GIS-Based Walking Map Isochrones in Measuring Transit Catchment: A Spatial Approach to Urban Accessibility

Maisarah Abdul Halim [1,2], Bor Tsong Teh [2], Nur Aulia Rosni [2]

[1] Faculty of Built Environment, Universiti Teknologi MARA, Shah Alam, Malaysia – maisarahhalim@uitm.edu.my
[2] Centre for Sustainable Urban Planning & Real Estate (SUPRE), Faculty of Built Environment, Universiti Malaya, Malaysia – tehbortsong@um.edu.my, nurauliarosni@um.edu.my

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Abstract

Transit accessibility is an important element of sustainable urban mobility and is often assessed in transit-oriented development (TOD) design using fixed-distance radial buffers. These methods however tend to oversimplify real-world accessibility by assuming straight-line movement and ignoring physical barriers. This study uses a GIS network-based isochrone method to improve the delineation of transit station catchment regions and examines the effect of the method on accessibility analysis. Walking isochrones of 5, 10 and 15 minutes were used for selected rail transit stations in Klang Valley, Malaysia using open-source geospatial data as well as open-source tools such as QuickOSM and QNEAT3. These were compared with the regularly used standard Euclidean radial buffers of 400 m, 800 m and 1500 m. Within each delineation, we assessed spatial indicators that are catchment area size, population coverage and land use mix. Results show that radial buffers consistently overestimate or occasionally underestimate accessible areas, resulting in inaccurate estimation of catchment area, population coverage or land-use diversity. Catchments based on isochrones tend to be smaller, less regular in shape and more vulnerable to changes in roadway connectivity and physical barriers. These results indicate that relying on radial buffers might lead to false perceptions of transit accessibility and service coverage. This study may guide other cities in more accurate transit accessibility planning using open-source data and replicable GIS techniques. The suggested approach improves the accuracy of service catchment analysis and enables a more context-aware TOD design.

1. Introduction

As urban populations grow, major cities worldwide face increased pressure to enhance public transportation systems that are both efficient and accessible. A crucial factor in public transport effectiveness is its accessibility from surrounding transportation systems such as rail or bus stations that are within walking distance. Official documents such as transit-oriented development (TOD) development guidelines tend to create service area using circular Euclidian buffers around transit stations. This fails to capture real-world walking paths and barriers.

1.1 Background

Transit-Oriented Development (TOD) is a planning approach that promotes compact, mixed-use, and pedestrian-friendly development surrounding public transportation nodes. The major purpose of TOD is to increase public transit and reduce dependence on private automobiles that may contribute to more sustainable urban development. The TOD principles typically stress high-density development, mixed land uses, improved pedestrian access and greater connectivity between transit systems and neighbouring urban areas.

Many catchment analyses overlook pedestrian network constraints, leading to overestimation of accessibility and potentially incorrect planning outcomes. There is a crucial need to refine transit accessibility assessment through pedestrian-oriented models. This study aims to delineate accurate pedestrian-based transit catchment areas using open-source GIS-based isochrones, comparing walking-based catchments with traditional buffer method and assessing the spatial distribution of land use mix, population and catchment area within the walkable zones. This research is able to answer questions on how walking-based and Euclidean methods differ in capturing the spatial extent of transit station catchments.

1.2 Literature Review

Transit catchment areas are the geographic areas from which a public transportation station is likely to be reached (Sunoto & Ponrahono, 2019). They are often used in transportation planning to assess accessibility, estimate prospective ridership, and inform transit-oriented development (TOD) policies. Traditionally, transit catchment areas are defined as fixed-distance radial buffers, typically between 400 and 800 metres. This usually means region they can walk to in around 5 to 10 minutes time (Barton et al., 2021). This also assumes the willingness of commuters to walk to these distances to reach public transport facilities.

The Malaysian TOD guideline separates the ridership expectations into the distance groups where the demand from buses is projected to increase from the lowest in its core 400 m zone, increasing when going up to the primary and the highest in the final secondary zone. These zones are 0 to 400 meters, 400 meters to 800 meters and 800 meters to 1.5 km accordingly as shown in Figure 1 (PLANMalaysia, 2018). This approach is popular due to its simplicity and convenience of use and application in planning guidelines and policy frameworks. The simple radial or Euclidean buffering methods are commonly adopted but have significant drawbacks. Euclidean buffers suggest free travel along straight lines between origin and destination and ignore the complexity of actual environment. Walking is confined in actual terms by physical barriers, gated developments, crossings and the presence of pedestrian infrastructure, such as pavements and zebra crossings.

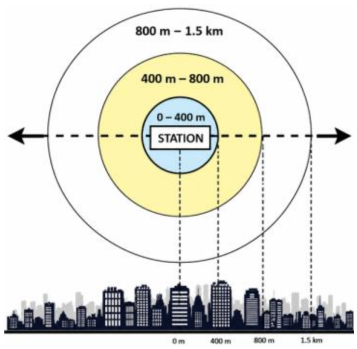

Figure 1. Malaysian TOD Transit Area of Influence (PLANMalaysia, 2018)

Several studies (Ab Majid et al., 2021; Ruslan et al., 2023) have found that accessibility is influenced not just by distance but also by the connectivity of surrounding built environment. Some of the important factors affecting the commuters are street network density, pedestrian connectivity, land use mix and availability of walkable infrastructure. Accessibility and transit usage are often higher in areas with integrated roadway networks and mixed land uses (Aston et al., 2021). Low accessibility is often related to areas with a fragmented road system or insufficient pedestrian infrastructure.

Isochrone analysis has been widely used in transport and urban studies to evaluate accessibility to public transport facilities, health care services, commercial centres and other urban facilities (O'Sullivan et al., 2000; Panjaitan, 2025). In transit studies, walking isochrones are commonly generated using time intervals of 5, 10 or 15 minutes, which are considered as realistic pedestrian access to transit stations. It has been shown that the shapes and extents of isochrone-based catchment areas are significantly different from radial buffers, especially in areas with irregular street networks or physical barriers. This indicates that the conventional buffer methods may inaccurately represent the actual population and land uses accessible to transit stations.

In Malaysia, transit-oriented development is an essential component in urban planning plans, especially in Klang Valley where rail transport networks are currently being expanded. PLANMalaysia's national TOD planning standards focus on transit influence zones around stations and the need to increase pedestrian accessibility and bus services. But the key to success of TOD is to correctly identify those places that are accessible to commuters. The use of normal radial buffers may result in an over-simplification of accessibility criteria and ignore spatial disparities in pedestrian access.

Accurate delineation of transit catchment areas through GIS-based walking isochrones can therefore support more effective TOD planning. Planners can then use this information to target underserved areas with poor connections for interventions such as upgrading pedestrian infrastructure, modifying bus routes, and modifying land uses. In this sense, the integration of walkability research with TOD planning provides useful insights into how urban surroundings can better support sustainable mobility and improve access to public transit systems.

2. Study Area and Methodology

The study area is located in Petaling Jaya, Selangor. It is a developed urban municipality in Klang Valley, Malaysia. The investigation is centred on the three rail transit stations along the Kelana Jaya Line of the rail network, that is Taman Paramount (KJ22), Asia Jaya (KJ21) and Taman Jaya (KJ20) as shown in Table 1.

Station	Station Name
KJ22	Taman Paramount
KJ21	Asia Jaya
KJ20	Taman Jaya

Table 1. Study Area

These stations are located in a heavily urbanized area with mixed land uses, established residential neighbourhoods and strong commercial activity. Petaling Jaya is a well-developed urban area with a relatively high population density, a large road network and a diversity of land use. As such, it is a suitable case for studying pedestrian accessibility and transit catchment delineation in a mature transit-oriented development (TOD) setting.

2.1 Methodology

The QNEAT3 plugin in QGIS was used to outline walking catchments for the specified transit stops. This analysis was performed to establish realistic pedestrian accessible zones around each station based on actual walking routes, rather than linear distance measures. In Table 2, data for official documents were retrieved from the Malaysian Open Data and PlanMalaysia. The analysis method is based on the configuration of the road and pedestrian network versus standard Euclidean radial buffers, so that the catchment areas better reflect real-world walking accessibility.

Data	Source
Population	Malaysia Open Data
Land Use	PlanMalaysia
Road Network	OpenStreetMap

Table 2. Data Source

The pedestrian network used in this study was created based on OpenStreetMap (OSM) road network data and imported into QGIS for network analysis using QuickOSM. Prior to the investigation, network data were verified and prepared to verify the right connectivity between road segments. Where applicable, road segments where pedestrian mobility is not possible such as highways or impassable ways were excluded. The network layer was projected into a coordinate reference system so that precise distance and area estimates could be made. Figure 2 below displays extracted road map overlaying the base map.

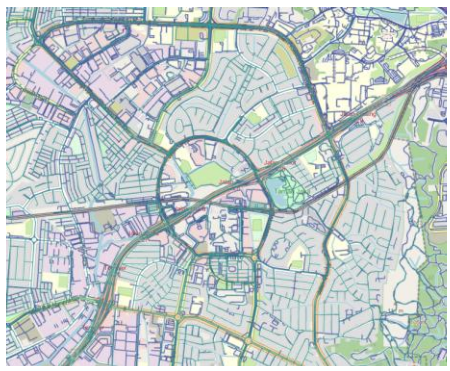

Figure 2. Road data retrieved from QuickOSM

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The locations of the selected rail stations were prepared as point features and used as origin points for the isochrone analysis. Walking isochrones were generated using the "Iso-Area as Polygon (from Layer)" function available in the QNEAT3 plugin. A standard pedestrian walking speed of 5 km/h was applied throughout the analysis to represent average walking conditions. Three walking thresholds were generated for each station, namely 5-minute, 10-minute, and 15-minute walking catchments. The corresponding travel costs were defined in seconds, where 5 minutes equals 300 seconds, 10 minutes equals 600 seconds, and 15 minutes equals 900 seconds. The generated polygons represent the maximum spatial extent reachable from each station within the specified walking durations using the existing pedestrian network.

Following the delineation process, the resulting isochrone polygons were used for further spatial analysis. The coverage area of each catchment was calculated in square kilometres, and the estimated population within the catchments was assessed using proportional area-based population allocation techniques. This method was adopted due to the limitations in obtaining highly detailed population data at finer spatial scales. The estimation was conducted by calculating the proportion of the administrative population unit that intersects with the walking isochrone catchment area and then allocating the population proportionally based on the area overlap. The approach assumes that population is uniformly distributed within each administrative boundary.

The entropy index, commonly referred to as land use mix, is based on Song et al. (2013). The entropy index approach usually applied in urban and transport planning studies to measure the diversity and distribution of land use categories within a defined catchment area. The value ranges from 0 to 1. Values approaching 0 indicate homogenous land use patterns dominated by a single land use category, while values approaching 1 indicate a more balanced and diverse distribution of land uses.

The isochrone catchments were next compared with conventional Euclidean radial buffers commonly used in transit-oriented development (TOD) planning to evaluate the differences between distance-based accessibility and actual network-based pedestrian accessibility. This was done using the buffer tool for 400 meters, 800 meters, and 1500 meters. As shown in Figure 3, the sample 5-minute walk and typical 400 meters buffer show a substantial difference in area that are 0.502 km^2 and 0.197 km^2 for buffer and isochrone respectively.

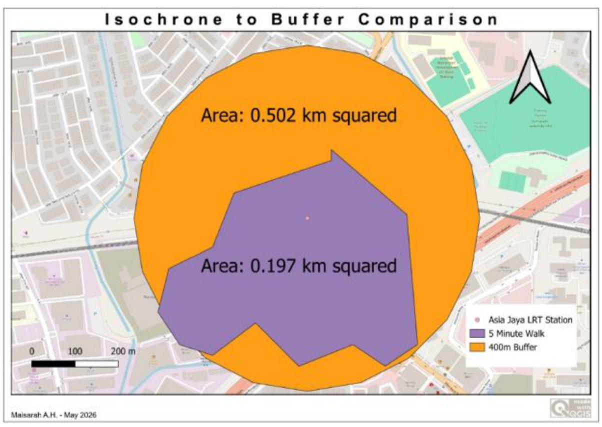

Figure 3. Isochrone to Buffer Comparison.

3. Results

Comparative assessments were made based on total catchment area, percentage differences including land use mix and population distribution. These findings provide insights into the feasibility of alternative catchment delineation methods for transit accessibility analysis and service catchment planning in a transit-oriented development (TOD) setting.

3.1 Catchment Area Coverage

Table 3 shows the coverage areas of selected rail transit stations determined by standard radial buffer catchment delineation. The results reveal that the catchment coverage area is proportional to the buffer distance, where the 400 m, 800 m, and 1500 m buffers for KJ21 (Asia Jaya) are 0.502 km^2, 2.010 km^2, and 7.062 km^2, respectively. The increase in coverage area with increased buffer distance is due to the geometric nature of Euclidean buffers that presume uniform accessibility in all directions from the station centroid. Similar patterns were seen for the other stations, whereby increased buffer distances result in much broader catchment extents. These results illustrate the quick expansion of the estimated service coverage area when using radial buffers independent of the real conditions of the pedestrian network or physical limits on accessibility.

Catchment Area	Station	Coverage Area (km^2)
400m Radial Buffer	KJ22	
	KJ21	0.502
	KJ20	
800m Radial Buffer	KJ22	
	KJ21	2.010
	KJ20	
1500m Radial Buffer	KJ22	
	KJ21	7.062
	KJ20	

Table 3. Buffer Coverage Area

Table 4 shows the coverage areas obtained by network-based walking isochrones and the differences compared to radial buffers. The results show that all walking isochrone catchments had less coverage area than their respective radial buffers. For the 5-minute walking isochrone, coverage areas ranged from 0.197 km^2 to 0.420 km^2, corresponding to decreases of 16.3% to 60.8% relative to the 400 m radial buffers. Similarly, the coverage areas of 10-minute walking isochrones ranged from 0.697 km^2 to 1.444 km^2, 28.2% to 65.3% smaller than the corresponding 800 m radial buffers.

Catchment Area	Station	Coverage Area (km^2)	Difference to Radial Buffer (%)	Interpretation
5 Minutes Walk	KJ22	0.420	-16.3	Smaller
	KJ21	0.197	-60.8	Smaller
	KJ20	0.343	-31.7	Smaller
10 Minutes Walk	KJ22	1.444	-28.2	Smaller
	KJ21	0.697	-65.3	Smaller
	KJ20	0.891	-55.7	Smaller
15 Minutes Walk	KJ22	3.249	-54.0	Smaller
	KJ21	1.872	-73.5	Smaller
	KJ20	2.036	-71.2	Smaller

Table 4. Isochrone Coverage Area

The highest changes occurred for the 15-minute walking isochrones, where the coverage areas ranged from 1.872 km2 to 3.249 km2, or reduced from 1500m radial buffers of 54.0% to 73.5%. For all thresholds of catchment, KJ21 showed the highest percentage of reduction among the considered stations, which suggests that the differences between theoretical accessibility (Euclidean) and real accessibility (network-based for pedestrians) are significant. These results imply that traditional radial buffers can significantly overstate transit catchment coverage by not accounting for street network layouts, pedestrian routes and physical movement impediments. Walking isochrones, however, give a more accurate picture of the areas that can be reached in a reasonable walking time.

3.2 Estimated Population

Table 5 illustrates the expected population coverage within the standard radial buffer catchment areas around the selected rail transit stations. The results suggest that the overall population collected within the catchment areas grows significantly with higher buffer lengths. The population of the 400 m radial buffer was estimated to be 3,307 people, which rose to 13240 persons in the 800 m buffer and further to 46517 persons in the 1500 m buffer. These values may not truly reflect the actual residential concentration patterns as it is just assuming a uniform population distribution. Due to the difficulty of acquiring finer-scale population data at the neighbourhood or census block level, all stations considered were based on the same administrative-level population information. Therefore, the parameters of population distribution were similar among the stations in the same administrative boundaries. Although this limitation could limit the spatial accuracy of population representation at the station level, the dataset can still be useful to indicate, in general terms, the concentration of population at the different catchment scales. Future studies using better resolution population datasets, such as gridded population surface or building-level residential occupancy data, could further enhance the accuracy of the transit accessibility study.

Catchment Area	Station	Population
400m Radial Buffer	KJ22	3307
	KJ21	
	KJ20	
800m Radial Buffer	KJ22	13240
	KJ21	
	KJ20	
1500m Radial Buffer	KJ22	46517
	KJ21	
	KJ20	

Table 5. Buffer Estimated Population

Table 6 shows the estimated proportional population based on isochrones network calculation. The percentage differences found in the population analysis closely reflect the values found in the catchment coverage area analysis. The similarity in the values is mainly due to the use of demographic statistics at the administrative level with a rather homogeneous population distribution in the research area. The projected population values were proportionally distributed according to the spatial extent of each catchment. This means that smaller walking isochrone coverage regions had lesser population estimates than the larger Euclidean radial buffers, naturally. This implies that the fall in estimated accessible population was mostly due to the loss in coverage of catchment area and not due to major fluctuation in localized population density.

Catchment Area	Station	Population	Difference to Radial Buffer (%)	Interpretation
5 Minutes Walk	KJ22	2766.54	-16.3	Smaller
	KJ21	1297.639	-60.8	Smaller
	KJ20	2259.341	-31.7	Smaller
10 Minutes Walk	KJ22	9511.628	-28.2	Smaller
	KJ21	4591.139	-65.3	Smaller
	KJ20	5869.017	-55.7	Smaller
15 Minutes Walk	KJ22	21401.16	-54.0	Smaller
	KJ21	12330.86	-73.5	Smaller
	KJ20	13411.13	-71.2	Smaller

Table 6. Isochrone Estimated Population

3.3 Land Use Mix

Table 7 shows the land use mix values using the Entropy Index within the traditional radial buffer catchment regions around the selected rail transport stations. Different amounts of land use variety were found among the analysed stations and catchment thresholds. The results indicated that the overall entropy values ranged from 0.338 to 0.631, indicating that the land use mix in the station catchments varied moderately. For all the buffer distances inside the analysed stations, KJ21 had the highest entropy values, with values of 0.599, 0.631 and 0.585 correspondingly at the 400 m, 800 m and 1500 m buffers. These results suggest a relatively good mix of land uses around the station with a wide mix of land uses. On the other hand, KJ22 showed the lowest entropy values, particularly in the 400 m buffer (0.338), which means more homogenous land use composition with fewer land use categories dominating the area.

The results also show that the land use mix does not necessarily expand proportionally with greater catchment regions. For example, the entropy value for KJ22 grew from 0.338 inside the 400 m buffer to 0.444 within the 1500 m buffer. Whereas KJ20 showed a little drop in entropy values with the expansion of the catchment. This indicates the existence of other dominating land uses in bigger catchment regions that diminish the general balance of land use distribution.

Results show that various station sites exhibit varying degrees of land use diversity that may impact pedestrian activity and accessibility within the surrounding transit catchments.

Catchment Area	Station	Entropy Index
400m Radial Buffer	KJ22	0.338
	KJ21	0.599
	KJ20	0.555
800m Radial Buffer	KJ22	0.361
	KJ21	0.631
	KJ20	0.546
1500m Radial Buffer	KJ22	0.444
	KJ21	0.585
	KJ20	0.523

Table 7. Buffer Entropy Index

Table 8 displays the land use mix values for the network-based walking isochrone catchment regions and their percentage variations from the corresponding Euclidean radial buffers. The results of the entropy index, as opposed to the coverage area and population assessments, did not present a consistent pattern of reduction inside the walking isochrones. Alternatively, rises and declines of land use mix were seen across stations and catchment limits.

Catchment Area	Station	Entropy Index	Difference to Radial Buffer (%)	Interpretation
5 Minutes Walk	KJ22	0.361	6.8	Larger
	KJ21	0.559	-6.7	Smaller
	KJ20	0.592	6.7	Larger
10 Minutes Walk	KJ22	0.389	7.8	Larger
	KJ21	0.613	-2.9	Smaller
	KJ20	0.606	11.0	Larger
15 Minutes Walk	KJ22	0.382	-14.0	Smaller
	KJ21	0.572	-2.2	Smaller
	KJ20	0.539	3.1	Larger

Table 8. Isochrone Entropy Index

The entropy values for KJ22 and KJ20 were marginally higher for the 5-minute walking isochrones than for the comparable 400 m radial buffers, increases of 6.8% and 6.7%, respectively. In comparison, the entropy value of KJ21 decreased by 6.7%. Similar trends were seen for the 10-minute walking isochrones, where KJ22 and KJ20 increased by 7.8% and 11.0% respectively and KJ21 decreased slightly by 2.9%.

The 15-minute walking isochrones produced more distinct results. KJ20 showed a little rise of 3.1% compared to the 1500 m radial buffer, while KJ22 and KJ21 showed decreases of 14.0% and 2.2% respectively. These results suggest that network-based isochrones may represent different land use compositions than Euclidean radial buffers due to the impact of actual pedestrian accessible routes and street network topologies. The results show that walking isochrones may tend to yield smaller catchments but potentially capture more concentrated or balanced combinations of land uses along accessible pedestrian pathways. In contrast, radial buffers consider all land uses within a set geometric distance, independent of actual accessibility. Therefore, the use of network-based walking isochrones can provide a more realistic picture of the land use contexts encountered by pedestrians reaching transit stations.

3.4 Conclusion

In conclusion, walking isochrones provide a more realistic alternative to standard radial buffers for accessibility analysis. An isochrone is the region that can be reached from a specific point within a given journey time, taking into account the real transit or pedestrian network. Isochrone analysis, unlike Euclidean buffers, accounts for actual routes used and allows researchers and planners to estimate accessibility based on actual movement and network conditions.

In addition, isochrone analysis allows for the incorporation of built environment variables into accessibility studies. Variables such as land use mix, population density, building footprint density, pedestrian connectivity, and points of interest (POIs) can be spatially examined within service regions to better understand their link with transit utilization. Walking isochrones are particularly useful for fast-urbanizing areas, where there are big differences in the urban form and pedestrian accessibility of neighborhoods. GIS-based isochrone analysis can help in making better planning decisions, enhance evaluation of transit service coverage, and lead to more sustainable and inclusive urban transport systems through a better depiction of actual walking accessibility.

This study showed that GIS-based walking isochrone analysis may be successfully used to designate transit catchment regions around rail transit stops. The results consistently demonstrated that the walking isochrone catchments were much lower than the equivalent radial buffers for most stations and all walking durations. These discrepancies suggest that radial buffering techniques tend to overstate the actual accessible space and population around transit stops, as they presume that people may travel freely in all directions on foot. In contrast, the walking isochrone technique considers street connectivity and movement limits, offering a more realistic perspective of pedestrian accessibility in metropolitan settings. The methodology established in this study can be a valuable basis for future studies on urban transport and accessibility incorporating network-based spatial analysis in general.

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