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Assessing the Level of Spatial Integration of Surabaya City Public Transportation

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***Abstract*—This research investigates the integration of public transportation services in Surabaya City, focusing on the Suroboyo Bus and its feeder lines. Using spatial assessment techniques and graph theory, the study evaluates Node Connectivity (NC), Line Connectivity (LC), and Transfer Center Connectivity (TCC) index across 18 zones. Results show significant disparities in connectivity levels, with zones along the *North-South* corridor through central Surabaya consistently demonstrating high integration. In contrast, zones along the eastern ring road and the northeastern part of Surabaya show poor integration, revealing critical areas needing improvement. Factors such as zone density and the number of transit nodes influence these outcomes, underscoring the importance of balanced service distribution. The study emphasizes the necessity for future research to address imbalances and improve the overall efficiency of Surabaya City's public transportation network.**

***Keywords*—Spatial Integration, Public Transportation, Connectivity, Suroboyo Bus, Wira-wiri**

I. INTRODUCTION

One way to improve public transit service and reduce the number of vehicles in big cities is to develop integrated public transit systems. Integrated public transportation can provide customers with more options and lower costs, allowing public transportation to compete with private vehicles for city residents. Effective and sustainable urban public transportation may provide an alternative means to move around a city [1].

Surabaya City's existing public transportation system has various integration issues. Suroboyo Bus, Wira-wiri, Trans Jatim, and Angkot are Surabaya City's current public transit options. Suroboyo Bus has been an inner-city bus service since 2018, and it currently operates on four routes. Wira-wiri is a feeder transport system designed to serve as a feeder for Suroboyo Bus. Meanwhile, Angkot (Angkutan Kota) is an older transit service in Surabaya. Prior to the introduction of Suroboyo Bus and Wira-wiri, Angkot was the primary mode of transit in Surabaya, with over 50 routes [2]. Angkots are typically minivans or small buses painted with various colors and routes, making them easily recognizable. These vehicles operate along specific routes within a city, picking up and dropping off passengers along the way. Angkot usually follow fixed routes, but it can also be flagged down to stop anywhere along its path. Suroboyo Bus has received a negative response from Angkot drivers due to overlapping routes [3]. This creates competition between Suroboyo Bus and conventional Angkot services. The minimum average headway for Suroboyo Bus is 16.3 minutes [4]. Integration between modes of transportation, such as Suroboyo Bus and conventional angkot services as a feeder, has not been successful resulting in an indistinct division of routes and service areas [5].

In Surabaya, the lack of effective integration and socialization between different public transportation services has led to several challenges. Passengers often face difficulties in transferring between different modes of transport due to the lack of coordinated schedules and physical connectivity. Even today, many Surabaya residents mistakenly believe that commuting with the Suroboyo Bus ***still*** requires bringing plastic bottles. This misinformation adds to the inconvenience, further discouraging the use of public transport.

The absence of fare integration exacerbates these issues, as passengers are required to purchase separate tickets for different transit services. This problem is further complicated by the lack of institutional integration in Surabaya, with different authorities overseeing Suroboyo Bus, Trans Semanggi, and Wira Wiri services. This fragmentation hinders the development of a cohesive and efficient public transportation system. Additionally, the lack of comprehensive information about transit services further complicates the experience for passengers. Without access to clear and accurate information about routes, schedules, and fares, passengers find it challenging to use public transit.

Public transportation integration can facilitate intermodal (trips using two or more modes of transportation) and multimodal (trips that use different forms of transportation for different purposes). The integration of public transportation can benefit both passengers and providers. Several research on methods and indicators have been conducted in an attempt to quantify and evaluate the extent of integration and its influence on public transportation. For example, a calculation was proposed for determining the level of integration in public transportation system planning [6]. Another methodology employs a heuristic modeling approach based on existing public transportation networks and implementation plans [7]. Additionally, the accessibility of bicycle modes in public transit locations as a means of integration has been investigated [8]. The educational backgrounds of users of an integrated public transportation system were also assessed [9]. In general, transportation integration in urban settings can take several shapes and sorts. This research focuses on using spatial

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assessment-based integration to analyze the level public transit integration in Surabaya.

The concept of public transit integration encompasses various dimensions, including physical integration, fare integration, information integration, and institutional integration [6]. Physical integration refers to the infrastructure to ensure seamless transfer between different modes of transport. Fare integration involves the harmonization of fare systems across different transit services, enabling passengers to use a single ticket for multiple modes. Information integration ensures that passengers have access to comprehensive and real-time information about different transit services, schedules, and routes. Institutional integration involves the coordination and collaboration among different transit agencies and stakeholders to provide a unified and efficient transit system.

II. RESEARCH SIGNIFICANCE

Assessing an area's spatial integration value indicates how well the area is connected to public transit routes. As a user, the higher the integration value, the better access to other places via public transit. This research seeks to determine the value of spatial integration of public transit services across multiple zones in Surabaya. The identification results can be used to guide further improvements to increase the integration level of the public transit services. The distribution of integration values also reflects the quality of public transportation services.

III. METHODOLOGY

The assessment of the spatial integration of Surabaya City's public transportation network focuses on the existing services provided by the Suroboyo Bus and its associated feeder lines. This research is confined to zones along the Suroboyo Bus corridor, selected due to its significance as the primary route for daily commuters in Surabaya. This study uses a graph theory technique, which is a mathematical framework used to examine the relationships between various points (nodes) and the connections (edges) between them, this study assesses the network's integration [10], [11]. Spatial performance data, including travel times, fleet numbers, and speeds, are used to conduct this analysis.

A. Data Collection

This research utilized attribute data on transportation route characteristics. Data for the existing public transport system were collected through a primary survey, including information on three Suroboyo Bus routes and seven feeder lines. Zonal characteristics data were based on the Detailed Spatial Planning of Surabaya (RDTR Kota Surabaya 2018-2038), which includes land use and zoning plans. These data were used to classify Surabaya into several zones. The characteristics of these zones were important in calculating integration, as they are related to the attractiveness of land use within each zone.

Figure 1 presents a thematic map of Surabaya's existing public transport system. The 52-kilometer-long bus corridors connect key points across the city: UNESA in the west, ITS in the east, Terminal Purabaya in the south, and Jl. Rajawali in the north, as well as running along Surabaya's eastern ring road (MERR).

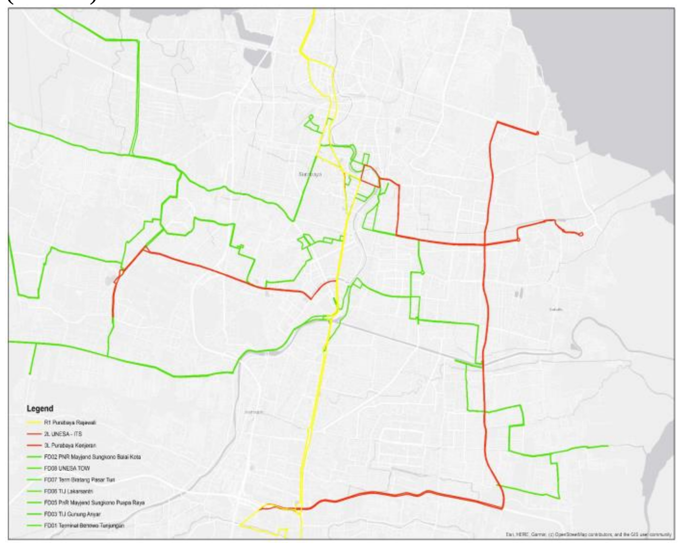

Figure 1 PT Services in Surabaya

B. Analysis

There are 18 zones formed, marked by serial numbers 1-18. The methodology used in this research is different at each level of the transportation system. Nodes, networks, and regions have unique formulations (NC, LC, and TCC). These calculations eventually serve as zone properties. Transit system nodes and links are aligned with connectivity assessment in graph theory.

a. Node Connectivity Index

A node's connectivity is defined as its total connecting strength based on all transportation routes (lines) that pass through it [11], [12]. Nodes are limited to transit points/bus stops.

$$P_{l,n}^{t} = \alpha C_l \times \beta V_l \times \gamma D_{l,n} \times A_{l,n} \qquad (1)$$

where P is total connecting power of Line “l” at node “n”, C is line capacity, V is the line average speed, D is distance, and A is the density of respective zone.

Zone density ($A_{l,n}$) is the ratio of activity centers inside each zone (public facilities, industries, commerce and services, offices, and warehouses). This number demonstrates how the zone may become an attraction (attraction zone) for public transit users. Scaling factor (α,β,γ) represents the scale factor for each variable. The scaling factor is expressed as the average inverse value.

b. Line Connectivity Index

Line's total connectivity index is the average number of total node connectivity across all nodes that pass through the line.

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Line connectivity index is defined as follows:

$$\theta_l = (|S_i| - 1)^{-1} \Sigma P_l^t \qquad (2)$$

where θ is connectivity index for Line "l", S is a set of stops in Line "l", and P is total connecting power of Line "l".

The zone's integration value contains the overall connectivity of all nodes and paths in that zone, which has been scaled based on the number of nodes to prevent computation inconsistencies caused by an unbalanced number of nodes in each zone.

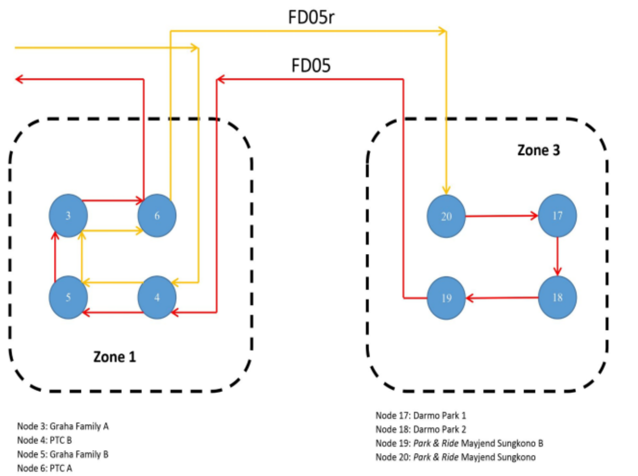

Figure 2 LC Calculation, Illustrated

Figure 2 illustrates the Line Connectivity (LC) calculation process. The Feeder Route FD05 is used in the LC calculation based on Equation (2). FD05 starts from the node Park and Ride Mayjend Sungkono and proceeds to node Darmo Park 1, Darmo Park 2, Mayjend Sungkono B, and exits Zone 3. FD05 does not pass through any nodes outside Zone 3. Subsequently, FD05 enters Zone 1 and passes through node PTC B, Graha Family B, Graha Family A, and PTC A. The node connectivity values at each node traversed by FD05 are accumulated and divided by the total number of nodes traversed to obtain the LC value for FD05. The same process applies to the return route (FD05r).

c. Transfer Center Connectivity Index

Transfer center is a group of nodes within a zone that are located at certain distance and are easily transferable between modes due to the availability of distance relations or walking time between these nodes. The transfer center assessment includes the Suroboyo Bus, Feeder service, Trans Jatim, and local train station considering that the transfer zone must be able to facilitate modal shift to and from bus service. The overall connectivity index of a zone with multimodal facilities is calculated by multiplying the average number of node connectivity in that zone by the reception rate.

The transfer center connectivity index seeks to capture how many passengers can be served in multimodal zones. The node connectivity formula is multiplied by the model $y = 1.3189 \exp^{-0.0872x}$, where the function y represents the number of passengers who can change modes at a walking time rate of x [11], [13]. This model is based on a case study from East Asia and has an R-square value of 0.9846. This suggests that the variable of walking time between nodes accounts for 98.46% of the reception rate of passengers going through the transfer zone.

$$\theta_{tc} = (|S_\omega| - 1)^{-1} \sum P_l^t \times (\rho_{n1,n}) \qquad (3)$$

where θ is connectivity index for transfer center, S is a set of stops within the transfer center, and P is total connecting power of Line "l". ρ (y) is reception rate.

IV. RESULTS

a. Node Connectivity Index

Figure 3 presents the results of the Node Connectivity (NC) index. Zones 8, 7, and 5 reveal the highest level of connectivity, with value of 126.57, 50.76, and 40.33 respectively, indicating dense networks of bus stops and high accessibility. Zone 4 also shows good connectivity with the value of 40.83. Moderate connectivity is observed in Zones 9 and 10, with 32.52 and 31.36.

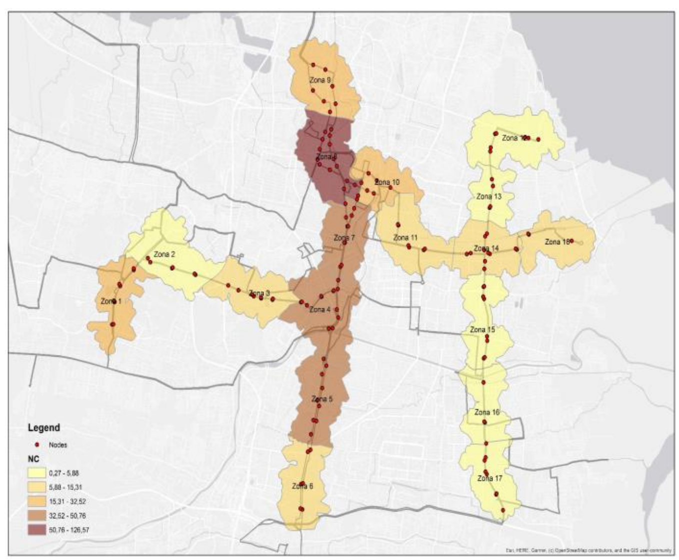

Figure 3 NC Results

Conversely, Zones 2, 14, and 3 show low connectivity with 5.88, 7.23, and 13.01. Zones 11, 15, and 17 show poor integration, while Zones 12 and 13 have the lowest connectivity with the value of 0.39 and 0.27, indicating significant network issues in these zones. These findings highlight areas needing targeted infrastructure and service

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upgrades to improve the overall public transportation network in Surabaya.

b. Line Connectivity Index

The Line Connectivity (LC) index measures the number of bus lines passing through a zone, without counting repetitions, and provides a spatial-based value when overlaid on the corresponding zone. Unlike the Node Connectivity (NC) index, which cumulatively calculates routes passing through nodes/zones multiple times, the LC index focuses on unique bus lines within a zone.

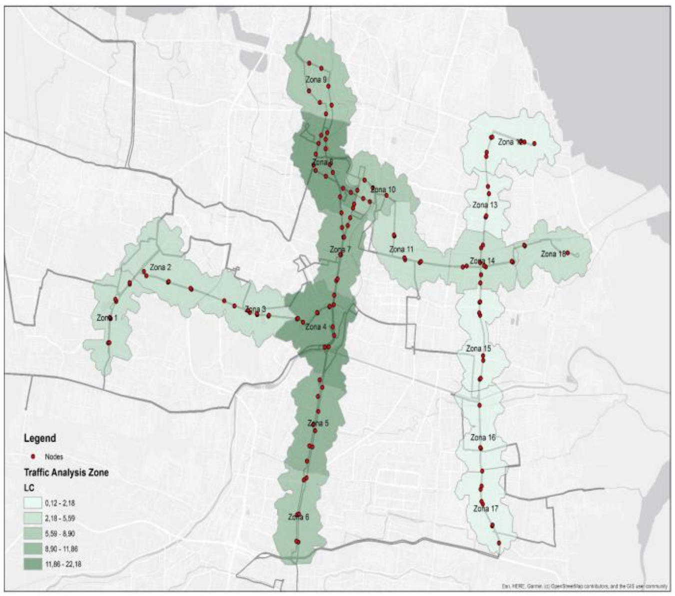

Figure 4 LC Results

Figure 4 presents the results of the LC index assessment. Zone 8 exhibits the highest LC index at 22.18, followed by Zone 4 at 16.79 and Zone 7 at 11.86. Zones 5 and 10 also show good connectivity, with values of 9.89 and 8.90, respectively.

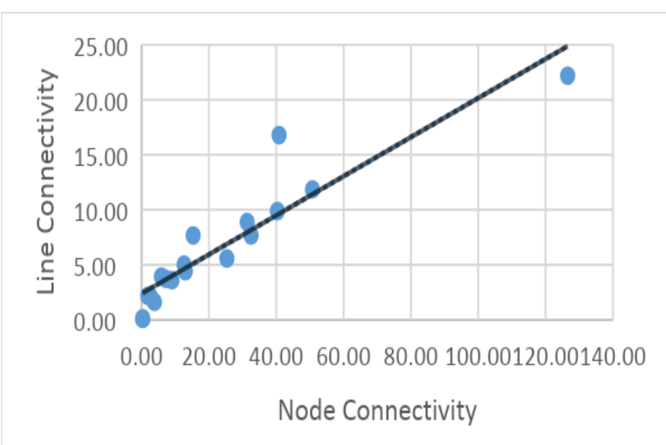

Figure 5 LC NC Correlation

In comparison to the NC results (Figure 5), Zones 8, 4, and 7 consistently show high connectivity. Conversely, Zones 2 and 3, which had low NC value, also show low values. Zones 12 and 13 have the lowest LC value at 0.12, consistent with their low NC value, these results mean there are significant issues in public transit services in these zones. Another distinction from NC calculation is that in the LC calculation result, the distribution of zones is more in the middle-value class rather than the lower-value class.

Comparatively, the LC and NC assessments reveal common patterns of connectivity. Zones 8, 4, and 7 are identified as well-integrated areas, while Zones 12, 13, 16, 17, and 18 require significant improvements.

c. Transfer Center Connectivity Index

A transfer center is defined as a set of nodes where transfers between different modes of transportation are easily facilitated. This is typically achieved through a coordinated schedule at a single node or through the availability of connections between nodes within a specific distance. In this research, a transfer center zone is identified as a zone containing more than eight nodes. This is based on the configuration where a pair forms four bus stops positioned opposite each other, with each stop being no more than 800 meters from its adjacent nodes.

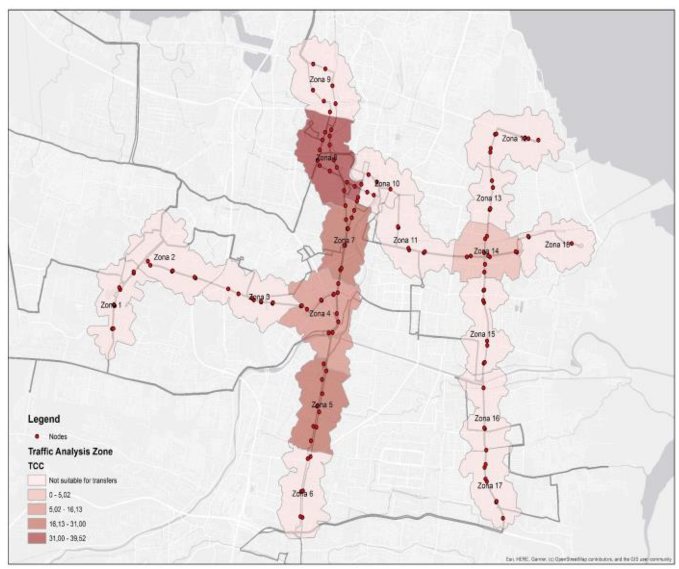

Figure 6 TCC Results

Table 1 presents attributes of each zone, including the average distance to adjacent nodes and the number of additional nodes, such as Trans Jatim and railway stations. The average distance is converted into minutes to align with the TCC integration calculation formula, as specified in Equation (3) [14].

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Table 1 Attributes of Zones

Zones	Number of Nodes	Average Distance to Adjacent Nodes (meters)	Walking Time (minutes)
Zone 1	8	436,5	5,72
Zone 2	6	524,8	6,87
Zone 3	8	335,7	4,40
Zone 4	**14**	**362,1**	**4,74**
Zone 5	**10**	**466,6**	**6,11**
Zone 6	6	560,5	7,34
Zone 7	**9**	**373,1**	**4,89**
Zone 8	**16**	**357,7**	**4,68**
Zone 9	7	450,0	5,89
Zone 10	7	395,9	5,18
Zone 11	6	395,2	5,17
Zone 12	7	266,9	3,49
Zone 13	4	389,8	5,10
Zone 14	**11**	**529,9**	**6,94**
Zone 15	8	489,8	6,41
Zone 16	3	723,7	9,48
Zone 17	8	423,6	5,55
Zone 18	3	908,3	11,89

Zones such as 4, 5, 7, 8, and 14 are identified as functional transfer centers due to their adequate number of node and average walking times. Other zones, including Zone 2, 3, 6, 11, 13, 15, 16, 17, and 18, are not utilized as transfer centers due to either excessive distances between nodes or insufficient node counts. TCC value shows that in Zone 14, there are 5 users who can be facilitated to change modes or routes in 6 minutes (Table 2 and 3).

The Transfer Center Connectivity (TCC) results highlight significant variations in connectivity across the assessed zones. Zone 8 emerges as the most well-integrated area with the highest TCC value of 39.52, indicating superior connectivity and accessibility due to its high number of nodes (16) and relatively short average walking time (357.69 meters). Zones 7 and 5 also show strong performance with TCC values of 31.00 and 27.37.

Factors contributing to the results of the transfer zone analysis include the number of nodes, distance between nodes, and the quality of transit services. These factors are quantitatively represented by Node Connectivity (NC) and Line Connectivity (LC) values. The NC value reflects the connectivity of a node, while the LC value indicates the capability of the route passing through that node. Overall, these metrics provide information about the connectivity of the zone.

In contrast, thirteen other zones do not have TCC values, suggesting that they do not facilitate transfers. Nodes in these zones are isolated due to a lack of alternative modes or because the walking distance between nodes is too long. This isolation can greatly affect the efficiency of the public transit system, as passengers in these zones have limited options to change routes or modes, resulting in longer travel times and less comfort.

Table 2 summarizes the spatial integration values of all existing zones. The NC and LC values vary each zone, however zone 3, 4, 7, and 8 consistently have high values.

Table 2 Summary

Zones	NC	LC	TCC
Zone 1	25,33	5,59	-
Zone 2	5,88	3,92	-
Zone 3	13,01	4,43	-
Zone 4	40,83	16,79	14,89
Zone 5	40,33	9,89	27,37
Zone 6	15,31	7,68	-
Zone 7	50,76	11,86	31,00
Zone 8	126,57	22,18	39,52
Zone 9	32,52	7,68	-
Zone 10	31,36	8,90	-
Zone 11	12,61	5,04	-
Zone 12	0,39	0,12	-
Zone 13	0,27	0,12	-
Zone 14	7,23	3,72	5,02
Zone 15	3,83	1,63	-
Zone 16	2,51	2,18	-
Zone 17	1,84	2,18	-
Zone 18	9,01	3,60	-

V. DISCUSSION

The Impact of Area Density

Area density significantly impacts the outcomes of the analysis. Zones with nodes served by the same public transit services can yield significantly different integration results due to variations in zone densities. Literature defines zone density as the level of development such as population density, employment levels, and housing density, and serves as a multiplication factor in the calculation formula [Equation 1, 2]. This density illustrates how effectively a zone attracts public transit users, influencing the level of integration.

Research Limitations

It is important to note that all analysis results are based on observed data and are subject to the author's assumptions and limitations. Future improvements are always possible, and as a result, the zones, nodes, and routes discussed in this research may differ from those implemented in the future. Technical factors such as fleet speed, fleet size, occupancy levels, and route fluctuations can significantly impact the calculation outcomes, potentially making this analysis less relevant over time. Despite these limitations, this research proposes a modified approach for analyzing public transportation integration, building on previous studies [11], [13], [15].

Disparities in PT Services

The zones considered in this research extend from the bus stops, and the analysis reveals that certain zones show very high service levels, while others do not. To ensure equal quality of service across Surabaya City, further research is necessary to investigate whether the service imbalances in these zones result from varying demand or if other factors contribute to these disparities. As shown in the results, aside from zones with low integration values, many areas in Surabaya, particularly in the densely populated northern regions, remain underserved by public transport. Understanding the causes of these imbalances will be essential for developing strategies to improve the overall integration and effectiveness of Surabaya's public transportation network.

VI. CONCLUSION

High Connectivity Zones

Zones 8, 4, and 7 exhibit the highest integration values across NC, LC, and TCC indexes. These zones benefit from a dense network of bus stops and well-connected routes, indicating strong connectivity and service efficiency. Specifically, Zone 8 stands out with the highest overall integration, emphasizing its pivotal role in the city's transit network.

Low Connectivity Zones

Conversely, Zones 12, 13, and 16-18 display low connectivity values, with significant issues in both bus stop density and route connections. These zones require targeted interventions to enhance their public transportation services. The absence of TCC values in 13 zones suggests a lack of effective transfer centers, further limiting intermodal connectivity and passenger convenience.

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