Classification of urban bus-stop catchments for selecting appropriate sidewalk facility on access roads

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This study presents a rational procedure to classify urban bus-stop catchments in view of selecting appropriate sidewalk facility on access roads to nearby bus stops. In the absence of such classification, ensuring sidewalk facility with stipulated engineering features and standards becomes critical. The study proposes a two-step procedure, where various types of road geometric features of access roads are used as variables. The study demonstrates the application of catchment classification information for preparing an implementation plan of sidewalk facility in line with the available design standards of guidelines and manuals for best practices.

Keywords: Access road geometry, bus-stop catchment, classification, sidewalk facility.

In order to promote bus service as an attractive and sustainable travel option[1] for urban citizens in India, an improvement of accessibility to this service by walk-mode[2] appears to be an inevitable requirement in recent times. In line with this requirement, many recent policies for promoting city bus usage are shifting towards a new paradigm, where an effective integration[3,4] between walk-mode and bus service has primarily gained attention. In the recent past, the Government of India (GoI) emphasized on the above integration through many of its initiatives such as the Atal Mission for Rejuvenation and Urban Transformation[5], SMART CITY[6], etc. These initiatives specifically focused on 'first-and-last mile' connectivity towards an overall improvement of transit-oriented development (TOD) in an urban area. However, a systematic development of walk-oriented infrastructure or more specifically sidewalk facility is often neglected[7], and therefore the likelihood of considering walk as a practical option[8] for access mode is gradually diminishing.

In the context of an urban area, a bus-stop catchment may be defined[8,9] by the geographical extent around a bus stop within which bus users are expected to have either of their trip-ends. Any such catchment is primarily constituted of access roads, which are generally used for accessing city bus service by walk-mode. In order to develop a suitable sidewalk facility within a bus-stop catchment, transport planners often refer to the existing manuals and guidelines for best practices. These guidelines[10–13] usually mandate the provision of a specific pedestrian right of way (RoW), side-walk buffer, crosswalk, kerb, ramp profiles, etc. However, in many instances, it was observed[14] that the implementation of appropriate sidewalk facility following these guidelines often faced bottlenecks due to the presence of lateral space constraints and other implementation restrictions usually observed on access roads. Besides, ensuring sidewalk facility with appropriate engineering features and standards becomes an even more critical issue, when various types of access roads are found within a catchment and even across various catchments. In such a situation, framing of implementation plan for appropriate sidewalk facility becomes crucial. In order to meet this requirement, the classification of bus-stop catchments consisting of various types of access roads and running lengths becomes an inevitable requirement.

It is evident that classification of any urban bus-stop catchment is likely to be based upon the type of access road within that catchment. Therefore, before proceeding to classify any given catchment as an aggregate, it becomes necessary to prepare a classification of all possible types of access roads within a catchment. Any urban road classification system is usually represented in the form of a hierarchical structure[12] in which the functional classification system (FCS) is the most predominant and traditional method. However, FCS was primarily developed considering the movement of motorized vehicles[12,15]. Needless to mention that the requirements and characteristics of any access road are usually different from those of motorized corridors. In light of these requirements, this study presents an alternative classification procedure for bus-stop catchments commensurate with the walk-oriented facility needs by following a two-step procedure. In the first step, access roads within a catchment are classified using a hierarchical method called binary recursive partitioning (BRP). In this step, we consider various types of road geometric features of access roads as input variables, and thus overcome the shortcomings of the traditional FCS. In the second step, a novel catchment classification index (CCI) is proposed to be estimated, which

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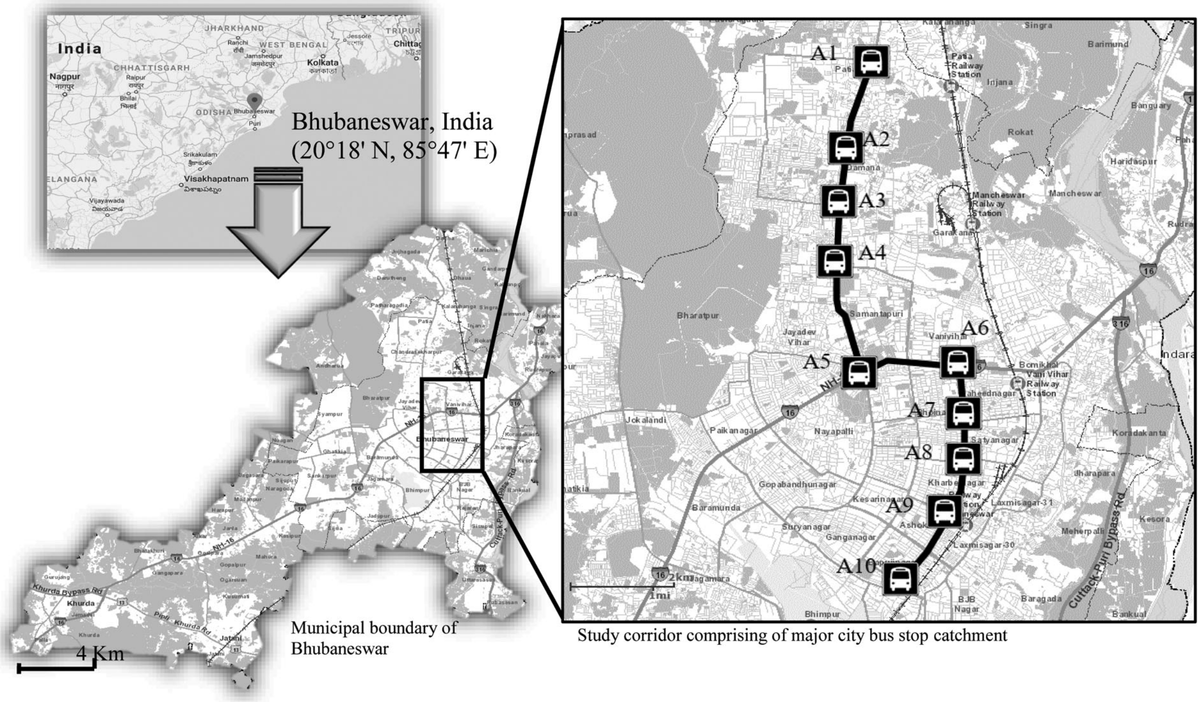

Figure 1. Bus-stop catchments along the study corridor.

Table 1. List of bus-stop catchments along the study corridor

Catchment	Catchment code
Patia Square	A1
Chandrashekharpur	A2
Damana Square	A3
OMFED Square	A4
Jaydev Vihar Square	A5
Vani Vihar Square	A6
Saheed Nagar	A7
Satya Nagar	A8
Master Canteen	A9
Rajmahal Square	A10

measures the aggregate homogeneity of various classes of access roads within a catchment. These CCI values are then used to designate any catchment by a specific class. The classification information helps in preparing an overall implementation plan of sidewalk facility in line with the design standards of guidelines and manuals for best practices.

Bus-stop catchments along the study corridor and dataset development

In this study, we considered a major bus-service corridor in Bhubaneswar, Odisha, India, which passes through major residential and various other economic/social activity areas such as KIIT Square, Patia, Chandrasekharpur, OMFED-Square, Jaydev Vihar, Vani Vihar, Master Canteen, Rajmahal Square, etc. (Figure 1). Major boarding and alighting activities usually happen along this corridor, and bus passengers are mostly walk-accessed bus users, i.e. those bus users who use walk-mode to access the city bus service. On this corridor, an array of 10 bus-stop catchments were identified for the study (Figure 1). Table 1 provides the names of these catchments and their assigned area codes. Several previous studies[9,16–19] have reported that walking distance for such walk-accessed commuters varied between 200 and 600 m. A study conducted by the Indian Institute of Technology (IIT), Bhubaneswar (unpublished Final Report for Housing and Urban Development, Government of Odisha) revealed that walk-accessed bus users were usually found to access nearby bus stops within an ambit of about 550 m. Therefore, in the present study data collection was carried out within an area having a Euclidian radius equivalent to the above walking distance.

It was observed during the reconnaissance survey that each catchment consists of a small network of access roads reaching a nearby bus stop. Any such access road within a catchment was found to have varying geometric features along its running length. Figures 2 and 3 show the typical network of access roads within two separate bus-stop catchments located in Chandrashekharpur and Saheed Nagar area of the city. The study identified primarily four types of road space constraints, viz. absence of pedestrian RoW, inadequate pedestrian RoW, availability of pedestrian RoW, but only on one side of the road, and unpaved shoulder space. However, it was also

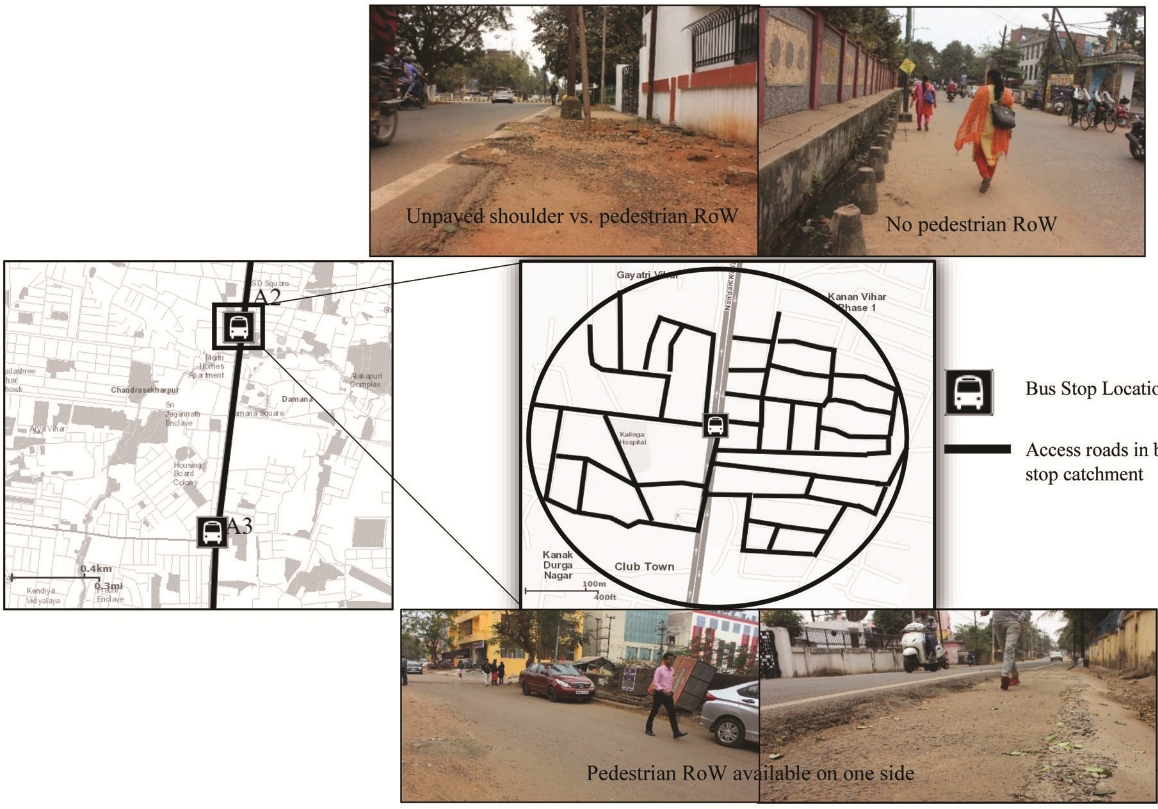

Figure 2. Access roads showing geometric features of varying nature in a bus stop catchment located at Chandrashekharpur area, Bhubaneswar (A2 in Figure 1).

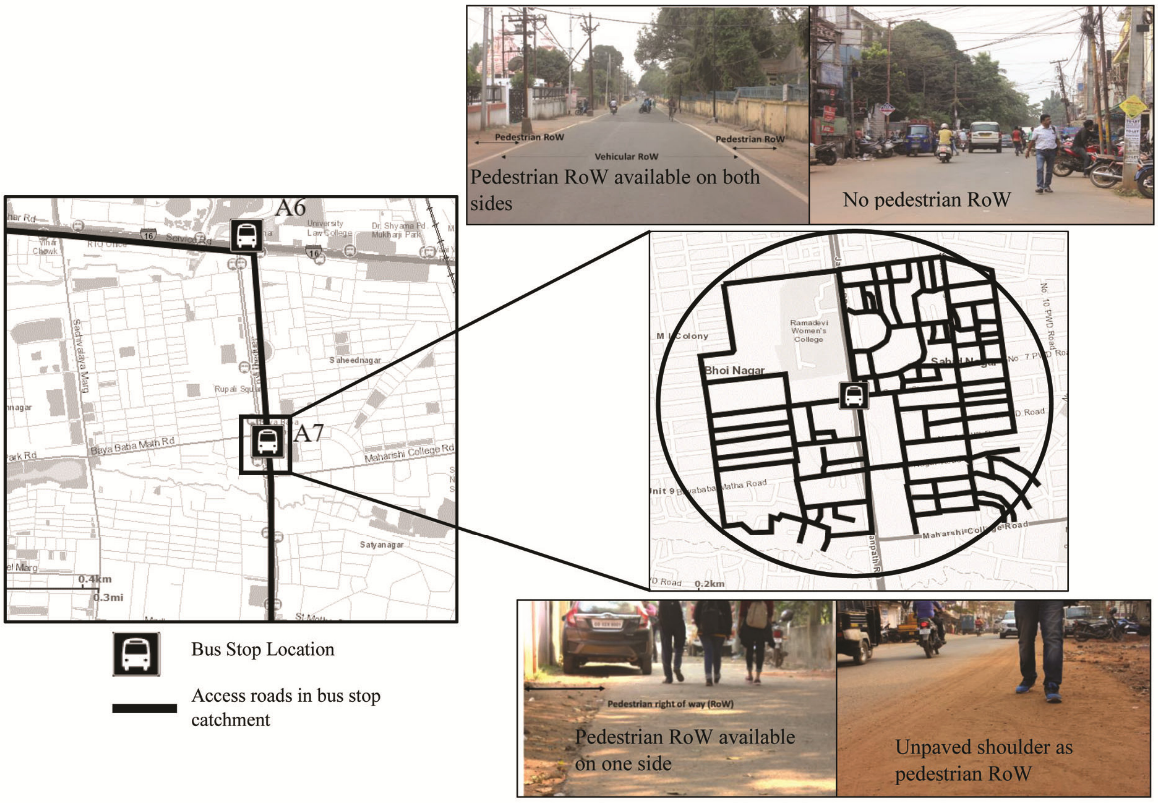

Figure 3. Access roads showing geometric features of varying nature in a bus-stop catchment located at Saheed Nagar, Bhubhaneswar (A7 of Figure 1).

noticed that the type of road space constraint was not uniform throughout the running length of the access road. Due to this, each access road was segmented into a few short lengths in such a way that space constraint for any segment remained uniform throughout of its length. Each such uniform segment is hereafter called road link.

In each of the catchments, these road links were numbered, and their start and end locations were located using GPS codes. Next, the GPS information was decoded to obtain the length of each uniform road link. In this manner, the total number of road links, usually ranging between 8 and 12 was observed in each of the study catchments. The length of these road links varied between 60 and 700 m. A total of 96 such road links were considered for this analysis, which totals a running length of about 24 km (Table 2). In line with the observations made in all of the study catchments, a set of road geometric variables was identified and used in the classification procedure adopted in this study (Table 3). These variables constitute the basic geometric consideration for implementation of any sidewalk facility. A primary field study was carried out to record site information relating to all of these variables and for all 96 road links. A symbolic excerpt of such a dataset is shown in Table 4, which illustrates the geometric features of all road links in the bus-stop catchment located in Chandrashekharpur.

Classification procedure

As stated, the present study follows a two-step procedure involving classification of the accessed road links within a bus-stop catchment, and then designation of the catchment by a specific class using of the above classification information. Each of the steps is described in the following sub-sections.

Classification of access road links using BRP

BRP is a hierarchical method[20], based on building a decision tree. BRP is technically called binary because any main node (also called parent node) is always split into two subsidiary nodes (also called child nodes). This method is also called recursive because it is repeated every time by treating each child node as a parent node for the next level of hierarchy. BRP proceeds iteratively by searching a solution of the following two decision problems – first, which variable is to be selected for node-splitting and secondly, at what value of the aforementioned variable the node-splitting may be carried out. In this way, a hierarchical tree is generated, where each child node is classwise purer than its parent node. BRP essentially attempts to eradicate or minimize any 'impurity' in the parent node by splitting it into a set of more homogeneous or 'pure' child nodes. The splitting of node(s) begins at a root node. This node includes all observations in the dataset, and then seeks the best possible explanatory variable, say X, to split any node into two child nodes. In order to find the best variable, all possible splitting variables (called splitters) along with their possible values are examined.

Mathematically, at f be any impurity function, then the impurity of any node N is given by

$$I(A) = \sum_{j=1}^{C} f(p(X \mid N)), \tag{1}$$

where C is the number of child nodes at node N and $p(X|N)$ is the probability of occurrence of X at node N.

The two possible forms for the impurity function f are called the Information gain and the Gini index. The measure of these two forms differs slightly, and previous empirical evidence[21] showed that they nearly resulted in the same split point. The information gain at each node is given by eq. (2) below

$$f = -p(X|N) \log p(X|N). \tag{2}$$

This function is estimated twice–once before and once after splitting of any parent node. Their difference is then estimated in order to derive a measure called entropy (eq. (3)) which is a measure of the 'disorder' or variability in the dataset[22]. The lesser the entropy after node-splitting, or alternatively, more is the change in entropy, lesser is the variability in the dataset and therefore, more is the homogeneity.

$$E = \sum_{\text{Before split}}^{\text{After split}} -p(X \mid N) \log p(X \mid N). \tag{3}$$

The other impurity function, i.e. the Gini index is a measure of how often a randomly chosen variable could incorrectly be identified[21] during node-splitting. In the process, BRP chooses a variable during node-splitting in

Table 2. Description of access road links in bus stop catchment

Catchment code	No. of access road links	Maximum link length (m)	Minimum link length (m)	Total link length (m)
A1	8	640	270	3510
A2	9	700	150	2576
A3	12	400	75	2375
A4	12	400	130	3440
A5	10	700	150	3095
A6	9	400	60	1351
A7	8	700	150	2426
A8	11	410	96	1947
A9	8	410	106	1467
A10	9	300	102	1680
Total	96	700	60	23,867

Table 3. Variables for model estimation

Variable	Symbol	Data type	Description
Link length	L	Quantitative and continuous	Length of the road section
Total available RoW	TRoW	Quantitative and continuous	Value of total available width
Carriageway width	CW	Quantitative and continuous	Value of available width for vehicles only
Pedestrian RoW	PRoW	Quantitative and continuous	RoW available for pedestrians
Shoulder width	SW	Quantitative and continuous	Width on the left, right, inside, and outside shoulders
Median width	MW	Quantitative and continuous	Median width (otherwise 0, if median is not available)
Shoulder type	ST	Qualitative and dummy	Dummy coded variables for type of shoulder (whether paved/ unpaved, earth)

Row, Right-of-way.

Table 4. A typical database developed for each catchment

Catchment	Link#	L (m)	ST	PRoW (m) (right)	PRoW (m) (left)	CW (m)	MW (m)	TRoW (m)
Chandrashekharpur (area code: A2)	1	170	Unpaved shoulder	1.60	2.10	6.40	0.35	10.45
	2	300	Unpaved shoulder	3.00	2.10	6.00	0.35	11.45
	3	150	Unpaved shoulder	3.20	2.80	6.40	0.30	12.7
	4	161	Unpaved shoulder	2.40	1.80	5.50	0.18	9.88
	5	150	Unpaved shoulder	2.00	1.75	7.00	0.33	11.08
	6	700	Unpaved shoulder	2.00	0.90	7.20	0.00	10.1
	7	350	Block type	1.30	1.40	9.00	0.00	11.7
	8	445	Concrete	2.60	2.60	5.20	0.00	10.4

such a manner that it results in the lowest Gini Index. This index is given by

$$G = 1 - \sum_{x=1}^{C} (p(X \mid N))^2. \tag{4}$$

The present study employs BRP in order to identify any geometric variable (as referred in Table 3) of a road link at its optimum splitting node by maximizing the change in entropy or minimizing the Gini index. In this regard, numerical methods are employed to optimize the above two parameters as mentioned in eqs (3) and (4). In this manner, the application of BRP results in a hierarchy structured classification tree for all the access road links.

Classification of catchments

The application of BRP results in the formation of a hierarchical tree of access road links containing one root node, and several other internal and terminal nodes. The terminal nodes of the lowermost hierarchical level were examined in order to designate the access road links by a specific class. Now in order to designate a catchment by a specific class, the various classes of access road links were first assigned with numerical scores. That is, if a score s_i is assigned to the ith class access road link, then this assigned score is used to estimate CCI. The CCI values for any given catchment are estimated using the weighted mean score (eq. (5)) of all road links located within that catchment. In this regard, the running lengths (L, Table 3) of road links are taken as weights. If L_i is the length for the ith class of road link, then the CCI value of any catchment, say k, is expressed as given below.

$$\mathrm{CCI}_k = \frac{\sum_i s_i \times L_i}{\sum_i L_i},$$
$$i \in \{\text{all road links within catchment } k\}. \tag{5}$$

The above CCI value is then rounded-off to the nearest whole number. This value may be considered as a measure of the aggregate homogeneity of access road links within a given catchment. The above estimated index value (rounded-off) is then cross-referred with the same numerical scores that have been previously assigned to the access road links. That is, if the CCI value of any catchment is estimated to be s_i, then that catchment may be designated as the ith class. Figure 4 is a flow chart of the overall procedure of classification.

Results and discussion

As described in the previous section (and also illustrated in Figure 4), the designation of any catchment by a specific class was carried out using the observed datasets in Bhubaneswar.

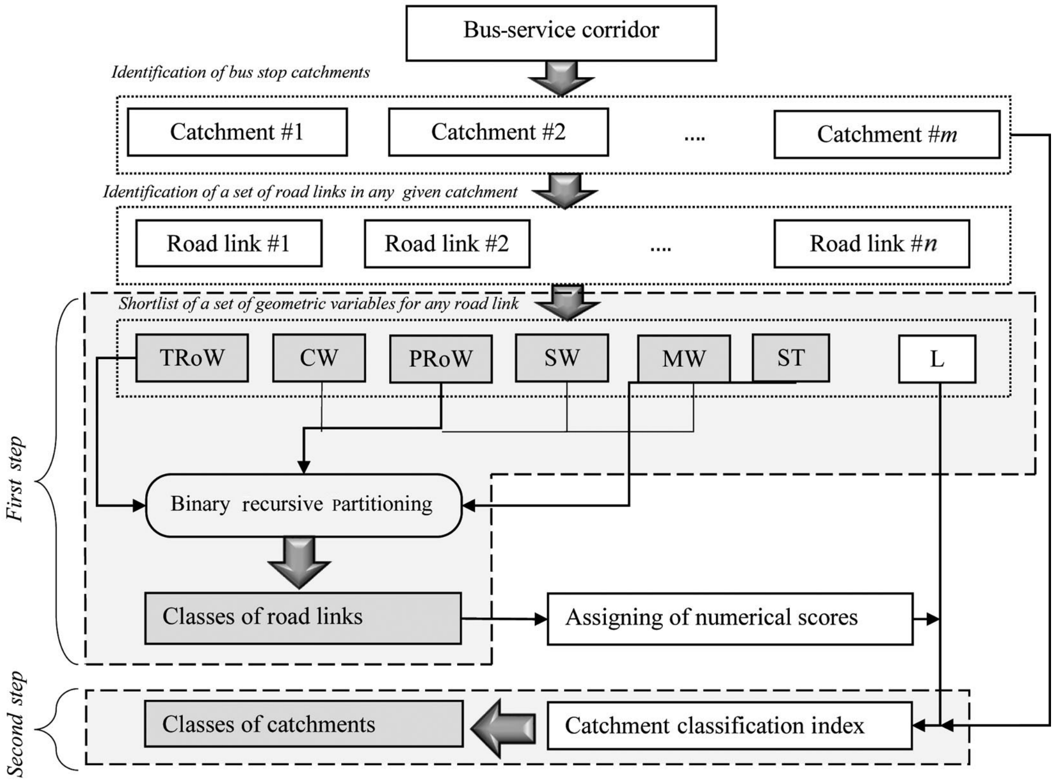

Figure 4. Flow chart of the procedure.

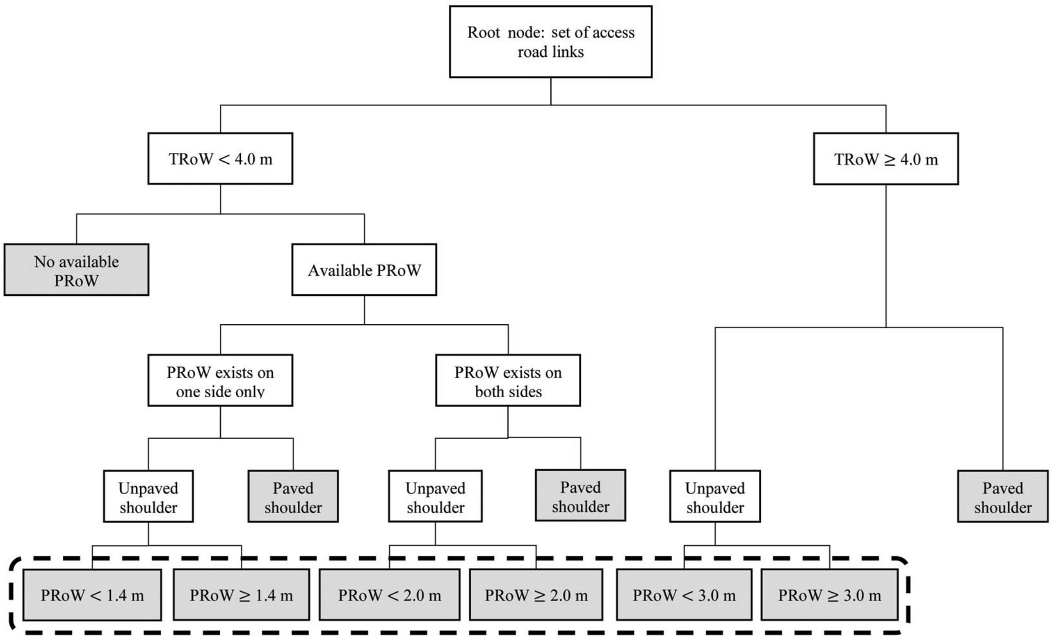

Figure 5. Hierarchical tree of access road links.

Classification of access road links

Figure 5 shows the hierarchical tree estimated for the access road links. The tree comprises of a total of 19 nodes, of which nine are internal (shaded in white, Figure 5) and the remaining 10 nodes are terminal (shaded in grey, Figure 5). The classification starts from the root node representing a set of all access road links used in the study. The first hierarchical level is represented by the variable TRoW (Table 2), which results in two child nodes or classes; one with TRoW < 4.0 m and the other with TRoW ≥ 4.0 m. In the second hierarchical level the variable is PRoW (refer Table 2). This hierarchical level is observed only for those road links whose TRoW < 4.0 m, but not for TRoW ≥ 4.0 m. At this hierarchical level, one of the terminal nodes is found to occur for the case of road links having no available-PRoW. The other node at this level, i.e. road links having available-PRoW is found to be further split into the third hierarchical level by generating two nodes, viz. PRoW is available only on one side of the road link, and PRoW is available on both sides of the road link. Each of the two nodes is again found to be split into the fourth hierarchical level describing the shoulder type (ST). In a similar way, it is observed that the node at the second hierarchical level representing TRoW ≥ 4.0 m, can be directly split into this fourth hierarchical level. At this level, the terminal nodes are encountered for all those cases where road links have paved shoulder as their shoulder type. The rest of the internal nodes, i.e. road links with unpaved shoulder are split into the fifth hierarchical level describing the various ranges of PRoW values for various classes of road links. At this level, the hierarchical tree is found to terminate, and thus reveals a total of six classes for all access road links under consideration. It may be mentioned that during estimation of the above hierarchical tree, the variables CW, MW and SW (Table 3) were not found as the optimum splitting nodes, and hence they do not reflect in any of the hierarchical levels (Figure 5).

The hierarchical tree generated in the study is found to be suitable as represented by the acceptable[23,24] values of Gini index (0.174) and Entropy (0.217) (Table 5). It can be observed in the hierarchical tree that PRoW values are in the form of unbounded inequalities. In the cases where only the lower-bound PRoW values are identified, the upper-bound PRoW values will then be restricted by the value of TRoW as observed in the second hierarchical level. In this way, the ranges of PRoW values for each of the classes are defined, and then they are designated by appropriate nomenclature say A, B, C, D, E and F (Table 6). It may be mentioned that the above nomenclature of classes does not convey any sense of superiority or designate any order of preference to a particular class. Table 7 reveals the number of access road links falling under the aforementioned classes in each of the catchments. The results show that majority of the road links

Table 5. Statistical indices showing goodness-of-fit of the hierarchical tree

Parameters	Value
Gini index	0.174
Information gain before split	0.891
Information gain after split	0.674
Entropy	0.217

fall under class B (27%) and class D (24%). The percentage share of class A and class C road links is also quite significant, i.e. about 17 and 20 respectively. However, the presence of class E and class F road links is found to be less, i.e. about 8% and 4% respectively. After classification of the road links, we proceeded to designate various catchments by specific classes using the CCI values.

Classification of bus-stop catchments

In order to designate a catchment by a specific class, various classes of access road links were assigned with numerical scores (Table 8). The CCI values were then estimated for each of the catchments using eq. (5). Table 9 and Figure 6 show the classification of bus-stop catchments. They reveal that eight (all but A6 and A8) out of the ten catchments fall under either class C or class D. This implies that all these eight catchments have access roads with TRoW < 4.0 m and pedestrian RoW 247 on both sides with unpaved shoulder. Three of these eight catchments, viz. A1, A3 and A7 have pedestrian RoW < 2.0 m and the remaining five catchments, viz. A2, A4, A5, A9 and A10 have pedestrian RoW ranging between 2.0 and 4.0 m. Two other catchments, viz. A6 and A8 fall under class B. These two catchments have TRoW > 4.0 m, with pedestrian RoW only on one side of the road links and PRoW values ranging between 1.4 and 4.0 m. The study does not reveal any catchment of classes

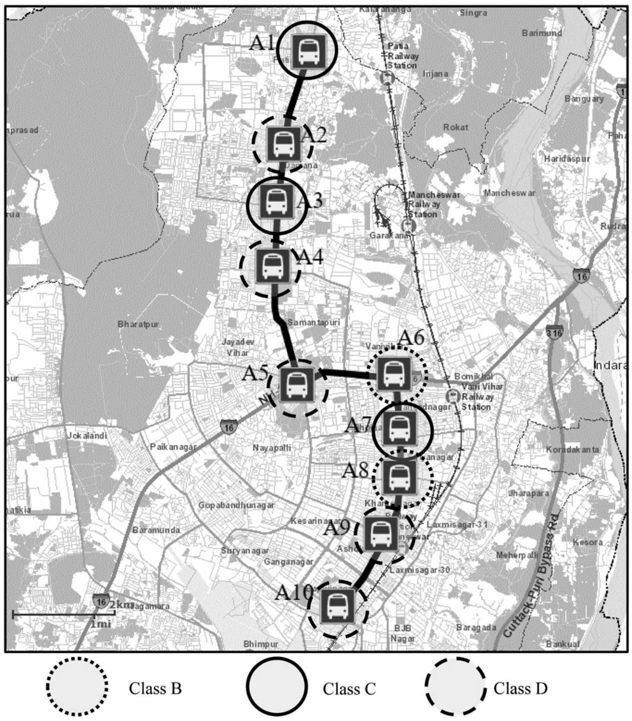

Figure 6. Various catchment classes observed along the study corridor.

Table 6. Classification of access road links and their descriptions

Description of class		
Main hierarchical node	Terminal node	Designated class
TRoW < 4.0 m and PRoW on one sides having unpaved shoulder	PRoW < 1.4 m	A
TRoW < 4.0 m and PRoW on one sides having unpaved shoulder	1.4 m < PRoW < 4.0 m	B
TRoW < 4.0 m and PRoW on both sides having unpaved shoulder	PRoW < 2.0 m	C
TRoW < 4.0 m and PRoW on both sides having unpaved shoulder	2.0 m < PRoW < 4.0 m	D
TRoW ≥ 4.0 m and PRoW on both sides	PRoW < 3.0 m	E
TRoW ≥ 4.0 m and PRoW on both sides	3.0 m ≤ PRoW < TRoW	F

Table 7. Access road link counts of various classes

	Number of road links observed in each class						Area-wise observation	
Area code	A	B	C	D	E	F	Total	% observation
A1	0	1	1	3	2	1	8	8.33
A2	0	3	1	5	0	0	9	9.38
A3	0	4	2	2	3	1	12	12.50
A4	0	3	2	4	0	2	12	12.50
A5	2	1	3	3	1	0	10	10.42
A6	3	4	1	1	0	0	9	9.38
A7	2	3	2	1	0	0	8	8.33
A8	4	5	2	0	0	0	11	11.45
A9	2	1	3	1	1	0	8	8.33
A10	3	1	2	2	1	0	9	9.38
Class-wise observation								
Total	16	26	19	23	8	4	96	
% Observation	16.67	27.10	19.77	23.96	8.33	4.17		100

Table 8. Numerical score structure used for the classification of bus-stop catchments

Class	Numerical score
A	1
B	2
C	3
D	4
E	5
F	6

Table 9. Classification of bus-stop catchments

Area code	CCI	CCI (rounded-off)	Class
A1	3.40	3	C
A2	4.10	4	D
A3	3.22	3	C
A4	3.83	4	D
A5	3.78	4	D
A6	2.15	2	B
A7	3.42	3	C
A8	2.32	2	B
A9	4.36	4	D
A10	4.39	4	D

CCI, Catchment classification index.

A, E and F. The classification information of catchments is expected to help transportation planners select the appropriate type of pedestrian-oriented infrastructure commensurate with the available road geometry of any given catchment.

Application of results for selecting appropriate sidewalk facility

The classification of bus-stop catchments can be used as an input in the selection of appropriate sidewalk facility on access roads within a bus-stop catchment commensurate with the available design standards of guidelines and manuals for best practices. In the urban setting of any developed and developing country, the design standards[13,25,26] recommend that minimum width of a sidewalk be 1.80 m. However, the Indian Roads Congress[13] stipulates that cases where the above minimum specification cannot be met, a provision of at least 1.50 m sidewalk needs to be introduced. In view of this design stipulation, the constraints of lateral space usually observed on access roads within a bus stop catchment in mid-sized urban areas pose a bottleneck for implementing a suitable sidewalk. In such a situation, this study may help in selecting appropriate type of sidewalk facility and its alignment in various classes of catchments.

It is observed that the catchments of class A have PRoW available only on one side, implying that the sidewalk could only be aligned on one side of the road. As the maximum value of PRoW for such class of catchments is

Table 10. Implementation plan of sidewalk facility for different catchment classes

Catchment class	Availability of PRoW	Sidewalk implementation plan	
		Alignment	Type of sidewalk
A	PRoW < 1.4 m and available on one side of the access road	One side of the access road	Marked sidewalk
B	1.4 m < PRoW < 4.0 m and available on one side of the access road	One side of the access road	Marked sidewalk, if 1.40 m ≤ PRoW < 1.50 m; raised sidewalk, if 1.50 m ≤ PRoW < 4.00 m
C	PRoW < 2.0 m and available on both sides of the access road	Both sides of the access road	Marked sidewalk, if PRoW < 1.50 m; raised sidewalk, if 1.50 m ≤ PRoW < 2.00 m
D	2.0 m < PRoW < 4.0 m and available on both sides of the access road	Both sides of the access road	Raised sidewalk
E	PRoW < 3.0 m and available on both sides of the access road	Both sides of the access road	Marked sidewalk, if PRoW < 1.50 m; raised sidewalk, if 1.50 m ≤ PRoW < 3.00 m
F	3.0 m ≤ PRoW < TRoW and available on both sides of the access road	Both sides of the access road	Raised sidewalk

bracketed at 1.40 m, therefore, a raised sidewalk cannot be recommended here. In such cases, a marked sidewalk (as per DoIT, Taipei City Government, 2012) may be recommended. Similar to the above, the sidewalk can also be aligned on one side of the access road for catchments of class B. Moreover, the PRoW value could lie between 1.40 and 4.0 m. Therefore, the marked sidewalk can be recommended in those cases where the PRoW value lies between 1.40 and 1.50 m, and raised sidewalk in those cases where the PRoW value lies between 1.50 and 4.0 m. The same philosophy is employed in order to decide appropriate type of sidewalk facility for catchments of class C and class E, but the alignment of facility will be on both sides of the access road. On the other hand, in the catchments of class D and class F, the raised sidewalk could be introduced without any lateral restrictions. Table 10 summarizes the overall implementation plan of sidewalk facility commensurate with the design standards[13] for the urban Indian context. It may be mentioned that the present study identifies a strategy for implementation of appropriate type of sidewalk facility by considering its various engineering features such as width, alignment and type of segregation. As mentioned, these engineering aspects are the basic needs for implementation of any sidewalk facility, and therefore should invariably be considered for all types of pedestrian purposes, including walk-accessed bus users. Although the implementation plan as prescribed in Table 10 refers to a typical example for an urban India context, the same approach may be adopted for similar implementation plans in urban areas of other countries commensurate with their design guidelines and manuals for best practices. Otherwise, the implementation plan as prescribed in Table 10 may be followed. It may be mentioned that the results of the present study could be beneficial not only for the walk-accessed bus users, but also for other pedestrians.

Summary and conclusion

In India, the systematic development of sidewalk facility, especially on access roads, is often neglected. In addition, the implementation plan of sidewalk facility on such access roads more often suffers due to the bottleneck of lateral space constrains and absence of implementation guidelines under such constraints. In order to overcome such deficiency, a systematic classification of bus-stop catchments commensurate with the existing road geometries of access roads is found inevitable. The present study addresses this research gap, and develops a rational procedure to designate a bus-stop catchment with a specific class. The classification procedure works in two steps. In the first step, access road links within a catchment are classified using a hierarchical method BRP. In the second step, CCI is proposed for measuring the aggregate homogeneity of various classes of access road links within a catchment. The CCI values are used to designate any catchment by a specific class.

This study has identified a total of six different classes of bus stop catchments based on the lateral space constraints. It prescribes the implementation plan of appropriate sidewalk facility for various classes of catchment types in commensurate with the Indian design standards[13]. These implementation strategies are mainly identified by considering various engineering features such as width, alignment and type of segregation. These aspects are the basic need for implementation of any sidewalk facility, and therefore should invariably be considered for all types of pedestrian purposes, including walk-accessed bus users. The implementation plan as demonstrated in this study refers to a typical example for an urban India context. The demonstrated approach may be adopted to prepare similar implementation plans for urban areas of other countries commensurate with their design guidelines and manual for best practices. It may be mentioned that the results of the present study could be beneficial not only for the walk-accessed bus users, but also for other pedestrians. As an alternative direction of current research, pedestrian-behavioural responses may be considered in order to identify the appropriate intervention areas for improvement of any given pedestrian environment.

1. Maitra, B. and Sadhukhan, S., Urban public transportation system in the context of climate change mitigation: emerging issues and research needs in India. In *Mitigating Climate Change*, Springer, Berlin, Germany, 2013, pp. 75–91.
2. Verma, A., Sreenivasulu, S. and Dash, N., Achieving sustainable transportation system for Indian cities – problems and issues. *Curr. Sci.*, 2011, **100**(9), 1328–1339.
3. Choudhury, C. F. and Ayaz, S. B., Why live far? – Insights from modeling residential location choice in Bangladesh. *J. Trans. Geogr.*, 2015, **48**, 1–9.
4. Sohoni, A. V., Thomas, M. and Rao, K. K., Application of the concept of transit oriented development to a suburban neighborhood. *Transp. Res. Procedia*, 2017, **25**, 3220–3232.
5. MoUD, Atal Mission for Rejuvenation and Urban Transformation: Mission statement and guidelines. Ministry of Urban Development (currently, Ministry of Housing and Urban Affairs), Government of India (GoI), 2015.
6. MoUD, Smart City Mission Transform Nation: Mission statement and guidelines. Ministry of Urban Development (currently, Ministry of Housing and Urban Affairs), GoI, 2015.
7. Badami, M. G., Urban transport policy as if people and the environment mattered: pedestrian accessibility the first step. *Econ. Polit. Wkly.*, 2009, 43–51.
8. Roy, S. and Basu, D., Ranking urban catchment as per service condition of walk-environment. *J. Transp. Eng. Part A*, 2019, **145**(4), 04019005-1–04019005-14.
9. Kittelson and Associates, Inc., KFH Group, Inc., Parsons Brinckerhoff Quade and Douglass, Inc., and K. Hunter-Zaworski, TCRP Report 100: Transit Capacity and Quality of Service Manual, Transportation Research Board, Washington DC, USA, 2003.
10. KMOCT, Design guide lines for road structures and facilities, Korea Ministry of Construction and Transportation, *Gwacheoun-si*, 1999.
11. KMOCT, Korean highway capacity manual, Korea Ministry of Construction and Transportation, *Gwacheoun-si*, 2001.
12. AASHTO, A policy on geometric design of highways and streets. American Association of State Highway and Transportation Officials, Washington, USA, 2004.
13. IRC-103:2012, Guidelines for pedestrian facilities, Indian Roads Congress, New Delhi, 2012.
14. Verma, A., Review of the book *Mobility Crisis: Agenda for Action 2010* (ed. Banerjee, S.). *Curr. Sci.*, 2011, **100**(7), 1087–1088.
15. Lämmer, S., Gehlsen, B. and Helbing, D., Scaling laws in the spatial structure of urban road networks. *Physica A*, 2006, **363**(1), 89–95.
16. Hsiao, S., Lu, J., Sterling, J. and Weatherford, M., Use of geographic information systems for analysis of transit pedestrian access. *Transp. Res. Rec.*, 1997, **1604**, 50–59.
17. Murray, A. T., Strategic analysis of public transport coverage. *Socio-econ. Plann. Sci.*, 2001, **35**, 175–188.
18. Horner, M. W. and Murray, A. T., Spatial representation and scale impacts in transit service, assessment. *Environ. Plann. B*, 2004, **31**, 785–797.
19. Foda, M. A. and Osman, A. O., Using GIS for measuring transit stop accessibility considering actual pedestrian road network. *J. Public Transp.*, 2010, **13**(4), 23–40.
20. Breiman, L., Friedman, J. H., Olshen, R. A. and Stone, C. J., *Classification and Regression Trees*, Wadsworth Pub, Belmont, CA, USA, 1984.
21. Raileanu, L. E. and Stoffel, K., Theoretical comparison between the Gini index and Information Gain criteria. *Ann. Math. Artif. Intell.*, 2004, **41**(1), 77–93.
22. Wang, Q. R. and Suen, C. Y., Analysis and design of a decision tree based on Entropy reduction and its application to large character set recognition. *IEEE Trans. Pattern Anal. Mach. Intell.*, 1984, 4, 406–417.
23. Lerman, R. I. and Yitzhaki, S., A note on the calculation and interpretation of the Gini index. *Econ. Lett.*, 1984, **15**(3–4), 363–368.
24. Sethi, I. K., Entropy nets: from decision trees to neural networks. *Proc. IEEE*, 1990, **78**(10), 1605–1613.
25. DULT, Guidelines for planning and implementation of pedestrian infrastructure, ver 1.0. Directorate of Urban Land Transport, Government of Karnataka, 2014.
26. Unified Traffic and Transportation Infrastructure (Planning & Engineering) Centre, Pedestrian design guidelines: ‘Don’t drive…walk’, Delhi Development Authority, New Delhi, 2009.

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