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Mitigating Geometric Bottlenecks in One-Way Systems: Empirical Evaluation and Intervention Models in Critical Urban Arteries

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Abstract: Urban congestion represents a critical challenge in metropolitan transportation systems, particularly in one-way traffic corridors experiencing geometric bottlenecks. This study evaluates the implementation of one-way systems on Jalan Gading Indah Raya and proposes evidence-based intervention models to enhance traffic performance at Pintu Satu Gading, North Jakarta. Employing mixed-method triangulation, the research integrates field surveys, Indonesian Road Capacity Manual (PKJI) analysis, and PTV Vissim microsimulation modeling to assess existing conditions and evaluate intervention scenarios. Field data revealed peak traffic volumes reaching 6,804 vehicles per hour with speeds declining to 16 km/h, indicating severe saturation conditions. Three intervention scenarios were simulated, incorporating geometric modifications, signal timing optimization, and traffic management strategies. Results demonstrate that integrated interventions can improve degree of saturation by 23-31%, enhance average speeds by 18-27%, and elevate the level of service from D/E to B/C categories. The study validates microsimulation as an effective tool for evaluating traffic interventions in complex urban networks and provides actionable recommendations for transportation authorities managing geometric bottlenecks in one-way arterial systems.

Keywords: one-way traffic system, geometric bottleneck, traffic microsimulation, degree of saturation, urban arterial management

INTRODUCTION

Urban transportation systems worldwide face unprecedented challenges from rapid motorization, population growth, and constrained infrastructure capacity (Ardalan et al., 2024; Raza et al., 2022). Traffic congestion not only reduces mobility efficiency but also generates substantial economic losses, environmental degradation, and diminished quality of urban life (Dikshit et al., 2023; Rahman et al., 2022). In response to these pressures, transportation authorities have implemented various traffic management strategies, with one-way systems representing a common intervention for optimizing traffic flow in geometrically constrained corridors (Chow et al., 2021; Nisumanti et al., 2025).

One-way traffic systems theoretically offer several advantages, including increased effective road width, simplified intersection movements, enhanced traffic flow continuity, and improved safety through reduced conflict points (Fan et al., 2024). However, empirical evidence regarding their long-term effectiveness remains mixed. While some implementations demonstrate improved capacity and reduced delays, others reveal unintended consequences such as increased travel distances, route circuity, and potential congestion displacement to parallel corridors (Chow et al., 2022; Elefteriadou, 2021). The effectiveness of one-way systems appears highly context-dependent, influenced by network topology, traffic demand patterns, intersection configurations, and complementary traffic management measures (Osei et al., 2021; Treiber & Kesting, 2020).

Geometric bottlenecks locations where road capacity abruptly decreases due to lane reductions, inadequate intersection design, or physical constraints—represent critical impediments to traffic flow efficiency (Niu et al., 2022; Raharjo & Rahayu, 2020). In one-way systems, geometric bottlenecks can negate theoretical capacity benefits and create severe localized congestion, particularly at entry and exit points where traffic transitions between different network configurations (Bari et al., 2022; Nguyen et al., 2020). Understanding the interaction between one-way system design and geometric constraints is essential for developing effective mitigation strategies.

The Pintu Satu Gading area in North Jakarta exemplifies these challenges. Located in the Kelapa Gading District, this critical urban node experiences severe congestion despite the implementation of a one-way system on Jalan Gading Indah Raya. The corridor serves multiple functions including residential access, commercial activity, and regional through-traffic, creating complex demand patterns that stress existing infrastructure (Hao et al., 2023; Shi & Abdel-Aty, 2021). Preliminary observations indicate persistent congestion during peak periods, with traffic volumes exceeding design capacity and speeds falling below acceptable thresholds.

Advanced traffic microsimulation tools, particularly PTV Vissim, have emerged as powerful instruments for evaluating traffic system performance and testing intervention strategies before implementation (Hafram et al., 2023; Ganguly et al., 2022). Microsimulation enables detailed modelling of individual vehicle behavior, signal operations, and network interactions, providing insights that traditional analytical methods cannot capture (Abdel-Wahed et al., 2024; Chen et al., 2020). When properly calibrated and validated against field data, microsimulation models offer reliable predictions of intervention effectiveness, supporting evidence-based decision-making (Al Asif, 2024; Wang et al., 2021).

Despite extensive research on traffic management strategies, significant gaps remain in understanding how to effectively mitigate geometric bottlenecks within one-way systems, particularly in the context of developing Asian megacities characterized by mixed traffic conditions, high motorcycle proportions, and limited enforcement capacity (Matrosov & Filimonov, 2024; Ibrahim et al., 2020). This study addresses these gaps through comprehensive empirical analysis of the Pintu Satu Gading corridor, integrating field surveys, standard traffic engineering analysis, and advanced microsimulation modeling.

The research objectives are threefold: (1) to comprehensively assess existing traffic performance conditions in the one-way system at Pintu Satu Gading using multiple evaluation metrics including degree of saturation, level of service, and speed-flow relationships; (2) to develop and evaluate alternative intervention scenarios using calibrated microsimulation models, incorporating geometric modifications, signal timing optimization, and traffic management strategies; and (3) to provide evidence-based recommendations for transportation authorities managing similar geometric bottlenecks in urban one-way systems.

This study contributes to transportation engineering practice by demonstrating an integrated methodological approach combining traditional analysis with advanced simulation, validating intervention strategies in a real-world context, and providing transferable insights for managing geometric bottlenecks in one-way arterial systems. The findings have direct applicability for the North Jakarta Transportation Agency (Sudinhub Jakarta Utara) and broader relevance for transportation professionals addressing similar challenges in rapidly urbanizing contexts.

METHOD

1. Research Design and Approach

This research employs a mixed-method approach integrating quantitative traffic analysis with qualitative stakeholder insights, following established triangulation methodology to enhance validity and reliability (Qadri et al., 2024; Lee et al., 2024). The triangulation framework combines multiple data sources (field surveys, administrative records, stakeholder interviews), multiple methods (observation, measurement, simulation), and multiple analytical approaches (descriptive statistics, capacity analysis, microsimulation modeling) to develop a comprehensive understanding of traffic system performance and intervention effectiveness.

The research was conducted from January 2025 to July 2025, encompassing data collection, model development, scenario evaluation, and validation phases. The study area encompasses the Pintu Satu Gading corridor, specifically focusing on the intersection network formed by Jalan Pegangsaan Dua and Jalan Gading Indah Raya within the Kelapa Gading District, North Jakarta Administrative City, DKI Jakarta Province.

2. Study Area Characteristics

The Pintu Satu Gading area represents a critical transportation node characterized by complex traffic patterns and multiple land use functions. The corridor serves as a primary access route to the Kelapa Gading residential and commercial district, one of North Jakarta's most developed areas. The one-way system on Jalan Gading Indah Raya was implemented to manage increasing traffic demand, but persistent congestion indicates potential geometric and operational deficiencies requiring systematic investigation.

The study network comprises four primary intersections: (1) Jalan Arteri Kelapa Gading with Jalan Gading Indah Raya; (2) Jalan Pegangsaan Dua with Jalan Gading Indah Raya; (3) Jalan Pegangsaan Dua with Jalan Satu Arah Pegangsaan Dua; and (4) Jalan Arteri Kelapa Gading with Jalan Satu Arah Pegangsaan Dua. Each intersection exhibits distinct geometric configurations, traffic control systems, and operational characteristics that collectively determine network performance.

3. Data Collection Methods

Primary Traffic Data Collection

Traffic volume data were collected through comprehensive manual counting supplemented by video recording at all major intersection approaches. Trained survey teams conducted 12-hour counts (06:00-18:00) on typical weekdays, classifying vehicles into four categories following Indonesian practice: motorcycles (MC), light vehicles (LV), heavy vehicles (HV), and medium vehicles (UM). Peak hour identification followed standard procedures, with morning peak (07:00-08:00) and evening peak (17:00-18:00) selected for detailed analysis based on maximum hourly volumes (Cheng et al., 2023; Jia et al., 2021).

Traffic speed surveys employed the Moving Car Observer method, a well-established technique for arterial speed measurement (Bosire et al., 2024; Dey et al., 2020). Survey vehicles equipped with GPS data loggers traversed the study corridor multiple times during peak and off-peak periods, recording travel times, speeds, and delay locations. The method provides representative speed data reflecting actual driving conditions including acceleration, deceleration, and stopped delay (Agafonov et al., 2024).

Turning movement counts were conducted at each intersection to establish origin-destination patterns and traffic distribution characteristics. Observers recorded vehicle movements for all approach-exit combinations during peak periods, enabling development of turning proportion matrices essential for microsimulation model calibration (Maquiran et al., 2024; Zhou et al., 2023).

Geometric and operational inventory documented detailed physical characteristics including lane widths, intersection dimensions, signal phasing and timing, pavement conditions, parking restrictions, and roadside friction sources. This information provides the foundation for accurate network representation in microsimulation models (Abdel-Wahed et al., 2024; Alhadidi et al., 2024).

Secondary Data and Qualitative Information

Administrative maps, existing traffic studies, and planning documents were obtained from the North Jakarta Transportation Agency (Sudinhub Jakarta Utara) and Kelapa Gading District Transportation Unit (Kasatpelhub Kecamatan Kelapa Gading). These materials provided historical context, previous intervention attempts, and institutional perspectives on traffic management challenges.

In-depth interviews were conducted with key informants including transportation agency officials, district traffic management personnel, and regular corridor users. Interview protocols focused on understanding operational challenges, implementation constraints, enforcement issues, and stakeholder perspectives on potential interventions. Qualitative insights complement quantitative analysis by revealing contextual factors that influence intervention feasibility and effectiveness (Nisumanti et al., 2025; Aziz et al., 2020).

4. Analytical Framework

Indonesian Road Capacity Manual (PKJI) Analysis

Traffic performance evaluation employed the Indonesian Road Capacity Manual (PKJI), the national standard for capacity analysis adapted to Indonesian traffic conditions including high motorcycle proportions and mixed traffic behavior. PKJI analysis determines key performance metrics including degree of saturation (DS), level of service (LOS), and average speed calculations (Hafram et al., 2023; Elefteriadou, 2021).

Degree of Saturation (DS) represents the ratio of traffic volume to capacity, expressed as $DS = Q / C$, where Q = traffic volume (pcu/hour) and C = capacity (pcu/hour). DS values exceeding 0.85 indicate approaching saturation, while values above 1.0 represent oversaturated conditions with queue formation and extensive delays (Hafram et al., 2023; Treiber & Kesting, 2020).

Level of Service (LOS) classification follows PKJI criteria relating DS values to qualitative service categories ranging from A (free flow) to F (forced flow with extensive delays). LOS provides an intuitive performance metric for communicating traffic conditions to stakeholders and decision-makers (Osei et al., 2021).

Microsimulation Modeling with PTV Vissim

PTV Vissim was selected as the microsimulation platform based on its widespread use in traffic engineering practice, robust car-following and lane-changing models, comprehensive signal control capabilities, and proven effectiveness in evaluating complex urban networks (Fan et al., 2024; Hao et al., 2023; Ganguly et al., 2022). Vissim's psycho-physical driver behavior model, based on the Wiedemann car-following logic, effectively replicates observed traffic phenomena in mixed traffic conditions (Farrag et al., 2020; Papathanasopoulou & Antoniou, 2020).

5. Model Development Process

Network coding translated field-surveyed geometric characteristics into Vissim's graphical interface, ensuring accurate representation of lane configurations, intersection geometries, and traffic control devices. Links, connectors, conflict areas, and priority rules were coded following Vissim best practices to replicate observed traffic interactions (Al Asif, 2024; Liu et al., 2022).

Traffic demand input utilized observed volume data converted to passenger car units (pcu) using PKJI equivalency factors accounting for vehicle type performance differences. Vehicle composition distributions matched field observations, with separate input definitions for motorcycles, light vehicles, heavy vehicles, and medium vehicles (Chow et al., 2022; Guo et al., 2021).

6. Model Calibration and Validation

Model calibration adjusted driver behavior parameters to match observed traffic performance, following established microsimulation practice (Hafram et al., 2023; Wang et al., 2021). Key calibration parameters included Wiedemann 74 parameters (CC0, CC1) for motorcycle behavior, Wiedemann 99 parameters (CC0-CC9) for motorized vehicle behavior, lane change parameters, speed distribution parameters, and gap acceptance parameters at unsignalized conflicts.

Calibration employed iterative parameter adjustment guided by comparison between simulated and observed traffic volumes, speeds, and queue lengths. The GEH statistic assessed volume matching, with GEH < 5 considered acceptable for individual movements (Farrag et al., 2020; Hafram et al., 2023).

Validation tested calibrated model performance against independent datasets not used in calibration, confirming model transferability and predictive capability. Validation metrics included mean absolute percentage error (MAPE) for speeds and volumes, with MAPE < 15% considered acceptable (Ganguly et al., 2022; Chen et al., 2020).

7. Scenario Development

Three intervention scenarios were developed based on traffic engineering principles, stakeholder input, and preliminary sensitivity analysis:

Scenario 1: Geometric Optimization - Modifications to intersection geometry including lane additions where feasible, improved channelization, enhanced pavement markings, and optimized lane assignment to reduce conflicts and improve capacity utilization (Abdel-Wahed et al., 2024).

Scenario 2: Signal Timing Optimization - Systematic optimization of signal timing parameters including cycle length adjustment, phase duration reallocation, coordination between adjacent signals, and implementation of vehicle-actuated control where appropriate (Cheng et al., 2023; Qadri et al., 2024).

Scenario 3: Integrated Intervention - Combined implementation of geometric improvements and signal optimization, representing a comprehensive approach to bottleneck mitigation (Lee et al., 2024; Maquiran et al., 2024).

Each scenario was simulated for multiple random seed runs (minimum 10 runs per scenario) to account for stochastic variation in traffic arrivals and driver behavior. Performance metrics were averaged across runs to provide robust estimates of intervention effectiveness (Agafonov et al., 2024; Bao et al., 2021).

8. Performance Evaluation Metrics

Scenario evaluation employed multiple metrics capturing different performance dimensions: degree of saturation (DS), level of service (LOS), average speed, queue length, travel time, delay, and stops (Niu et al., 2022; Ardalan et al., 2024). Comparative analysis assessed percentage improvements relative to baseline conditions, enabling quantitative evaluation of intervention effectiveness and benefit-cost considerations.

RESULTS AND DISCUSSION

1. Existing Condition Analysis

Traffic Volume Characteristics

Field surveys revealed substantial traffic volumes throughout the study corridor, with peak hourly volumes reaching 6,804 vehicles per hour at critical locations. Traffic composition reflected typical Indonesian urban patterns with motorcycles comprising 42-48% of total volume, light vehicles 45-50%, and heavy vehicles 3-7%. This mixed traffic composition creates complex operational dynamics requiring careful consideration in capacity analysis and intervention design (Bari et al., 2022; Yang et al., 2023).

Morning peak period (07:00-08:00) exhibited slightly lower volumes than evening peak (17:00-18:00), with evening peak showing more pronounced congestion due to concentrated departure patterns from commercial areas. Directional distribution showed strong peak-direction flows consistent with commuting patterns, with morning inbound flows and evening outbound flows dominating (Zhang et al., 2022).

Turning movement analysis revealed complex traffic distribution patterns at major intersections. The intersection of Jalan Arteri Kelapa Gading with Jalan Gading Indah Raya experienced particularly heavy through movements combined with substantial left-turn demands, creating operational conflicts that reduced effective capacity. Right-turn movements, while theoretically conflict-free in the one-way system, contributed to friction through weaving manoeuvres and lane-changing requirements (Abdel-Wahed et al., 2024; Zhu et al., 2021).

Speed and Travel Time Performance

Moving Car Observer surveys documented severe speed degradation during peak periods. Average corridor speeds declined to 16 km/h during peak hours, representing only 27% of the posted 60 km/h speed limit and 32% of typical off-peak speeds (50 km/h). Speed distribution analysis revealed substantial variability, with 15th percentile speeds as low as 8 km/h indicating stop-and-go conditions and extensive queuing (Farrag et al., 2020; Dey et al., 2020).

Speed-flow relationships exhibited characteristic congestion patterns, with speeds declining sharply as volumes approached capacity. Critical speed reduction occurred at volumes exceeding 5,500 vehicles per hour, suggesting capacity constraints in this range. Individual intersection approaches showed varying speed-flow characteristics, with geometric bottlenecks producing more severe speed degradation than signal-controlled locations with adequate capacity (Niu et al., 2022; Xu et al., 2020).

Corridor travel times during peak periods averaged 8.5 minutes for the 2.3 km study section, yielding an average speed of 16.2 km/h. Off-peak travel times averaged 2.8 minutes (average speed 49.3 km/h), indicating a peak-to-off-peak travel time ratio of 3.0—a clear indicator of severe congestion (Dikshit et al., 2023; Kang et al., 2021).

Capacity Analysis and Degree of Saturation

PKJI capacity analysis revealed critical saturation conditions at multiple locations. The intersection of Jalan Pegangsaan Dua with Jalan Gading Indah Raya exhibited the highest degree of saturation (DS = 1.18) during evening peak, indicating oversaturated conditions with queue spillback and extensive delays. Other critical intersections showed DS values ranging from 0.89 to 1.05, all exceeding the 0.85 threshold for acceptable operation (Tang, 2024; Han et al., 2022).

Capacity calculations incorporated PKJI adjustment factors for geometric conditions, traffic composition, and signal timing. Base capacity values ranged from 2,800 to 3,600 pcu/hour depending on intersection configuration, with effective capacity reduced by side friction, inadequate lane width, and suboptimal signal timing (Hafram et al., 2023; Elefteriadou, 2021).

Critical movement analysis identified specific bottleneck locations including: (1) Through movements on Jalan Gading Indah Raya approaching Jalan Arteri Kelapa Gading (DS = 1.12); (2) Left-turn movements from Jalan Arteri Kelapa Gading to Jalan Gading Indah Raya (DS = 1.05); (3) Through movements on Jalan Pegangsaan Dua approaching Jalan Satu Arah Pegangsaan Dua (DS = 0.98). These locations consistently exhibited queue formation, spillback to upstream intersections, and degraded level of service (Ardalan et al., 2024; Ma et al., 2021).

Level of Service Assessment

Level of service analysis classified most critical movements as LOS D or E during peak periods, indicating unstable flow with significant delays. The most congested intersection approaches reached LOS F, representing forced flow with stop-and-go conditions and extensive queuing. Off-peak conditions showed LOS B or C, confirming that capacity deficiencies rather than absolute demand levels drive congestion (Osei et al., 2021; Rahman et al., 2022).

LOS spatial distribution revealed progressive degradation along the corridor, with congestion originating at geometric bottlenecks and propagating upstream through queue spillback. This pattern suggests that targeted interventions at critical bottlenecks could yield system-wide benefits through reduced queue spillback and improved flow continuity (Bari et al., 2022; Nguyen et al., 2020).

2. Microsimulation Model Calibration and Validation

Calibration Results

Model calibration achieved acceptable agreement between simulated and observed traffic performance across multiple metrics. Volume calibration produced GEH statistics below 5.0 for 87% of movements and below 10.0 for 98% of movements, meeting standard acceptance criteria (Hafram et al., 2023; Farrag et al., 2020).

Speed calibration yielded mean absolute percentage error (MAPE) of 11.3% for corridor average speeds and 14.7% for individual link speeds, both within acceptable ranges. Simulated speed distributions closely matched observed distributions, particularly in the critical 10-30 km/h range representing congested conditions (Ganguly et al., 2022; Chen et al., 2020).

Queue length calibration proved more challenging due to measurement difficulties in the field, but visual observation comparison confirmed reasonable queue length representation at critical locations. Calibrated Wiedemann parameters reflected aggressive driving behavior typical of Indonesian urban conditions, with shorter following distances and more frequent lane changes than default parameter sets (Al Asif, 2024; Papathanasopoulou & Antoniou, 2020).

Validation Results

Independent validation using data from alternate survey days confirmed model transferability. Volume validation produced GEH statistics of 4.2 (mean) with 91% of movements below 5.0. Speed validation yielded MAPE of 12.8%, slightly higher than calibration but still acceptable. Travel time validation showed MAPE of 9.5%, confirming accurate representation of corridor-level performance (Chow et al., 2022; Wang et al., 2021).

Validation results provide confidence that the calibrated model accurately represents existing conditions and can reliably predict intervention scenario performance. The successful validation supports using the model for scenario evaluation and decision-making (Hafram et al., 2023; Shi & Abdel-Aty, 2021).

3. Intervention Scenario Evaluation

Scenario 1: Geometric Optimization Results

Geometric optimization interventions produced substantial performance improvements across multiple metrics. Degree of saturation at the most critical intersection decreased from 1.18 to 0.91 (23% reduction), moving from oversaturated to acceptable operating conditions. Average corridor speeds increased from 16.2 km/h to 19.8 km/h (22% improvement), and level of service improved from D/E to C/D for most critical movements (Abdel-Wahed et al., 2024; Alhadidi et al., 2024).

Specific geometric modifications contributing to these improvements included: (1) Lane addition at the Jalan Arteri Kelapa Gading approach to Jalan Gading Indah Raya intersection, increasing capacity by approximately 900 pcu/hour; (2) Improved channelization separating through and turning movements, reducing conflicts and improving flow efficiency; (3) Enhanced pavement markings and signing clarifying lane assignments and reducing last-minute lane changes; (4) Removal of parking and loading zones creating additional effective width at critical bottleneck locations (Tang, 2024; Niu et al., 2022).

Queue length analysis showed 35% reduction in maximum queue length and 42% reduction in average queue length at the most congested approach. Queue spillback to upstream intersections was eliminated, improving network flow continuity. Travel time analysis revealed 18% reduction in peak period corridor travel time (from 8.5 to 7.0 minutes), with corresponding improvements in travel time reliability. The 85th percentile travel time decreased by 23%, indicating particularly strong benefits for travelers experiencing worst-case conditions (Dikshit et al., 2023; Jia et al., 2021).

Scenario 2: Signal Timing Optimization Results

Signal timing optimization achieved performance improvements comparable to geometric modifications but through different mechanisms. Degree of saturation at critical intersections decreased to 0.88-0.94 (average 21% reduction), with improvements distributed across multiple approaches rather than concentrated at single bottleneck locations (Cheng et al., 2023; Chala & Kóczy, 2024).

Key signal timing modifications included: (1) Cycle length optimization increasing from 120 to 140 seconds at major intersections, providing additional green time for critical movements while maintaining acceptable delay for minor movements; (2) Phase duration reallocation shifting 8-12 seconds of green time from under-utilized movements to oversaturated movements based on demand patterns; (3) Coordination between adjacent signals reducing progression stops by 28% and improving flow continuity; (4) Implementation of vehicle-actuated control at one location, enabling dynamic response to fluctuating demand patterns (Lee et al., 2024; Qadri et al., 2024).

Average corridor speeds increased to 20.5 km/h (27% improvement), slightly exceeding Scenario 1 benefits. This superior speed performance reflects reduced stopping frequency through improved signal coordination, even though capacity increases were more modest than geometric modifications. Stops per vehicle decreased by 31%, from 4.2 to 2.9 stops per corridor trip, directly contributing to improved speeds and reduced fuel consumption. Delay analysis showed 26% reduction in average stopped delay, with benefits distributed relatively evenly across the corridor (Agafonov et al., 2024; Matrosov & Filimonov, 2024).

Level of service improvements were similar to Scenario 1, with most critical movements reaching LOS C. However, the most constrained geometric bottleneck remained at LOS D, confirming that signal timing optimization alone cannot fully address capacity-limited locations (Chala & Kóczy, 2024; Bosire et al., 2024).

Scenario 3: Integrated Intervention Results

The integrated intervention scenario, combining geometric improvements and signal timing optimization, produced synergistic benefits exceeding either individual strategy. Degree of saturation at the most critical intersection decreased to 0.81 (31% reduction from baseline), providing substantial capacity reserve for future demand growth (Maquiran et al., 2024; Zhou et al., 2023).

Average corridor speeds reached 22.3 km/h (38% improvement), and level of service improved to B/C for most movements. The most constrained location achieved LOS C, representing acceptable operating conditions. Queue lengths decreased by 48% on average, with complete elimination of queue spillback under typical peak conditions (Ardalan et al., 2024; Zhang et al., 2022).

Travel time analysis revealed 32% reduction in peak period corridor travel time (from 8.5 to 5.8 minutes), approaching off-peak performance levels. Travel time reliability improved substantially, with coefficient of variation decreasing from 0.42 to 0.23, indicating more predictable trip durations (Bosire et al., 2024; Bao et al., 2021).

Comparative analysis demonstrated that integrated interventions achieve approximately 85% of the combined benefits of individual scenarios rather than 100%, suggesting some diminishing returns but still substantial synergistic effects. The cost-effectiveness analysis indicated that integrated interventions provide superior benefit-cost ratios due to synergistic effects and comprehensive problem addressing (Raza et al., 2022; Rahman et al., 2022).

4. Sensitivity Analysis

Sensitivity analysis tested intervention robustness under varying demand scenarios, including 10% and 20% demand growth projections. Results confirmed that Scenario 3 (integrated intervention) maintains acceptable performance (DS < 0.95) under 20% demand growth, while Scenarios 1 and 2 reach saturation at approximately 15% growth. This finding supports integrated intervention as the most future-proof strategy (Niu et al., 2022; Shi & Abdel-Aty, 2021).

Signal timing sensitivity analysis revealed that optimized timing plans remain effective across ±10% demand variations without adjustment, but larger variations require timing updates. This finding supports implementing adaptive signal control for long-term effectiveness (Matrosov & Filimonov, 2024; Chala & Kóczy, 2024).

5. Comparison with Previous Studies and Broader Context

The findings align with international evidence on one-way system performance and bottleneck mitigation. Chow et al. (2021) reported similar challenges in Kuala Lumpur, where one-way systems initially improved capacity but created route circuity and potential long-term congestion increases. The current study confirms that one-way systems require complementary interventions addressing geometric and operational constraints to realize sustained benefits (Chow et al., 2022; Elefteriadou, 2021).

Nisumanti et al. (2025) evaluated one-way system implementation in Palembang, Indonesia, reporting degree of saturation below 0.47 and LOS B-C after implementation. The contrasting results compared to the current study (DS up to 1.18, LOS D-E) highlight the importance of geometric adequacy and demand management. Palembang's success likely reflects more favorable geometric conditions and lower absolute demand levels (Nisumanti et al., 2025; Treiber & Kesting, 2020).

International studies on geometric bottleneck mitigation report improvement magnitudes consistent with current findings. Abdel-Wahed et al. (2024) documented 57% capacity increases through median U-turn intersection implementation in Egypt, while the current study achieved 23-31% capacity improvements through less extensive geometric modifications. Osei et al. (2021) reported up to 50% capacity increases through roundabout signalization in Ghana, again demonstrating that geometric interventions can produce substantial benefits when properly designed (Abdel-Wahed et al., 2024; Osei et al., 2021).

Signal timing optimization results align with findings from Cheng et al. (2023), who reported 23.3% improvement through snake-optimization-based timing in China, and Lee et al. (2024), who documented 20% travel time reduction through two-stage optimization in South Korea. The current study's 21-27% improvements fall within this range, confirming the effectiveness of systematic signal timing optimization (Cheng et al., 2023; Lee et al., 2024).

Microsimulation methodology validation confirms findings from Hafram et al. (2023) and Ganguly et al. (2022) regarding calibration requirements and validation criteria for Vissim applications. The successful calibration and validation in mixed traffic conditions adds to the evidence base for microsimulation effectiveness in developing country contexts (Hafram et al., 2023; Ganguly et al., 2022; Chen et al., 2020).

6. Implementation Considerations

Stakeholder interviews revealed several implementation considerations affecting intervention feasibility. Right-of-way constraints limit geometric expansion possibilities at some locations, requiring creative design solutions such as lane narrowing, parking removal, or minor property acquisition. Political and community acceptance represents another critical factor, as some interventions may face opposition from affected businesses or residents (Raza et al., 2022; Aziz et al., 2020).

Enforcement capacity emerged as a crucial implementation requirement. Optimized traffic management strategies require consistent enforcement of parking restrictions, lane discipline, and signal compliance. Inadequate enforcement could undermine intervention effectiveness, as observed in other developing country contexts (Karmakar et al., 2021; Dikshit et al., 2023).

Cost considerations favor signal timing optimization as a lower-cost intervention with substantial benefits, making it an attractive initial strategy. However, the superior long-term performance of integrated interventions justifies higher initial investment through sustained benefits and future-proofing against demand growth (Maquiran et al., 2024; Zhang et al., 2022).

Phased implementation represents a pragmatic approach, beginning with signal timing optimization to achieve near-term benefits while planning geometric improvements requiring longer implementation timelines. This strategy enables early benefit realization while building political and community support for more extensive interventions (Bosire et al., 2024; Zhou et al., 2023).

7. Limitations and Future Research Directions

Several limitations warrant acknowledgment. First, the study focuses on a single corridor, limiting generalizability to other contexts with different geometric configurations, demand patterns, or traffic compositions. Future research should evaluate intervention effectiveness across multiple corridor types to develop more generalizable design guidelines (Ardalan et al., 2024; Han et al., 2022).

Second, the analysis focuses on traffic performance metrics without comprehensive evaluation of environmental impacts, safety effects, or broader accessibility considerations. Future research should adopt multi-criteria evaluation frameworks incorporating these dimensions (Raza et al., 2022; Xu et al., 2020).

Third, long-term performance monitoring was not possible within the study timeframe. Implementation should include comprehensive before-after evaluation to validate predicted benefits and identify necessary adjustments (Niu et al., 2022; Kang et al., 2021).

Fourth, the study evaluates discrete intervention scenarios rather than systematically optimizing across the full solution space. Future research could employ formal optimization algorithms to identify globally optimal intervention combinations (Qadri et al., 2024; Agafonov et al., 2024).

Finally, the analysis assumes static demand patterns without considering induced demand, modal shifts, or behavioral responses to improved traffic conditions. Dynamic traffic assignment models or activity-based models could provide more comprehensive evaluation of intervention impacts (Dikshit et al., 2023; Guo et al., 2021).

CONCLUSION

This research provides comprehensive empirical evidence on geometric bottleneck mitigation in one-way urban arterial systems through integrated field analysis and microsimulation modeling. The study demonstrates that the one-way system on Jalan Gading Indah Raya experiences severe capacity constraints during peak periods, with degree of saturation reaching 1.18, average speeds declining to 16 km/h, and level of service degrading to D/E categories. These conditions result from complex interactions between geometric constraints, signal timing limitations, and high traffic demands.

Three intervention scenarios evaluated through calibrated Vissim microsimulation reveal that geometric optimization, signal timing optimization, and integrated interventions can achieve degree of saturation reductions of 23%, 21%, and 31% respectively, with corresponding speed improvements of 22%, 27%, and 38%. The integrated intervention scenario provides superior performance across all metrics while maintaining acceptable operation under future demand growth scenarios, supporting its selection as the preferred strategy.

The research validates microsimulation as an effective tool for evaluating traffic interventions in complex urban networks characterized by mixed traffic conditions, demonstrating that properly calibrated models can reliably predict intervention effectiveness. The successful application in the Indonesian context adds to the evidence base for microsimulation use in developing country transportation planning.

Practical recommendations for the North Jakarta Transportation Agency include: (1) prioritize implementation of signal timing optimization as a near-term, cost-effective intervention achieving substantial benefits; (2) develop phased geometric improvement plans addressing critical bottleneck locations with highest degree of saturation; (3) implement comprehensive monitoring and evaluation systems to validate intervention effectiveness and guide adaptive management; (4) strengthen enforcement of parking restrictions and lane discipline to maximize intervention benefits; and (5) consider adaptive signal control systems for long-term effectiveness under changing demand patterns.

The findings have broader applicability for transportation agencies managing similar challenges in rapidly urbanizing contexts. Key transferable insights include the importance of addressing both geometric and operational constraints through integrated interventions, the value of microsimulation for evidence-based decision-making, and the necessity of considering implementation feasibility alongside technical effectiveness.

Future research should extend this analysis to multiple corridor types, incorporate multi-criteria evaluation frameworks encompassing environmental and safety dimensions, employ formal optimization algorithms to identify globally optimal solutions, and conduct long-term monitoring to validate predicted benefits and understand behavioral responses. Such research will further advance the science and practice of urban traffic management in one-way arterial systems.

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