient in service, and 2. To reduce the burden of private vehicles on transport network by policy implications.
A detailed analysis of parking statistics for three land-use is carried out which depicts few problems that are to dealt with. At Atta market, it is seen that SC1 has less demand compare to designed capacity while at SC2, the demand is as high as 3 times the capacity. Hence, the dedicated area for car parking at SC1 should have integration with the SC2 to alleviate the high bike parking demand. Also, it was observed that illegal parking of bikes affects the traffic operation, which might be proved hazardous in some cases. The management authority should draw attention on these conditions for the improvements. Further, Table 1 shows the average parking duration of 82 min with the std. deviation of 63 min for SC2 which depicts higher range. This area is well connected with the bus and metro within the distance of 250 meters. Thus, the people should be encouraged to use the public transit, particularly that group which uses parking space for higher duration. The same strategy can also be applicable to OB3, OB4, and OB6 parking lots. The parking demand profiles at residential areas depict that even during a daytime, the average occupancy remains 75%. It suggests most of the cars remain stagnant, and they are not used for day-to-day purpose. Hence, it is required to make policy implications with considerations of parking restrictions and parking pricing in order to reduce/stable the vehicle ownership.

In the case study application, a search + park time for both market areas are high for weekends, which contribute to the lower LOS. The surveys revealed that the search time

is dominated among the combination of search + park time. In parking lots, people usually do not know whether there are empty spaces or not. The development of mobile applications offers the opportunity to counter this problem. For example, the San Francisco city in US utilizes the technology to find the number of spaces available in the parking lots via smartphones (Perez, 2012). Besides, an efficient guidance system tends to reduce the search time for parking space. The use of intelligent transport system (ITS) can significantly alleviate issue by installing street panels which provide the routes to the nearby parking lots as well as empty parking space inside a parking lot (Ji et al., 2014).

It is essential to maintain the balance between on-street and off-street parking. Parking price differentiation and proper guiding and information system are the two main aspects to alleviate it. Currently, the parking price in the studied areas for both type of parking facilities is same (INR 20/hr.). It is required to keep higher parking fees for on-street parking compared to the off-street parking. Also, there should be cumulative increase in the fees with respect to the duration. It will encourage the long-term parker to use the off-street parking rather than to go for on-street. Also, the parking price should be kept in such a way that it has positive impacts on effective utilization of parking space. It is recommended to set the price to maintain 85-90% occupancy rate, which is called *performance-based or responsive* pricing (Shoup, 2005).

Parking issue can be solved by Push and Pull strategy, which is applicable to surveyed areas. Push strategy includes more traffic restrictions in CBDs such as parking and private vehicle usage restrictions. It should promote the use of public transit and park-and-ride facilities. Pull strategy considers proper pedestrian facilities and better first and last mile connectivity in addition to the efficient public transit and vehicle-sharing, which would reduce/stable parking demand.

10. Conclusion

This study develops a parking facility LOS measuring method quantitatively based on user's perception. An analysis is done by providing parking statistics at each location. Four parameters are considered for PPI to evaluate the parking service quality level. It can be observed from this study that developed PPI is the key indicator to measure parking system (off-street or on-street for both) performance quantitatively. K-means clustering technique has been used to define four levels of PPI. Based on the analysis, the case study is described to check the applicability of the PPI. Further, few parking management strategies have also been discussed in brief looking to the current scenarios of parking environment mainly in the study region. Parking systems improvement program needs prioritization for which decision can be made using these PPI levels. Prioritization can be made based on the PPI. This might be a case when funding is limited. In that case, the parking lot with higher PPI value (i.e., lower LOS) should be given a priority for the improvements since it required more attention. This study is basically useful for the practitioners and planners to provide needful improvements. The proposed methodology is flexible to be adopted globally with the required adjustments according the place of implementation, more comprehensive list of the evaluation parameters, etc.

In this study, the performance evaluation is done based on the user's perception data. Study can further be extended by considering the management's viewpoint for optimized use of the parking system. The applicability of the developed PPI is checked for shopping and business areas, which can further be checked for various types of land uses as well as mixed land uses.

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