Developing Parking Accumulation Levels to Formulate Land-Use Based On-Street Parking Policies in a Indian city - A case study

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Abstract

Demand for on-street parking is function of land use and therefore, it becomes imperative to investigate the effect of land-use type on on-street parking characteristics for developing land-use based on-street parking policies. To comprehend the aim, two diverse representative land-use types namely commercial and hospital were selected in the central business district (CBD) area of Rajkot city, India. Microscopic investigation was carried out by collecting demand data at every 10min monitoring interval during peak parking hours using license plate method. Investigation revealed that, land-use type significantly affected on-street parking characteristics and therefore, it becomes necessary to develop land-use based on-street parking policies. Parking index was identified as potential measure to formulate land-use based on-street parking policies, which was outlined into different levels representing parking accumulation levels (PAL). In context to the developed accumulation levels based on land-use type, the study proposes to formulate on-street parking policies based on turnover, if parking index delineates in PAL A and PAL B respectively. However, if parking index encompasses other than PAL A and PAL B, then only accumulation of parking demand should be considered for formulation of paid parking policies. The developed PAL provides a common platform for viewing on-street parking as a land-use based phenomenon.

Keywords: CBD; Land-use type; Parking demand characteristics; Parking accumulation level

1. Introduction and Background

The rapid rate of motorization coupled with urbanization has resulted in significant increase in traffic demand, which has consequently increased the saturation of the road network. One of the major problems associated with increase of traffic is the acute shortage of parking space, especially in urban centers. (Stockholmsstad, 2013). Each vehicle making a trip needs a parking space at its origin and destination, regardless of the parameters defining the trip (Spiliopoulou and Antoniou, 2012). Parking is a critical and central element of urban transportation planning and research (Davis et al., 2010; Khodaii et al., 2010; Shoup, 2006; Barata et al., 2011). Effectively managing on-street parking in an ongoing battle especially for large central cities as they face competing and contradictory objectives along with an ever-increasing demand for space (De Cerreno, 2004).

Parking is a critical land use issue (Ison and Mulley, 2014; Marsden, 2014). Parking and trip generation rates/equations are used to evaluate the requirements of transportation network as well as size of parking facilities for each type of land-use. Parking and trip generation contributes in formation of urban morphology and assists planners in planning any urban area (Sahili and Hamadneh, 2016). Excessive on-street parking supply may negatively affect the level of service of road network due to the obstructions from parked vehicles. Furthermore, deficiency in providing sufficient parking spaces for different land-uses creates negative economic impacts. On the other hand, the size of parking supply might exhaust road network and negatively affect its operating level of service. In crux, establishing parking generation for different land uses contribute in managing parking supply for each land-use, and consequently avoid congestion generated by parking. Douglass and Abley (2011) prepared a research study to compare New Zealand, Australia, UK, and USA information on trip and parking related to land uses and reviewed current trip generation survey and data manuals from these four countries. The research considered seasonal traffic and parking variations and identified the practical parking design demand for a whole year as the 85th percentile satisfaction, which is also the 50th highest hour. Independent variables such as GFA (gross leasable floor area), number of employees, and activity units were derived from survey process. The study concluded that the most practicable unit for the district plans is spaces per 100-m^2 GFA.

Chen et al. (2015) studied parking characteristics like parking indexes, parking saturation, peak-parking ratio, parking turnover rate, and parking duration for different land-use types and different parking facilities in Shanghai. Authors observed that market areas and food- and drink-oriented areas exhibit high parking saturation. However, in business and office-oriented areas, the total parking space supply is sufficient to meet current parking demands, but the proportion of spaces open for visitor parking is insufficient. In market areas and business and office-oriented areas, the occupancy of unfenced surface parking lots is generally higher than that of fenced car parks or garages. Further, the authors concluded that pricing differentiation strategies and information technology (such as parking guidance technology and "smart meters" with demand-responsive pricing) should be applied to rebalance the use of all parking facility types and to provide drivers with more parking choices in Shanghai. Dave et al. (2019a) concluded that data monitoring interval has a significant effect on on-street parking characteristics. Based on their investigations the authors concluded 30min and 50min as optimized data monitoring interval for commercial and hospital land-use respectively. Further, Dave et al. (2019b) developed parking efficiency levels for commercial land-use type based on on-street pakring turnover values which acted as a benchmark to formulate performance based on-street parking policies. Cats et al. (2016), proposed a survey methodology to empirically measure the impacts of on-street parking policies based on automated parking transaction data. Authors compared the average and maximum parking occupancy levels, throughput, parking duration and total fare collection for before and after the introduction of a new parking scheme for visitors to Stockholm inner-city, Sweden. The results indicated that the policy fulfilled its objective to increase the ease of finding a vacant parking place in the central areas and even resulted in underutilized parking spaces.

Review of available literature revealed that substantial researches on the development of parking standards (space requirements) for different land-use type and parking generation rates exists. However, effect of land-use types on on-street parking demand characteristics seems unexamined. Moreover, assessment of on-street parking demand as a function of land-use type in developing countries like India is not reported. Parking pricing as a measure of demand management is often compromised in developing countries like India primarily because of irrational approach adopted in policy formulation in addition to social reluctance and political unacceptability. Therefore, with such intricacy, it becomes inevitable to assess parking demand characteristics based upon land-use types, for formulation of parking rationing mechanism. With this motivation, the objectives of the present study are formulated, firstly, to microscopically investigate the influence of land-use on on-street parking demand characteristics. Thereafter, the study is further oriented towards developing *parking accumulation levels* as a potential measure to formulate land-use based on-street parking policies. In light of the framed objectives, the scope of the study is strictly restricted to two land-use types, mainly commercial and hospitals, which are predominant in CBD areas of Indian cities. Further, the study is strictly limited in developing land-use based on-street parking demand management measures, rather than developing off-street parking standards for different land-use types.

2. Research Framework

The methodological framework adopted to develop parking accumulation levels is illustrated in Figure 1.

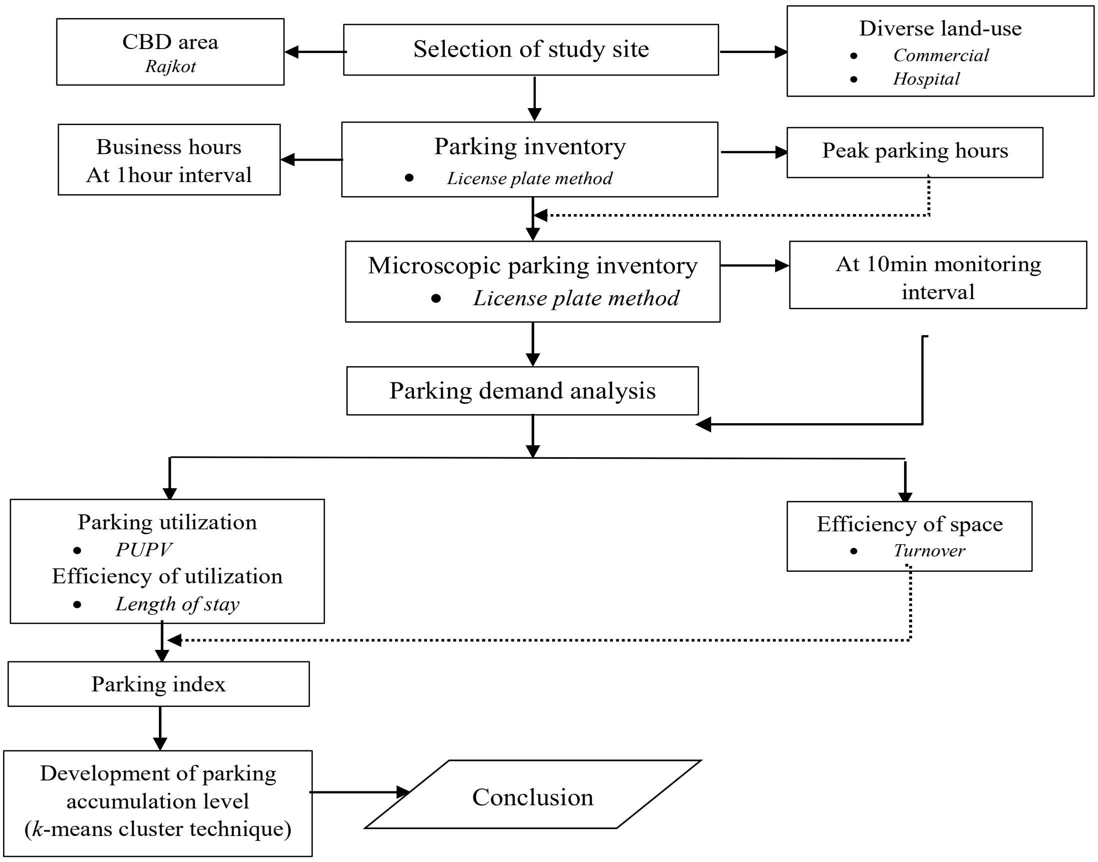


Figure 1: Proposed Methodology

The research methodology consists of following steps:

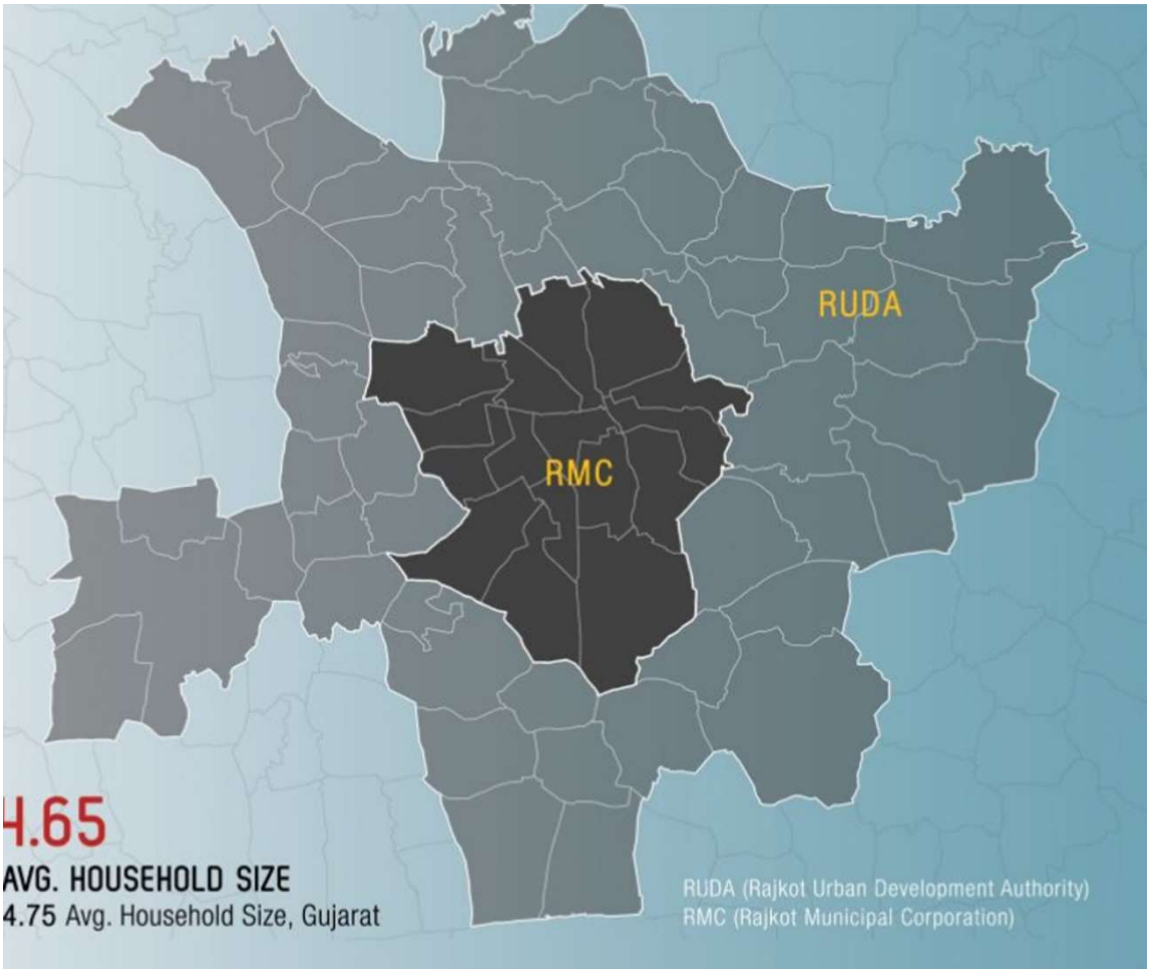
i. Selection of study site (diverse land-use types namely commercial and hospital)
ii. Preliminary parking inventory during business hours at 1hr interval using license plate method to determine peak parking hours.
iii. Microscopic parking inventory at 10min monitoring interval during peak hour for normal weekday (NWD) and weekend (WEND) using license plate method.
iv. Analysis of parking demand data. Analysis is performed in two steps:
    a) Parking utilization: Involves extraction of percentage of unique parked vehicles (PUPV) for subject land-use types. Further, efficiency of utilization, reflected by length of stay is also calculated.
    b) Efficiency of space: Involves turnover calculation
v. Based on investigation results on parking utilization, efficiency of utilization and efficiency of parking space, parking index were calculated. Parking accumulation levels were delineated using parking index values, in order to modify performance-based demand management measures.

The detailed explanation for step (i-iii) is presented in section "Study Site and Data"; whereas comprehensive explanation for step (iv-v) is illustrated in "Data Analysis and Results" and "Parking Accumulation Levels" sections respectively. Finally, recommendations and conclusions are reported in "Conclusion" segment of the paper.

3. Study Site and Data

To develop parking accumulation levels, two study sites with diverse land-use in CBD area of Rajkot city along the western frontier of India in the state of Gujarat were selected. The population of Rajkot city was recorded as 1.39 million as per 2011 census survey and estimated to reach upto 2.2 million by 2021. Rajkot is 28th urban agglomeration in India and is ranked as 22nd World's fastest growing cities and urban areas for the period 2006 to 2020. The Rajkot Municipal Corporation (RMC) area covers 105 km^2, while, Rajkot Urban Development Authority (RUDA) area covers 668 km^2. Rajkot has a strong manufacturing economic base, with a market that extends beyond not only the state of Gujarat, but also across the national boundaries. In its early history, Rajkot was organized around the textile mills. More recently, the city economy has shifted to small and medium industries dominated by foundries, manufacture of oil engine, machine tools, engineering and automobile works, castor oil processing, gold and silver jewellery, handicrafts, readymade ladies' garment, spices, medicines and wall clocks. The major modes of transport in Rajkot are motorized 2-wheeler (M2-W) and auto-rickshaw (an IPT (Intermediate Para-transit) mode of transport).

Rajkot city has witnessed an extraordinary vehicular growth during past five years, with registration of average 241 motorized two-wheelers (M2-W) and 24 cars per day amounting to average annual growth of 8.5-9%. This amplified vehicular growth has consequently led to increased demand for on-street parking spaces. Exorbitant vehicular growth coupled with inefficient public transport has developed proclivity towards usage of personalized vehicles, restricting the mode share of public transportation (10%) though the city has initiated a well-planned BRTS system along major urban corridors. Figure 2 illustrates the boundary limits of RMC and RUDA.



(Source:: Rajkot Urban Development Authority)
Figure 2: Boundary limits of RMC and RUDA

3.1 Study Site and On-street parking scenario

Two study sites in CBD area with diverse land-use type namely commercial and hospital were selected. The definition of the selected study site is given below:

a) **Commercial:** Buildings in these areas are primarily markets and shops, and shopping is the main purpose of trips to these areas.
b) **Hospital:** Building in these areas are basically hospitals and medical stores and medical related visits are prime reasons for trips attracted to these areas.

The location of study area and aerial view of selected sites are shown in Figure 3(a) and 3(b) respectively. Garment shops and home utility products (average share 60%) dominates the commercial setup; whereas, hospitals and medical stores (average share 65%) dictates the hospital land-use structure. For the selected study-sites, saturated on-street parking spaces are predominantly observed throughout the business hours, although well-developed off-street parking facilities in accordance to parking standard set by local authority are provided. On-street parking for both the study-sites is either monitored by parking wardens or traffic police. Moreover, parking meters are also not provided to monitor on-street parking and this has thus ensued disorganized and chaotic on-street parking. Chaotic on-street parking including double parking by both cars and motorcycles

(M2-W) is a major problem for the subject study sites. As a result, there exists daily conflicting scenes of on-street parking demand spill over, which interlude smooth flow of through traffic as depicted in Figure 2 (b-d). On-street parking demand is regulated by ***odd-even date free-of-cost*** on-street parking scheme for commercial land-use. However, no such regulatory measures are adopted for hospital land-use. Parking sign is provided for commercial land-use structure, which describes parking policy in regional language as depicted in Figure 2(d). For both study sites, right angle parking for M2-W and kerb side parallel parking for cars and auto-rickshaw (auto-rickshaw is an IPT (Intermediate Para-Transit) mode of transport) is permitted. Road inventory details of two road sections (land-use representative) selected for the study are presented in Table 1.

Table 1. Road Inventory details of subject study locations

Urban Road	Right of Way(m)	Width of carriageway (m)	Parking space width (m)	Length of street	Land-use type	Road type
Sir Lakhajiraj Road (RR1)	17m	10 m	2	600m	Commercial	Two-way
Vidyanagar Main road (RR2)	10m	7 m	2	748m	Hospital	One-way

3.2 Data collection methodology

Since license plate survey method gives realistic and accurate representation of parking demand and was therefore adopted in the present study. Primarily, parking inventory using license plate was carried out on both subject roads (land-use representative) at 1hr interval for 12hrs (8am-8pm) during business hours on a normal working day, to determine peak parking hours. Further, microscopic assessment of parking demand was carried out during peak parking hours by collecting demand data at 10min monitoring interval (Chimba and Onayango, 2012) during mid-2016 covering a normal weekday (NWD) and weekend (WEND) using license plate method in order to account variation in on-street parking demand over the days. Parking survey traps of different lengths were considered at different location along the entire street to capture variation in parking demand due to discrepancy in activity types and to exemplify parking characteristics of the entire street. Individual bays were not demarcated on the study site and hence number of bays were calculated as per guidelines given in IRC SP: 12-2015. Table 2 summarizes parking inventory schedule.

Table 2. Parking Inventory schedule detail

Road Name	Peak Hour	Survey day	Length of study trap	Number of Bays
RR1 (Commercial land-use)	5:10-8:10 pm	NWD	85 m	100
		WEND	85 m	100
		NWD	80 m	94
		NWD	80 m	94
R2 (Hospital land-use)	9.00am -12 noon	NWD	85 m	100
		NWD	85 m	100
		NWD	92 m	108
		WEND	92 m	108

Figure 3(a): Study area location

Figure 3(b) Aerial view of study sites RR1 and RR2

Figure: 3(c): On-street parking scenario of commercial Lamd-use road RR1

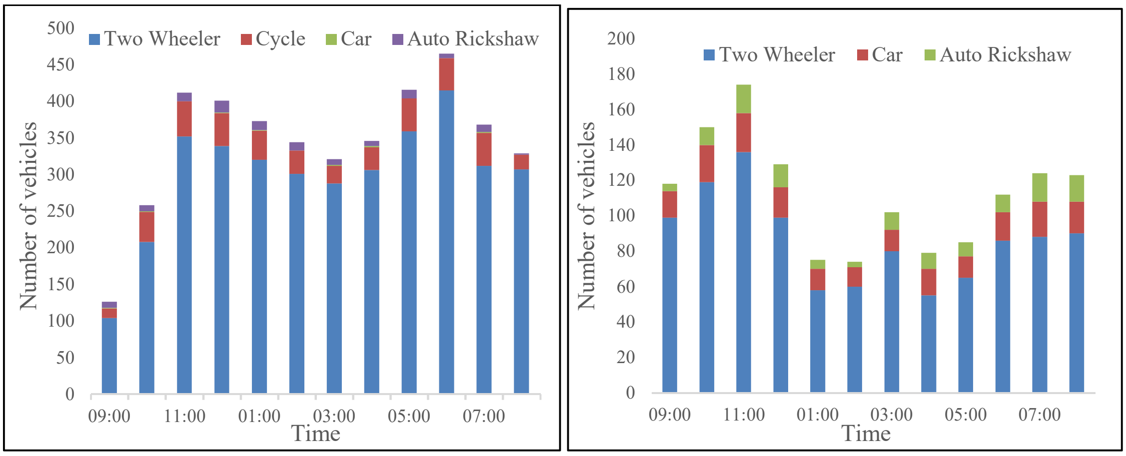
Figure: 3(d): On-street parking scenario of Hospital Land-use road RR2

Figure 3(e): On-street parking information in local language

Figure 3 presents the on-street parking scenario of both land-use types for the subject city. Dominance of 2-Ws and chaotic parking behaviour is common feature of both the study sites exhibiting high on-street parking demand.

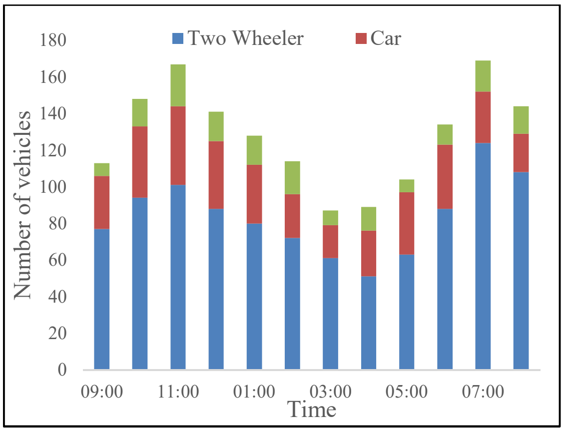
4. Data Analysis and Results

The data analysis essentially revolves around extraction of various parking characteristics like parking duration (length of stay), utilization in terms of percentage of unique parked vehicles and efficiency in terms of turnover for different data monitoring intervals for both subject land-use types. Comprehensive investigation of effect of land use on parking demand characteristics was performed. Since no parking regulation exists for road representing hospital land-use, either sides of the road were considered, while only legal (authorized parking) side was considered for commercial land-use type. Empirical observation revealed heterogeneity in parking demand, with dominance of motorized two wheelers (M2-W) and is represented in Figure 4.



(a) Commercial land-use

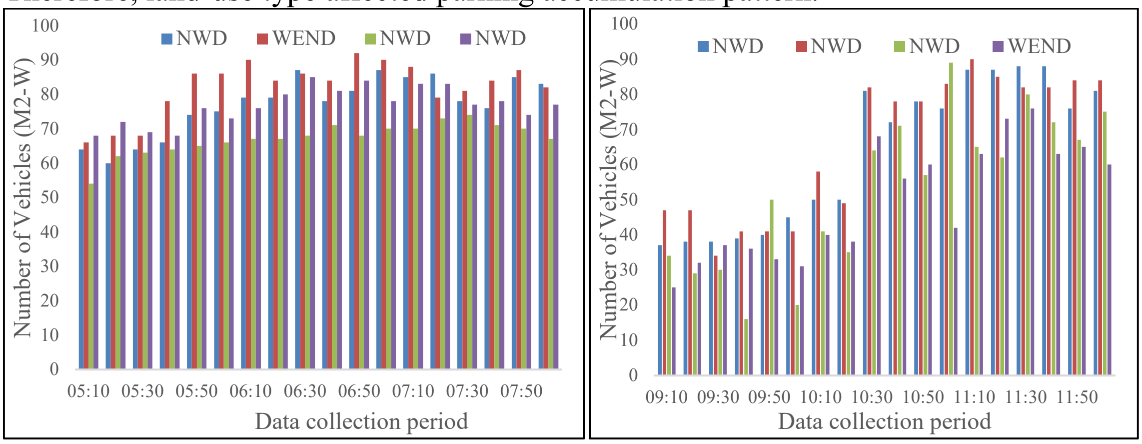
(b) Right side Hospital Land-use



(c) Left side Hospital Land-use

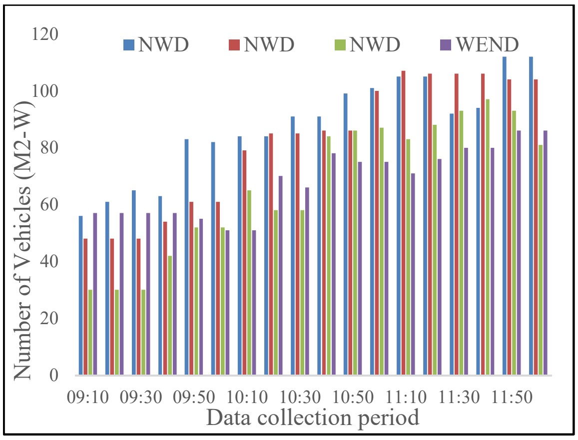
Figure 4: Parking demand accumulation during business hours (a) Commercial land-use (legal) (b) Right-side Hospital land-use (c) Left-side Hospital land-use

From Figure 4 it can be noted that maximum parking demand accumulation was observed during 5-8pm for road serving commercial land use while 9am-12noon for the road serving hospital land use. This shows significant influence of land use type on peak parking hours. Since, parking demand had dominance of M2-Ws; hence, it was found appropriate to convert recorded parking demand into M2-W demand. To normalize, cars and auto-rickshaws were converted into equivalent 2-W space (E2WS), where one car was considered as four M2-Ws while one auto-rickshaw was considered as two M2-Ws (Table 6.2, IRC SP: 12-2015). Figure 5 represents the parking demand accumulation during peak parking hours for four days for both subject land-use types. It can be observed that temporal fluctuation in parking demand followed consistent trend within the day for entire data collection period while the same varied significantly among the days. Profile of parking accumulation varied between commercial and hospital land-use setup. It can be noted; parking demand accumulation observed a sudden increase post 10am with consistent accumulation till 12 noon for both sides of hospital land-use. On the other hand, parking accumulation nearly followed a uniform pattern for commercial land-use. Therefore, land-use type affected parking accumulation pattern.



(a) Commercial Land-use

(b) Hospital Land-use- Right side



(c) Hospital Land-use –Left side

Figure 5: Parking demand accumulation in terms of E2WS for (a) Commercial land-use (legal) (b) Right-side Hospital land-use (c) Left-side Hospital land-use

Recorded parking demand (RPD) was obtained to facilitate further investigation. Recorded parking demand (RPD) for different data monitoring intervals is summarized in Table 3 below. Mathematically, recorded parking demand is given as:

$$Recorded\ parking\ demand\ RPD_j = \sum_{i=1}^{n} P_i)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where, P_i = number of vehicles (M2-W) for particular observation interval
j= monitoring interval (ranges from 10-60min)
i= ranges from 1to n, n= number of observation interval (n= 18 for 10min, n=9 for 20min, n= 6 for 30min, n= 4 for 40min and n= 3 for 50min and 60min) for 3 hours.

Table 3: Recorded parking demand (E2W) for different data monitoring intervals

Land-use type	Day/Data monitoring interval	10 Min	20 Min	30 Min	40 Min	50 Min	60 Min
Commercial land-use type	NWD	1387	697	448	395	296	228
	WEND	1479	744	490	413	328	244
	NWD	1210	599	397	327	259	191
	NWD	1382	692	454	386	303	227
Hospital land-use type (right side)	NWD	821	409	255	230	109	117
	NWD	913	446	295	181	119	141
	NWD	857	415	266	257	126	113
	WEND	935	468	302	206	142	135
Hospital land-use type (left side)	NWD	758	378	243	159	108	115
	NWD	821	398	278	154	113	133
	NWD	798	377	262	147	109	135
	WEND	832	421	275	156	121	174

From Table 3, it can be noted for both subject land-use type, recorded parking demand decreased as the monitoring interval increased. Higher the frequency (10-30min), higher the recorded parking demand and vice-versa. Higher demand at higher frequency can be attributed to repetitive observance of same vehicles throughout the survey period. Further, significant difference between recorded parking demands for different land-use type was observed. Therefore, land-use type significantly affected recorded parking demand.

4.1 Parking utilization

To probe further, behaviour of parking demand was analysed by extracting percentage of unique parked vehicles from the recorded parking demand at different data monitoring intervals for both subject land-use patterns. In developing countries like India, robust mechanisms like parking meters to monitor the actual number of users who used the given parking spaces are absent and to further expedite analysis, percentage of unique parked vehicles were extracted. In context of the study, percentage of unique parked vehicles (PUPV) were defined as ***"distinct vehicles (non-repetitive) which used given parking space for a given period"***. In simple word, PUPV does not account for repetitive vehicles and therefore, represent parking volume for individual data monitoring interval. PUPV were extracted from recorded parking demand for different monitoring intervals to normalize unique vehicles at different monitoring intervals with respect to their demand. Methodology to extract PUPV is explained below.

Consider parking demand data collected at 60min data monitoring interval for three hours. Therefore, data needs to be collected for three times at interval of 60min to represent parking scenario for three hours. Table 4 below illustrates data recorded at 60min monitoring interval. Here, alphabets (A, B, etc.) in the table represents license plate of individual vehicle.

Table 4: Parking inventory sheet

5:30pm	6:30pm	7.30pm
A	B	C
B	F	D
C	G	E
D	H	F
E	A	H
F		

As per Equation (1), RPD= number of vehicles at 5.30pm+ number of vehicles at 6.30pm+ number of vehicles at 7.30pm. Therefore, RPD_{60min}= 6+5+5 = 16. Now, all the vehicles recorded at 60min data monitoring interval were stacked in a single vertical column. Thereafter, duplicates vehicles from the column are removed, to give unique vehicles. These unique vehicles were distributed, for different observation interval, which gave parking duration of individual parked vehicle. Table 5 represents data sheet for estimation of PUPV and length of stay.

Here in Table 5, column *(5)* represents parking duration (min) where **"1"** represents 60min, **"2"** represents 120min and **"3"** represents 180min respectively. As, shown in Table 5, number of vehicles in column *(1)* signifies unique vehicle. PUPV is obtained by dividing unique vehicle with recorded parking demand. Mathematically, PUPV is represented as:

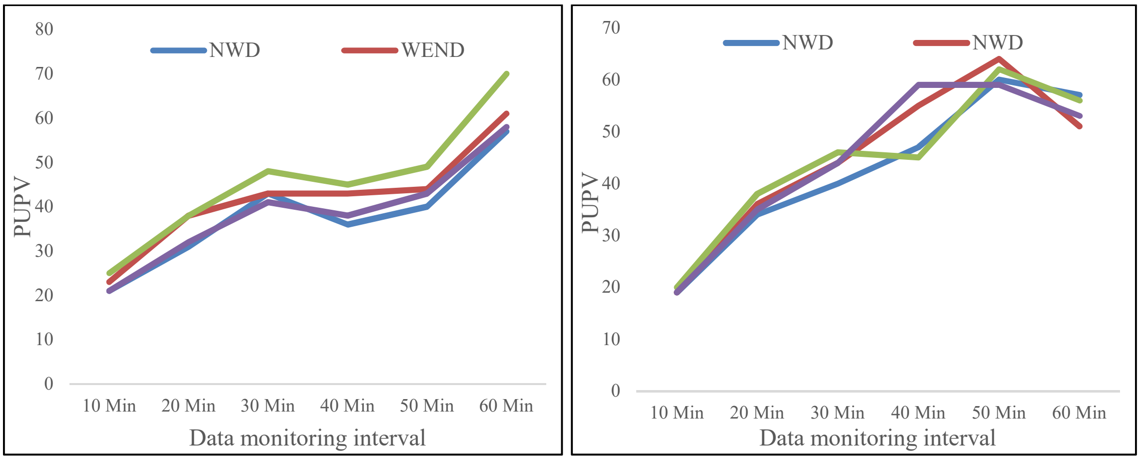
$$PUPV_j = \frac{unique\ vehicles\ (M2-W)\ for\ jth\ monitoring\ interval * 100}{recorded\ parking\ demand\ (M2-W)\ for\ jth\ monitoring\ interval} \quad (2)$$

Where, j represents data monitoring interval

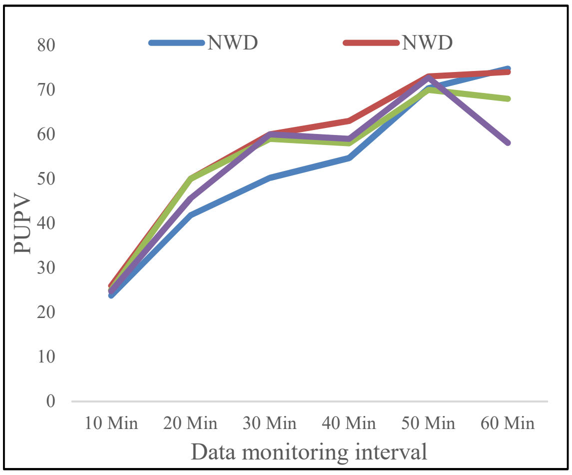
Table 5: Data sheet for PUPV

Vehicles *(1)*	5:30pm *(2)*	6:30pm *(3)*	7.30pm *(4)*	Parking duration (min) *(5)*
A	A	A		"2"
B	B	B		"2"
C	C		C	"2"
D	D		D	"2"
E	E		E	"2"
F	F	F	F	"3"
G		G		"1"
H		H	H	"2"

Now using the above Equation (2), for the present case, PUPV = 8*100/16 =50%. Similar exercise was performed to obtain PUPV and the length of stay for different data monitoring intervals. Figure 6 represents the trend of PUPV for both subject land-use type.



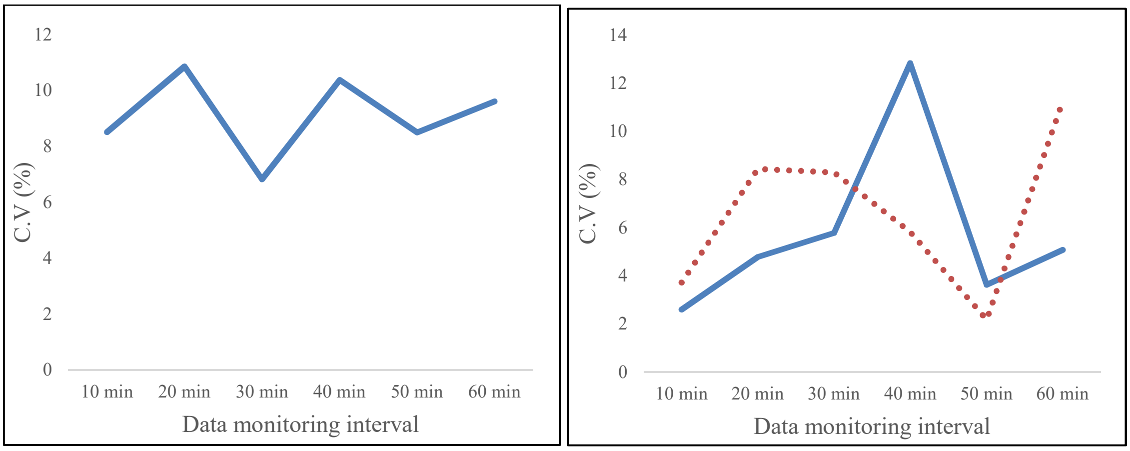
(a) Commercial Land -use (b) Hospital Land-use – Right side



(c) Hospital Land-use – Left side

Figure 6: PUPV trend for (a) commercial land-use (legal) (b) Hospital land-use-Right-side (c) Hospital land-use- Left-side

It can be noted; in case of commercial land-use, PUPV follows a progressively increasing trend upto 30min, then decreased for 40min monitoring interval and subsequently increased. A consistent trend was observed for all survey days of RR1. However, for hospital land-use, PUPV increased upto 50min monitoring interval and then decreased. A uniform pattern was observed for either side for all survey days of RR2 also. Therefore, PUPV followed a consistent trend for a particular land-use and varied significantly between land-use types. The statistical validation of this observation was carried out by performing one-way ANOVA on PUPV between subject land-use types at 5% significance for null hypothesis that *"no difference in PUPV between different land-use exist"*. The null hypothesis was rejected in reference *p*-value (0.005). Hence, it can be inferred that the land-use type has significant effect on behaviour of on-street parking demand. To scrutinize further, consistency of PUPV, was obtained by calculating coefficient of variation (C.V) of PUPV for different data monitoring intervals for both subject land-use types. Since PUPV varied with respect to data monitoring interval, therefore to build a platform for further investigation of influence of land-use type on parking demand characteristics, consistency of PUPV was calculated. Figure 7 represents coefficient of variation of PUPV for different monitoring frequency. Here in Figure 6(b), dotted line indicates left-side, while solid line signifies right side for hospital land-use structure. From Figure 7, it can be noted that, behavioural consistency exists at 30min and 50min data monitoring interval for commercial and hospital land-use types respectively.



(a) Commercial Land-use (b) Hospital Land-use

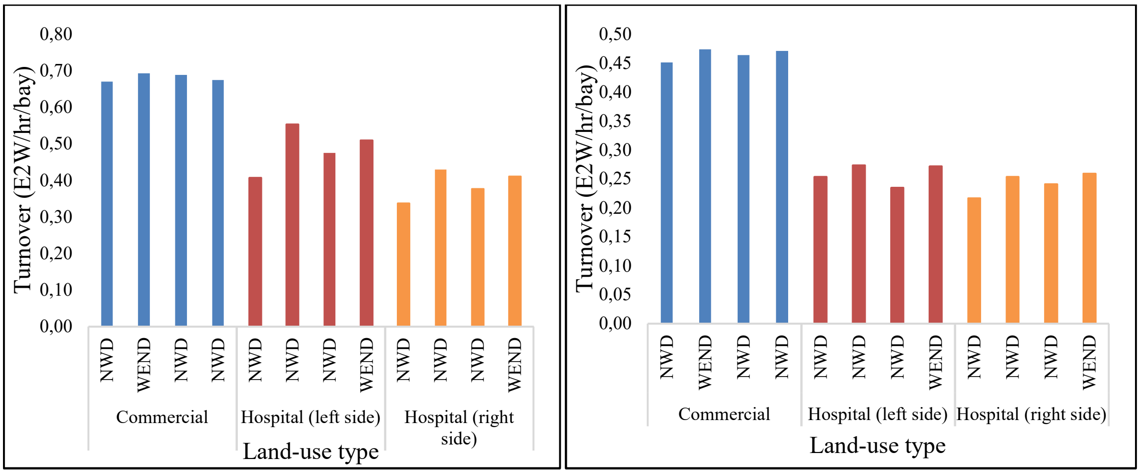
Figure 7: Coefficient of variation (C.V) of PUPV for different data monitoring interval for (a) Commercial land-use (b) Hospital land-use

4.2 Efficiency of space

Since parking demand behaviour (PUPV) was found to be consistent at 30min and 50min data monitoring intervals for commercial and hospital land-use structure, it was found appropriate to calculate efficiency of space (turnover) at 30min and 50min data monitoring interval. Turnover (M2-W/hr/bay) was evaluated from unique vehicles and not on recorded parking demand.

$$Average\ Turnover\ (M-2W/hr/bay)_j = \frac{unique\ vehicles\ (M2-W)\ for\ jth\ monitoring\ interval}{number\ of\ bays*survey\ hours} \quad (3)$$

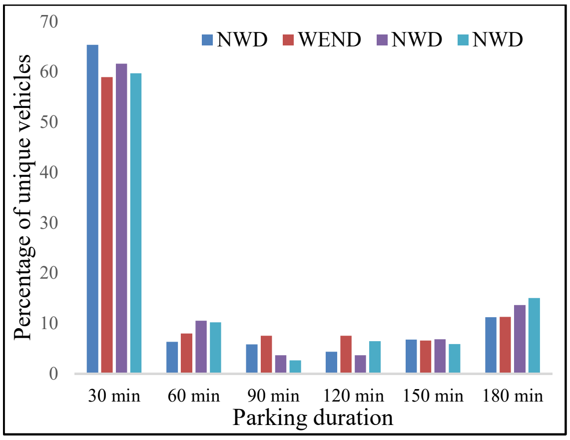
Where, j represents data monitoring interval.



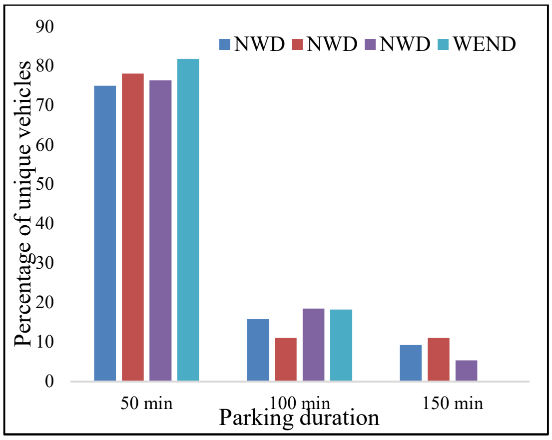
(a) Turnover at 30 min (b) Turnover at 50 min

Figure 8: Turnover (E2W/hr/bay) for subject land-use type at (a) 30min (b) 50min

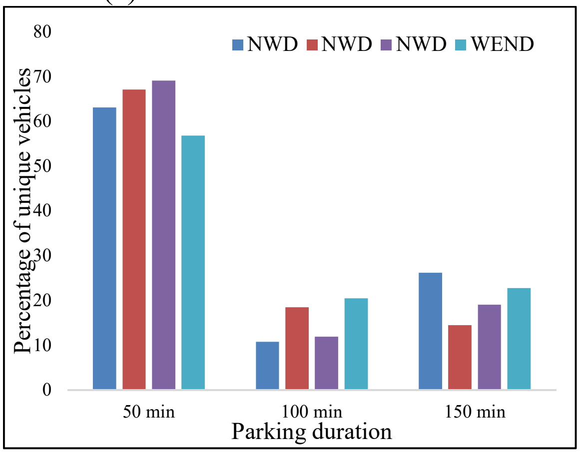
It can be observed that, at respective consistent demand monitoring intervals (30min and 50min for commercial and hospital land-use type respectively), commercial land-use is found to be efficient as compared to hospital land-use. Therefore, it can be inferred that land-use type affects efficiency of on-street parking, further corroborating the hypothesis of effect of land-use on on-street parking demand characteristics. Further examination was carried out by extracting efficiency of parking utilization in terms of length of stay of parked vehicles at consistent demand for both subject land-uses and is presented in Figure 9 below. Here length of stay is distribution of PUPV at a particular interval throughout the data collection period. Further length of stay of parked vehicles at 30min and 50min data monitoring interval for both hospital and commercial land-uses were compared and is summarized in Table 6.



(a) Commercial Land-use



(b) Hospital Land-use- Right- side



(c) Hospital Land-use- Left-side

Figure 9: Parking Duration at consistent demand for (a) Commercial land-use structure (b) Right-side Hospital land-use (c) Left-side Hospital land-use

From Figure 9, it can be observed that nearly 60-65% of the vehicles had parking duration of 30min for commercial while 55-80% of parked vehicles had a maximum length of stay of 50min for hospital land-use. Moreover, at individual demand consistency, hospital land-use (55-80%) had higher utilization efficiency compared to commercial land-use (60-65%), which is reflective from Table 6. Therefore, efficiency of parking utilization is much higher for hospital land-use compared to commercial land-use at consistent parking demand (30min and 50min data monitoring intervals respectively).

Table 6: Percentage of parking demand at consistent demand monitoring interval

Land-use type	(%) of parking demand at consistent demand monitoring interval Data monitoring interval	
	30min	50min
Commercial	**50-65**	**55-70**
Hospital	60-77 (Right side)	75-80(Right side)
	40-60(Left side)	**60-70(Left side)**

Performance based parking demand management measures aims at (i) charging on-street parking based on its turnover values (less parking fee for higher turnover and vice-versa) (ii) shifting long-term parkers to off-street facility by levying high parking fee for long-term parkers (Barter, 2008). Now, for the present study, adopting performance-based parking management measure would result in high parking fee for hospital land-use structure because of lesser turnover, though utilization efficiency (covered with parked vehicles) is higher compared to commercial land-use structure. If higher parking fee (based on less turnover) is applied for hospital land-use, may severely hurt economic vitality of the street. Hence, performance-based parking management measures cannot be directly adopted and therefore, promulgates the need to develop a measure, which can potentially consider the above aspect and facilitate formulation of land-use based on-street parking policies.

5. Parking Accumulation Levels

Turnover implicitly represent occupancy rates, henceforth, determinants to develop land-use based on-street parking policies where in accordance to occupancy-rates (accumulation). Primarily, parking index was calculated to reflect on the usage of the available number of parking bays for a small interval of time. In the present study, parking index (occupancy) is defined as the ratio of number of vehicles parked at particular instance to the capacity (number of bays) of parking trap area.

$$Parking\ Index\ (P.I.)\ = \frac{number\ of\ parked\ \ vehicles\ (E2W)\ at\ a\ particular\ instance}{available\ number\ of\ bays\ in\ parking\ trap}$$

Since recorded parking demand (RPD) was converted into E2W demand, parking index (P.I.) may have values greater than 1. It was observed, parking index (P.I.) had a greater spectrum i.e. from highly under-utilized to over-utilized which is reflected from Figure 4. Hence, it was deemed as a potential measure, which can facilitate development of land-use based on-street parking schemes. P.I was outlined into different levels using k-means clustering technique to represent parking accumulation levels (PAL). K-means clustering technique is based on the minimization of the Euclidean distance (distance from a data point to the cluster mean) based on some random iterations (Kanungo et al., 2002; Frey and Dueck, 2007; Xia et al., 2008; Cokorilo et al., 2014). It was found appropriate to classify data set into six groups representing PAL A through PAL F respectively. Further, the delineated thresholds were validated for the percentile values to check whether the definite sets of cluster data fall within the quartile range as shown in Figure 10 below. Threshold of parking accumulation levels are summarized in Table 7.

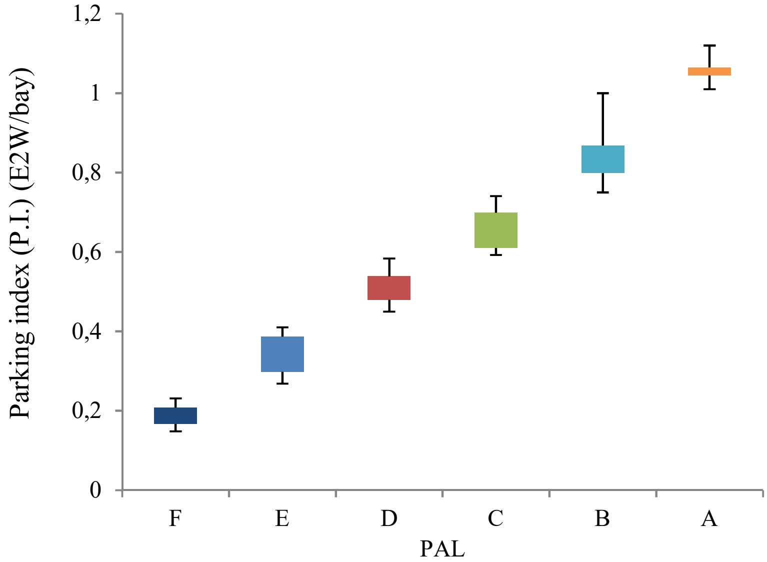


Figure 10: Box-plot of different parking accumulation levels based on parking accumulation index (E2W/bay)

Table: 7 Thresholds for parking accumulation levels

Parking Accumulation levels	P.I. (E2W/bay)
PAL A	>1
PAL B	>0.75-1.00
PAL C	>0.59-0.75
PAL D	>0.45-0.59
PAL E	>0.27-0.45
PAL F	<0.27

For the present study, commercial land-use encompassed PAL B, while hospital land-use circumscribed in PAL C. Further, percentile distribution of parking index for both subject land-use was plotted as depicted in Figure 11. Conventional approach to set parking standards are generally based on 85th percentile demand curves (which means that 85 out of 100 sites will have occupied parking spaces even during peak periods), an 85th occupancy rate (a parking facility is considered full if 85% of spaces are occupied) (Litman, 2016). In addition, prices that produce an occupancy rate of about 85 percent are termed as performance-based (Shoup, 2006). Henceforth, for the present study, 85th percentile, which matches well with PAL B in threshold range (refer Table 7) was adopted as benchmark, to facilitate formulation of land-use oriented parking policies.

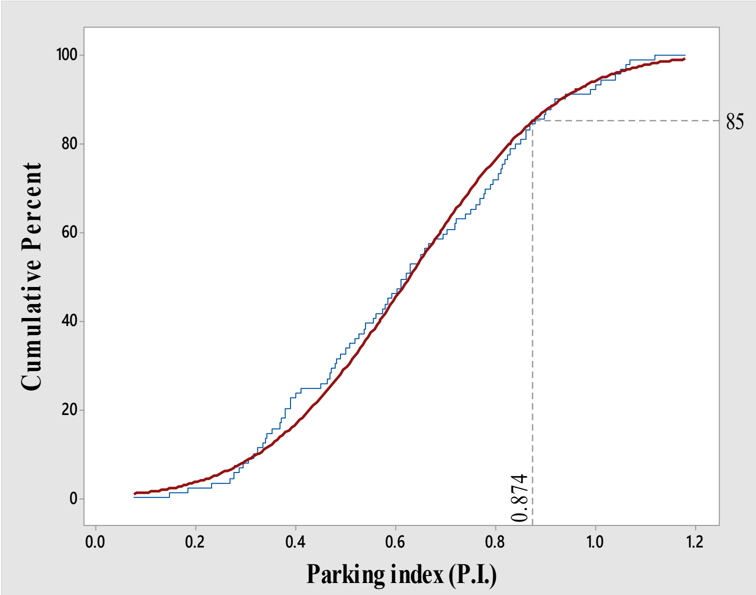


Figure: 11. Cumulative percentile plots for parking accumulation index

5.1 Application of PAL concept

Practical application of the developed PAL concept is as explained below. Primarily, parking index for any land-use type needs be calculated. This calculated parking index forms base for formulation of parking policies for any land-use structure. Therefore, if (P.I.) delineates in PAL A and PAL B, then only turnover (performance based) can be considered to develop demand management measures. However, if the same, encompasses other than PAL A and PAL B, accumulation (utilization of space) should be considered as a criterion for formulation of demand management measures. Now for rational formulation of parking policies for any given land-use type whose parking index delineates other than PAL A and PAL B, length of stay (parking duration) of parked vehicles should be considered. Therefore, if demand is dominated by short-term parkers and parking index delineates other than PAL A and PAL B, then parking pricing can be subsidized to maintain the economic vitality of the street. For the present study, parking index for commercial land-use structure (0.78) matches well with PAL B, while that for hospital land-use (0.65 considering both sides) matches with PAL C (refer table 7). Hence, turnover should be only criteria to formulate parking policies for commercial land-use structure. However, accumulation should be criteria for hospital land-use. Furthermore, short-term parkers dominated the demand for hospital land-use structure and therefore, appropriate subsidized parking fee can be a potential alternative policy measure.

6. Conclusions

The present study attempts to microscopically investigate the influence of land-use type on parking demand characteristics. Thereafter, parking accumulation levels were developed to formulate land-use based on-street parking policies. On-street parking characteristics were accessed and compared for two land-use type namely hospital and commercial in CBD area of Rajkot city. The following conclusions are drawn from the study:

1. Land-use type significantly affects peak parking accumulation. Morning peaks were observed for hospital land-use, while evening peaks were observed for commercial land-use structure.
2. Land-use type has significant effect on profile of on-street parking demand. Parking demand is observed to be consistent for a particular land-use type, while varies significantly between different land-use types.
3. Assessment of on-street parking characteristics is highly influenced by data monitoring interval and to formulate appropriate on-street parking policy, a consistent monitoring interval need to be worked out as per land-use characteristics.
4. Percentage of unique parked vehicles (PUPV) is a useful indicator to analyze parking demand behavior for different data monitoring intervals. The trend of PUPV varies based on land-use, as validated through statistical analysis. Importantly, parking characteristics consistency is affected by land-use type.
5. Parking duration at respective consistent demand revealed greater efficiency in parking utilization for hospital land-use compared to commercial land-use. It suggests that formulation of parking policies based on mere efficiency of parking space utilization may affect economic vitality of the subject area.
6. In context to the developed parking accumulation levels, study recommends PAL B as a base to modify performance-based parking management measures. The study proposes to formulate parking policies based on turnover, if parking index delineates in PAL A and PAL B respectively. However, parking index encompasses other than PAL A and PAL B, only accumulation of parking demand should be considered for formulation of paid parking policies.

The results obtained in this study provides a fundamental understanding on development of parking accumulation levels, which can be used as a potential measure to formulate land-use based on-street parking policies. The authors anticipate that the developed PAL provides a common platform for viewing on-street parking as a land-use based phenomenon and thereby would strongly help planners and policy makers for formulation of rational parking policies. The authors also foresee that the study result can add new information to the present state-of-art on on-street parking. The study also provides a significant insight that extensive studies on on-street parking, subjective to different land-uses is required to develop generalized parking accumulation levels.

References

Barata, E. Cruz, L. and Ferreira, J.P. (2011) Parking at UC campus: Problems and solutions. Cities, 28 (5), 406-413. https://doi.org/10.1016/j.cities.2011.04.001.

Cokorilo, O., M. De Luca, and G. Dell'Acqua, (2014), "Aircraft Safety Analysis Using Clustering Algorithms", *Journal of Risk Research, Vol. 3, No. 1, pp. 1–27.*

Cats, O. Zhang, C. and Nissan, A. (2016) Survey methodology for measuring parking occupancy: Impacts of an on-street parking pricing scheme in an urban center. Transport Policy, 47, 55–63. https://doi.org/10.1016/j.tranpol.2015.12.008

Chen, Q. Wang, Y. and Pan, S. (2015) Characteristics of Parking in Central Shanghai, China. Journal of Urban Planning and Development, https://ascelibrary.org/doi/10.1061/%28ASCE%29UP.1943-5444.0000293.

Chimba, D. and Onyango, M. (2012) Optimization of short-term on-street park-pay license plate surveying. Journal of Infrastructure Systems, 18 (1), 194-201. https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%29IS.1943-555X.0000087.

Dave, S., Joshi, G.J., Ravinder, K., and Gore, N. (2019a). "Data monitoring for the assessment of on-street parking demand in CBD areas of developing countries, *Transportation Research Part A: Policy and Practice,* 2019. Vol. 126, pg no. 152-171. https://doi.org/10.1016/j.tra.2019.05.009

Dave, S., Joshi, G.J., Ravinder, K., and Gore, N. (2019b). Formulation of Performance-Based On-street parking policies for CBD areas of developing economies. Journal of Urban Planning and Development, 2019. DOI. 10.1061/(ASCE)UP.1943-5444.0000553.

Davis, A. Pijanowski, B. Robinson, K. and Engel, B. (2010) The environmental economic costs of sprawling parking lots in the United States. Land Use Policy, 27 (2), 255–261. https://doi.org/10.1016/j.landusepol.2009.03.002.

De Cerreno, A. (2004) Dynamics of on-street parking in large central cities. Transportation Research Record. Journal of Transportation Research Board, Washington, DC, 1898, 130–137. https://doi.org/10.3141/1898-16.

Douglass, M., and Abley, S., (2011), "Trips and Parking Related to Land Use" (Report No. 453), Retrieved from *NZ Transport Agency Research*. <http://www.nzta.govt nz/resources/research/reports/453/

Frey, B. J., and D. Dueck (2007), "Non-metric Affinity Propagation for Unsupervised Image Categorization", Proc., *11th International Conference on Computer Vision, ICCV, IEEE, New York, pp. 14–21*.

Indian Roads Congress, Special Publication. Guidelines for parking facilities in urban areas, IRC code of practice, Special publication, SP-12, New Delhi, India, 2015.

Ison, S., and Mulley, C., (2014), "Introduction", *Transport and Sustainability, 5. pp. 1–9.*

Kanungo, T., D. Mount, N. Netanyahu, C. Piatko, R. Silverman, and A, Wu. (2002), "An Efficient k-Means Clustering Algorithm: Analysis and Implementation", *IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 24, No. 7, 2002, pp. 881–892. 22.*

Khodaii, A., Aflaki, E., and Moradkhani, A. (2010), "Modeling the effect of parking fare on personal car use", *Scientia Iranica – Transaction A: Civil Engineering, 17(3), 209–216.*

Litman, T., (2016), "Parking Management: Strategies, Evaluation and Planning", *Victoria Transport Policy Institute*, Retrieved from www.vtpi.org/park_man.pdf.

Marsden, G., (2014), "Parking policy", *Transport and Sustainability, 5. pp. 11–32*.

Sahili, K.A., and Hamadneh, J., (2016), "Establishing-parking generation rates/models of selected land-uses for Palestinian cities", *Transportation Research Part A 91 (2016) 213–222.*

Shoup, D.C. (2006), "The price of parking on great streets", planetizen March29, 2006. Available from /http://www.planetizen.com/node/19150S (accessed 20.06.11.).

Spililpoulou, C. and Antoniou, C. (2012) Analysis of illegal parking behaviour in Greece. Procedia-Social and Behavioural Sciences, 48 (2012), 1622-1631. https://doi.org/10.1016/j.sbspro.2012.06.1137.

Stockholmsstad, (2013a). *Mobility Strategy: Parking plan Mars 2013 (in Swedish).*

Xia, D. Y., F. Wu, X. Q. Zhang, and Y. T. Zhuang (2008), "Local and Global Approaches of Affinity Propagation Clustering for Large-Scale Data", *Journal of Zhejiang University SCIENCE A, Vol. 9, No. 10, 2008, pp. 1373–1381.* http://dx.doi.org/10.1631/jzus.A0720058. 24.