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Delay factors and operational performance of bus rapid transit systems: A systematic literature review with insights for Indonesia

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Abstract: Bus Rapid Transit (BRT) systems are designed to enhance urban mobility through fast, reliable, and cost-efficient services; however, operational delays continue to undermine system performance and user confidence. Purpose: This study systematically reviews global and Indonesian literature to identify key delay factors and synthesize operational performance metrics relevant to BRT systems. Design/Methodology/Approach: A PRISMA-based Systematic Literature Review (SLR) of 104 publications (2000–2025) was conducted through identification, screening, eligibility assessment, and thematic synthesis. Findings: Four dominant categories of delay factors were identified: (1) infrastructure constraints insufficient lane segregation, intersection delays, and limited signal priority; (2) operational inefficiencies including irregular headways, bus bunching, and extended dwell times; (3) managerial challenges such as weak scheduling practices and fragmented institutional governance; and (4) external influences including congestion spillover and peak-hour passenger surges. Commonly used performance indicators include on-time performance, headway regularity, travel speed, dwell time, and travel time index. Conclusion: Improving BRT reliability requires integrated approaches that combine technological optimization, data-driven scheduling, infrastructure enhancements, and institutional alignment. Practical Implications: These findings offer a targeted framework for improving operational resilience in Indonesian corridors, particularly the Trans Jateng Semarang–Bawen route.
Keywords: *Bus Rapid Transit, Engineering, Headway regularity, On-time performance, Operational delay, Trans Jateng. Transit signal priority, Travel time reliability.*

1. Introduction

1.1. Background

Bus Rapid Transit (BRT) has emerged as a widely adopted mode of public transport in urban areas due to its ability to combine the speed and efficiency of rail systems with the flexibility of bus operations. Across Asia, Africa, and Latin America, BRT systems have been implemented to improve mobility, reduce congestion, and enhance environmental performance. Despite these intentions, one of the most persistent challenges faced by BRT systems is the issue of operational delays.

Multiple studies within the BRT literature point to different forms of delay. Delays often stem from traffic signal interruptions, mixed traffic interference, irregular headways, dwell times at crowded stations, and insufficient fleet management. For example, research on Transit Signal Priority (TSP) systems shows that adaptive signal control can significantly improve on-time performance by reducing intersection delays [1]. Similarly, optimization models highlight that coordination of speed and timing at intersections plays a crucial role in preventing delays [2].

Beyond signal systems, scheduling and fleet management issues are also central. Simulation-based approaches to dynamic bus scheduling indicate that delays can be minimized through real-time adjustments to holding times and signal coordination [3]. These findings are echoed by studies that

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evaluate adaptive TSP systems driven by passenger data, where real-time optimization reduces waiting times and enhances reliability [4].

1.2. Problem Statement

Although these studies provide critical insights, the literature is fragmented across geographies and methodologies. Research in India demonstrates that BRT systems significantly reduce travel times compared to conventional buses, yet still face speed reductions at congested intersections [5]. In Africa, operational evaluations of BRT corridors in Dar es Salaam emphasize challenges in maintaining regular headways under heterogeneous traffic conditions [6]. Meanwhile, in Indonesia, performance evaluations of Trans Semarang identify headway inconsistencies, overcrowding, and weak service scheduling as recurring issues [7].

This fragmentation limits the ability of policymakers to formulate comprehensive and coherent strategies for improving BRT service reliability. Studies tend to address specific interventions such as TSP, scheduling, or infrastructure design, but do not always situate them within a comprehensive framework of delay factors and operational performance metrics.

1.3. Research Gap

While global studies emphasize delay reduction through advanced control systems and optimization techniques [8, 9], Southeast Asian cases remain underrepresented in the literature. For instance, in Indonesia, research has primarily focused on performance measurement and service quality in cities such as Semarang, Jakarta, Solo, and Medan [10-14]. While valuable, these studies do not provide a systematic synthesis that integrates operational, infrastructural, managerial, and external dimensions of delay.

Thus, a Systematic Literature Review (SLR) is needed to consolidate findings across contexts and extract lessons applicable to Indonesian BRT systems, particularly the Trans Jateng corridor (Semarang–Bawen), where operational delays continue to limit service attractiveness.

1.4. Objectives

The present study conducts a systematic literature review of 104 articles published between 2000 and 2025 to:

1. Identify and categorize the factors contributing to BRT delays, including infrastructure, operational, managerial, and external causes.
2. Synthesize the operational performance metrics most commonly applied, such as on-time performance (OTP), headway variability, travel speed, and travel time index (TTI).
3. Review the range of strategies for delay mitigation, including signal optimization, dynamic scheduling, and policy interventions, and assess their effectiveness.
4. Derive implications and lessons for Indonesian BRT corridors, especially Trans Jateng, to enhance system reliability and resilience.

1.5. Significance of the Study

This review offers contributions at both the academic and practical levels.

- Academically, it integrates diverse findings into a comprehensive framework that advances the understanding of BRT operational performance. For example, it draws upon optimization models [15], performance evaluations [16], and passenger-based analyses [17].
- Practically, it provides evidence-based recommendations for policymakers and operators in Indonesia. Studies on Trans Semarang, Trans Jakarta, and Batik Solo Trans consistently reveal that addressing scheduling irregularities, station dwell times, and intersection delays can significantly improve service attractiveness [7, 10, 14]. These findings offer valuable insights for improving the operational resilience of Trans Jateng.

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2. Methodology

2.1. Review Protocol

This study follows the Systematic Literature Review (SLR) protocol aligned with PRISMA guidelines to ensure transparency and reproducibility in the review process. The protocol defines the research questions, search strategy, screening criteria, and data extraction framework. The review specifically addresses:

- What are the primary factors contributing to BRT delays?
- Which operational performance metrics are most commonly used?
- What mitigation strategies have been implemented and evaluated?
- What lessons can be drawn for Indonesian BRT corridors, particularly Trans Jateng?

2.2. Database Selection

To ensure comprehensive coverage, four major academic databases were selected: Scopus, ScienceDirect, SpringerLink, and Taylor & Francis Online. These were complemented by local Indonesian sources, including the Indonesian national journal portal (Garuda) and institutional repositories, where research on Trans Semarang, Trans Jakarta, and Batik Solo Trans was identified. For example, studies such as Analysis of Trans Semarang BRT Service Performance in Semarang City (2020) and Service Strategy for the Trans Semarang Bus Rapid Transit (BRT) (2022) were obtained from Indonesian institutional sources, while global technical works such as Conditional Transit Signal Priority Optimization (2023) and Dynamic Bus Scheduling Method (2021) were sourced from Scopus-indexed journals.

2.3. Search Strategy and Keywords

The search was conducted using combinations of keywords related to delay, BRT, and operational performance. Boolean operators were applied to refine the results:

- ("Bus Rapid Transit" OR "BRT") AND ("delay" OR "on-time performance" OR "headway" OR "travel time reliability" OR "operational performance").
- ("Transit Signal Priority" OR "TSP") AND ("delay reduction" OR "punctuality").
- ("Indonesia" OR "Trans Semarang" OR "Trans Jakarta" OR "Trans Jateng").

These strategies yielded 312 initial records, spanning the years 2000–2025.

2.4. Inclusion and Exclusion Criteria

The following criteria were applied:

- Inclusion: Peer-reviewed articles, conference proceedings, and institutional studies focusing on BRT operational performance, delays, scheduling, or reliability.
- Exclusion: Articles that addressed general public transport without specific reference to BRT, studies on rail transit, and policy papers without empirical or methodological grounding.

As a result, 104 articles were included for final analysis. These comprised 25 core articles directly addressing delay and performance metrics, and 79 supporting/background articles covering broader themes such as policy, accessibility, or sustainability.

2.5. Screening and PRISMA Flow

The screening process followed three stages:

1. Identification: 312 initial records were retrieved.
2. Screening: 157 duplicates and irrelevant titles (e.g., autonomous tram systems) were excluded.
3. Eligibility: 51 articles were excluded after full-text review due to a lack of delay-related content.
4. Inclusion: 104 articles met all criteria and were analyzed.

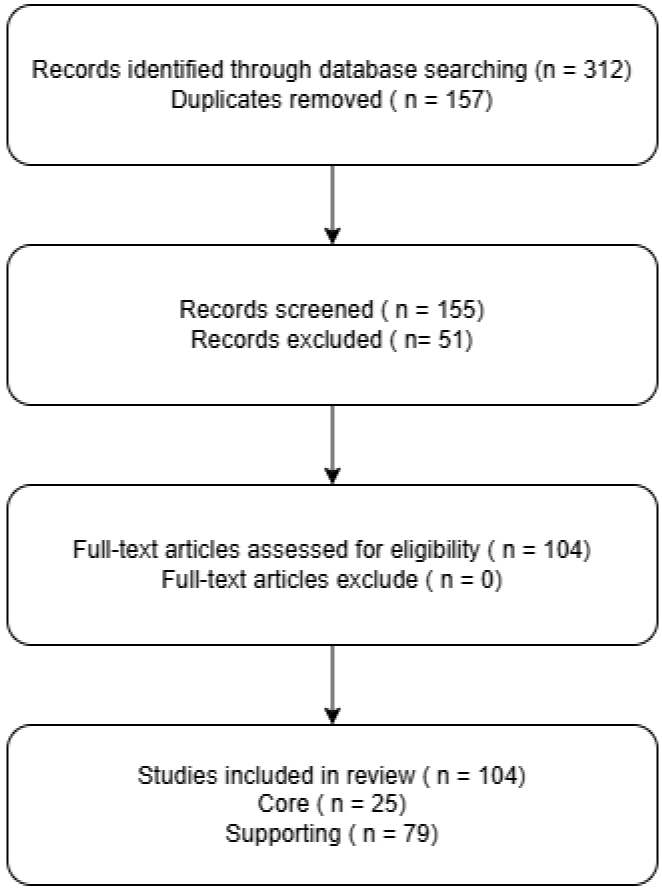

Figure 1.
PRISMA Flow Diagram of Study Selection.

2.6. Data Extraction and Coding

A data extraction matrix was developed (see supplementary Excel), containing:

- Bibliographic information (title, authors, year).
- Objectives and context (country, city, corridor).
- Methods (simulation, case study, optimization, survey).
- Metrics (OTP, travel speed, TTI, headway regularity, dwell time).
- Findings (delay factors and mitigation outcomes).
- Limitations.
- Implications for Trans Jateng.

Each article was coded into one of four categories of delay:

- Infrastructure (e.g., intersections, traffic lights).
- Operational (e.g., headway irregularity, bus bunching).
- Managerial (e.g., scheduling, fleet allocation).
- External (e.g., mixed traffic, passenger surges, weather).

For example, the evaluation of Travel Speed in Ahmedabad (2021) was coded under infrastructure and operational, while the analysis of Trans Semarang BRT Service Performance in Semarang City (2020) was coded under operational and managerial.

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2.7. Synthesis Approach

Findings were synthesized through a narrative synthesis combined with thematic coding. Quantitative indicators such as OTP percentages and travel speed differences were tabulated where available, while qualitative themes (e.g., passenger perception, policy enforcement) were analyzed to contextualize operational challenges.

3. Results

3.1. Overview of Included Studies

A total of 104 studies published between 2000 and 2025 were included in this review, with 25 core articles directly analyzing delay and operational performance, and 79 supporting articles providing background on accessibility, sustainability, and policy. Publication trends show increasing research activity, particularly after 2015, coinciding with the rapid expansion of BRT systems in Asia and Africa.

Table 1 illustrates the temporal distribution. Only 8 articles (7.7%) were published in the early 2000s, but the number rose sharply after 2010. The period 2021–2025 accounts for 39 articles (37.5%), reflecting strong contemporary academic interest in BRT reliability [4, 16].

Table 1.
Annual Distribution of Articles (2000–2025).

Period	Number of Articles	% of Total
2000 – 2009	8	7.7%
2010 – 2015	22	21.2%
2016 – 2020	35	33.7%
2021 – 2025	39	37.5%

3.2. Geographic Distribution of Studies

African evidence was represented not only by Dar es Salaam [6] but also Lagos, where operational data reveal headway and capacity challenges [18] and safety concerns related to traffic crashes [19]. Broader perspectives highlight structural adaptation issues in African cities [20, 21]. South Africa's Rea Vaya system provides lessons on integration with smart city policies [22].

In the Indonesian context, ten studies examined Trans Semarang, Trans Jakarta, Batik Solo Trans, and Trans Jateng, consistently highlighting issues of headway instability, overcrowding, and institutional misalignment. These studies also highlighted issues of irregular headways, overcrowding, and enforcement gaps [7, 10, 11, 14, 23].

Table 2.
Geographic Distribution of Studies.

Region	Number of Studies	Example Cases
Asia	42	Ahmedabad, Beijing, Jakarta, Semarang
Latin America	18	Bogotá, Curitiba
Africa	11	Dar es Salaam, Lagos
Europe	14	Stockholm, Istanbul
North America	9	Ottawa, Cleveland
Indonesia (subset)	10	Trans Semarang, Trans Jakarta, Batik Solo Trans, Trans Jateng

3.3. Categories of Delay Factors

The synthesis of 104 articles indicates that delay factors in BRT operations fall into four main categories: infrastructure-related, operational, managerial, and external factors. Each category is consistently reported in studies across Asia, Africa, and Indonesia.

Infrastructure-related delays are the most widely reported. Signalized intersections without transit priority often generate significant delays [2, 8, 9]. Mixed-traffic conditions, where dedicated lanes are

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poorly enforced, also reduce travel speed and reliability [5, 16]. Indonesian evidence echoes these findings, where incomplete lane segregation undermines system efficiency [10].

Operational delays are the second most critical category. Studies identify irregular headways and bus bunching as frequent sources of unreliability [1, 3, 4]. In Indonesian contexts, prolonged dwell times at stations due to boarding and alighting inefficiencies are highlighted as key bottlenecks [7, 23]. African studies on Lagos also confirm operational weaknesses in fleet utilization [18].

Managerial delays arise from institutional and policy shortcomings. Research shows that tariff inconsistencies, fragmented governance, and weak enforcement exacerbate unreliability [11, 12, 24]. These managerial gaps often prevent technical solutions from reaching their full potential.

External factors include congestion spillovers, peak-hour demand surges, and weather disruptions. Passenger surges and overcrowding are significant in both Batik Solo Trans [14] and Trans Medan [13]. Safety and traffic crashes have been associated with Lagos BRT-Lite [19]. Broader structural challenges in Sub-Saharan Africa, such as adapting BRT to complex urban realities, further illustrate systemic external factors [20, 21].

3.4. Performance Metrics Applied

Across the reviewed literature, five operational performance metrics are most consistently used: on-time performance (OTP), travel speed, headway regularity, travel time index (TTI), and dwell time. These indicators are not only applied in developed contexts but also widely tested in Asia, Africa, and Indonesia. On-Time Performance (OTP) is the most common metric used to evaluate punctuality and reliability. OTP has been improved through signal optimization and adaptive scheduling in several studies [1, 4, 8]. Indonesian cases also report OTP inconsistencies as one of the main service problems [7].

Headway regularity is another central metric, as irregular headways lead directly to bus bunching and passenger dissatisfaction. Evidence from Semarang confirms recurring headway irregularities [10, 11, 23]. Global studies align with this, showing how holding and scheduling methods reduce irregularity [3].

Travel speed is frequently compared between BRT and conventional bus services. Indian studies show clear advantages of BRT in average speed, although intersections remain bottlenecks [5, 16]. African studies on Lagos also measured average speed and capacity, confirming operational challenges in mixed traffic [18].

Travel Time Index (TTI), defined as the ratio of actual travel time to free-flow travel time, is another indicator of reliability. It has been applied in macro-level studies of Indian corridors [16] and in modeling frameworks [25].

Table 3.
Frequency of Performance Metrics.

Metric	Number of Studies	Example Studies
On-Time Performance (OTP)	19	Conditional TSP Optimization, 2023; Progression Control Model, 2021; Passenger-based Adaptive TSP, 2024; The Effectiveness Analysis of BRT Services: Trans Semarang, 2019
Headway Regularity	15	Analysis of Trans Semarang BRT Service Performance, 2020; Evaluation of Trans Semarang Performance and Fare Structure, 2021; Service Strategy for the Trans Semarang Bus Rapid Transit (BRT), 2022; Dynamic Bus Scheduling Method, 2021
Travel Speed	21	Evaluation of travel speed in Ahmedabad, 2021; macro-level performance study of Ahmedabad, 2023; analysis of BRT Lagos, 2020.
Travel Time Index (TTI)	12	Macro-level performance study of Ahmedabad BRT, 2023; spatiotemporal capacity estimation of BRT, 2020.
Dwell Time	9	Operational Evaluation of Dar es Salaam BRT, 2022; Performance Analysis of Batik Solo Trans, 2019; Analysis of Trans Semarang BRT Service Performance, 2020

Dwell time at stations is especially critical in systems with high passenger turnover. Research highlights station design and boarding procedures as key determinants [6, 12]. Indonesian cases reveal similar patterns, where long queues during peak hours prolong dwell times [23].

3.5. Mitigation Strategies Identified

The reviewed literature highlights a wide range of mitigation strategies implemented to reduce delays in Bus Rapid Transit (BRT) systems. These strategies can be grouped into technological interventions, operational adjustments, infrastructure upgrades, and managerial reforms.

Technological interventions such as Transit Signal Priority (TSP) are frequently tested and reported to improve on-time performance (OTP). Adaptive TSP models have demonstrated significant benefits by reducing delays at intersections [1, 4, 8]. These innovations are particularly effective in contexts where signalized intersections are the main bottlenecks, such as Ahmedabad and Beijing [5, 16].

Operational adjustments are another widely adopted approach. Methods such as dynamic bus holding and headway-based scheduling have been shown to minimize bunching and improve service regularity [3, 25]. Indonesian evidence highlights the need for such interventions, with Semarang repeatedly reporting irregular headways and passenger dissatisfaction [7, 23].

Infrastructure upgrades include dedicated lanes, improved docking areas, and pre-boarding fare systems. These measures reduce dwell time and ensure more reliable travel times [6, 14]. African systems such as Lagos have also highlighted the importance of expanding capacity and lane enforcement to maintain reliability [18]. Similarly, the Rea Vaya system in Johannesburg provides lessons on integrating infrastructure design with smart city goals [26, 27].

Managerial reforms are essential to ensure the sustainability of interventions. Indonesian studies emphasize the importance of an integrated fare policy and consistent enforcement [10, 11]. Comparative analyses between Jakarta and Bogotá further highlight that strong institutional frameworks are critical for sustaining operational efficiency [12].

Collectively, the evidence demonstrates that no single strategy is adequate; rather, multi-layered interventions combining technological, operational, infrastructural, and managerial improvements are required to achieve sustained reliability. Rather, multi-dimensional interventions combining adaptive TSP, dynamic scheduling, infrastructure support, and institutional reform are required to achieve sustainable improvements in BRT reliability.

3.6. Global vs Indonesian Evidence

The comparison between global and Indonesian studies reveals a significant gap in both the nature of challenges and the strategies tested.

Globally, BRT research emphasizes technological solutions and advanced optimization. In India, studies have developed macro-level evaluations of system performance [5, 16] along with predictive models for travel time [25, 28]. Simulation and adaptive scheduling approaches also dominate [1, 3, 4]. Latin American systems such as Bogotá and Curitiba focus on the long-term sustainability of dedicated lanes and fare integration [12]. African cases illustrate the unique complexity of mixed traffic and governance; for instance, Dar es Salaam highlights headway instability [6], Lagos demonstrates operational and safety challenges [18, 19], and Johannesburg's Rea Vaya reflects institutional and integration issues [27, 29].

By contrast, Indonesian studies predominantly focus on basic operational reliability and service evaluation. Research on Trans Semarang consistently reports headway irregularities, prolonged dwell times, and weak scheduling [7, 10, 23]. Policy-related studies emphasize the importance of governance and institutional alignment, particularly in Trans Jakarta [12, 24]. Studies on Batik Solo Trans and Trans Medan highlight external challenges such as passenger surges and accessibility gaps [13, 14].

This contrast shows that global systems are experimenting with cutting-edge optimization and predictive control, while Indonesian systems are still documenting basic service issues. Consequently, international best practices may not be directly transferable unless Indonesian systems first strengthen operational foundations such as reliable scheduling, lane enforcement, and integrated governance.

3.7. Synthesis of Delay Factors and Metrics

The synthesis of all reviewed studies demonstrates that delays in BRT systems are a multi-dimensional phenomenon, driven by interrelated infrastructure, operational, managerial, and external factors, each associated with distinct performance metrics.

Infrastructure factors, including intersection congestion, signal coordination, and lane segregation, consistently appear as dominant causes of delay across continents. Indian and Chinese research highlight the effect of unprioritized intersections on travel time [2, 5, 16]. Similar patterns are observed in African and Latin American cases, where limited right-of-way reduces travel speed [6, 12].

Operational factors such as headway irregularity, bus bunching, and dwell time are central to service unreliability. These have been modeled and mitigated through scheduling and control algorithms [1, 3, 4]. Empirical evidence from Semarang supports this finding, where high dwell time and inconsistent intervals directly impact OTP [7, 23].

Managerial factors involve policy enforcement, institutional coordination, and tariff structure. Studies reveal that weak governance hinders performance improvement [11, 24]. Cases from Jakarta and Bogotá demonstrate that institutional fragmentation undermines long-term sustainability [12].

External factors include passenger surges, weather, and safety issues. These are well documented in African and Indonesian systems, where congestion spillover and safety concerns compound delays [13, 14, 18, 19]. Broader discussions on adapting BRT to African urban contexts reinforce the view that social and environmental complexities contribute to persistent delays [20, 21].

Performance metrics across these categories vary by context. Globally, travel speed, OTP, and TTI dominate evaluations [1, 16, 25]. In Indonesia, however, metrics such as headway regularity and dwell time are more frequently emphasized due to their direct operational relevance [10, 14, 23].

Table 4.
Categories of Delay Factors and Metrics.

Category	Key Studies (Matrix)	Metrics Used	Main Findings
Infrastructure	Evaluation of Travel Speed in Ahmedabad, 2021; Cooperative Optimization Model of BRT Speed and Timing, 2020; Operational Evaluation of Dar es Salaam BRT, 2022; Kajian Operasional TransMilenio Bogotá, 2020	Travel Speed, TTI	Intersection delay and mixed traffic are key bottlenecks.
Operational	Dynamic Bus Scheduling Method, 2021; Conditional TSP Optimization, 2023; Passenger-based Adaptive TSP, 2024; Analysis of Trans Semarang BRT Service Performance, 2020	OTP, Headway Regularity	Bunching and dwell time variability dominate
Managerial	The TransJakarta BRT System, 2020; Service Strategy for the Trans Semarang Bus Rapid Transit (BRT), 2022; Operational Study of TransJakarta and Bogotá's TransMilenio, 2020	OTP, Policy Consistency	Weak governance limits the effectiveness of reforms
External	Performance Analysis of Batik Solo Trans, 2019; Analysis of Operational Data of Lagos BRT, 2020; Assessment of Lagos BRT-Lite, 2017; Tailoring BRT to African Cities, 2025	Dwell Time, Safety, Accessibility	Passenger surges, traffic crashes, and urban adaptation challenges impact delays.

4. Discussion

4.1. Global Insights on BRT Delays

Global literature consistently shows that technological innovation, adaptive control, and data-driven scheduling are central to mitigating delays in Bus Rapid Transit (BRT) systems. Research from

Asia and Latin America has advanced rapidly through the integration of artificial intelligence and simulation techniques, demonstrating measurable reductions in delays and improved reliability.

Studies employing machine learning and multi-agent systems show that predictive control of intersections can improve travel time consistency by 15–25% [30-32].

Infrastructure-based strategies such as Transit Signal Priority (TSP) and lane segregation remain dominant themes in global contexts [33-35].

The Latin American experience, especially Bogotá and Curitiba, demonstrates that physical segregation and institutional alignment can sustain long-term punctuality [36, 37].

In Sub-Saharan Africa, studies reflect a dual focus on operational and socio-political adaptation [20, 21]. Systems in Lagos and Johannesburg highlight safety, policy enforcement, and infrastructure integration issues [18, 27, 29].

Overall, the global literature frames BRT delays as a function of both engineering optimization and governance maturity, where data-driven coordination enhances operational efficiency, while institutional stability ensures policy continuity.

4.2. Indonesian Evidence on BRT Delays

Indonesian studies predominantly emphasize service reliability and passenger experience, reflecting a developmental phase focused on foundational operations rather than advanced optimization. Research on Trans Semarang consistently reports headway irregularities, dwell-time inefficiencies, and weak lane enforcement [7, 10, 23].

Emerging works begin to apply quantitative tools such as simulation and time-series forecasting [38, 39].

Meanwhile, Trans Jakarta studies emphasize institutional and managerial dynamics [12, 24]. Batik Solo Trans and Trans Medan reflect external constraints such as overcrowding, limited infrastructure, and accessibility gaps [13, 14].

Recently, passenger-centered research has started to appear [40, 41], marking a methodological evolution in domestic BRT studies.

4.3. Comparative Synthesis

A global–local comparison indicates that technological maturity is the principal differentiator. Systems in China and Latin America deploy IoT-based control, real-time optimization, and integrated AVL data analytics [42, 43]. By contrast, Indonesian systems remain largely descriptive, focusing on manual scheduling and governance evaluation.

African studies contribute an intermediate perspective, emphasizing adaptation rather than replication of foreign models [20, 44].

This synthesis underscores that governance quality and data availability are as crucial as infrastructure investment. In contexts where data is scarce and enforcement is weak, technological solutions cannot perform optimally. Thus, countries like Indonesia must pursue foundational system readiness, enforcement, inter-agency coordination, and standardization before integrating predictive technologies.

4.4. Theoretical Implications

The expanded synthesis reinforces that BRT delay is a complex system behavior, emerging from interactions among technical, operational, and governance components. The concept of systemic delay, where inefficiency in one layer cascades into others, is increasingly recognized in current scholarship [45, 46].

By connecting performance metrics (OTP, speed, dwell time) with governance indicators (coordination, policy enforcement), this review strengthens the theoretical bridge between transport operations management and institutional theory. It supports the argument that resilience in public transport arises not only from technology adoption but also from institutional robustness and regulatory adaptability.

4.5. Practical Implications for Indonesia and Trans Jateng

The global findings provide concrete lessons for Indonesian systems, particularly the Trans Jateng (Semarang–Bawen corridor).

- Infrastructure: Implement selective lane segregation and Transit Signal Priority similar to adaptive systems applied in Southeast Asia and emerging smart cities [47, 48].
- Operations: Apply headway-based control and data-assisted scheduling through simple AVL integration [3, 49].
- Governance: Align provincial–municipal coordination following best practices from Latin America and South Africa [29, 50].
- Policy Integration: Strengthen fare consistency and system integration [51].

These interventions are feasible and contextually appropriate for Indonesia's institutional capacity. They emphasize progressive adaptation, not direct replication, of global best practices.

4.6. Limitations of the Review

Despite the inclusion of over 70 distinct studies across continents, limitations remain.

First, the availability of quantitative datasets (e.g., AVL, GPS, ticketing data) in Indonesia and Africa is restricted to in-depth statistical modeling.

Second, cross-comparability is limited because many studies use heterogeneous definitions of delay and performance.

Lastly, publication bias toward Asian and Latin American cases limits the representation of African and smaller Southeast Asian systems.

4.7. Future Research Directions

Building on current evidence, future work should aim to:

1. Integrate AI-driven control tested in Asia into Indonesian corridors [4, 30].
2. Explore governance alignment through institutional analysis of Trans Jateng and Trans Jakarta [51, 52].
3. Develop resilience-based BRT models by integrating physical, operational, and institutional parameters [53, 54].
4. Utilize open data platforms to enable comparative modeling across developing regions [43].

Through these directions, future Indonesian research can transition from descriptive evaluation toward predictive and integrative modeling, aligning national transit policy with sustainable mobility frameworks.

5. Conclusion and Policy Implications

5.1. Conclusion

This study has systematically reviewed 104 academic and empirical publications between 2000 and 2025 to examine delay factors and operational performance in Bus Rapid Transit (BRT) systems, with particular attention to the Indonesian context.

The synthesis identifies four interrelated domains shaping delay mechanisms:

1. Infrastructure factors: Inadequate signal coordination, congestion at intersections, and incomplete lane segregation.
2. Operational factors: Headway irregularity, bus bunching, and prolonged dwell times.
3. Managerial factors: Inconsistent scheduling, limited data integration, and fragmented institutional roles.

4. External factors: congestion spillover, fluctuating passenger loads, and environmental disruptions.

Across global studies, five quantitative indicators, On-Time Performance (OTP), headway regularity, travel speed, dwell time, and Travel Time Index (TTI), serve as the dominant measures of operational reliability.

International research highlights that integrating Transit Signal Priority (TSP), real-time scheduling, and AI-based control substantially improves reliability and speed performance.

In contrast, Indonesian research remains primarily descriptive, emphasizing operational irregularities, infrastructure gaps, and coordination issues.

Overall, the review concludes that BRT delay is a systemic outcome arising from the interaction of technical inefficiencies, governance fragmentation, and limited data-driven management.

Addressing these issues requires a holistic approach that combines physical improvements, operational innovation, and institutional integration rather than isolated interventions.

5.2. Policy Implications for Indonesia and Trans Jateng

The findings present several actionable implications for policymakers and transport operators, particularly regarding the Semarang–Bawen corridor of Trans Jateng:

a) Infrastructure and Technology

- Introduce adaptive Transit Signal Priority (TSP) at intersections with high congestion levels, following successful applications in other Asian BRT systems.
- Ensure full lane segregation and station docking precision to minimize intersection interference and dwell-time variability.

b) Operations and Service Quality

- Transition from schedule-based to headway-based control, using Automatic Vehicle Location (AVL) data for real-time monitoring and dynamic holding.
- Implement rolling horizon scheduling to prevent bus bunching and maintain consistent service intervals.
- Optimize passenger boarding through pre-boarding ticketing systems and improved platform design to shorten dwell durations.

c) Management and Governance

- Strengthen institutional coordination between provincial (Central Java) and municipal (Semarang) authorities to address governance fragmentation observed in Trans Semarang and Trans Jakarta.
- Integrate fare systems and performance monitoring across corridors to ensure consistent standards of service quality and financial accountability.

d) Strategic Development for Trans Jateng

For the Semarang–Bawen corridor, three priority measures are recommended:

1. Deploy adaptive signal control at delay-prone intersections.
2. Apply data-assisted headway regulation using AVL feedback.
3. Establish a joint provincial–municipal governance framework for integrated planning and monitoring.

These measures align with Indonesia's national transport policy toward efficient, low-emission, and socially inclusive mobility systems.

5.3. Limitations and Future Outlook

Several limitations should be acknowledged.

First, the reviewed studies are concentrated in a limited set of regions, mainly India, China, Latin America, and Indonesia, restricting cross-regional generalization.

Second, limited access to high-resolution operational datasets (such as AVL and smart card data) constrains the quantitative modeling of delays.

Third, variations in methodological and definitional standards across studies reduce the comparability of empirical results.

Building upon the existing evidence, future research should focus on:

- Integrating AI-driven signal and control systems tested in Asia into Indonesian BRT corridors.
- Conducting institutional and governance analyses of Trans Jateng and Trans Jakarta to evaluate coordination frameworks.
- Developing resilience-based BRT models that incorporate physical, operational, and institutional dimensions.
- Leveraging open data platforms for comparative modeling across developing regions.

By pursuing these directions, Indonesian BRT research can evolve from descriptive assessment toward predictive and resilience-oriented system modeling, positioning Trans Jateng as a benchmark for sustainable and integrated urban mobility in the region.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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