Sustainable Transport Assessment through Passenger Density and Operational Headway

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ABSTRACT

This study investigates the operational performance and sustainability of two urban minibus routes D41 (Gandaria–Cibinong) and D37 (Cibinong–Kampung Rambutan) in the Depok–Bogor region of Indonesia. Using field observations and GPS-assisted time tracking, three indicators were analyzed: passenger load factor, operational headway, and travel time. Results show that while both routes exceeded the government's 70% load factor benchmark during peak hours, performance dropped below 50% at midday. Headway generally remained within the acceptable range of 2–5 minutes, but D37 exhibited the shortest intervals during morning peaks. D37 also experienced prolonged travel times, often exceeding 80 minutes. These findings highlight the inefficiencies of informal public transport systems, particularly their inability to scale services to match fluctuating demand. This study proposes a low-cost, data-driven framework for assessing route efficiency and supports the integration of informal routes into broader transport planning. The results are relevant to urban mobility reform in developing cities.

Keywords: urban transport; load factor; headway; sustainable mobility; informal transit

A. Introduction

Urban transportation has become one of the most critical components of sustainable development in rapidly growing cities (Hamurcu & Eren, 2020; Sumasto et al., 2020). In developing countries such as Indonesia, the increasing population density in metropolitan regions like Jabodetabek (Jakarta, Bogor, Depok, Tangerang, and Bekasi) has intensified the demand for efficient and reliable public transportation (Ahuja et al., 2020; Hapsari et al., 2017). The resulting congestion, long travel times, and environmental degradation highlight the systemic failures in urban mobility infrastructure (Rodrigue et al., 2016). These challenges underscore the urgent need for empirical studies to evaluate and optimize public transit operations.

Minibus-based public transport, locally referred to as *angkot*, continues to serve as a primary mode of urban mobility for millions of people in Indonesia (ITDP, 2019; Sefriyadi et al., 2023; Siahaan et al., 2020). These informal and semi-regulated services fill critical gaps in mobility, especially in suburban and peri-urban areas where larger transit systems have limited coverage (Beaudoin et al., 2015; Sumasto, 2019). However, the operational performance of such systems is often overlooked in official transportation planning, which results in inefficiencies such as overlapping routes, unpredictable schedules, and underutilization or overloading of vehicles (Ochoa et al., 2021; OECD, 2020). Understanding the functional dynamics of these routes is essential for transitioning toward sustainable urban transport.

Depok and Cibinong, located in West Java, are experiencing increased commuter traffic as satellite cities for Jakarta. Residents rely heavily on minibus routes like D41 (Gandaria–Cibinong) and D37 (Cibinong–Kampung Rambutan), which connect residential zones with key economic, educational, and administrative centers. Despite their strategic importance, there is a lack of systematic evaluation of these routes in terms of passenger density, operational headway, and travel time. This gap limits both the potential for policy reform and the development of more sustainable, data-driven mobility systems.

Urban transport sustainability involves three interrelated pillars: efficiency, social equity, and environmental responsibility (Sumasto et al., 2020; Wang et al., 2024). Evaluating minibus routes through indicators such as load factor and headway offers a practical method for measuring service efficiency and accessibility. Furthermore, by assessing travel times against established regulatory benchmarks (Menteri Perhubungan, 2013), researchers can gauge the impact of congestion and route design on urban mobility. Unfortunately, most public transportation assessments in Indonesia still focus on macro-level systems like commuter trains or BRT, leaving local minibuses relatively under-researched.

The current study addresses this critical research gap by conducting a performance assessment of two minibus routes, D41 and D37, based on key operational metrics. These metrics headway, passenger density (load factor), and travel time are measured during peak and off-peak hours to understand temporal variations in service quality. By doing so, the study captures real-world dynamics that affect both users and operators in everyday urban commuting. These findings are contextualized within government transportation standards and broader sustainability goals.

The novelty of this study lies in its dual-route comparative analysis using standardized performance indicators combined with environmental and transport management perspectives. Unlike prior studies that typically examine a single route or aggregate city-level data, this paper focuses on operational behavior at the corridor level. Moreover, the inclusion of human-centric data collection such as direct observation at major transit points adds depth and realism to the analysis. This integrative approach enables policymakers and transit planners to identify actionable insights for route optimization and resource allocation.

The core problem identified in this study is the disconnect between the increasing reliance on minibus services and the lack of performance-based governance in managing these systems. While commuter demand continues to rise, the services remain vulnerable to inefficiencies caused by non-integrated scheduling, unbalanced passenger loads, and external congestion factors. Without a clear understanding of these parameters, transportation improvements remain speculative and reactive rather than strategic. This study attempts to bridge that gap through empirical evidence and performance modeling.

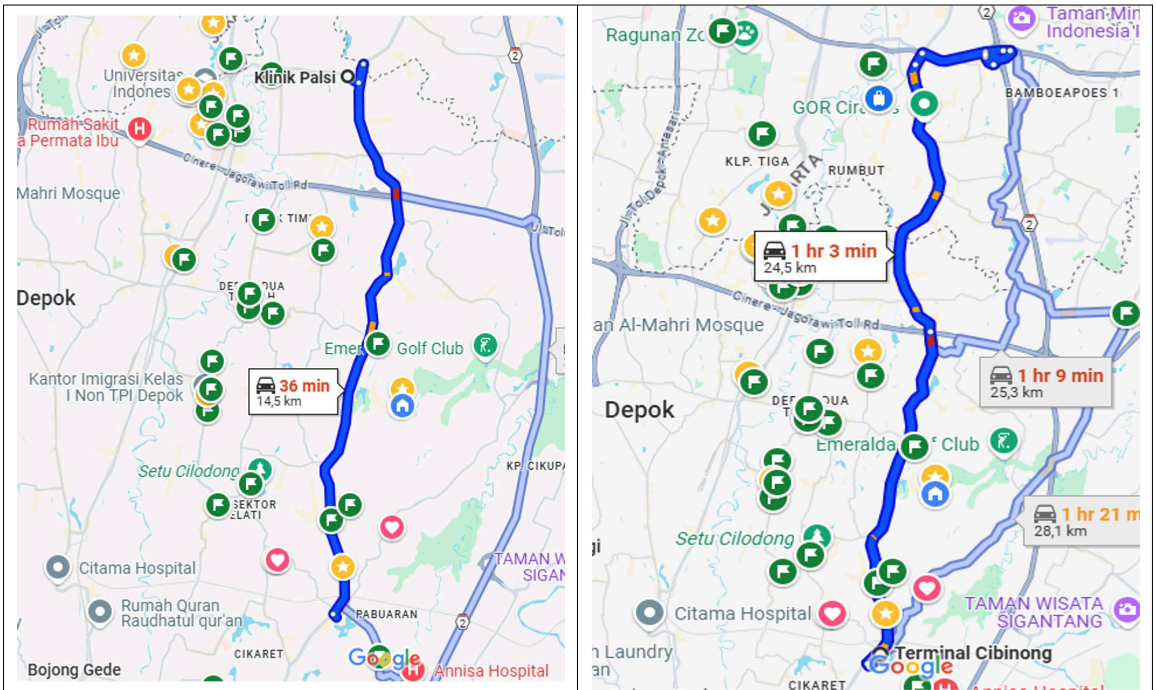
Thus, the objective of this research is to evaluate the sustainability and operational performance of the D41 and D37 minibus routes using real-time data and standardized benchmarks. Specifically, the study seeks to measure the load factor, headway intervals, and total travel time across multiple time periods and locations. By analyzing these parameters, the research aims to propose practical recommendations for improving service quality and environmental sustainability. Ultimately, this work contributes to the body of knowledge in urban transport studies and offers a replicable model for evaluating informal transit systems in other developing urban regions.

B. Methods

This research adopts a quantitative, field-based observational methodology aimed at analyzing operational and passenger-based performance metrics for two vital urban minibus routes D41 (Gandaria–Cibinong) and D37 (Cibinong–Kampung Rambutan) within the Depok–Bogor region (Table 1). The study is designed to assess urban transportation sustainability through three primary indicators: passenger density (load factor), operational headway, and travel time. These parameters are used as benchmarks for evaluating efficiency and accessibility, referencing service standards set forth by the Indonesian Ministry of Transportation (Menteri Perhubungan, 2013). The emphasis is not only on measuring performance but also on revealing underlying transport inefficiencies and exploring implications for transit policy and environmental sustainability.

The geographic focus of this study covers the southern segment of the Jakarta metropolitan area, particularly within the administrative regions of Depok, Bogor Regency, and East Jakarta. Both routes under investigation serve as commuter backbones, linking suburban and peri-urban neighborhoods to core urban activity centers. Route D41 connects Gandaria in Depok to the Cibinong Terminal, passing through residential and market zones such as Pal Depok and Cisalak. In contrast, route D37 provides a more extended connection from Cibinong to Kampung Rambutan, intersecting dense traffic corridors such as Jalan Raya Bogor, Cijantung, and Pasar Rebo.

To capture the operational performance of these routes under real-world conditions, primary data were collected through direct field observation. Observations were conducted over three temporal windows morning peak (06:30–07:30), midday off-peak (13:30–14:30), and evening peak (18:30–



(a) Route D41 (Gandaria–Cibinong) (b) Route D37 (Cibinong–Kampung Rambutan)

Figure 1. Route Map of D41 and D37 in the Depok–Bogor Region

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Table 1 Route Characteristics and Operational Features

Feature	Route D41	Route D37
Start Point	Gandaria (Depok)	Cibinong Terminal (Bogor)
End Point	Cibinong Terminal	Kampung Rambutan Terminal (Jakarta)
Approximate Distance (km)	12–14 km	20–25 km
Area Type Traversed	Suburban–Urban	Suburban–Periurban–Urban
Key Congestion Points	Pal Depok, Pasar Cibinong	Jalan Raya Bogor, Cijantung
Intermodal Access	Low	Moderate (connects to BRT, KRL)

Note: Route characteristics affect travel time and scheduling flexibility.

19:30) on both weekdays and weekends. Key observation points were strategically chosen based on their traffic intensity and passenger interaction. For D41, data were collected at SPBU Gandaria, the Pal Depok intersection, and Cibinong Terminal, while D37 observations were conducted at Simpang Pasar Cibinong, Halte Gongseng/Cijantung, and Kampung Rambutan Terminal.

The core variables observed included the number of angkot units passing per hour, headway intervals, total number of passengers per unit, and travel time per complete trip. Observers used stopwatches and tally counters for precise timing and vehicle frequency, while mobile GPS applications (Google Maps and Waze) were used to verify and triangulate travel time estimates. Estimated passenger capacity per vehicle was standardized at 12 passengers for D41 and 14 passengers for D37, based on structured interviews with drivers and route operators. This approach enabled the study to produce consistent, comparative data across routes and time frames.

To assess load factor (LF) a critical measure of route efficiency the following formula (1) was applied:

$$LF = \frac{\text{Total number of passengers}}{\text{Vehicle capacity x Number of vehicles}} x\ 100\% \quad (1)$$

This value was evaluated against Indonesia's national guideline of 70% minimum load factor for acceptable urban transport performance (PP RI, 1993). Load factor was calculated for each observation period to detect demand fluctuations and identify potential mismatches in service provision. This variable also functions as a proxy for fuel efficiency and revenue predictability in minibus operations.

Headway, defined as the interval between two consecutive vehicles at a given observation point, was another key metric. It was calculated using the formula (2)

$$H = \frac{T}{f} \quad (2)$$

Where T is the total observation duration in minutes, and f is the frequency (number of vehicles observed). According to Ministry standards (Menteri Perhubungan, 2013), ideal headway for urban minibuses is 2–5 minutes. Measuring this indicator helps determine both the consistency of service and the risk of operational overlap or scarcity, particularly during off-peak hours when route coordination is often weakest.

For travel time, data were collected by recording departure and arrival times at each terminal, supported by real-time traffic information from GPS applications (Byon et al., 2006; Xinghao et al., 2013). This metric is essential in understanding delays, congestion impact, and passenger satisfaction (Buran, 2025; Gbenga, 2025). In alignment with Indonesian service norms, the recommended

Table 2 Regulatory Benchmarks for Urban Transport Performance

Performance Metric	National Standard (Indonesia)	Reference Source
Load Factor	≥70% occupancy	(Menteri Perhubungan, 2013)
Headway	2–5 minutes	(Menteri Perhubungan, 2013)
Travel Time	Ideal: ≤90 minutes (max 180 min)	(Presiden Republik Indonesia, 1993)

Note: Benchmarks used for evaluating route efficiency and user service satisfaction.

travel duration for urban minibus routes is 1–1.5 hours, with a maximum allowable time of 3 hours under congested conditions. These values provide a contextual baseline to judge route-specific challenges, such as bottlenecks and route length variability (Table 2).

What distinguishes this methodology is its integration of quantitative precision with human-scale field realism, combining empirical rigor with on-ground adaptability. Rather than relying solely on transport agency data or simulation models, this research adopts a "mobility from below" perspective that centers real passenger experience and vehicle behavior (Li et al., 2016; Yuan et al., 2019). The study's novelty lies in its dual-route comparative framework, time-based sampling strategy, and incorporation of multiple performance dimensions in one integrative sustainability assessment. This method not only evaluates transportation efficiency but also contributes practical insights to improve route planning, service frequency, and environmental accountability in similar urban contexts.

C. Results and Discussion

This section presents the empirical findings from the field observations conducted on routes D41 (Gandaria–Cibinong) and D37 (Cibinong–Kampung Rambutan). The data collection focused on three performance indicators: passenger load factor, operational headway, and travel time, gathered across three time slots: morning peak, midday off-peak, and evening peak. Observations were systematically recorded at multiple strategic locations along each route to ensure consistency and spatial coverage. These results provide a baseline for interpreting the operational quality and sustainability of each route.

The first key parameter examined was the load factor, which reflects the percentage of a vehicle's seating capacity that is occupied by passengers during a given time interval. Load factor is a direct measure of service efficiency, passenger demand, and route relevance. For route D41, the average load factor during the morning peak was approximately 68.5%, which is just below the Ministry of Transportation's benchmark of 70%. This suggests relatively high demand but points to a slight underutilization or inefficiency in trip timing.

During the midday off-peak period, the load factor on D41 dropped significantly to 42.3%. This sharp decline may indicate an oversupply of vehicles relative to passenger volume during non-commute hours. Such inefficiencies are common in informal transit systems, where schedules are not demand-responsive (Beaudoin & Lawell, 2017). From a policy perspective, these findings emphasize the importance of time-of-day operational adjustments to avoid unnecessary fuel usage and financial losses.

By contrast, the evening peak for D41 showed a significant rebound, with load factors rising to 79.2%. This surpasses the regulatory standard and suggests high occupancy as commuters return home. These figures affirm the route's strategic importance during high-demand periods and suggest that targeted interventions could focus on optimizing only off-peak frequencies. These peak efficiencies also imply strong ridership trust in the route

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Table 3 Passenger Load Factor (%) by Time Period

Time Period	D41 (%)	D37 (%)
Morning	68.5	74.1
Midday	42.3	46.5
Evening	79.2	81.3

Note: Values ≥70% are considered efficient (Menteri Perhubungan, 2013).

during times of day when alternatives may be limited.

For route D37, the morning peak load factor was measured at 74.1%, exceeding the national standard. This indicates strong commuter reliance on the D37 route, likely due to its access to key employment hubs in East Jakarta. The relatively higher capacity of D37 minibuses (14 seats) may contribute to this efficiency without compromising passenger comfort. It also reinforces the need to preserve and strengthen intercity feeder systems that operate along major arterial roads like Jalan Raya Bogor. To assess service efficiency, the passenger load factor was measured across different time intervals. While both D41 and D37 surpassed the 70% benchmark during peak hours, significant declines were noted in midday. These variations are summarized in Table 3.

However, D37 experienced a midday drop to 46.5%, a pattern consistent with D41. This reinforces the hypothesis that the current angkot system lacks flexibility in adjusting to temporal demand. Unchanged vehicle frequency during off-peak hours results in underutilization and unnecessary congestion. The environmental cost of this inefficiency mainly increased emissions from low-occupancy vehicles is a critical consideration for future route planning (Ehsan et al., 2010; Wang et al., 2024).

Evening observations on D37 showed a load factor of 81.3%, the highest of any measured interval across both routes. This reaffirms the route's critical role in post-work urban mobility. Despite heavier traffic congestion in the evening, the continued high demand suggests user dependence and a limited set of viable alternatives. These numbers validate the operational potential of D37 for inclusion in any future mass-transit integration or upgrade plan.

The second performance indicator assessed was operational headway, defined as the time interval between two consecutive vehicle arrivals at a specified observation point. For D41, the average morning headway was measured at 2.1 minutes, indicating a consistent and frequent service rate. This value falls within the national standard range of 2–5 minutes, indicating effective vehicle deployment during peak morning hours. Such consistency enhances passenger satisfaction and minimizes wait time.

The midday headway for D41, however, increased to 4.5 minutes, reflecting either a drop in vehicle supply or elongated turnaround times due to lower demand. While still within the regulatory range, this shift indicates a lack of demand-responsive scheduling. More concerning is that this inefficiency leads to overlapping routes and contributes to urban congestion, especially at shared junctions. Addressing this could involve coordination with other routes or dynamic route management systems.

By evening, D41's headway improved slightly to 2.8 minutes, suggesting an uptick in operational frequency to meet rising passenger volumes. This adjustment reflects an intuitive or experience-based response by drivers or operators, typical in informal transport networks. Still, the absence of data-driven scheduling mechanisms raises concerns about long-term sustainability and reliability. These fluctuations underscore the need for professional route planning and real-time data integration.

On D37, the morning headway was

Table 4 Average Operational Headway (minutes)

Time Period	D41 (min)	D37 (min)
Morning	2.1	1.7
Midday	4.5	3.9
Evening	2.8	2.4
Note: Optimal headway range is 2–5 minutes based on national urban service standards.		

recorded at 1.7 minutes, indicating a very high frequency of service during peak commute times. While this may benefit passengers through reduced wait times, it also raises concerns about road saturation, vehicle crowding, and operator competition. The short headway reflects the high demand but may also indicate inefficient fleet distribution without centralized coordination. A more strategic deployment could enhance route productivity while reducing traffic density.

During midday, D37's headway extended to 3.9 minutes, consistent with the observed decrease in passenger volume. This adjustment may reflect natural throttling by drivers waiting for passengers rather than a structured schedule. It highlights a key weakness of the informal system: its inability to scale back efficiently without financial risk to operators. Such behavior could be improved through targeted subsidies or dynamic scheduling tools tied to passenger analytics.

The evening headway on D37 was observed at 2.4 minutes, maintaining optimal service frequency during high-demand hours. This operational consistency affirms the responsiveness of drivers to market signals but again reveals the lack of formal scheduling infrastructure. Even though passengers benefit from reduced waiting times, the long-term consequence includes higher fuel consumption and maintenance costs. A digital scheduling or dispatch system could address this challenge. The consistency of vehicle arrival was evaluated by measuring operational headway. As shown in Table 4, most headways fell within the Ministry's 2–5 minute guideline, with D37 achieving the shortest intervals in morning peaks.

The final metric assessed was total travel time, which directly affects user experience and environmental emissions. On D41, the average travel time was 48 minutes in the morning, increasing to 65 minutes in the evening due to heavier traffic. These durations are well within acceptable standards but point to bottlenecks at key junctions such as Pal Depok and Cibinong Market. Identifying and mitigating these choke points could significantly improve route efficiency.

In contrast, D37's travel time was significantly higher, averaging 85 minutes in the morning and rising to 90 minutes in the evening. These durations exceed the preferred maximum of 1.5 hours and suggest systemic congestion along Jalan Raya Bogor and Cijantung. The findings support broader concerns about urban corridor saturation and inadequate traffic management in metropolitan peripheries (Dong et al., 2024; Sun et al., 2014). Incorporating this route into a dedicated bus lane or priority transit corridor could alleviate delays. Travel duration reflects both route length and traffic conditions. While D41 maintained moderate durations, D37 consistently exceeded the optimal 90-minute

Table 5 Average Travel Time (minutes)

Time Period	D41 (min)	D37 (min)
Morning	48	85
Midday	55	80
Evening	65	90
Note: Recommended maximum is 90 minutes; values exceeding this indicate inefficiency.		

threshold. Table 5 illustrates the detailed time measurements.

The study also observed that real-time navigation data (Google Maps, Waze) consistently matched manual measurements within a 3–5% margin of error. This validates the use of mobile applications as reliable tools for transit research in low-infrastructure environments. Their integration into transport planning systems can enhance route analysis, especially in contexts lacking formal ITS (Intelligent Transport Systems). The reliability of such tools opens opportunities for cost-effective data collection in other urban areas across Indonesia.

Overall, the results highlight clear temporal and route-based disparities in operational efficiency between D41 and D37. While both routes achieve high load factors during peak periods, their performance deteriorates during off-peak hours due to oversupply and congestion. Headway values remain within acceptable limits, though often more by habit than planning. Travel time on D37, in particular, exceeds policy thresholds, underscoring the urgency for targeted intervention.

From a sustainability perspective, D41 appears more efficient in balancing load factor and travel time, while D37 performs better in peak demand absorption but struggles with congestion. These insights offer actionable recommendations for improving scheduling, route optimization, and resource allocation. The study provides a compelling case for integrating informal transit data into urban transport policy, particularly in transitional cities like Depok and Cibinong. The findings also contribute to the global discourse on informal public transport in developing countries, emphasizing the value of structured observation and local knowledge.

The findings of this study reveal significant insights into the operational performance of two essential minibus routes in the Depok–Bogor region D41 and D37. By analyzing their load factors, headways, and travel times across three time periods, the study uncovers both strengths and inefficiencies in current angkot operations. The data demonstrates a dynamic interplay between supply, demand, and congestion, which must be addressed to improve urban mobility. Moreover, this research underscores the importance of localized assessments in informing sustainable transportation planning.

One of the most compelling results relates to load factor variability across time periods. Both routes demonstrated strong passenger density during morning and evening peaks, with values consistently exceeding the 70% efficiency benchmark. This suggests that angkot remains a reliable and preferred mode of transport for many daily commuters. The implications here are clear: when scheduled intuitively, informal transit systems can deliver capacity-efficient services, especially in under-served suburban areas.

However, the stark decline in load factors during midday signals an inefficiency in resource allocation. Vehicles continue to operate at similar frequencies despite significant drops in passenger demand. This not only leads to underutilized capacity but also exacerbates fuel consumption and traffic congestion. These inefficiencies point to a systemic issue in the absence of data-driven scheduling or dynamic fleet management.

D41, in particular, showed a notable midday inefficiency with a load factor dropping to 42.3%, while D37 followed closely at 46.5%. These figures confirm what many field researchers have long suspected: without centralized control, informal transit systems operate in “flat mode,” failing to adapt to fluctuating demand (Beaudoin et al., 2015). This rigidity is rooted in financial structures that reward drivers by trip count rather than load optimization. As such, vehicles remain on the road regardless of passenger density, leading to diminishing returns.

From a sustainability perspective, these midday patterns have broader implications. The continuation of low-occupancy trips during off-peak hours contributes to unnecessary fuel use and increased CO_2 emissions. Urban environments like Depok and Cibinong, which already suffer from air quality degradation, cannot afford such inefficiencies in public transport operations (Wang et al., 2024). Addressing this requires policy-level support, such as driver incentives tied to performance-based metrics and environmentally conscious fleet rotations.

Operational headway emerges as another critical measure in understanding transit efficiency and user experience. In general, both D41 and D37 met the national standard of 2–5 minutes across all time periods, with D37 often demonstrating shorter headways. This is a positive sign from the user's perspective, indicating a consistent flow of available vehicles. However, shorter headways do not always translate into optimal efficiency, especially when demand is low.

The challenge lies in distinguishing between responsive frequency and oversupply. For instance, D37's 1.7-minute morning headway may be interpreted as either a responsive adaptation to demand or an unregulated vehicle surplus. In informal transit networks, where driver competition is high, short headways can reflect inefficiencies rather than effective planning (Rodrigue et al., 2016). This study suggests that route-level monitoring and coordination are essential to balance supply and demand more intelligently.

Interestingly, evening headways stabilized across both routes, indicating an inherent temporal equilibrium. Drivers appear to adjust operational pacing based on lived experience rather than formal scheduling. While this reflects the adaptive nature of informal systems, it also raises concerns about standardization, fairness, and service predictability. Sustainable transport requires not only adaptability but also accountability, which can only be achieved through structured planning mechanisms.

When assessing travel time, route D37 stands out as significantly underperforming. With morning and evening durations averaging over 85 minutes, D37 consistently exceeds the Ministry's recommended 1.5-hour maximum (PM RI, 2013). The underlying reason is likely its longer geographic reach and exposure to multiple congestion zones, particularly along Jalan Raya Bogor and Cijantung. These areas are known chokepoints that severely delay vehicles during peak times.

D41, although more compact, also experienced extended travel times in the evening. This is consistent with citywide trends where return-commute traffic peaks during 6:00–7:30 PM. These patterns confirm that infrastructure limitations and peak-hour congestion are the leading contributors to increased trip duration. Sustainable transport planning, therefore, must integrate spatial traffic modeling and infrastructure investment to mitigate such chronic delays.

In light of these findings, one of the major contributions of this study is its dual-route comparative framework, which allows for a more nuanced analysis than single-route studies. By examining both an intra-urban route (D41) and a cross-city route (D37), this research illustrates how geographic span, network complexity, and urban density shape transport performance. This level of comparison helps inform differentiated policy responses, such as prioritizing route upgrades based on congestion sensitivity and passenger volume.

Another layer of novelty lies in the use of real-time GPS data from mobile apps to validate travel time estimates. In resource-constrained settings, mobile navigation tools offer a viable proxy for time-motion studies, especially when formal GPS-equipped fleets are absent. This methodological innovation contributes to the growing field of low-cost urban mobility research in developing countries. It also demonstrates how publicly available technologies can be harnessed for empirical transit evaluation (Ehsan et al., 2010).

Furthermore, this study humanizes the transport conversation by centering the lived experiences of passengers and drivers. The measurements reflect real waiting times, crowding levels, and route congestion as

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Table 6 Summary of Key Findings

Indicator	**Route D41**	**Route D37**
Peak Load Factor	79.2% (Evening)	81.3% (Evening)
Off-peak LF	42.3%	46.5%
Morning Headway	2.1 min	1.7 min
Max Travel Time	65 min	90 min
Key Weakness	Midday inefficiency	High travel time
Sustainability Fit	Moderate (balanced)	Low (congestion-sensitive)

experienced in daily commutes. Unlike macro-level modeling or policy abstracts, these findings deliver grounded insights that are actionable and locally relevant. In this way, the study serves as a bridge between operational realities and high-level planning.

Despite its strengths, the study also acknowledges several limitations. The sample was restricted to one-hour observations per time period and did not include weekend fluctuations or seasonal variability. Furthermore, there was no direct engagement with angkot operators or municipal regulators to assess governance dynamics. These are areas for future research, particularly if this model is to be scaled or replicated in other cities.

The discussion also suggests that headway and load factor are not only indicators of operational efficiency but also predictors of environmental and economic sustainability (Table 6). Low headways with high load factors are desirable, but when headways are low and load factors are poor as seen during midday periods the system becomes both ecologically and financially unsustainable. Aligning scheduling with demand patterns will be key to balancing these dimensions.

Finally, these findings reinforce the need for formal integration of informal systems into the wider urban transport framework (Table 7). Angkot routes like D41 and D37 play a pivotal role in daily mobility, yet remain disconnected from mass transit corridors such as commuter rail or bus rapid transit. Integrating these services through shared hubs, unified fare systems, and digital scheduling would significantly enhance urban mobility efficiency.

In conclusion, this study offers empirical evidence and practical guidance for optimizing minibus operations in suburban Indonesia. It highlights the urgent need for smarter scheduling, better route governance, and infrastructure coordination. By doing so, it contributes to both the academic literature on sustainable transportation and the practical agenda of urban planners and policy makers.

Table 7 Policy Recommendations Based on Operational Findings

Issue Identified	**Recommendation**	**Stakeholder Involved**
Midday inefficiency	Dynamic fleet scheduling	Operator Associations, Local Government
Prolonged travel time (D37)	Dedicated lane or peak-time signal priority	Transport Dept., Urban Planner
Lack of digital oversight	Real-time GPS & headway monitoring system	Local Gov., App Developers
Environmental inefficiency	Gradual transition to electric-powered angkot	Provincial Government, OEMs
Route isolation from BRT/KRL	Integrate minibus stops with existing transit hubs	Transport Authority, MRT/BRT

The insights gained here can help shape more responsive, equitable, and sustainable transit systems for growing metropolitan regions.

Limitations and Future Research

This study is limited by several factors. Firstly, the data collection was confined to one-hour observation windows per time period and did not capture variations across entire weekdays, weekends, or seasonal shifts. Secondly, the study focused solely on operational parameters (load factor, headway, and travel time) without integrating passenger satisfaction or qualitative aspects of service quality. Additionally, no interviews were conducted with angkot operators or government officials, which could have enriched the understanding of governance and regulatory influences.

Future studies should consider expanding the temporal scope of data collection to include full-day and week-long patterns, as well as incorporating passenger surveys to capture user perspectives on service quality. Further research could also explore the impact of emerging technologies such as real-time tracking, dynamic scheduling apps, and electric vehicles on the sustainability of informal transit systems. Finally, comparative studies across multiple urban regions would help validate the transferability of this study's framework to broader contexts.

D. Conclusion

This study assessed the performance of two critical urban minibus routes D41 and D37 within the Depok–Bogor corridor, using three operational indicators: load factor, headway, and travel time. The research revealed that during peak hours, both routes consistently met or exceeded the government benchmark of a 70% load factor, reaching as high as 79.2% for D41 and 81.3% for D37 in the evening. However, during midday periods, both routes suffered from low occupancy rates 42.3% and 46.5% respectively despite maintaining short headways of approximately 4 to 5 minutes. These mismatches between demand and supply highlight systemic inefficiencies in the absence of demand-responsive scheduling.

In terms of headway, both routes maintained service intervals within the acceptable range of 2–5 minutes, with D37 performing slightly better, especially in the morning (1.7 minutes). Travel time, however, presented a notable disparity: D41 maintained a moderate average of 48–65 minutes, while D37 consistently exceeded 80 minutes, reaching 90 minutes in the evening far beyond the ideal maximum. These findings confirm that while D37 absorbs higher passenger loads, it faces significant congestion challenges, particularly on Jalan Raya Bogor and around Kampung Rambutan. The imbalance between high demand and extended travel time points to a need for route restructuring or priority transit integration.

Overall, the study provides empirical validation that minibus routes like D41 and D37 are vital yet vulnerable components of urban mobility in Indonesian cities. Their efficiency is evident during peak demand, but the lack of flexible scheduling and real-time planning causes inefficiencies during off-peak periods and in high-traffic zones. The research introduces a replicable and low-cost framework for evaluating informal transport using mixed methods, including manual field observation and mobile GPS data. As urban populations grow and sustainability becomes urgent, these findings serve as a foundation for more intelligent, adaptive, and inclusive transport systems in developing regions.

This study also faced limitations in terms of observation scope and the absence of qualitative insights. Future research is recommended to expand the temporal coverage of data collection to include full-day patterns, weekends, and seasonal variations. Additionally, incorporating passenger satisfaction surveys and engaging with operators and regulatory stakeholders would provide a more holistic understanding of service quality and governance dynamics. Exploring the integration of real-time tracking technologies and evaluating the impact of alternative propulsion systems, such as electric vehicles, could further enhance the sustainability and efficiency of informal transit networks. Comparative studies across different urban regions are also encouraged to validate the broader applicability of the proposed assessment framework.

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