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Banjar to Banjar: Designing a Public Transport Network in Denpasar Using Community Centers as Bus Stops

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Abstract

In Denpasar, motorized vehicles increase at an average rate of 15.97% annually, while road infrastructure expands only by 1.79%, leading to severe traffic congestion. A public transport network was introduced to address this (The Trans Metro Dewata), but its temporary suspension highlighted the urgent need for a more community-oriented and spatially efficient solution. This study aims to optimize Denpasar's bus network using the Minimum Spanning Tree (MST) method, with Banjar (community centers) serving as alternative bus stop locations. The methodology involves four stages: data collection, spatial preprocessing and filtering, route generation using MST, and comparative analysis. Results show that the redesigned network increases coverage from 44.58 km² to 52.81 km², significantly improving access to underserved areas while maintaining logical route divisions. Comparative analysis indicates that the proposed corridors outperform the existing system in terms of spatial balance, connectivity, and community integration. While operational feasibility requires further testing, this research provides a promising people-centered public transport network. By combining graph-based optimization with cultural geography, the study offers a scalable model for other urban areas with strong community structures and underutilized transit systems.

Keywords
Traffic, Trans Metro Dewata, Network, Minimum Spanning Tree, and Banjar.

1. Introduction
Denpasar, the capital of Bali, is facing severe traffic congestion, worsened by the steady rise in private vehicle ownership. Between 2010 and 2020, the number of private vehicles grew by an average of 15.97% each year, while road infrastructure development lagged far behind at just 1.79% annually (Suthanaya & Upadiana, 2019).This

mismatch has created frequent bottlenecks, particularly at key intersection points such as the Udayana University junction, a high-traffic area due to multiple educational institutions and service facilities (Suthanaya & Upadiana, 2019). Poorly planned road networks also contribute to the issue, as many were not designed to handle the current volume of vehicles, let alone future growth (Lu et al., 2020). Without timely improvements in traffic management and infrastructure planning, congestion in Denpasar will likely worsen, bringing safety risks and slowing down the city's economic activity (de Souza et al., 2017).

Public transportation in Denpasar, particularly the Trans Metro Dewata (TMD), temporarily ceased operations in January 2025 after years of struggling to gain traction. Despite initial efforts to modernize public transit in the city, TMD faced ongoing issues like limited route coverage, unreliable schedules, and a lack of public trust in the system (Hermawati et al., 2023; Hidayat et al., 2022). These challenges reflected broader weaknesses in the public transport framework, especially around accessibility and service quality, that made it challenging to attract consistent ridership (Surya Tapa et al., 2022; Wardana et al., 2024). Financial sustainability was also a longstanding concern, with the system heavily dependent on government subsidies. The service became unsustainable once that support was withdrawn (Putri et al., 2021). With the temporary shutdown of TMD, the need for a well-planned, community-focused public transport solution has become even more urgent, especially as Denpasar continues to see rising traffic congestion and growing dependence on private vehicles (Erviantono & Azhar, 2023).

One way to tackle Denpasar's ongoing transportation issues is by rethinking how bus stops are placed—using community centers, or banjar, could be an innovative and practical solution. Banjar is deeply rooted in Balinese society and is an active hub for local events, meetings, and daily community life. By utilizing these familiar and lively locations as bus stops, public transport could become more accessible and better connected to where people live and gather (Mchome & Nzoya, 2023). The experience with Trans Metro Dewata (TMD) has demonstrated that without proper planning and integration with land use, public transport often fails to reach areas where it is needed most (Hermawati et al., 2022). Involving community centers in transport planning improves access and could also help build public trust and engagement, often lacking in top-down transport projects (Joni et al., 2024). By centering mobility networks around banjar, Denpasar can create a people-focused and more sustainable system in the long run (Duman et al., 2021). This study addresses the central problem of inadequate route design and poor integration between public transportation and community structure in Denpasar. The failure of TMD reveals the urgent need for a reimagined system that is spatially, socially, and economically sustainable.

1.1 Objectives

This study aims to address the inefficiencies of Denpasar's public transport system by designing a more inclusive and spatially optimized bus network. The specific objectives of this research are to (1) map and identify banjar across Denpasar that can feasibly serve as candidate bus stop locations, based on street accessibility and spatial distribution, (2) develop route networks that connect filtered banjar, and (3) compare the proposed route network with the existing Trans Metro Dewata corridors to evaluate improvements in spatial coverage.

2. Literature Review

Urban transportation systems face increasing pressure due to rapid urbanization, growing private vehicle ownership, and limited public transportation infrastructure. To design effective, accessible, and efficient public transit networks, researchers and planners are increasingly turning to algorithmic and computational models. Among these models, the Minimum Spanning Tree (MST) approach has proven valuable in optimizing transportation network design by connecting nodes, such as bus stops or community centers, with minimal overall distance or cost.

The MST is a classic problem in graph theory, where the objective is to connect all points (or nodes) with the shortest possible total edge weight while avoiding any cycles. This characteristic makes it ideal for initial layout designs in transportation networks, where infrastructure cost, distance, or route simplicity is a primary constraint. MST algorithms, particularly Prim's and Kruskal's, are frequently utilized in transport planning to establish base networks that are both efficient and scalable. Kim et al. (n.d.) demonstrated the practical application of Prim's algorithm in designing schematic transit networks, highlighting its effectiveness in producing cost-minimizing layouts that can be customized to local planning goals.

Similarly, Rahmadi & Reffa Herdianti (2024) applied Kruskal's algorithm to optimize tourism transport routes in Indonesia, utilizing MST to identify effective and cost-efficient connections between attractions. Their study exemplifies how MSTs are especially beneficial when resource constraints exist or when simplicity and reach are prioritized over redundancy.

In urban transport planning, MSTs often serve as a foundational structure rather than the final configuration, providing a starting skeleton from which more sophisticated routing or scheduling systems can develop. Once the base routes are established using MST, additional factors—such as traffic flow, rider demand, or neighborhood priorities—can inform more complex network adaptations.

Tools like Geographic Information Systems (GIS) and Python-based libraries like NetworkX are critical in implementing such graph-based models in spatial contexts. GIS aids in analyzing real-world spatial distributions, such as population density or road widths, and aligns abstract graph models with actual geography. NetworkX, on the other hand, facilitates computational graph operations, including MST generation, path optimization, and network visualization. These tools empower planners to create route networks that are theoretically optimal and grounded in the real urban landscape.

While Location-Allocation Models (LAMs) are often discussed alongside MST in public transport studies, this research primarily focuses on MST as a practical approach for generating baseline routes. However, previous studies (e.g.,Van Oudheusden et al. (1987)) suggest that integrating MST with LAMs can improve outcomes when network structure and user accessibility are prioritized.

Overall, MST-based design has been demonstrated to produce efficient, implementable bus routes in many cities where physical constraints, budget limitations, or fragmented urban sprawl restrict more complex solutions. When enhanced with GIS spatial filtering and modern computational tools like NetworkX, MST offers a highly replicable, data-driven method for improving transport coverage, particularly in areas where community-based anchors, such as banjar in Denpasar, play a significant role in daily mobility.

3. Methods

This research adopts a computational and spatial analysis approach to redesign Denpasar's bus route network using the Minimum Spanning Tree (MST) method. The aim is to create an efficient, community-focused transport network by leveraging geographic data and community infrastructure as bus stop nodes. The methodology consists of four main stages:

Step 1: Data Collection. This stage involves gathering the necessary spatial and attribute data, including the geographic coordinates of all banjars in Denpasar and the current Trans Metro Dewata (TMD) bus corridors for benchmarking and comparison.

Step 2: Spatial Preprocessing and Filtering. In this phase, a filtering process is applied to assess each banjar's eligibility as a potential bus stop. Only eligible banjars are retained to form the candidate nodes for route network planning.

Step 3: Route Network Generation with MST. A complete distance graph is constructed between all eligible banjar nodes, with edge weights representing the travel distance along the road network. Using the MST algorithm, an initial backbone network connects all banjars with minimal total distance. This network is then manually segmented into several logical bus corridors based on spatial flow, route continuity, and operational feasibility.

Step 4: Comparative Analysis. The final stage compares the proposed MST-based corridors with the existing TMD corridors. Key comparison metrics include area coverage, service area balance, community integration, feasibility, and connectivity.

4. Data Collection

The initial phase of this research centered on gathering accurate and relevant data to support the redesign of Denpasar's bus route network.

A comprehensive list of 376 banjar (traditional community centers) in Denpasar was retrieved from the official website of the Denpasar City Government. Since the source did not provide geographic coordinates, the spatial locations (latitude and longitude) for each banjar were manually obtained using Google Maps. The process involved searching for each banjar by name and extracting its precise coordinates to ensure accurate spatial representation. The resulting data was compiled into a geospatial dataset for further analysis using Python-based tools. Figure 1 visualizes the spatial data of banjar in Denpasar grouped by districts.

The following data set is the Existing Trans Metro Dewata (TMD) Corridors. Corridor information for the existing Trans Metro Dewata (TMD) bus network was collected from the official Trans Metro Dewata Instagram account. The data included visual maps of corridors K1B through K5B. Since no formal GIS shapefile was publicly available, route paths were manually reconstructed based on these maps using reference points and landmarks. The reconstructed TMD routes were georeferenced to align with the same spatial coordinate system used for the banjar dataset. Figure 2 visualizes the existing Trans Metro Dewata corridors.

This collected data formed the foundational inputs for spatial filtering, network modeling using MST, and comparative analysis conducted in later stages.

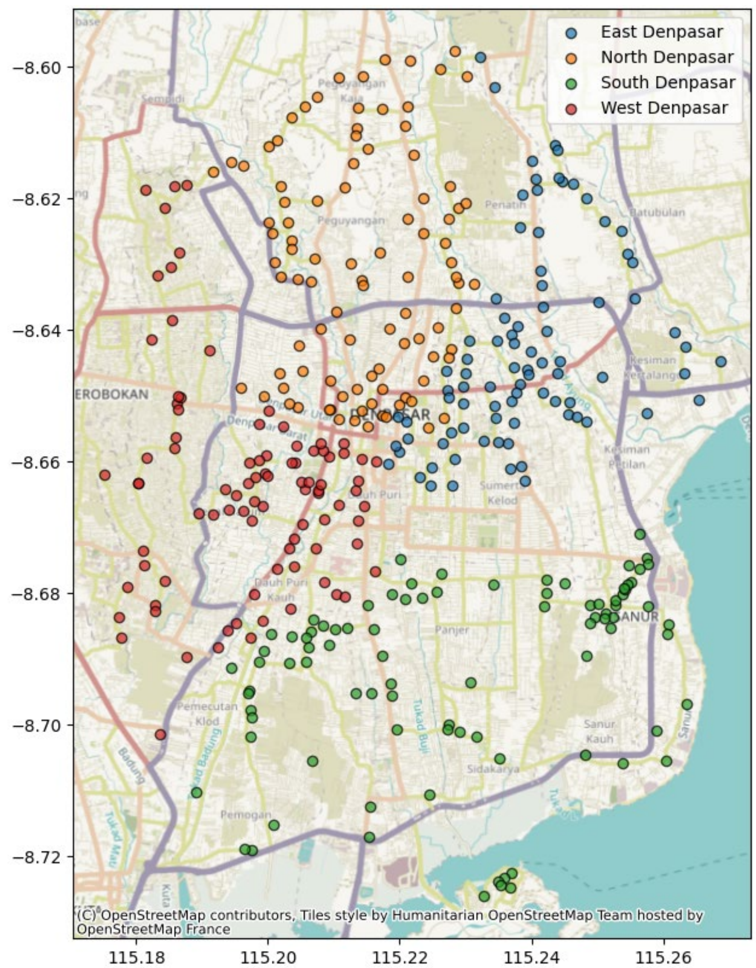

Figure 1. Existing banjar across Denpasar City

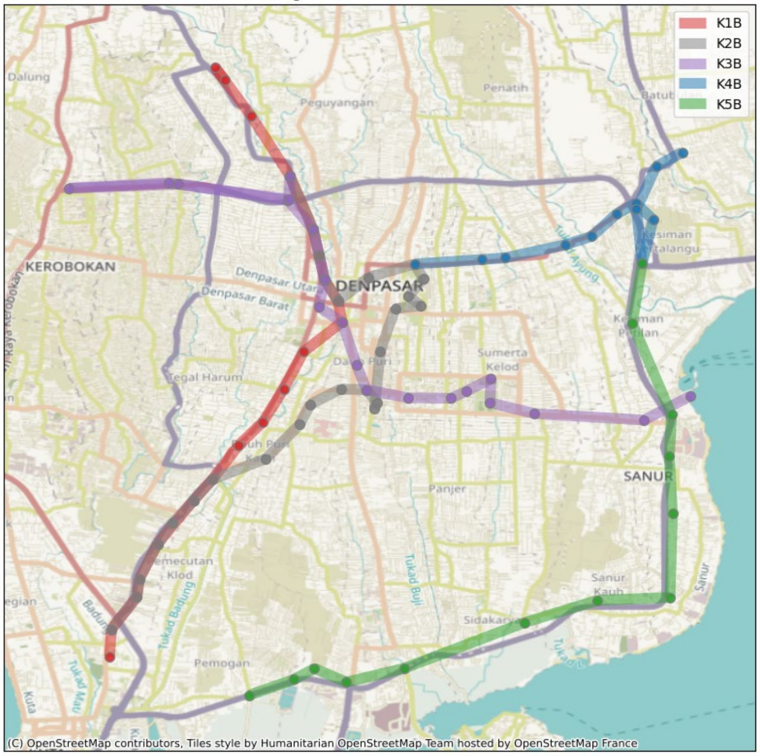

Figure 2. Existing Trans Metro Dewata Corridors

5. Results and Discussion

This section presents the key outcomes of the spatial analysis and network modeling to propose a redesigned bus route network for Denpasar. The process involves three main stages: (1) spatial preprocessing and filtering of potential bus stop locations (banjar), (2) route generation using the Minimum Spanning Tree (MST) method, and (3) comparative analysis between the recommended and existing Trans Metro Dewata (TMD) routes.

5.1 Spatial Preprocessing and Filtering

A filtering process was conducted from the initial dataset of 376 banjar locations to determine which banjars could serve as viable bus stops. This was based primarily on road width accessibility, and only banjars with roads wide enough to accommodate bus traffic were retained. After manual inspection using satellite imagery and street view from Google Maps, 118 banjars were identified as "bus-eligible" (Figure 3).

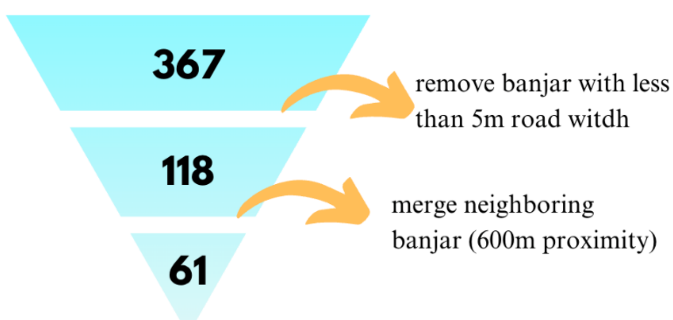

Figure 3. Banjar Filtering Process

Spatial clustering was conducted using a 600-meter proximity threshold to reduce redundancy further and improve efficiency, reflecting the average walkable distance to bus stops in tropical cities (Stjernborg & Mattisson, 2016). Banjars within this distance were grouped, and one representative banjar was selected per cluster. A Minimum Spanning Tree (MST) was then constructed to determine logical connectivity between these nodes, ensuring minimal total route length while maintaining coverage. The result seen in Figure 4 is a dataset of 61 nodes constructed solely from bus-eligible banjars (Figure 4).

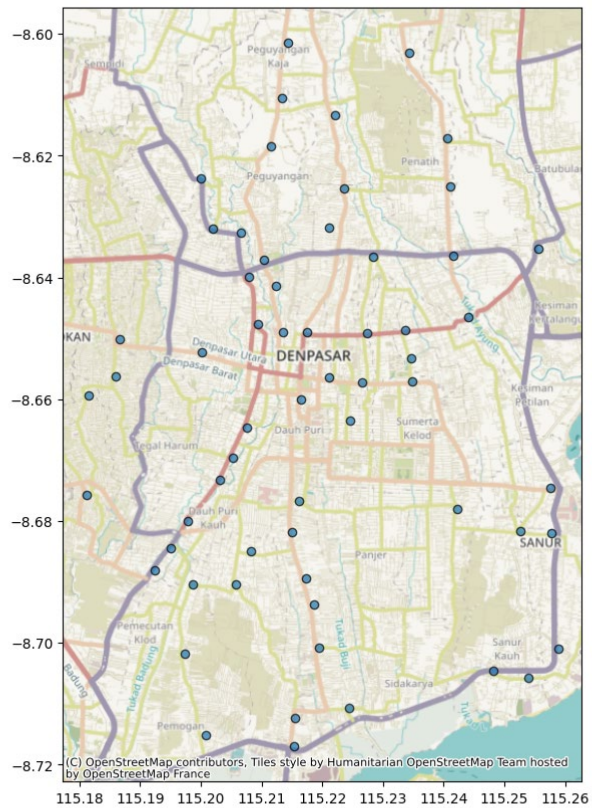

Figure 4. Bus-eligible Banjar in Denpasar

5.2 Route Generation and Proposed Corridors

Using the filtered set of 61 banjar nodes, a fully connected undirected graph with edge weights based on Euclidean distances between locations was generated. The Minimum Spanning Tree (MST) was computed using Kruskal's algorithm, ensuring optimal coverage with minimal redundancy. The resulting MST (Figure 5) served as a baseline structure from which more realistic route corridors could be derived.

The tree was manually segmented into seven logical corridors representing a proposed bus network to be compared with the existing TMD network. The segmentation was based on natural travel flows, significant road alignments, and potential intersection points where passengers could transfer. Adjustments were made to prevent sharp turns or indirect paths, ensuring each route would make sense from operational and commuter perspectives. The final design, as seen in Figure 6, reflects both network efficiency and spatial logic, maximizing community accessibility while minimizing operational complexity.

5.3 Comparative Analysis

A comparative analysis of key operational and spatial aspects reveals that the proposed MST-based network significantly improves the existing Trans Metro Dewata (TMD) system. Regarding coverage, the current TMD routes are confined mainly to major arterial roads, resulting in a service area of 44.58 km². In contrast, the proposed corridors extend deeper into residential areas through banjar-based nodes, expanding total coverage to 52.81 km², an 18% increase.

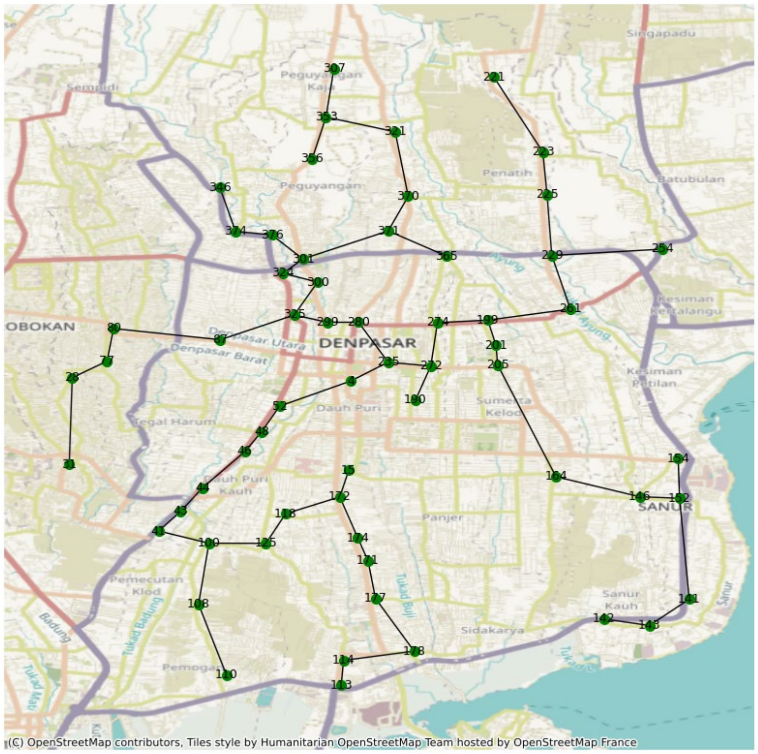

Figure 5. Minimum Spanning Tree Result

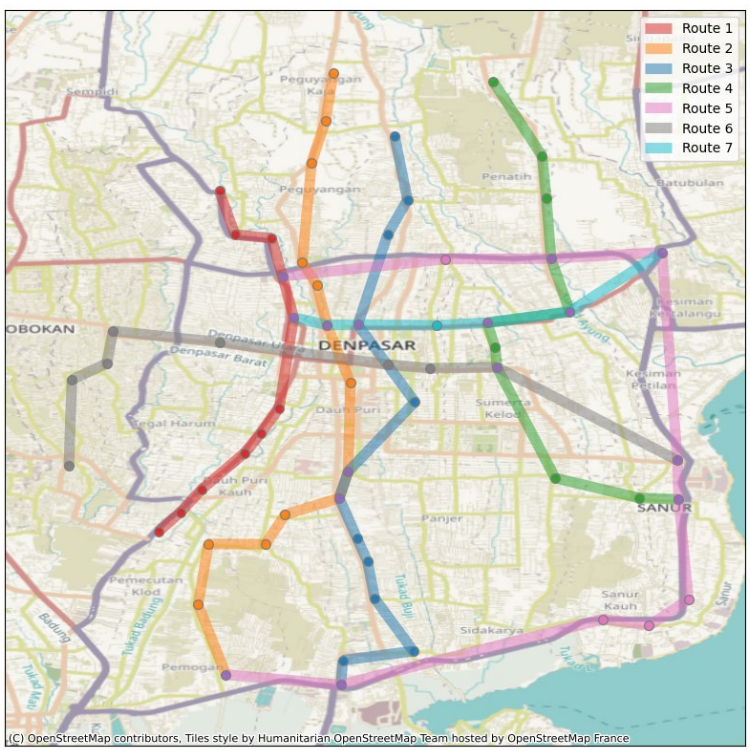

Figure 6. Proposed Bus Corridor Network

The proposed system's design approach is fundamentally different. While TMD follows a corridor-based model with limited flexibility, the new model is based on a network structure optimized through the Minimum Spanning Tree (MST) method. This ensures efficient connectivity and logical routing without unnecessary redundancy. Consequently, route redundancy is significantly reduced in the proposed design due to fewer overlapping bus stops.

Community integration is another key advantage. The existing service rarely accounts for local settlement structures like banjar, limiting accessibility. In contrast, the proposed model intentionally uses banjar as anchor nodes, aligning the service more closely with daily life patterns, commutes, and fostering public trust and usage.

Regarding connectivity, the TMD system provides limited inter-route connections, often necessitating long detours or transfers. The proposed corridors, however, are designed to intersect at logical points, improving passenger transferability and route flexibility. Additionally, the distribution of the service area is more balanced, with the proposed network extending to the northern, southern, and eastern parts of Denpasar—areas often underserved by the central-focused TMD system.

While the feasibility of the TMD network has been demonstrated through actual operation, the proposed network remains a theoretical construct awaiting real-world validation. Nevertheless, it is built on robust spatial analysis and optimization logic, offering a solid foundation for pilot testing and future implementation (Table 1).

Table 1. Summary of Comparison between Existing TMD and Proposed Corridors

Aspect	**Existing TMD Corridor**	**Proposed Corridors**
Coverage Area	44.58 km^2	52.81 km^2
Design Approach	Corridor-based	Network-based, MST-informed
Community Integration	Low (not based on banjar)	High (banjar-focused nodes)
Route Redundancy	Medium to high	Low
Connectivity	Poor inter-route connections	Improved connectivity & intersections
Service Area Balance	Uneven (central-focused)	Balanced across north, south, east
Feasibility	Operationally proven	Logically constructed, pending pilot

5.4 Complexity Analysis

The Minimum Spanning Tree (MST) was computed using Kruskal's algorithm, implemented with the NetworkX library in Google Colaboratory. For the complete undirected graph under study (61 vertices and 1,830 edges), Kruskal's algorithm has a time complexity of $O(E \log E)$. The computation completed in under one second, reflecting the modest problem size and effective filtering applied prior to execution.

6. Conclusion

This study introduces a redesigned bus route network for Denpasar based on the Minimum Spanning Tree (MST) method and community-centered planning. The proposed approach addresses longstanding weaknesses in the city's public transportation system, particularly the limited coverage, poor connectivity, and low community engagement witnessed in the now-defunct Trans Metro Dewata (TMD) network.

By utilizing banjar locations as key nodes and applying spatial filtering, the research ensures that the proposed routes are both relevant to community life and spatially optimized. The MST algorithm facilitated the development of an efficient base network with minimal route overlap and enhanced interconnectivity. Consequently, the new network design expands the coverage area from 44.58 km^2 to 52.81 km^2, providing better access to underserved residential areas while maintaining logical route separations.

Comparative analysis confirms that the proposed corridors outperform the existing system regarding coverage, connectivity, community integration, and spatial balance. While operational feasibility remains to be validated through pilot testing, the research presents a promising framework for sustainable and community-focused transport planning.

Overall, this study contributes a novel integration of graph-based optimization and cultural geography, offering a replicable model for other urban areas with strong community structures and underutilized transit systems.

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