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Evaluation of opportunity based urban road network accessibility using GIS

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Abstract The structural performance of any transport network may be mainly evaluated using connectivity, accessibility, hierarchy and morphology. The evaluation of accessibility is one of the most important aspect in defining the performance of a road network structure. The present study is concerned with proposing a methodology for the city—level opportunity (or) urban services and distance based accessibility evaluation. The various opportunities (or) urban services like schools, colleges, ATM's, banks, hospitals, police stations, petrol bunks, bus stops, parks and theatres up to a specified distance of 0–5 km radius were considered for the analysis. The weights were assigned to different opportunities and were analyzed using Weighted Scoring Model. The Mean Weighted Accessibility Index has been determined for each location to identify the level of accessibility in a particular location. The study attempts to define the level of road network accessibility at different locations in the study area. In the later stage, this study tried to establish the relationship between the number of opportunities and trip attraction rates and the results were discussed. The present work was also intended to prove the efficiency of Geographical Information Systems in opportunity based accessibility assessment.

Keywords Accessibility · Opportunity · Weights · Mean weighted accessibility index · GIS

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1 Introduction

The way people and goods move through a city is largely governed by its transport system, which is an important source of sustainability in urban areas. In urban framework, the urban transport network structure plays a major role. In the current situation, many researchers are emphasizing on the transport structure. The most significant issue of transport network structure is the evaluation of its accessibility. For achieving better urban growth and viable improvement of a city, transport accessibility is the crucial one. The relationship between the urban form and travel pattern can be depicted in urban cities by accessibility determination. The convenience of travel to jobs, services and other places of interest has been observed as primary to the improvement of viable transportation, landuse and spatial planning design. The attention towards viable development of cities has intensified the necessity of accessibility for fiscal expansion, environmental protection and reasonable access for all classes of people to core services. Accessibility determination is finding of likely means for a person to reach the desired destination, depending on a set of components and variables that are measurable. This study aims to evaluate the urban road network accessibility based on the distance and number of opportunities. The study also attempted to define the level of road network accessibility in different locations selected for the analysis.

Various studies carried out on assessment of road network accessibility are discussed here. Accessibility is defined in many ways and by many researchers such as "the potential of opportunities for interaction" [1], "the ease with which any land use activity can be reached from a location using a particular transportation system" [2], "the freedom of individuals to decide whether or not to participate in different activities" [3], and the benefits provided by a transportation or land use system". In the context of transport studies, accessibility indicates the ability of people to reach their destinations which they must visit in order to meet their needs, and desire to visit to fulfill their wants. All accessibility measures have two major components: the first is the attractiveness component and the second is the impedance function. The attractiveness component is usually measured as the number of opportunities at destinations. The impedance function decreases the probability of being attracted to such destinations based on distance or travel time. Accessibility often incorporates land use pattern, network topology, and travel behavior. Accessibility measure is modeled as a utility-based measure [4], topological measure [5], gravity measure [1], cumulative opportunity measure [6], and constrained based measure [7]. There were some reviews on different accessibility measures with mathematical formulations and the reviews represented that, to determine the land use and transportation performance accessibility is the essential measure [8]. Accessibility may be classified into relative and integral accessibility. Relative accessibility is defined as "the degree to which two places or points on the same surface are connected" and integral accessibility as "the degree of interconnection with all other points on the same surface" [9]. Accessibility figure-out the expenditure for movement of persons and shifting of goods from one place to another place. It is concerned with distance to be travelled between two places and also the time taken to travel that distance [10]. Accessibility measures may be divided into three classes such as infrastructure based measures which concentrate on characteristics of infrastructure such as road density, speeds on roads, etc., activity based measures which are related to activities such as working, shopping, recreation, etc., mixed measures which are related to both of the above classes such as distance between residential areas and bus stops [7]. The spatial accessibility of Wuhan metropolitan road network has been quantitatively analyzed based on space syntax. This study was carried out to identify the efficiency of the road network in the study area in terms of accessibility [11]. Spatial analysis method on road network assessment was established based on the GIS spatial analysis technology, some urban road network accessibility evaluation models were built up using ESRI Arc GIS Engine components [12]. A simple GIS—based tool was developed to allow the rapid analysis of accessibility by different transport modes, showing the different patterns of accessibility across the city [13]. A facility-based planning methodology for rural roads has been proposed using spatial techniques. The accessibility for different facilities such as education facilities, medical facilities, economic activities and transport and communication facilities is quantified and analyzed in terms of Village Facility Index (VFI). A GIS-based rural road database was developed to improve the accessibility for different facilities from habitations and expand the infrastructure for current and future requirement [14].

2 Methodology

The geo-referenced map of Hyderabad road network was obtained from Hyderabad Urban Development Authority office (HUDA). This base map was imported into Arc GIS 10.1 software and used for evaluation and analysis of accessibility in the study area. Thirty locations in the Hyderabad city were selected randomly covering the maximum pat of the city in all directions. Multiple ring buffers were drawn from center of the each location to 5 km radius (0–1, 1–2, 2–3, 3–4, 4–5 km). The various opportunities (or) urban services like schools, colleges, ATM's, banks, hospitals, police stations, petrol bunks, bus stops, parks and theatres were computed for each location at different radii. The weights were assigned to each opportunity based on their importance. Subsequently, these opportunities were analyzed according to their weights using Weighted Scoring Model (WSM) and the weighted scores were obtained. The weighted scores of each location at different radii were used to quantify the Mean Weighted Accessibility Index (MWAI). The MWAI values were used to define the level of accessibility at each location in the study area. In the later stage, the number of opportunities were correlated with the trip attraction rates to analyze the relationship between these two parameters. The flow

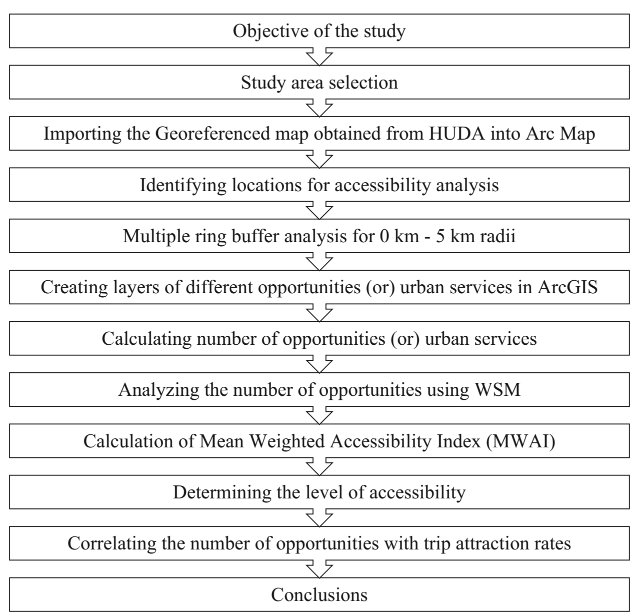

Fig. 1 Flow chart showing the methodology of the study

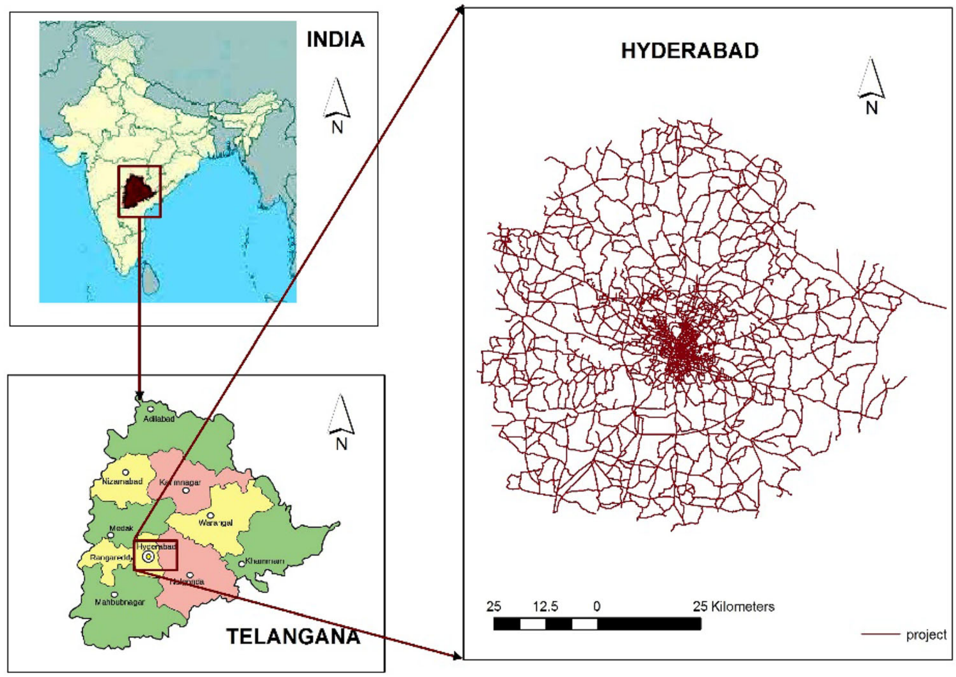

Fig. 2 Location of the study area

chart in Fig. 1 explains the step-by-step procedure followed in this study.

3 Study area and data preparation

The study area for this research is Hyderabad city, Capital of Telangana state; India. The location of the study area is shown in Fig. 2. The places selected for this study in Hyderabad city are Abids (AB), Kukatpally (KP), Mehadipatnam (MP), Dilshuknagar (DN), Secundrabad (SC), Panjagutta (PG), Jeedimetla (JM), Sikenderguda (SG), Nadergul (NG), Kothapet (KT), Ameerpet (AT), Banjara Hills (BH), Gandhi Nagar (GN), LB Nagar (LN), Malkajgiri (MJ), Hitech city (HC), Bhuvanagiri (BG), Ghatkesar (GS), Bhanur (BR), Moinabad (MB), Rama Chandra Puram (RCP), Shivampet (SP), Sangareddy (SR), Wargal (WL), Domarapochampally (DPP), Sitharampuram (SM), Kothur (KR), Golkonda Khurd (GK), Thummaloor (TR) and Ibhrahimpatnam (IBM). The Google earth map of

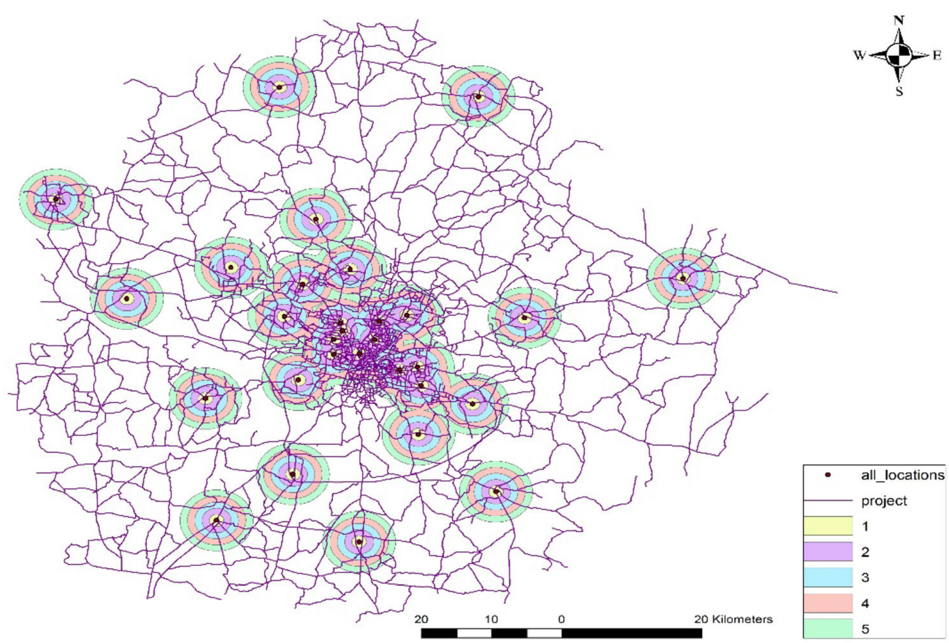

Fig. 3 Multiple ring buffers of different locations in Hyderabad city

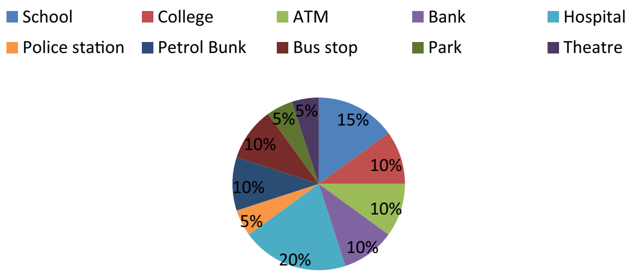

Fig. 4 Weights assigned to different opportunities

Hyderabad city was digitized using ArcGIS 10.1 software. Then the digitized road network map of the city is used for accessibility analysis. Multiple ring buffers were created around each location at 1 km, 2 km, 3 km, 4 km and 5 km radius respectively using multiple ring buffer analysis tools in Arc GIS 10.1 software. The multiple ring buffers of each location were shown in Fig. 3.

4 Results and discussions

4.1 Analysis of opportunities (or) urban services

The various opportunities like schools, colleges, ATM's, banks, hospitals, police stations, petrol bunks, bus stops, parks and theatres were computed for each location at different radii using Google earth and Arc GIS 10.1 software. The opportunities computed at each location were analyzed using Weighted Scoring Model (WSM) which is a method of Multi-Criteria Decision Analysis. A Weighted Scoring Model is a tool that provides a systematic process for selecting projects based on many criteria. Here, weights were assigned to the opportunities based on their importance as shown in Fig. 4.

After assigning the weights for each opportunity, the number of opportunities is multiplied with the weight given and the resulting values were added. Then the weighted

Table 1 Weighted Scores of each location at different radii

S. no.	Location	Abbreviation	1 km	2 km	3 km	4 km	5 km
1	Abids	AB	34.2	30.3	15.5	10.9	8.2
2	Kukatpally	KP	32.8	29.9	10.2	4.9	5.5
3	Mehadipatnam	MP	35.4	27.1	13.9	12.8	10.8
4	Dilshuknagar	DN	54.8	23.1	18.2	11.8	5.5
5	Secundrabad	SC	17.5	20.8	11.4	15.1	19.1
6	Panjagutta	PG	31.3	28.3	14.5	7.4	6.3
7	Jeedimetla	JM	4.15	19.4	14.8	10.5	3.3
8	Sikenderguda	SG	2	4.5	5.7	10.7	7.6
9	Nadergul	NG	2.3	3.5	0.5	0.7	3.1
10	Kothapet	KT	3.6	32.9	17.5	8.5	6.1
11	Ameerpet	AT	67.8	20.5	5.3	2	1.4
12	Banjara Hills	BH	22.9	46.8	25.7	33	9.2
13	Gandhinagar	GN	48.9	26.7	24.8	20.7	4.8
14	LB Nagar	LN	42.2	30.8	33.8	25.9	16.5
15	Malkajgiri	MJ	39.1	31.1	23.3	20.6	11.2
16	Hitech city	HC	22.1	41.6	15.9	3.7	3.1
17	Bhuvanagiri	BG	3.7	12.5	3.4	0.9	0.5
18	Ghatkesar	GS	11.8	4.2	3.4	3.7	2.4
19	Bhanur	BR	0.5	2.5	0.8	0.5	3.2
20	Moinabad	MB	10.9	0.7	1.6	2.4	0.4
21	Rama Chandra Puram	RCP	7.2	17.2	13.4	6.1	7
22	Shivampet	SP	1.1	0	0	0.2	0.15
23	Sangareddy	SR	11.7	8.5	4.5	5	1.5
24	Wargal	WL	1.2	0.9	0	0.6	0.4
25	Domara Pocham Pally	DPP	0.8	3.3	0.3	0.7	0.9
26	Sitharampuram	SM	0.6	1.2	2.6	2.2	3.8
27	Kothur	KR	2.9	0.3	0.8	0.4	0.5
28	Golkonda Khurd	GK	0.1	0	0.3	0.1	0.6
29	Thummaloor	TR	0.1	0.2	0.2	0.2	1.4
30	Ibhrahimpatnam	IBM	16.6	0.6	0.6	2.3	0.4

scores of each location at different radius were obtained and is presented in Table 1.

4.2 Evaluation of level of accessibility

The weighted scores presented in Table 1 were used to calculate the Mean Weighted Accessibility Index (MWAI)

Table 2 Categorization of the level of accessibility

Mean weighted accessibility index (MWAI)	Level of accessibility
0–10	Minimum accessibility
11–20	Moderate accessibility
21–30	Maximum accessibility

for different locations. The MWAI is the average of the weighted scores of the opportunities at each location in different radii. The level of accessibility of different locations can be categorized into minimum accessibility, moderate accessibility and maximum accessibility based on the MWAI value. The categorization for evaluation of accessibility is presented in Table 2. The level of accessibility of each location is evaluated based on the MWAI value and is presented in Table 3.

The level of accessibility for thirty locations is presented in Table 3. The locations within the category of minimum accessibility have to be considered for the improvement of accessibility. The transportation planners can try to implement better planning practices in order to improve the level of accessibility in those locations of minimum accessibility. The locations which fall in the category of minimum and moderate accessibility has to be considered

Table 3 Level of accessibility of different locations

S. no.	Location	Abbreviation	mwai value	Level of accessibility
1	Abids	AB	19.82	Moderate accessibility
2	Kukatpally	KP	16.66	Moderate accessibility
3	Mehadipatnam	MP	20	Moderate accessibility
4	Dilshuknagar	DN	22.68	Maximum accessibility
5	Secundrabad	SC	16.78	Moderate accessibility
6	Panjagutta	PG	17.56	Moderate accessibility
7	Jeedimetla	JM	10.43	Moderate accessibility
8	Sikenderguda	SG	6.1	Minimum accessibility
9	Nadergul	NG	2.02	Minimum accessibility
10	Kothapet	KT	13.72	Moderate accessibility
11	Ameerpet	AT	19.4	Moderate accessibility
12	Banjara Hills	BH	27.52	Maximum accessibility
13	Gandhinagar	GN	25.18	Maximum accessibility
14	LB Nagar	LN	29.99	Maximum accessibility
15	Malkajgiri	MJ	25.06	Maximum accessibility
16	Hitech city	HC	17.28	Moderate accessibility
17	Bhuvanagiri	BG	4.2	Minimum accessibility
18	Ghatkesar	GS	5.1	Minimum accessibility
19	Bhanur	BR	1.5	Minimum accessibility
20	Moinabad	MB	3.2	Minimum accessibility
21	Rama Chandra Puram	RCP	10.18	Moderate accessibility
22	Shivampet	SP	0.29	Minimum accessibility
23	Sangareddy	SR	6.24	Minimum accessibility
24	Wargal	WL	0.62	Minimum accessibility
25	Domara Pocham Pally	DPP	1.2	Minimum accessibility
26	Sitharampuram	SM	2.08	Minimum accessibility
27	Kothur	KR	0.98	Minimum accessibility
28	Golkonda Khurd	GK	0.22	Minimum accessibility
29	Thummaloor	TR	0.42	Minimum accessibility
30	Ibhrahimpatnam	IBM	4.1	Minimum accessibility
Accessibility Index of the Hyderabad city			11.01	Moderate accessibility

Table 4 Region wise average trip attraction rates (attraction rates per day/100 sq m). *Source*: Report on Data Compilation and Statistical Analysis, Consultancy services for Comprehensive Transportation Study (CTS) for Hyderabad Metropolitan Area (HMA) [15]

Ameerpet, Banjara Hills	Secundrabad	Gandhinagar, Abids	L.B. Nagar, Malkajgiri	Kukatpally, Hitech city
256	812	305	440	580

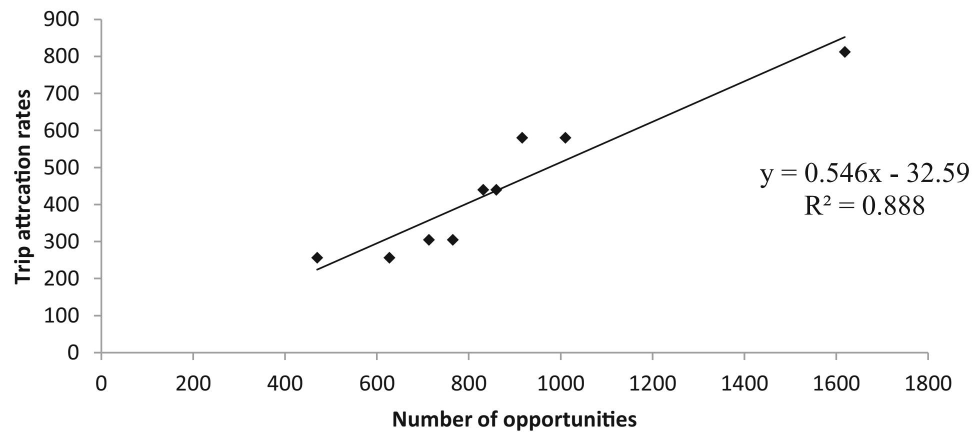

Fig. 5 Correlation between the number of opportunities and trip attraction rates

for the improvement to make the opportunities more accessible to the people. The accessibility index for the Hyderabad city as a whole is '11.01' which falls within the category of "Moderate Accessibility".

4.3 Correlation analysis

Based on the activity densities, nine locations were selected to study the impact of the number of opportunities on trip attraction rates. The total number of opportunities obtained at each location at different radius is correlated with trip attraction rates to know the relationship between these variables using correlation and regression analysis.

Trip attraction rate is the major parameter for traffic impact assessment studies. Trip generation rates are influenced by numerous factors including service type, size, accessibility to public transport, and catchment serving. The trip attraction rate was obtained by summing up the total number of visitors including the employees attracted towards the different opportunities during a working day and expressed in terms of attractions per 100 square meters of the gross floor area of the opportunity. The trip attraction rates for the selected locations are presented in Table 4.

The correlation between the number of opportunities and trip attraction rates is presented in Fig. 5. The scatter plot drawn between the number of opportunities in X-axis and Trip attraction rates in Y-axis shows a positively linear correlation between the parameters with an R^2 value of 0.888. This indicates that as the number of opportunities increases, the trip attraction rate also increases thereby the accessibility index also increases. This explains that there is a need to balance the opportunities (or) urban services at different locations in order to optimize the accessibility of the city.

5 Conclusions

This study has illustrated a methodology for estimation and evaluation of city—level accessibility based on different opportunities and distances. The weights were given to different opportunities with first preference to an emergency, second to education and then the remaining services. The level of accessibility in different locations of the study area is determined to understand the performance of the road network structure in terms of accessibility in a particular location. The regression analysis tried to analyze the impact of the number of opportunities on the trip attraction rates indicating "As the number of opportunities at a particular location increases, the trip attraction rates also increases thereby increasing the accessibility index." This study established the accessibility based performance standards for different locations of Hyderabad city and also for the city as a whole. The study area falls under the category of "Moderate Accessibility" which indicates that there is a need to improve the level of accessibility of the transport network structure in the entire city. The study also tried to categorize the level of accessibility in different locations of the study area based on the Mean Weighted

Accessibility Index (MWAI). The methodology proposed in this study may be used for different urban cities to evaluate the level of accessibility in the city. This study serves the decision-makers with a representation of relative accessibility of key opportunities at a given location within a specified radius. This accessibility analysis will be assisting the people for more available transport choices to establish better connectivity of different locations and providing convenience to different services. It can also be helpful in achieving viable goals like minimization of long-distance traveling, build-up low carbon transport and travel emissions diminishment. The policy-makers can now decide to bring out policies that can create a balance in providing the number of opportunities at different locations. This study also helps the urban transportation planning authorities to analyze the situations at different locations of the study area in order to optimize the level of accessibility in the study area. This study tried to prove the efficiency of the Geographical Information Systems software (ArcGIS 10.1) in the assessment and evaluation of transport network accessibility. The integration of GIS made the study more viable and reliable which helped in better decision making.

Compliance with ethical standards

Conflict of interest The authors declare that there are no potential conflict of interest.

References

1. Hansen, W. (1959). How accessibility shapes land use. *Journal of the American Institute of the Planners, 25,* 73–76.
2. Dalvi, M. Q., & Martin, K. M. (1976). The measurement of accessibility: Some preliminary results. *Transportation, 5,* 17–42.
3. Burns, L. D. (1979). *Transportation, Temporal and Spatial Components of Accessibility*. Lexington: Lexington Books.
4. Avika, B., & Lerman, (1977). Disaggregate travel and mobility choice models and measures of accessibility. In Hensherd & P. Stopher (Eds.), *Behavioural travel modelling* (pp. 654–679). London: Croom Helm.
5. Mackiewicz, A., & Ratajczak, W. (1996). Towards a new definition of topological accessibility. *Transportation Research Part B, 30*(1), 47–79.
6. Ahmed, G. M. E. I., & Levinson, M. D. (2006). *Access to destinations: Development of accessibility measures*. Minnesota: In research report published by Minnesota Department of Transportation.
7. Wu, Y. H., & Miller, H. J. (2002). Computational tools for measuring space-time accessibility within transportation networks with dynamic flow. *Journal of Transportation Statistics, 4*(2/3), 1–14.
8. Bhat, C., Handy, S., Kockelamn, K., Mahmassani, H., Chen, Q & Weston, L., (2002). Urban accessibility index: Literature review. Research Report TX 01/7-4938-01, Texas Department of Transportation, TX.
9. Ingram, D. R. (1971). The concept of accessibility: A search for an operational form. *Regional Studies, 5,* 101–107.
10. Handy, S. L., & Niemeier, D. A. (1977). Measuring accessibility: An exploration of issues and alternatives. *Environment and Planning A, 29,* 1175–1194.
11. Liu, C., & Yu, R. (2012). Spatial accessibility of road network in Wuhan metropolitan area based on spatial syntax. *Journal of Geographic Information System, 4,* 128–135.
12. Weiping, H., & Chi, W. (2014). Urban road network accessibility evaluation method based on GIS spatial analysis techniques. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *38* Part II, 114–117.
13. Ford, A. C., Barr, S. L., Dawson, R. J., & James, P. (2015). Transport accessibility analysis using GIS: Assessing sustainable transport in London. *ISPRS, International Journal of Geo Information, 4,* 124–149. https://doi.org/10.3390/ijgi4010124.
14. Modinpuroju, A., Prasad, C. S. R. K., & Chandra, M. (2016). Facility-based planning methodology for rural roads using spatial analysis techniques. *Innovative Infrastructure Solutions, 1,* 41. https://doi.org/10.1007/s41062-016-0041-8.
15. Report on Data Compilation and Statistical Analysis, Consultancy services for Comprehensive Transportation Study (CTS) for Hyderabad Metropolitan Area (HMA).

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