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Operational Performance Evaluation and Management Optimization Strategies for Campus Public Transportation at IPB Dramaga

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Abstract: The growing population at the IPB University Dramaga Campus has escalated daily private vehicle traffic, leading to gate congestion and excessive parking violations due to suboptimal public transportation. This study aims to evaluate the impact of population growth on campus traffic, assess shuttle bus performance, and formulate efficient management strategies to support a sustainable transportation master plan at IPB Dramaga Campus. Empirical data were gathered from historical records and field observations measuring load factor, circulation time, speed, and headway across the three corridors during peak and off-peak periods. Spatial connectivity, detour index, and route overlap were analyzed to design phased improvement schemes, including bus stop relocations (200–500 m) and route restructuring. The existing service exhibited suboptimal load factors (14.15%–41.66%), high route overlap between Corridors 1 and 2 (609.12 m; up to 41.25%), and limited carrying capacity, serving only 8.73% of the academic population at 70% capacity. Implementing an integrated optimization strategy—combining headway engineering on Corridor 1 (Scheme 3), stop adjustments on Corridor 3 (Scheme 2), and a linear routing alignment on Corridor 2—reduced cycle times and significantly improved operational efficiency. This integrated configuration increased the daily passenger carrying capacity to 5,691 passengers (18.20%) at 70% capacity and 6,840 passengers (21.88%) at 100% capacity. Optimizing circulation routes, eliminating unproductive turning loops, and restructuring designated bus stops can double campus shuttle bus service performance without major fleet additions. The proposed linear configuration provides an effective operational policy framework for sustaining the internal campus transit system.

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Keywords: campus transit; headway engineering; network connectivity; operational performance; route optimization; shuttle bus

1. Introduction

The academic community at IPB University Dramaga Campus continues to grow; by 2028, it is projected to reach 41,556 active students, 1,703 faculty members, and 1,563 educational staff [1]. Based on daily vehicle entry data recorded by the IPB Directorate General and Infrastructure in 2024, daily vehicle traffic on campus reached 14,003 motorcycles and 4,379 cars [1]. This growth will directly increase the need for facilities that support mobility on campus, requiring innovative and sustainable strategies. IPB has established a policy through IPB

Rector's Decree No. 240/IT3/LK/2015, which regulates restrictions on private vehicle use to minimize the negative impacts of this anticipated growth. The policy focuses on public transportation services, specifically electric cars, bicycles, and shuttle buses [2].

This strategy was designed to reduce dependence on private vehicles and improve mobility convenience on campus. However, in practice this public transportation service has not yet reduced private vehicle use. This is evidenced by three key indicators: traffic congestion at campus entrances during peak hours, widespread land-use violations in parking areas, and suboptimal public transportation operations. This has led to a preference for private vehicles, which are perceived as more flexible, easily accessible, and time-efficient [3]. Therefore, developing an adaptive and sustainable public transportation system has become a vital need on campus [4], particularly to optimize shuttle bus services.

The shuttle bus service is the primary means of mass transit on campus, designed to effectively support the movement of large numbers of the academic community. Shuttle buses have a high passenger capacity, expedite travel between facilities, and serve as a strategic solution to reduce reliance on private vehicles [5]. Therefore, addressing campus mobility issues has become urgent. Consequently, this study aims to identify the impact of the growing academic community population on campus vehicle volume, evaluate the operational and managerial performance of the shuttle bus system, and formulate effective and efficient shuttle bus management strategies to serve as a reference for developing a transportation master plan and guidelines for sustainable public transportation infrastructure at the IPB Dramaga Campus.

2. Methods

2.1. Time and Location

This study was conducted at the IPB University Dramaga Campus. Employing an empirical approach, this study integrates historical data analysis, direct field observations, and a comprehensive evaluation of operational performance. The study location is illustrated in **Figure 1**.

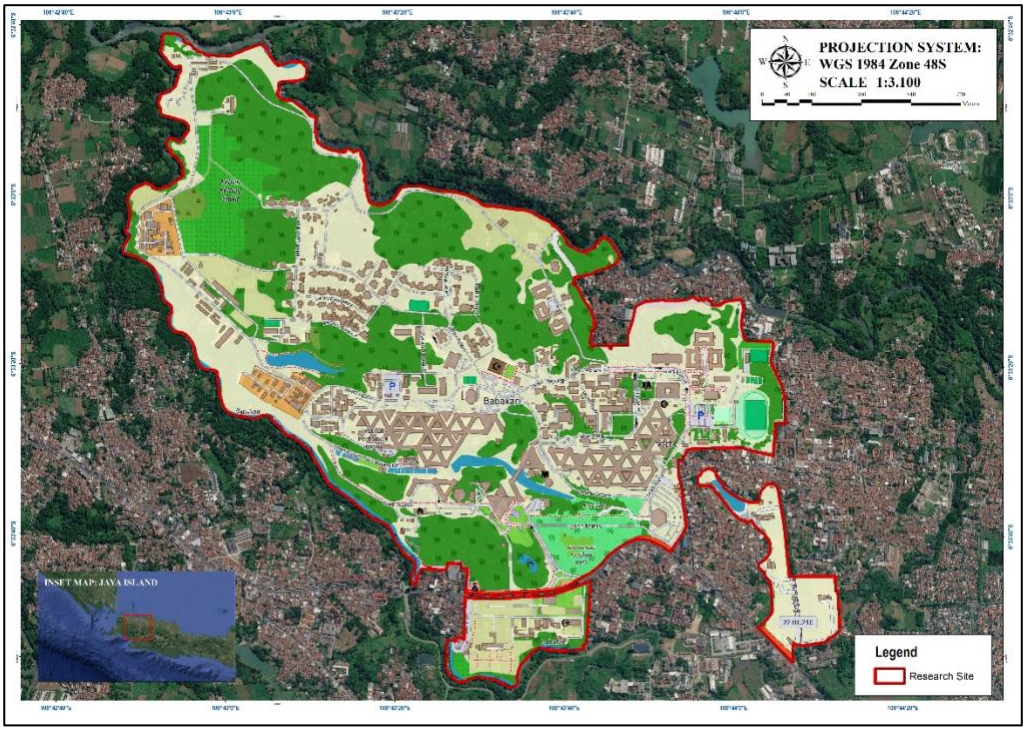


Figure 1. Map of the research location

2.2. Growth of the Academic Community Population and Number of Vehicles

Projections for active student growth were obtained using linear regression equations based on historical data from 2020 to 2025, sourced from the IPB Annual Performance Report [6–9]. Growth projections for lecturers and administrative staff were derived from the 2026 to 2028 IPB Strategic Plan [1]. Vehicle volume data were collected through a daily gate entry logging system managed by the Directorate of General Affairs and Infrastructure (DUI) from 2023 to 2025.

2.3. Performance of Shuttle Bus and Bus Stops

The shuttle bus performance analysis was conducted by referring to the decree of the Director General of Land Transportation No. SK.687/AJ.206/DRJD/2002 on Technical Guidelines for the Operation of Public Passenger Transport in Urban Areas on Fixed and Regular Routes [10]. The load factor is used to determine the passenger volume relative to the available bus capacity. The headway parameter indicates the time interval between consecutive bus arrivals, while the circulation time measures the time required to complete a trip from point A to point B. Data were collected through direct field observations measuring parameters such as the load factor, headway, travel time, and shuttle bus circulation time. The calculation of these parameters is presented in **Equations (1) -(3).**

$$LF = \frac{\sum \text{Pnp-km}}{(\sum \text{bus-km})\, c} \times 100\% \quad (1)$$

$$H = 60 \times \left(\frac{C}{P}\right) \times Lf \quad (2)$$

$$CT_{ABA} = (T_{AB}+T_{BA}) + (\sigma AB+\sigma BA) + (T_{TA}+T_{TB}) \quad (3)$$

where,

Lf	:	load factor, assumed to be 70%
ΣPnp – km	:	total passenger-kilometers (number of passengers × trip length per given unit of time)
Σbus – km	:	total bus-kilometers (number of bus trips × route length per given unit of time)
H	:	headway (minutes)
P	:	number of passengers per hour
C	:	vehicle capacity (passengers)
CT_{ABA}	:	cycle time from A to B and back to A
T_{AB}	:	travel time from A to B
T_{BA}	:	travel time from B to A
σAB	:	travel time variation/deviation from A to B
σBA	:	travel time variation/deviation from B to A
T_{TA}	:	dwell time at Terminal A
T_{TB}	:	dwell time at Terminal B

Field observations were conducted over three selected working days (Monday, Thursday, and Friday) to represent mobility dynamics across the beginning, middle, and end of the active academic week. Shuttle bus does not operate on weekends, as regular academic and administrative activities are concentrated from Monday to Friday. The field observation schedule and sampling periods are shown in **Table 1**.

Table 1. Field observation schedule and sampling periods

Sampling Period	Time (GMT +7)	Period Category	Purpose
Session 1	06:30–08:30	Peak hours	Morning peak mobility observation
Interval 1	09:00–10:00	Off-peak/Control	Data validation and control
Session 2	11:00–13:00	Peak hours	Midday peak mobility observation
Interval 2	14:00–15:00	Off-peak/Control	Data validation and control
Session 3	15:30–17:30	Peak hours	Afternoon peak mobility observation

Observations were divided into five sampling periods, where session periods represented peak mobility hours (peak hours) and interval periods served as data validation and control. The characteristics and efficiency of the transportation network were analyzed using four main parameters: the alpha index (α) to measure the ratio of actual circuits to the maximum possible circuits, the gamma index (γ) to calculate the ratio of links to their maximum possible capacity, the beta index (β) to evaluate connectivity based on the ratio of links to nodes, and the detour index to assess route efficiency. The calculation of these parameters is presented in **Equations (4) - (7).**

$$\alpha = \frac{e - v + p}{2v - 5} \tag{4}$$

$$\beta = \frac{e}{v} \tag{5}$$

$$\gamma = \frac{e}{3(v - 2)} \tag{6}$$

$$\mathrm{DI} = \frac{D_E}{D_A} \tag{7}$$

where,

α : representing the degree of network circuity or cyclicity
β : measuring the ratio of edges to vertices (network complexity)
γ : representing the ratio of actual edges to the maximum possible edges (network connectivity)
e : number of edges (links/route segments)
v : number of vertices (nodes/stops/intersections)
p : number of non-connected subgraphs (components, typically $p = 1$ for a fully connected network)
DI : detour index
D_E : straight-line distance (m)
D_A : actual route distance (m)

3. Result and Discussion

3.1. Projection of Academic Community Population Growth and Vehicle Growth

Projections of the growth in the academic community and vehicle volume serve as the primary basis for evaluating the campus transportation system [11–13]. As shown in **Figure 2**, the population shows a steady upward trend and is projected to reach 32,937 by 2028 ($R^2 = 0.99$). Meanwhile, data from IPB's

Strategic Plan project faculty lecturers to reach 1,731 and educational staff to reach 1,563 by 2028 [1]. These figures were not projected using linear regression because they are based on policies and regulations. Many factors influence this population growth, including campus capacity, admission quotas, budget availability, and strategic policies [14].

Academic community growth is directly proportional to increases in vehicle volume [9], with peak daily incoming vehicles reaching 14,002 motorcycles and 7,805 cars (**Figure 2**). The high volume of vehicles entering campus shows that growth in the academic community is driving traffic that may exceed the campus's capacity and spatial planning. The surge in daily vehicle volume has led to long lines at the campus gates, particularly during peak hours, and a high rate of land-use violations. Campus public transportation needs intervention to meet mobility needs resulting from future population growth.

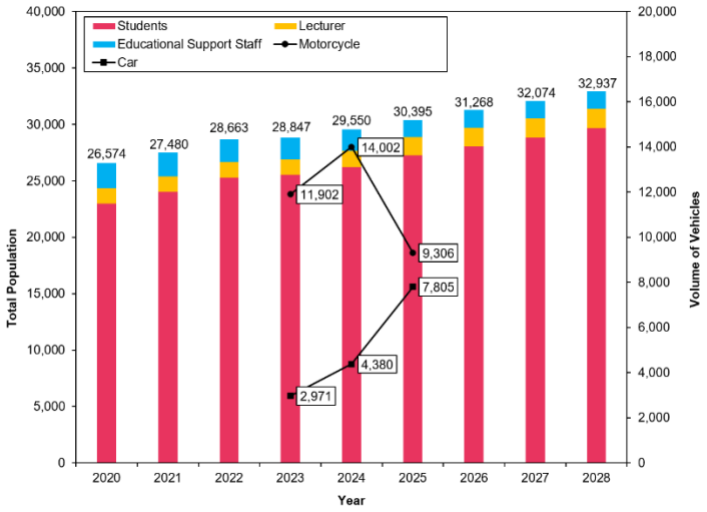


Figure 2. Projections for the academic community population and growth in the number of vehicles

3.2. Existing Conditions of Shuttle Bus Service

The on-campus shuttle bus currently operates along three primary corridors: Corridor 1 serves the GWW–SKHB route via CCR, Corridor 2 serves the GWW–SKHB route via LSI, and Corridor 3 serves the GWW–SKHB route via REKTORAT. The corridor details are shown in **Figure 3**.

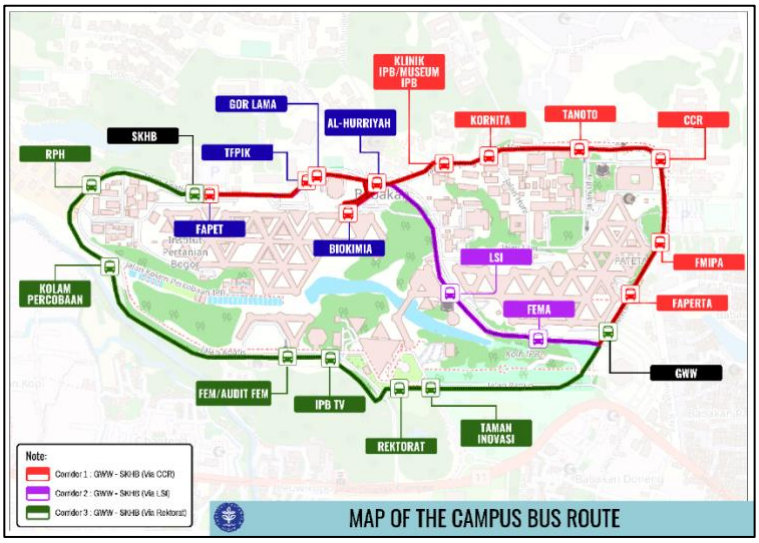


Figure 3. Map of the campus bus route

Figure 3 presents the detailed characteristics of the existing corridors at IPB University Dramaga Campus. Corridor 1 serves 14 bus stops with a total distance of 1,855 m. Corridor 2 serves 9 bus stops with a total distance of 1,477 m, while Corridor 3 serves 9 bus stops covering 1,931 m. These three corridors comprehensively represent the entire area of the IPB Dramaga Campus, indicating that the route network effectively accommodates the mobility needs of the academic community toward various destinations. Furthermore, an evaluation of the shuttle bus operational performance is required to ensure that the existing corridors sufficiently serve campus mobility, which is partly assessed through the load factor parameter. The load factor for Corridor is shown in **Figure 4**.

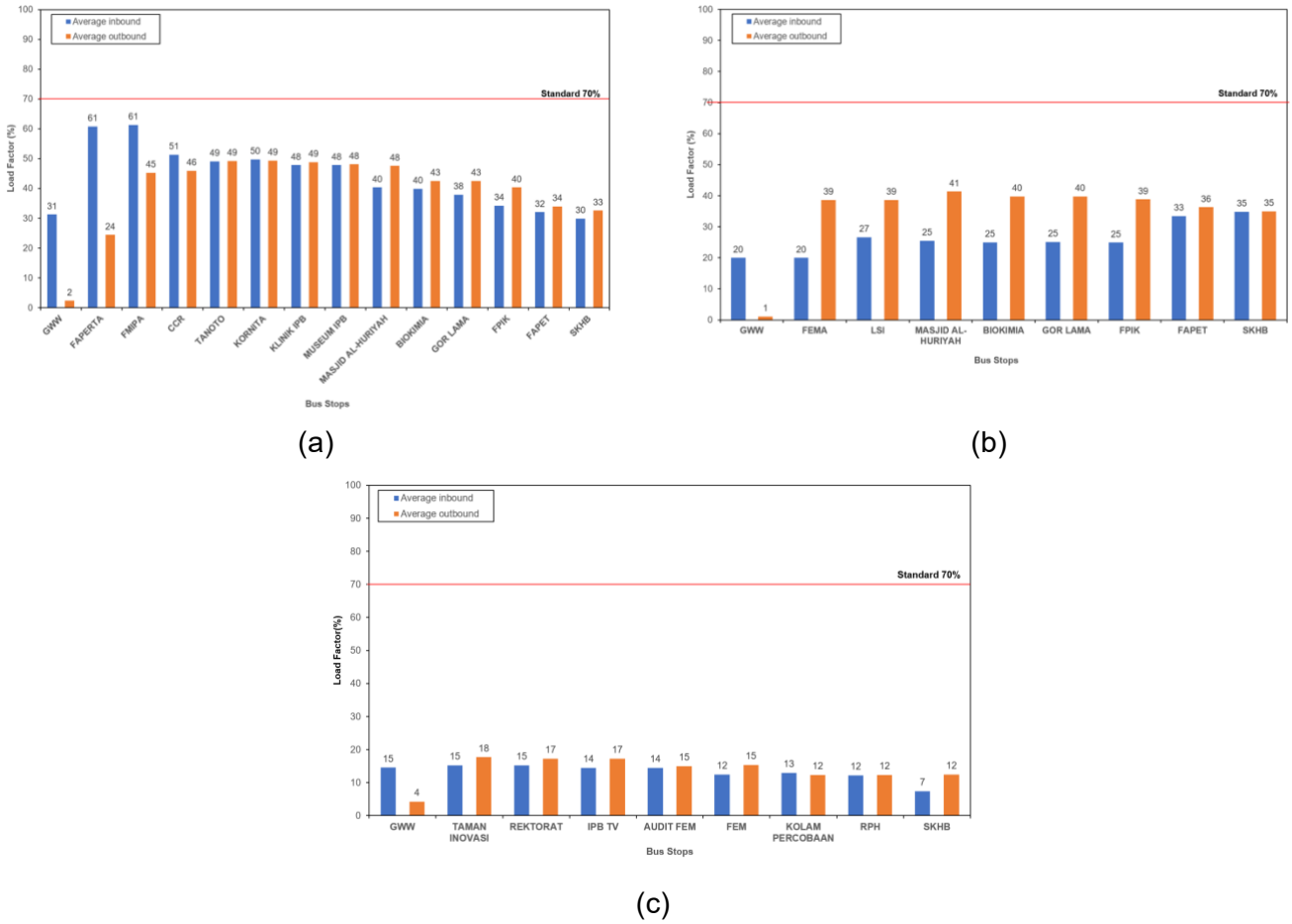
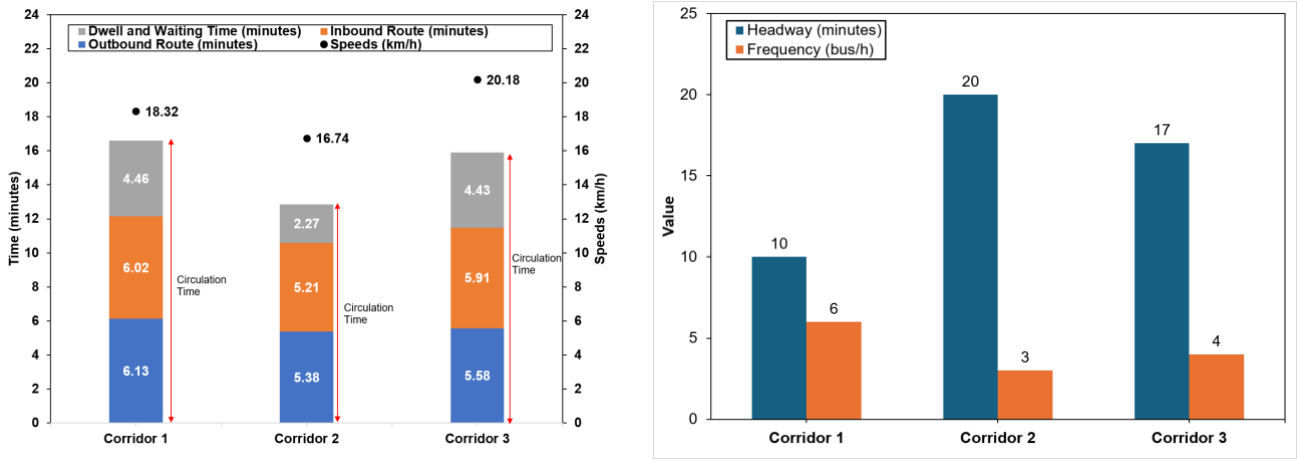


Figure 4. Summary of load factors for (a) corridor 1, (b) corridor 2, and (c) corridor 3

The load factor is determined by comparing the number of transported passengers with the total vehicle capacity [15]. Therefore, the performance evaluation results for the three operating corridors (**Figure 4**) show that the passenger load factor has not yet reached the ideal minimum service standard of 70%. **Figure 4a** shows that the average occupancy rate was only 41.66%, with the highest cumulative occupancy rate in the inbound direction at the FAPERTA and FMIPA bus stops (61%), before dropping to 30% at the SKHB bus stop. Meanwhile, in the return (outbound) direction, the highest cumulative occupancy rate was at the TANOTO and KORNITA bus stops (49%), before dropping to 2% at the GWW bus stop. **Figure 4b** shows that in Corridor 2, the average cumulative occupancy rate reached 31.72%. In the outbound direction, occupancy rates ranged from 20% to 35%, while in the return direction, they increased, peaking at 41% at the MASJID AL-HURIYAH bus stop before declining to just 1% at the GWW bus stop. **Figure 4c** shows that Corridor 3 has the lowest cumulative occupancy rate among the operating corridors, averaging only 14.15%. The highest point was at the TAMAN INOVASI bus stop.

The performance evaluation score based on cumulative occupancy has not yet reached the 70% standard. Shuttle buses are used more frequently during peak hours and between classes [15].

Passengers who reach their destinations before the final stop gradually reduce occupancy, potentially leading to near-empty trips (deadheading) and wasted transport capacity (idle capacity). This situation wastes Vehicle Operating Costs (VOCs), such as fuel consumption and driver wages, that are not commensurate with the transportation revenue generated [16, 17]. This phenomenon is similar to findings regarding campus buses at the University of Lampung [18] and Andalas University [19]. The operational performance of these shuttle buses was then evaluated using circulation time, travel speed, and headway as presented in **Figure *5***.



(a) (b)

Figure 5. Summary of (a) travel time, dwell time, and speed of shuttle buses; (b) headway

As passengers tend to prioritize routes with minimal travel impedance [20], empirical observations of these temporal metrics were analyzed. As depicted in **Figure 5a**, Corridor 1 has the longest circulation time, at 16.61 minutes, with a fleet operating speed of 18.32 km/h. Corridor 3 has a circulation time of 15.92 minutes and a fleet operating speed of 20.18 km/h, while Corridor 2 has the lowest circulation time at 12.86 minutes and a fleet operating speed of 16.74 km/h. In **Figure *6b***, Corridor 1 shows the best schedule reliability, with a bus frequency of 6 buses per hour and an inter-arrival time of just 10 minutes. Meanwhile, Corridor 2 shows the lowest reliability, with a 20-minute interval and a frequency of 3 buses per hour, while Corridor 3 has a 17-minute interval and a frequency of 4 buses per hour.

The fleet's operational speed across the three operating corridors (16.74–20.18 km/h) exceeds the operational feasibility standard for local roads with mixed traffic, which is 10–15 km/h (an additional standard from which). Travel time is significantly influenced by the proportion of dwell and waiting times, as well as route length and the number of stops along the route [21, 22]. As seen in Corridor 1 and Corridor 3, these dwell and waiting times account for 26%–27% of the total travel time per trip. In Corridor 1, queues form as passengers board and alight. Meanwhile, in Corridor 3, longer fleet wait times at the starting stop due to low ridership contributed to this [20]. This issue regarding schedule reliability aligns with the findings of an evaluation conducted by the University of Indonesia [11] and a study on campus shuttle services conducted by Brawijaya University [23], both of which identified that high headways can significantly reduce the utility of public transportation; this condition has the potential to lead to reliance on private vehicles and a shift in mode of transportation [24]. The analyzed existing route performance based on road network connectivity and corridor routes is illustrated in **Figure 6** and **Table 2**.

The network topology analysis indicates an alpha index value of 0.00 for all operating corridors (**Figure 6**, **Table 2**). Corridor 1 consists of 13 nodes (v) and 12 links (e), with a beta index of 0.92, a gamma index of 0.36, and a detour index of 0.91. Corridor 2 consists of 9 nodes and 8 links, with a beta index of 0.89, a gamma index of 0.38, and a detour index of 0.85. Meanwhile, Corridor 3 has 8 nodes and 7 links, with a beta index of 0.88, a gamma index of 0.39, and a detour index of 0.90. The detour

index values for these three corridors are still in the “good” category because they fall within the range of 0.85–0.91, approaching the ideal value of 1.

Table 2. Shuttle bus network connectivity index

Parameters	Connectivity Index Route		
	Corridor 1	Corridor 2	Corridor 3
Alpha	0.00	0.00	0.00
Beta	0.92	0.89	0.88
Gamma	0.36	0.38	0.39
Detour	0.91	0.85	0.90

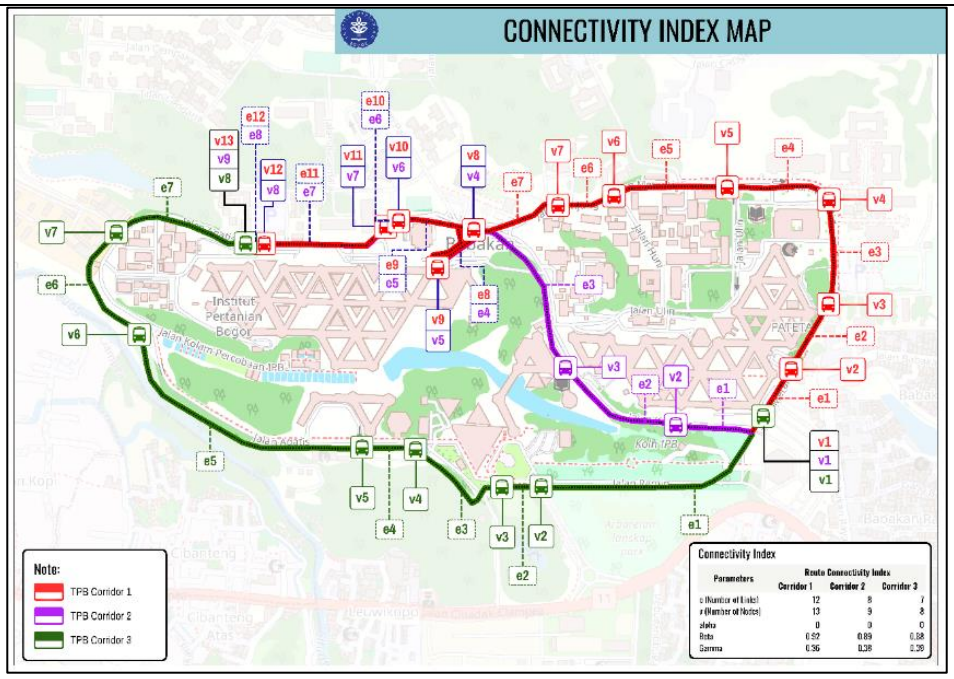


Figure 6. Connectivity index map

An alpha index value of 0.00 across all three operating corridors indicates that the route network pattern forms a purely linear network (tree/branch network), resulting in an open and self-contained network structure for each route. Beta index values below 1.00 (0.88–0.92) and low gamma index values (0.36–0.39) indicate that connectivity between nodes remains low and simple. This is evidenced by the fact that each bus stop connects to only one route segment, with no alternative routes [25]. Meanwhile, the detour index falls into the high category (0.85–0.91), indicating that the road paths are highly straight and close to the shortest distance to the bus stops, allowing routes to operate efficiently without excessive maneuvering [26, 27]. The geometric alignment will next be evaluated based on the parameter of overlap between corridors in the campus road network as shown in **Figure 7** and **Table 3**.

Table 3 shows that the greatest route overlap occurs between Corridor 1 and Corridor 2, spanning 609.12 meters (32.84% of Corridor 1; 41.25% of Corridor 2), which could trigger competition for demand on the overlapping road segments. In contrast, the overlap between Corridors 2 and 3 is minimal (31.01 meters; 1.61%–2.10%), while there is no overlap between Corridors 1 and 3 (0.00%). Shuttle bus operations are dominated by local roads serving as internal campus feeders, with the highest proportion in Corridor 3 (100.00%; 1,931.30 meters), followed by Corridor 1 (86.25%; 1,600.03 meters) and Corridor 2 (82.73%; 1,221.63 meters). These conditions require special attention to speed limits and managing lateral obstacles [28, 29]. Overlapping routes without proper fleet departure scheduling can lead to bus bunching and concentrate passengers on a single corridor. Consequently, this can reduce the passenger

load factor on other routes. These findings align with previous studies [23, 24], which confirmed that overlapping route segments can exacerbate traffic problems and increase headways; therefore, separating service corridors is needed as a technical measure to minimize potential obstacles and optimize bus operational performance.

Table 3. Percentage of route overlap across shuttle bus networks and road hierarchy

Corridor		Road Hierarchy	Overlapping Route		Road Segment Overlap	
			Overlapping Length (m)	Percentage (%)	Overlapping Length (m)	Percentage (%)
1	2 3	Local	609.12 -	32.84 -	1,600.03	86.25
2	1 3	Local	609.12 31.01	41.25 2.10	1,221.63	82.73
3	1 2	Local	- 31.01	- 1.61	1,931.30	100.00

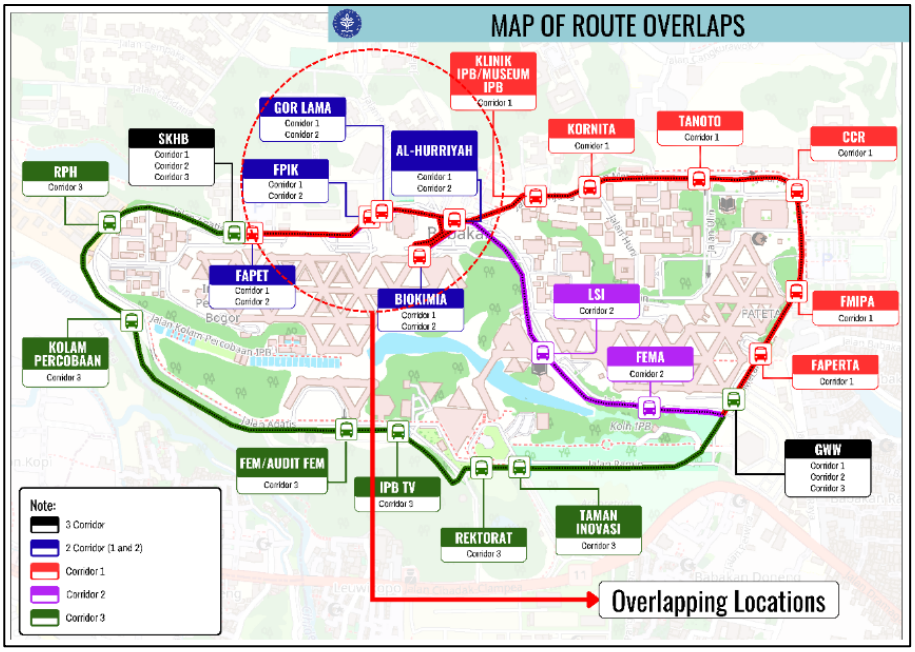


Figure 7. Map of route overlaps

3.3. Operational Performance Evaluation of the Shuttle Bus

The results of the shuttle bus operational performance evaluation in **Table 4** were then compared with the reference standards used in this study. None of the corridors met the minimum passenger load factor of 70%. Corridor 1 recorded the highest load factor (41.66%), followed by Corridor 2 (31.72%) and Corridor 3 (14.15%). This low load factor indicates that passengers (demand) have not fully used transport capacity (supply) because of high private vehicle use, route mismatches, and schedule inaccuracies [17, 30]. Corridor 1 has the most reliable headway and frequency (10 minutes; 6 buses/hour), followed by Corridor 2 (20 minutes; 3 buses/hour) and Corridor 3 (17 minutes; 4 buses/hour), with values approaching the 20-minute maximum. The distances between stops on Corridor 1 (132.50 m) and Corridor 2 (164.07 m) result in circulation times ranging from 12.85 to 16.61 minutes, with fleet operating speeds ranging from 16.74 to 20.18 km/h, average stop and wait times (2.27–4.46 minutes), and a 10-hour service period. This disparity in operational performance underscores the

mismatch between service capacity (supply) and passenger demand and travel patterns [17, 30]. Meanwhile, short distances between stops (<200 m) can cause excessive slowdowns and overly frequent stopping maneuvers, increasing the proportion of unproductive stop and wait times [31]. This finding aligns with a study conducted at the University of Indonesia [11], which found that long intervals between bus arrivals reduce service reliability and increase reliance on private vehicles.

Table 4. Shuttle bus performance evaluation

No	Criteria	Standard*	Corridor 1	Corridor 2	Corridor 3
1	Load Factor (%)	70	41.66	31.72	14.15
2	Headway				
	Average (Minutes)	5 - 10	10 [a]	20 [a]	17 [a]
	Maximum (Minutes)	10 - 20			
3	Bus Frequency (Buses/hour)	4 - 6	6 [a]	3	4 [a]
4	Distance between Bus Stops (Meters)	200 - 500	132.50	164.07	214.59[a]
5	Bus Travel Time (Circulation)	60 - 90 minutes	16.61	12.85	15.91
6	Speed (km/h)	10 - 15	18.32	16.74	20.18
7	Service Time (hours/day)	13 - 15	10	10	10
8	Dwell Time (Minutes)	5 - 10	0.89	0.45	0.89
9	Waiting Time (Seconds)	30 - 45 (a)	15	12	24

*The standard complies with the Technical Guidelines for the Operation of Public Passenger Transport in Urban Areas on Fixed and Regular Routes; [a]Complies with standards

3.4. Formulation of Strategies to Optimize Shuttle Bus Performance

An optimization strategy was developed to improve shuttle bus management in accordance with applicable service standards, while also enhancing the efficiency and effectiveness of on-campus passenger transportation. This strategy was developed using data on peak passenger loads per session to respond optimally to the dynamics of passenger demand [32, 33]. The strategy for optimizing shuttle bus performance was implemented through various improvement schemes categorized from low effort to high effort. **Table 5** presents these improvement schemes.

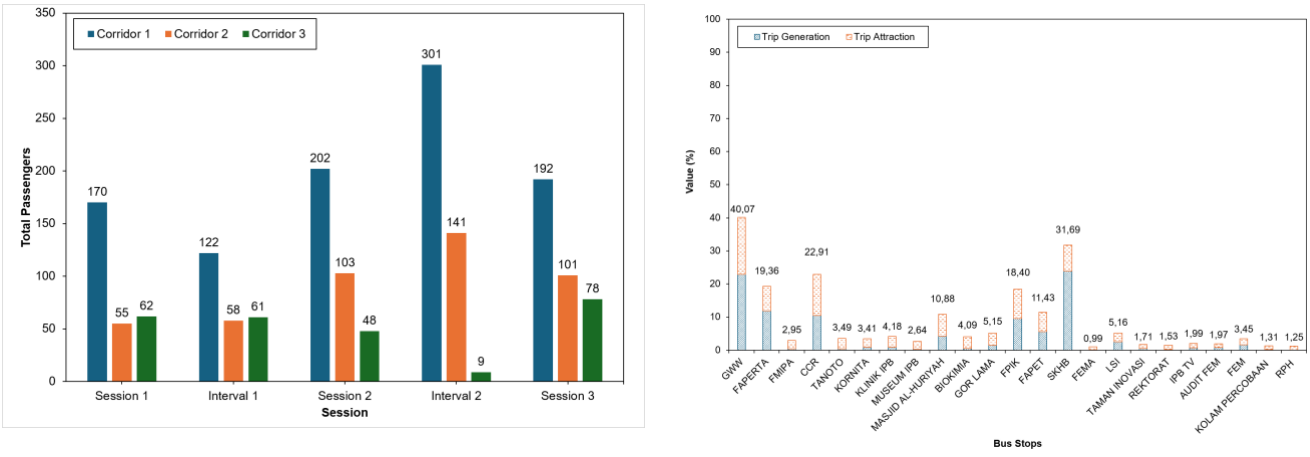
Table 5. Improvement Scheme for Shuttle Bus Management Optimization

Parameter	Scheme		
	1	2	3
Speed	✓	✓	✓
Dwell Time	✓	✓	✓
Waiting Time	✓	✓	✓
Headway*	✓	✓	✓
Bus Stop Points	X	✓	✓
Number of Buses	X	X	✓

✓ : Included/Accounted for; X : Not included; *obtained from calculation results

The improvement schemes in **Table 5** are organized by required level of effort: Scheme 1 focuses solely on operational management interventions through technical adjustments; Scheme 2 enhances Scheme 1 by incorporating spatial interventions through relocating designated bus stops based on trip generation and attraction; and Scheme 3 further refines Scheme 2 through headway engineering. The

passenger load distribution during peak periods, as well as the trip generation and attraction patterns at bus stops, are presented in **Figure 8**.



(a) (b)

Figure 8. Optimization planning for (a) peak passenger load; (b) trip generation and attraction at designated bus stops

Based on **Figure *8*a**, passenger volume across all observation sessions shows that Corridor 1 has a high peak in passenger traffic, particularly during Interval 2, which reached 301 passengers, while Corridor 2 had the highest passenger count at 141 passengers and Corridor 3 at 78 passengers. The distribution pattern of boarding and alighting between bus stops shows that movement is concentrated at four main points: GWW bus stop (40.07%), SKHB bus stop (31.69%), CCR bus stop (22.91%), and FAPERTA bus stop (19.36%). Meanwhile, the lowest percentages were at three bus stops: FEMA (0.99%), TRPH (1.25%), and KOLAM PERCOBAAN (1.31%). This concentration of demand at these key bus stops indicates a buildup of passengers during peak hours and provides a crucial basis for fleet relocation, headway adjustments, and campus shuttle bus route planning [31, 34]. The reduction or consolidation of underutilized stops and the increase in fleet frequency on Corridor 1 during peak hours to ensure bus capacity aligns with the surge in passengers on the ground [32, 33]. Scheme 2 requires adjusting the distances between bus stops to the 200–500 standard presented in **Figure *9*** and **Table 6**.

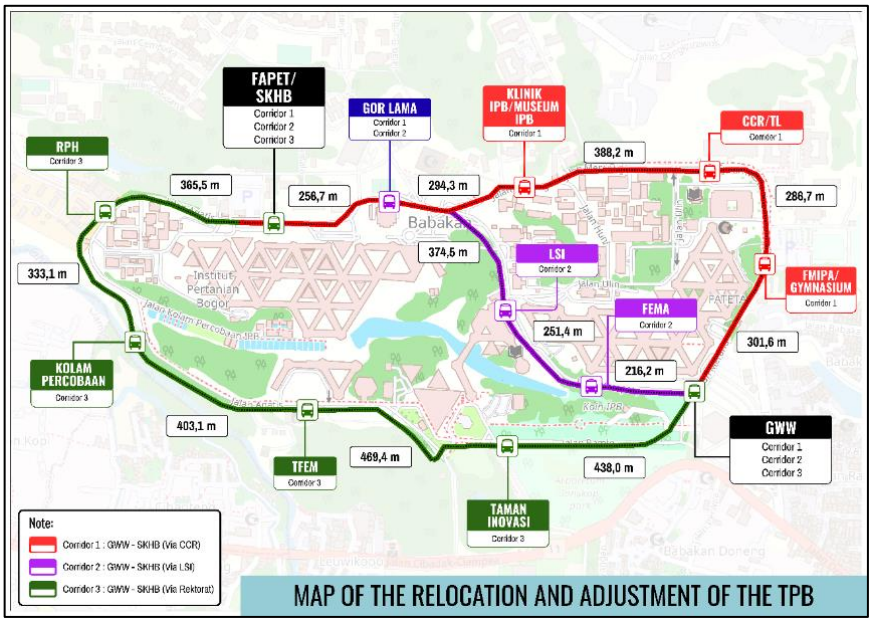


Figure 9. Map of the relocation and adjustment of the bus stops

Table 6. Relocation and adjustment of the bus stops

No	Corridor 1		Corridor 2		Corridor 3	
	Bus Stops	Distance	Bus Stops	Distance	Bus Stops	Distance
1	GWW		GWW		GWW	
2	FMIPA/GYMNASIUM	301.6	FEMA	216.2	TAMAN INOVASI	438
3	CCR/TL	286.7	LSI	251.4	FEM	469.4
4	KLINIK/MUSEUM	388.2	GOR	374.5	KOLAM PERCOBAAN	403.1
5	GOR	294.3	FAPET/SKHB	256.7	RPH	333.1
6	FAPET/SKHB	256.7			FAPET/SKHB	365.5
Total	**1,527.5**		**1,098.8**		**2,009.1**	

Based on **Figure *9*** and **Table 6**, the distances between bus stops were adjusted as follows: Corridor 1 was reduced from 13 to 6 bus stops; Corridor 2 was adjusted from 9 bus stops to 5 bus stops; and Corridor 3 was adjusted from 9 to 6 bus stops. This reorganization resulted in new distances between bus stops in Corridor 1 ranging from 256.7 to 388.2 meters, with a total track length of 1,527.5 meters. In Corridor 2, the distance between bus stops ranges from 216.2 to 374.5 meters, with a total route length of 1,098.8 meters. Meanwhile, Corridor 3 has bus stop distances ranging from 333.1 to 469.4 meters, with a total route length of 2,009.1 meters. All variations in the distances between bus stops resulting from these adjustments across the three corridors fall within the ideal standard range for public transportation service, namely 200–500 meters.

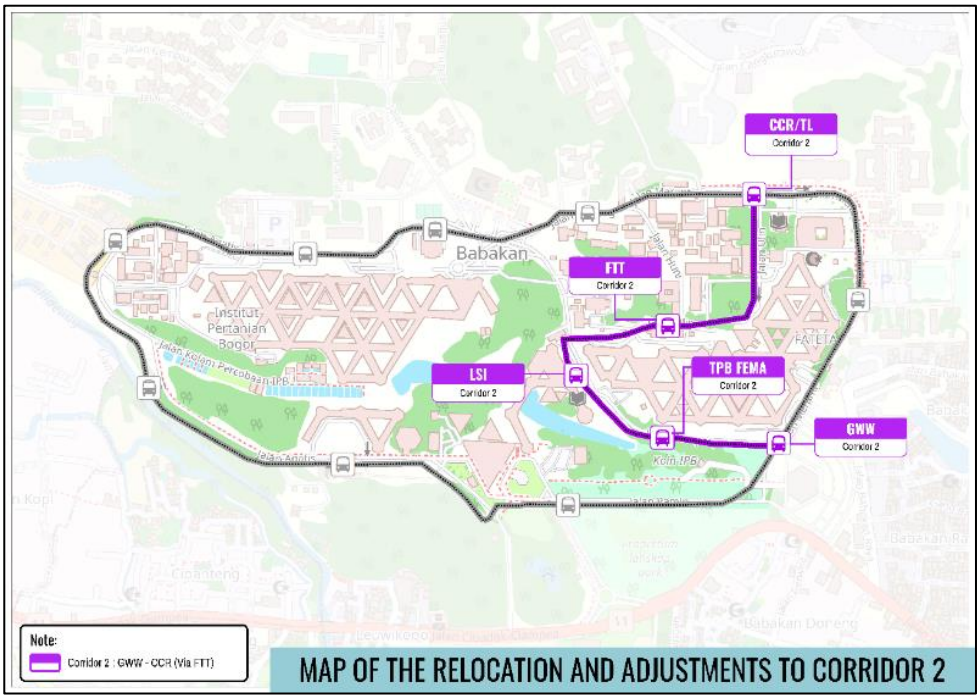


Figure 10. Map of the relocation and adjustment to corridor 2

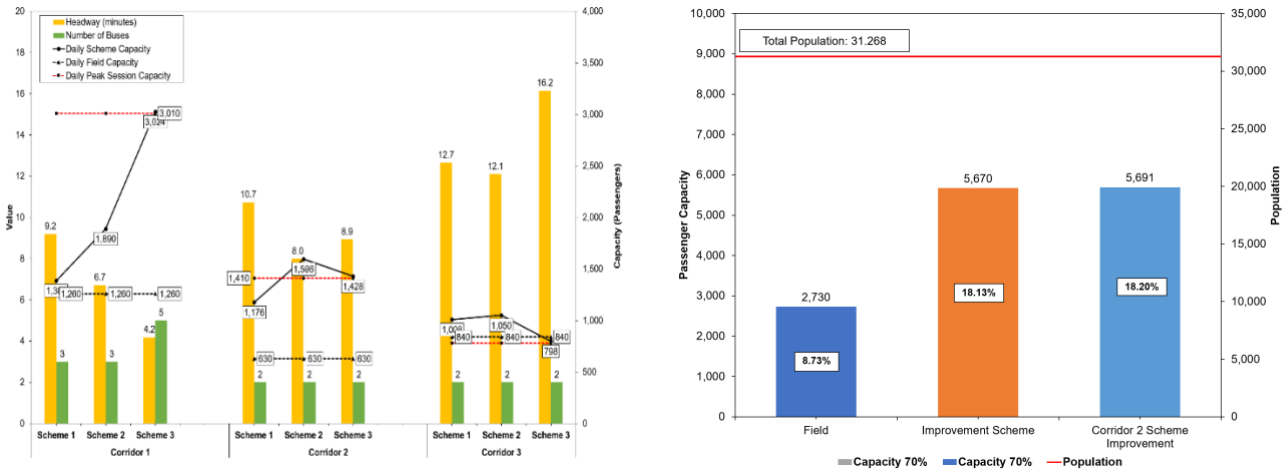
Based on **Figure *10*** and **Table 7** Corridor 2 was realigned to resolve overlap with Corridor 1 by creating a direct route connecting GWW and CCR/TL via an FTT-level tunnel. This adjustment results in Corridor 2 having 5 bus stops—namely GWW, FEMA, LSI, FTT, and CCR—with a total route length of 1,509.7 m, and all segments between bus stops now meet the 200–500 m distance range. This reduction in circulation time will impact passenger wait times at bus stops [35].

Table 7. Relocation and adjustment to corridor 2

No	Straight route	
	Bus Stops	Distance (meters)
1	GWW	
2	FEMA	216.2
3	LSI	204.7
4	FTT	266.2
5	CCR	372.6
Total distance	**1,059.7**	

3.5. Synthesis of Optimization Results for IPB Shuttle Bus Operational Performance

The Corridor 2 route adjustment scenarios in **Table 7** serve as the basis for optimizing the shuttle bus fleet's capacity. This scenario was evaluated against the improvement schemes in **Figure *11*a** to measure how effectively route modifications increase passenger capacity. Furthermore, the results of the analysis for Corridor 2 were integrated with the optimal schemes from the other corridors—Scheme 3 for Corridor 1 and Scheme 2 for Corridor 3—as presented in **Figure *11*b**. Based on **Figure *11*a**, Corridor 1 shows a gradual increase in capacity, reaching 3,024 passengers/day under Scheme 3. This figure exceeds the corridor's daily passenger demand of 3,010 passengers/day. In contrast, Corridor 2 already meets its daily demand under Scheme 2, carrying 1,596 passengers/day against a requirement of 1,410 passengers/day. A similar pattern appears in Corridor 3, where Scheme 2 achieves the largest increase, reaching 1,050 passengers/day against a daily demand of 840 passengers/day. The optimal configuration for maximizing daily capacity involves implementing Scheme 3 for Corridor 1, and Scheme 2 for Corridors 2 and 3. Furthermore, the results of the analysis for Corridor 2 were integrated with the optimal schemes from the other corridors, as presented in **Figure *11*b**.



(a) (b)

Figure 11. Optimization result (a) Shuttle bus management enhancement scheme; (b) Comparison of shuttle bus passenger capacity against total population across existing and improvement scenarios

An analysis of the shuttle bus fleet's service capacity relative to the total academic community population (31,268 people) shows a significant improvement across all proposed improvement plans compared to the current on-site conditions. Under current conditions, the fleet's carrying capacity is at its lowest point, serving only 2,730 passengers (8.73%) at 70% capacity. Implementing the improvement

schemes successfully increased the fleet's capacity to over 18% at 70% load. The Scheme for Corridor 2 recorded the best performance, with a capacity of 5,691 passengers (18.20%) at 70% capacity and 6,840 passengers (21.88%) at 100% capacity. These results surpassed those of the standard improvement scheme (5,670 passengers/18.13% at 70% capacity). Integrating Scheme 3 in Corridor 1, the route modification scheme in Corridor 2, and Scheme 2 in Corridor 3 shows that adjusting circulation routes and reallocating the fleet can more than double shuttle bus service performance compared to existing conditions. Successful implementation must be supported by keeping corridor routes and bus stops clear to maintain on-schedule dwell times, using a GPS-based fleet monitoring system to ensure compliance with bus arrival schedules, and conducting periodic evaluations during peak hours to anticipate changes in passenger movement patterns [36–38].

4. Conclusion

This study evaluated the operational performance of the IPB Dramaga Campus shuttle bus system and developed targeted, phased optimization strategies to address rising mobility demands and reduce reliance on private vehicles. The empirical baseline assessment revealed critical operational deficiencies in the existing service, including suboptimal passenger load factors (14.15%–41.66%), extensive route overlapping between Corridors 1 and 2 (up to 41.25%), and irregular headways, which collectively restricted transit capacity to serving merely 8.73% of the campus population at 70% capacity. By integrating spatial restructuring and operational management, this proposed configuration effectively doubled transit service performance, increasing the daily passenger carrying capacity to 5,691 passengers (18.20%) at 70% capacity without substantial fleet additions, thereby offering an effective operational policy framework to support a sustainable campus transit system when paired with dedicated lane enforcement, GPS-based fleet tracking, and periodic peak-demand assessments.

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