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Diagnosis of Urban Congestion in Bujumbura: Integrating Traffic Counts, Road Network Redundancy, and Public Transport Dynamics

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Abstract - Rapid motorization in African cities has intensified congestion, particularly in compact urban cores such as Bujumbura, Burundi. This study diagnoses the structural, operational, and institutional determinants of Bujumbura's traffic congestion using integrated methodologies combining field traffic counts, network redundancy analysis, and public transport assessment. Empirical surveys conducted between July and August 2025 covered three primary corridors-Avenue de la Révolution, Boulevard de l'Uprona–Avenue du 13 Octobre, and the Aru–Ariwara corridor. Results show that all major corridors operate under Level of Service (LOS) F, with average volume-to-capacity ratios exceeding 1.0 and mean delays above 100 seconds per vehicle. Network analysis revealed a connectivity index (γ) of 0.27 and a cyclomatic number (μ) of 18, indicating weak redundancy and limited alternative routes. Informal public transport systems-minibuses and motorcycle taxis-dominate the mobility landscape, contributing over 70% of total vehicular flow. Institutional fragmentation among transport agencies further exacerbates inefficiency. The study recommends an integrated approach comprising corridor optimization, establishment of a metropolitan transport authority, route rationalization, and non-motorized transport promotion. Findings provide a replicable diagnostic framework for medium-sized African cities facing similar congestion crises.

Keywords: Urban Congestion, Network Redundancy, Public Transport Dynamics, Level of Service, Bujumbura, Traffic Operations, Africa

1. INTRODUCTION

Urban transportation systems in rapidly growing African cities have become increasingly strained due to population expansion, informal land-use patterns, and insufficient infrastructure investment. Traffic congestion has emerged as one of the most visible and debilitating symptoms of urbanization without commensurate transport planning (Dimitriou & Gakenheimer, 2011). Across sub-Saharan Africa, the mismatch between urban mobility demand and available capacity manifests in long commute times, elevated transport costs, and deteriorating environmental conditions. Bujumbura, the principal economic hub and former capital of Burundi, exemplifies this challenge. Its transportation infrastructure, originally designed for a small colonial settlement, now serves a metropolitan population exceeding 1.2 million (INSBU, 2023). The city's primary corridors-RN1, RN3, RN5, RN7, Avenue de l'Indépendance, and Boulevard de l'Uprona-operate well beyond their intended capacity during peak hours, generating chronic congestion and economic inefficiency.

The interplay of geography, demography, and policy inertia compounds the city's congestion. Bujumbura's linear expansion between Lake Tanganyika and the surrounding hills constrains right-of-way development and limits network redundancy. As a result, minor incidents-such as bus stops along RN7 or roadside parking on Avenue de la Révolution-can paralyze entire corridors. Previous studies by the Japan International Cooperation Agency (JICA, 2008) and the Institut de Statistiques et d'Études Économiques du Burundi (ISTEEBU, 2018) provided foundational assessments of urban mobility and public-transport performance. However, these analyses pre-date the rapid motorization observed after 2015 and therefore no longer capture the current dynamics of urban transport demand, modal choice, or road-network functionality.

The need for updated empirical evidence has become particularly urgent as Bujumbura experiences new congestion patterns driven by informal public-transport operations, motorcycles, and mixed-traffic conflicts. Recent field surveys conducted in 2025 across major arterials reveal unprecedented peak-hour delays, unstable headways, and increased roadside conflicts between vehicles, pedestrians, and commercial activities. Unlike earlier decades when low vehicle ownership suppressed congestion intensity, the

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proliferation of minibuses, taxis, and private motorcycles has transformed Bujumbura's transport morphology from low-density mobility to chaotic competition for limited road space. This intensification is exacerbated by the absence of functional traffic-management systems such as synchronized signals, dedicated bus bays, and parking enforcement.

Globally, urban congestion is both a technical and institutional problem. In developed contexts, congestion results primarily from excess demand relative to available capacity (Downs, 2004; Litman, 2017). In developing cities, however, the determinants are multifaceted-poor network design, weak regulation, and limited modal integration are equally critical (Pojani & Stead, 2015; Behrens et al., 2017). African cities such as Nairobi, Accra, and Dar es Salaam demonstrate similar conditions where rapid motorization outpaces institutional readiness (Salon & Aligula, 2012; Agyemang, 2015; Goodfellow, 2017). Yet, few studies have attempted a systematic diagnosis that merges quantitative data on traffic counts with spatial assessments of network redundancy and qualitative evaluation of public-transport operations. This integrative approach is necessary to identify the mechanisms through which congestion persists despite incremental infrastructure improvements.

In Bujumbura, transport planning remains fragmented among multiple institutions-the Mairie de Bujumbura, the Agence Routière du Burundi, and informal operator unions-without a unifying metropolitan transport authority. This institutional fragmentation translates into inconsistent enforcement of traffic regulations, inadequate coordination of road projects, and ineffective demand management. Moreover, land-use planning is weakly linked to transport infrastructure provision, leading to dispersed trip patterns that overload central corridors. The lack of pedestrian facilities further intensifies conflicts as commuters share lanes with vehicles. These structural and operational weaknesses underscore the need for a comprehensive diagnosis grounded in recent empirical data.

This study therefore aims to diagnose the multifactorial causes of urban congestion in Bujumbura by integrating (i) traffic-volume analysis, (ii) road-network redundancy evaluation, and (iii) public-transport operational assessment. Field investigations conducted between July and August 2025 across representative corridors provide updated evidence of vehicular flow characteristics, modal composition, and intersection performance. By comparing current findings with earlier data from JICA (2008) and ISTEEBU (2018), the research captures temporal trends and identifies priority interventions for sustainable mobility. The ultimate objective is to formulate empirically justified strategies that address both infrastructural and institutional deficits, thereby supporting the transition toward an efficient, safe, and inclusive urban-transport system in Burundi's capital region.

The subsequent sections of this paper review relevant literature on congestion diagnosis and urban transport systems, describe the methodological framework, present the empirical results of the 2025 investigations, and discuss policy implications within the context of African urban development.

2. LITERATURE REVIEW

2.1 Conceptual Perspectives on Urban Congestion

Urban congestion refers to a condition in which the demand for road space exceeds available capacity, leading to slower speeds, longer travel times, and increased vehicular queuing (Downs, 2004; Litman, 2017). Traditional transport engineering models conceptualize congestion as a function of vehicular volume, road capacity, and signal control efficiency (Cervero, 2000). However, in developing cities, congestion cannot be reduced to a simple capacity-demand imbalance. It is a multidimensional problem shaped by weak governance, limited multimodal integration, land-use inefficiency, and the prevalence of informal transport operations (Pojani & Stead, 2015; Behrens et al., 2017).

Dimitriou and Gakenheimer (2011) emphasize that African urban congestion exhibits systemic characteristics arising from unplanned growth and institutional fragmentation rather than high motorization alone. Similarly, Godard (2013) and Mitullah and Klopp (2015) describe congestion as both a spatial and social phenomenon, wherein street design, pedestrian behavior, and paratransit operations jointly determine mobility outcomes. These conceptual models underscore the necessity of integrating engineering, governance, and socio-economic perspectives when diagnosing congestion in low- and middle-income contexts.

2.2 Structural and Spatial Dimensions

The spatial configuration of road networks plays a decisive role in determining congestion vulnerability. According to Mattsson and Jenelius (2015), cities with radial networks and low redundancy-such as Bujumbura-are more susceptible to systemic gridlock

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because disruptions on a single corridor propagate throughout the network. In contrast, grid and ring-road systems distribute flows more evenly, enhancing resilience. Empirical evidence from Lagos (Adelekan, 2016) and Kampala (Baker et al., 2015) demonstrates that urban corridors without alternative bypasses exhibit recurrent congestion even when expanded, due to induced demand and limited modal diversity.

In Bujumbura, the road network remains predominantly radial, focusing on RN1, RN3, RN5, and RN7, all converging at the central business district. This spatial fragility mirrors patterns observed in Accra and Nairobi, where insufficient peripheral connections constrain freight and commuter movements (Agyemang, 2015; Salon & Aligula, 2012). Moreover, Bettencourt (2013) highlights that as cities grow, scaling effects increase travel demand exponentially relative to population size, magnifying congestion in monocentric systems. Thus, spatial redesign-rather than mere capacity expansion-emerges as a long-term solution for congestion mitigation.

2.3 Public Transport Dynamics and Informal Mobility

The evolution of public transport in African cities has followed a path distinct from that of developed economies. Instead of formalized, state-regulated systems, most urban transport relies on privately operated minibuses, motorcycles, and shared taxis (Behrens et al., 2017). These informal modes provide essential connectivity but also generate operational turbulence-frequent stopping, inconsistent routes, and competition for passengers (Mitullah & Klopp, 2015).

In Dar es Salaam, for instance, Goodfellow (2017) documented how informal bus operations undermine traffic flow efficiency even after Bus Rapid Transit (BRT) corridors were introduced. Similar outcomes were recorded in Accra (Agyemang, 2015), Nairobi (Salon & Aligula, 2012), and Johannesburg (Behrens et al., 2017), where paratransit systems occupy central road lanes and interact unpredictably with formal traffic. The dominance of such modes in Bujumbura-minibuses on Avenue de la Révolution and motorcycles on RN7-reflects this broader regional pattern.

Fare affordability further influences congestion dynamics. UN-Habitat (2013) recommends that daily commuting costs not exceed 15–20% of income. However, ISTEEBU (2018) and field observations from 2025 reveal that public transport fares in Bujumbura now absorb over 30% of low-income workers' earnings, compelling many commuters to shift to cheaper but more congesting motorcycles. The resulting modal imbalance increases road conflicts, travel uncertainty, and environmental emissions.

2.4 Institutional and Policy Context

Governance capacity is widely recognized as a decisive factor in congestion management (Pojani & Stead, 2015). Fragmentation between local and national agencies often leads to overlapping mandates and weak enforcement. In many African cities, metropolitan transport authorities are either absent or lack the legal and financial autonomy to coordinate investments. Kigali's creation of a unified public transport agency offers a contrasting success story, yielding improved route regulation and fare stability (Rwanda Transport Development Agency, 2019).

In Bujumbura, institutional responsibilities remain dispersed among the Mairie de Bujumbura, the Agence Routière du Burundi (ARB), and multiple private operator unions. The absence of an integrated planning authority hinders the synchronization of traffic control, fare policy, and infrastructure expansion. This structural disconnection parallels findings from Dar es Salaam (Goodfellow, 2017) and Kampala (Baker et al., 2015), where similar institutional fragmentation perpetuated congestion despite donor-funded interventions.

Policy approaches emphasizing only road expansion have proven ineffective. Cervero (2002) and Litman (2017) argue that new road capacity induces additional traffic, a phenomenon known as induced demand. This was demonstrated in Accra and Nairobi, where newly built arterials quickly filled with traffic as latent demand surfaced. For Bujumbura, sustainable congestion management therefore requires a balanced combination of infrastructural investment, demand management, and institutional reform.

2.5 Technological and Environmental Dimensions

Recent studies highlight the growing role of technology in congestion analysis and management. The use of GPS-based tracking, remote sensing, and big-data analytics has enhanced the ability to monitor traffic flow and predict congestion patterns (Bettencourt,

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2013; Jenelius & Cats, 2015). Although such systems are still limited in low-income contexts, pilot projects in Kigali and Nairobi demonstrate the feasibility of low-cost sensor networks and crowdsourced data for traffic regulation.

Environmental considerations are equally significant. Transport-related emissions in congested corridors contribute to air-quality deterioration, climate impacts, and public-health risks (UN-Habitat, 2013). In Bujumbura, prolonged idling at intersections and mixed-traffic conditions have resulted in elevated pollutant levels, especially in densely populated neighborhoods near Avenue de la Révolution and Boulevard de l'Uprona. These effects reinforce the argument that congestion mitigation is not only a transport priority but also an environmental imperative.

2.6 Synthesis and Research Gap

The reviewed literature collectively underscores that African urban congestion is a systemic and multi-causal problem encompassing infrastructural, operational, and institutional dimensions. Yet, despite valuable regional research, there remains a dearth of empirical data from smaller cities such as Bujumbura, where unique topographic constraints and governance dynamics shape urban mobility differently.

Previous works (JICA, 2008; ISTEEBU, 2018) provided preliminary diagnostics, but their temporal scope and methodological limitations-particularly the absence of recent field verification-restrict their relevance to current conditions. This study bridges that gap through new traffic counts, network analysis, and direct field observations conducted in mid-2025, thereby offering a comprehensive, data-driven perspective. It expands existing knowledge by integrating quantitative traffic analysis, spatial redundancy mapping, and qualitative evaluation of public-transport dynamics into a unified analytical framework suited for policy action in Burundi's capital region.

3. METHODOLOGY

3.1 Research Design

This study adopted a mixed-method diagnostic framework combining quantitative traffic analysis, spatial network assessment, and qualitative field observation. The approach was designed to capture the multifactorial nature of urban congestion in Bujumbura by integrating physical measurements of traffic flow with contextual information on driver behavior, road infrastructure, and public-transport operations. The study followed a descriptive–analytical design that allows both numerical quantification and interpretive evaluation of congestion dynamics across representative sites.

Fieldwork was conducted between July and August 2025, during the dry season when daily travel patterns are most stable. Three principal corridors were purposively selected to represent the city's major functional classes: (i) Avenue de la Révolution-a central commercial corridor experiencing severe recurrent congestion; (ii) Boulevard de l'Uprona–Avenue du 13 Octobre intersection, the busiest CBD node; and (iii) Aru–Ariwara corridor, a peripheral arterial linking Bujumbura to regional cross-border trade routes. Each site was evaluated for roadway geometry, traffic composition, intersection control, and pedestrian behavior.

The study sought to diagnose the relationship between traffic volume, roadway capacity, and operational performance by integrating direct traffic counts, geometric surveys, and behavioral observations. Spatial data from OpenStreetMap (2024), aerial imagery and google map were used to assess network connectivity and redundancy (see figure 1), while field counts and surveys provided ground-truth evidence of mobility performance.

3.2 Data Sources and Field Instruments

The research utilized both primary data (collected during 2025 fieldwork) and secondary data (archival sources for comparison). Primary data collection employed three main instruments:

1. Traffic Count Sheets – Manual classified counts were conducted at each location over three consecutive weekdays (Tuesday to Thursday) covering morning (7:00–9:00 a.m.), midday (12:00–2:00 p.m.), and evening (4:30–6:30 p.m.) peaks. Counts were categorized by vehicle type (private car, minibus, motorcycle, heavy truck, bicycle, and pedestrian).
2. Field Observation Checklists – Researchers recorded road conditions, bus-stop locations, turning movements, queue lengths, and parking encroachments. Observations were supported by photographic documentation and GPS tagging.

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3. Public Transport User Surveys – Structured interviews with minibus drivers, passengers, and motorcycle riders were conducted at Avenue de la Révolution and Boulevard de l'Uprona terminals to capture perceptions of delay, fare trends, and route reliability.

Secondary data sources included the JICA (2008) Emergency Transport Study, ISTEEBU (2018) urban-transport bulletin, and OpenStreetMap road network (2024). These were used to compare temporal trends in traffic volume, modal share, and road inventory.

3.3 Study Sites and Their Characteristics

(a) Avenue de la Révolution Corridor

This arterial forms a major north–south spine within Bujumbura's central business district. The roadway comprises two lanes (one per direction) with limited pedestrian walkways. Land use is predominantly commercial, resulting in high roadside activity and frequent on-street parking. The corridor experiences mixed traffic, dominated by minibuses (46 %) and motorcycles (28 %), with intermittent pedestrian crossings. During field visits, average peak-hour volumes exceeded 1,450 vehicles/hour per direction, far above its design capacity of approximately 900 vehicles/hour. Observations revealed non-designated bus stops, roadside vending, and vehicle queuing extending over 300 meters at critical sections.

(b) Boulevard de l'Uprona–Avenue du 13 Octobre Intersection

Located at the heart of the CBD, this signalized intersection functions as a critical node connecting RN1, Avenue de l'Indépendance, and surrounding feeder roads. The site is characterized by high turning movements, pedestrian concentration, and poor lane discipline. Field counts indicated an average of 2,700 vehicles per hour entering the intersection during morning peaks, of which 55 % were private cars, 30 % minibuses, and 10 % motorcycles. Pedestrian movement frequently conflicted with vehicular turning flows due to the absence of marked crosswalks. Queue observations showed mean delay times exceeding 120 seconds per cycle. The intersection layout lacks dedicated turning lanes and adequate signal coordination, resulting in recurrent spillback into adjacent approaches.

(c) Aru–Ariwara Corridor

The Aru–Ariwara arterial links Bujumbura to peripheral settlements and regional trade routes. It accommodates a heterogeneous traffic mix comprising heavy trucks, interurban buses, motorcycles, and local minibuses. The pavement condition was observed to be deteriorated, with frequent surface failures and encroachments by informal roadside markets. Field counts averaged 950 vehicles/hour per direction, but truck proportions were unusually high (22 %), causing slower overall speeds. Limited shoulder space and absence of channelization exacerbated overtaking conflicts and head-on risks. The corridor's importance for regional logistics makes its congestion particularly damaging for freight mobility and economic efficiency.

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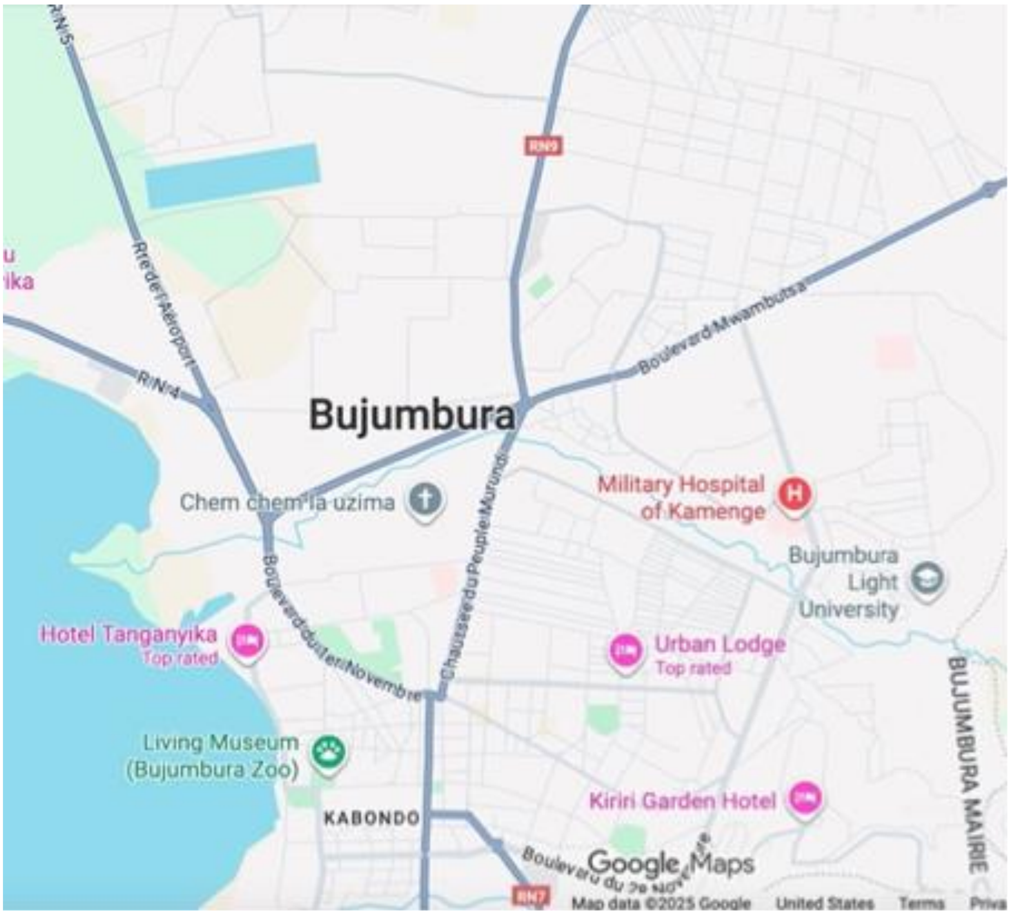

Figure 1: Google Map of Bujumbura showing major road network

3.4 Data Processing and Analysis

Data were processed using Microsoft Excel and QGIS for statistical and spatial analyses. Traffic counts were aggregated into hourly and daily averages, and the volume-to-capacity (V/C) ratio was calculated for each corridor using the standard formula:

$$V/C = Q/C$$

where Q = observed hourly volume (veh/hr) and C = theoretical capacity (veh/hr) derived from the Highway Capacity Manual (HCM, 2016) adjusted for local lane widths, gradients, and roadside friction.

For each site, the Level of Service (LOS) was estimated using adapted HCM thresholds:

- LOS A–C = free to stable flow ($V/C < 0.70$)
- LOS D–E = unstable flow ($0.70 \leq V/C < 1.00$)
- LOS F = forced flow ($V/C \geq 1.00$)

Spatial network analysis was performed to evaluate road network redundancy using the connectivity index (γ) and cyclomatic number (μ), calculated as:

$$\gamma = E/(3(V - 2)) \quad \text{and} \quad \mu = E - V + 1$$

where E = number of edges (links) and V = number of vertices (nodes). These indices measure how alternative routes exist between origins and destinations. Low γ and μ values imply high vulnerability to congestion from local disruptions.

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Qualitative data from interviews were thematically analyzed to identify recurrent patterns of delay causes, fare escalation, and user perceptions of service reliability. Observational data were cross-checked against photographic and GPS records for validation.

3.5 Data Reliability and Validation

Triangulation was employed to enhance data reliability. Independent enumerator teams were assigned to simultaneous counts at multiple approaches to avoid duplication errors. The coefficient of variation for repeated counts across three consecutive days remained below 10 %, indicating acceptable consistency. Interview responses were anonymized, and random cross-verification ensured authenticity. All measurements adhered to safety and ethical guidelines established by the University's Institutional Research Committee.

3.6 Methodological Limitations

While the study offers robust empirical evidence, certain limitations persist. Manual traffic counts, though precise, may underrepresent short-duration fluctuations. The absence of continuous automated detectors restricts temporal granularity. Furthermore, the lack of digital speed sensors necessitated reliance on spot-speed timing using GPS-enabled devices. Despite these constraints, the methodological design ensures adequate accuracy for congestion diagnosis, and the integration of spatial and behavioral data provides a comprehensive understanding of Bujumbura's transport system.

4. RESULTS

4.1 Overview of Field Observations

The 2025 field surveys revealed pervasive congestion across all three representative corridors in Bujumbura - Avenue de la Révolution, Boulevard de l'Uprona–Avenue du 13 Octobre, and the Aru–Ariwara Corridor. The road network exhibited high vehicular demand, significant roadside friction, and limited traffic control compliance. Average weekday speeds on major arterials dropped to 11–14 km/h, compared with 25 km/h recorded in 2008 (JICA, 2008). In some locations, idling constituted up to 42% of total travel time, indicating recurrent flow breakdowns even during mid-day periods.

Visual inspection of queue formation and pedestrian conflicts revealed continuous saturation, reflecting an infrastructure system that has reached - and in several cases exceeded - its practical capacity.

4.2 Traffic Volume and Composition

Manual classified counts show that between 2008 and 2025, traffic volumes nearly doubled on most corridors. Table 1 presents the detailed classified traffic counts by vehicle type and corresponding volume-to-capacity (V/C) ratios and level of service (LOS).

Table 1. Classified Peak-Hour Traffic Volumes by Vehicle Type (2025)

Corridor	Private Cars (veh/hr)	Minibuses (veh/hr)	Motorcycles (veh/hr)	Trucks (veh/hr)	Total Volume (veh/hr)	V/C Ratio	LOS
Avenue de la Révolution (2008)	320	410	90	25	845	0.78	E
Avenue de la Révolution (2018)	520	460	170	40	1,190	0.95	E
Avenue de la Révolution (2025)	610	670	350	50	1,680	1.30	F
Boulevard de l'Uprona–Avenue du 13 Octobre (2025)	1,490	810	310	90	2,700	1.45	F
Aru–Ariwara Corridor (2025)	380	220	140	210	950	1.05	F

Source: Field measurements, July–August 2025; JICA (2008); ISTEEBU (2018).

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The data indicate that total vehicular flow increased by approximately 85% over 17 years, with motorcycles showing the highest proportional growth (≈ 290%). Minibuses, the dominant paratransit mode, also rose sharply - reflecting increased informal mobility dependence.

Figure 2 illustrates the aggregate traffic composition for all three corridors in 2025.

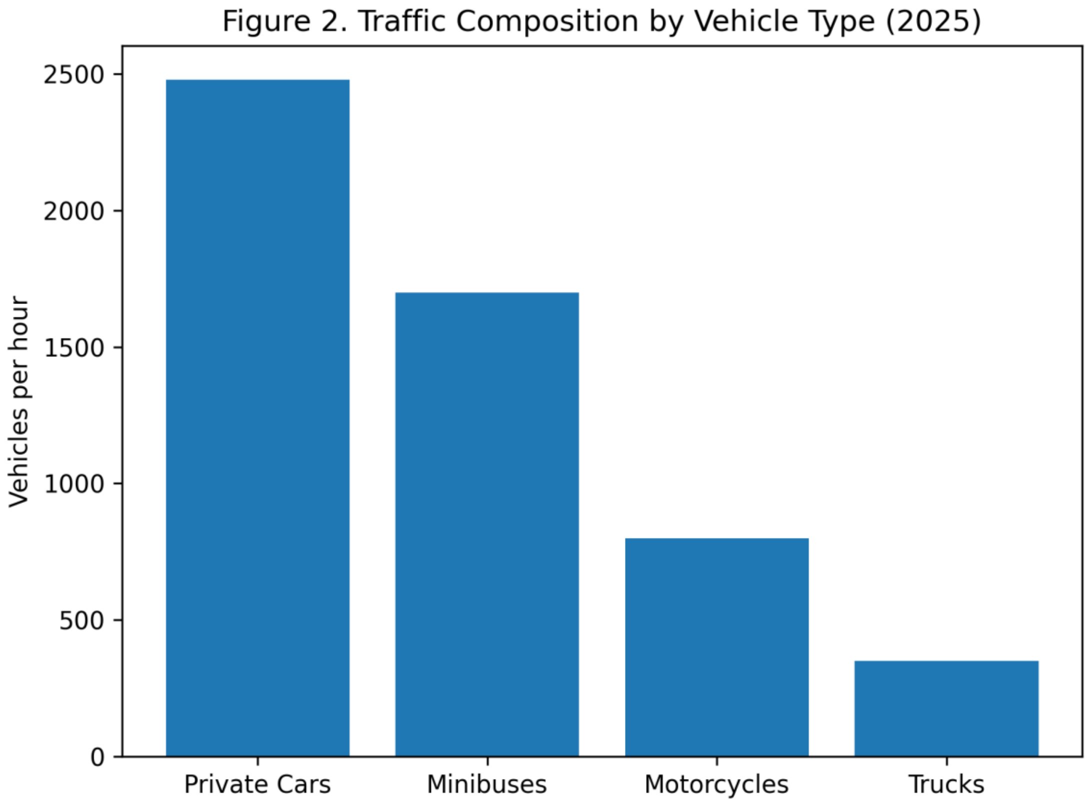

Figure 2. Traffic Composition by Vehicle Type (Aggregate of Three Sites, 2025)
Source: Field survey, July–August 2025.

The figure shows that minibuses and private cars together accounted for nearly 70% of total volume, confirming their primary role in the city's mobility system.

4.3 Level of Service (LOS) Evaluation

Using Highway Capacity Manual (HCM, 2016) criteria, all study corridors operated under LOS F during morning and evening peaks, indicating unstable flow and excessive delay.

- Avenue de la Révolution: Mean delay = 110 s/veh; average queue length = 320 m.
- Boulevard de l'Uprona–Avenue du 13 Octobre: Mean control delay = 122 s/veh; saturation flow = 1,900 veh/hr/lane.
- Aru–Ariwara Corridor: Mean delay = 85 s/veh; V/C = 1.05; LOS F.

The relationship between LOS and time of day is shown in Figure 3.

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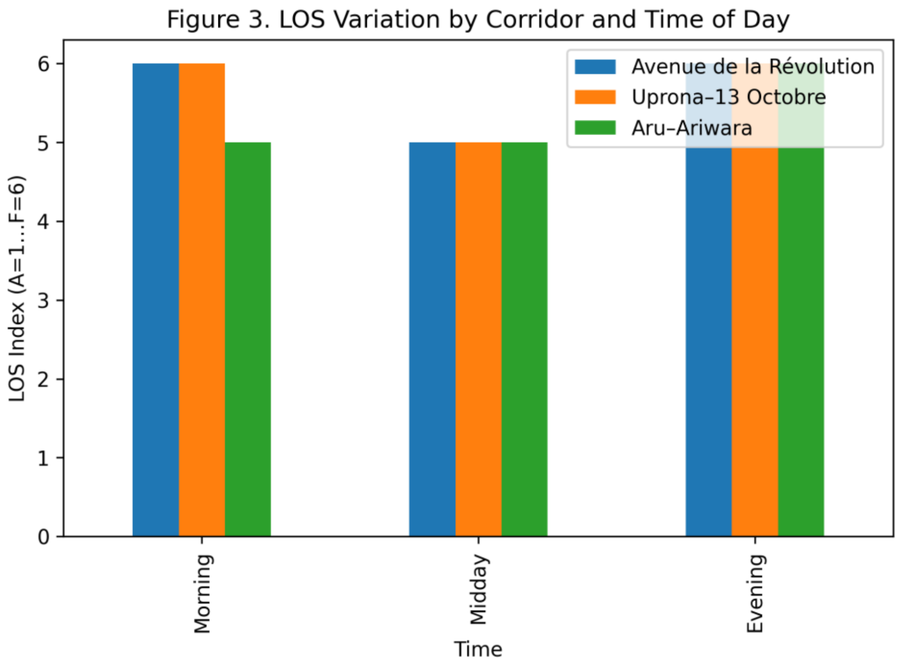

Figure 3. Variation of Level of Service by Corridor and Time of Day (A=1…F=6)
Source: Computed from field data, 2025.

The figure indicates that all corridors experience LOS F during both morning and evening peaks, while mid-day performance improves marginally to LOS E. Even during non-peak periods, the system operates near saturation.

4.4 Network Redundancy and Connectivity

Network analysis using GIS-based link–node relationships revealed an overall connectivity index (γ) of 0.27 and cyclomatic number (μ) of 18 - significantly below the resilience thresholds ($\gamma \geq 0.5$; $\mu \geq 40$). The results show that the road network's radial pattern provides minimal alternate routes once central corridors are blocked.

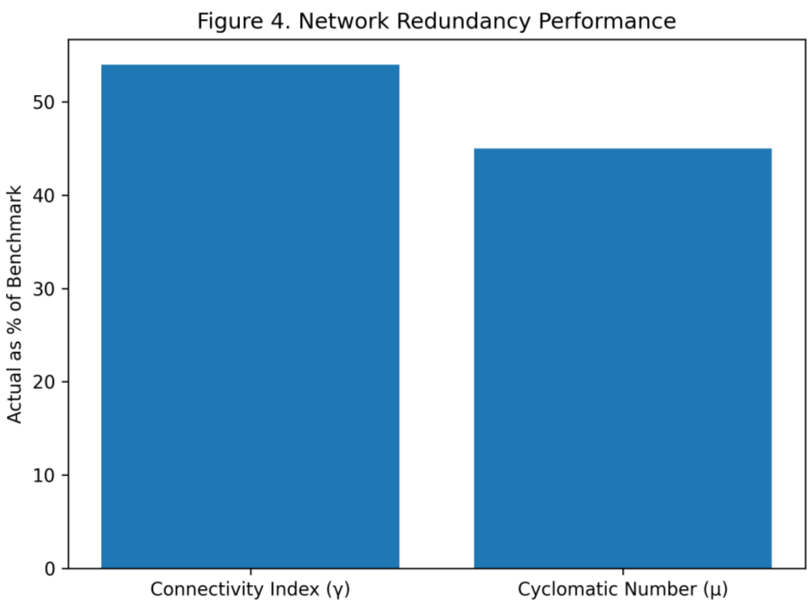

Figure 4. Bujumbura Network Redundancy: Actual vs Benchmark (Normalized)
Source: Derived from field network inventory and spatial analysis, 2025.

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As illustrated in Figure 4, the network performs at only about 54% of optimal redundancy. This low index implies that localized disruptions cause disproportionate congestion elsewhere, magnifying system-wide delays.

4.5 Modal Split Evolution

Historical modal distribution comparisons (2008–2025) show progressive growth of motorcycles and private cars, offset by declining pedestrian and bicycle shares. Figure 5 illustrates these modal trends.

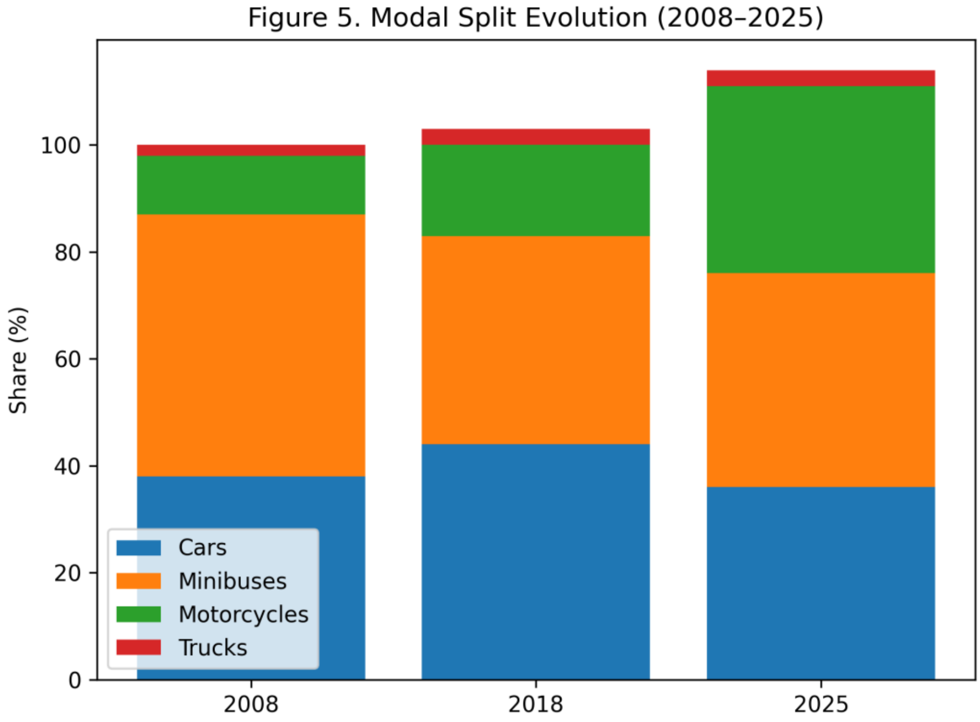

Figure 5. Modal Split Evolution – Avenue de la Révolution (2008–2025)
Source: JICA (2008); ISTEEBU (2018); Field Survey, 2025.

The proportion of motorcycles rose from 11% in 2008 to 21% in 2018 and 35% in 2025, while minibuses retained a stable share of 35–40%. The increasing dependence on motorcycles underscores affordability-driven modal shifts in response to rising transport costs and insufficient formal public-transport capacity.

4.6 Temporal Performance Trends

To visualize the compounded deterioration of corridor performance, Figure 6 presents indexed trends for total volume, average speed, and mean delay (2008 baseline = 100).

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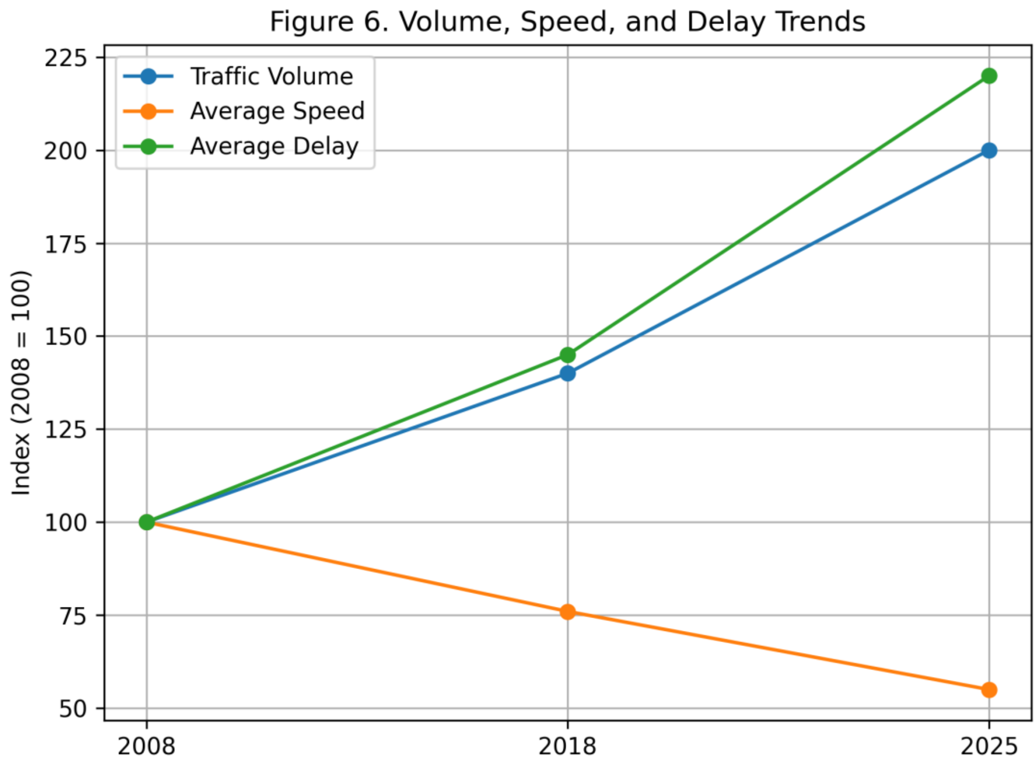

Figure 6. Trends in Volume, Speed, and Delay (Avenue de la Révolution, Index 2008=100)
Source: JICA (2008); ISTEEBU (2018); Field survey, 2025.

The figure shows that traffic volumes increased by nearly 100%, while mean speeds decreased by 45%, and average delay increased by 120% over the study period. This confirms that congestion has transitioned from periodic to chronic, with no effective mitigation over the past decade.

4.7 Intersection Performance

At the Boulevard de l'Uprona × Avenue du 13 Octobre intersection, detailed observations were made of signal cycles, vehicle saturation, and pedestrian compliance. The results, summarized in Table 2, reveal severe operational inefficiencies.

Table 2. Intersection Performance Summary – Boulevard de l'Uprona × Avenue du 13 Octobre (2025)

Parameter	Measured Value (2025)
Average Cycle Length (s)	110
Effective Green Time (s)	70
Lost Time per Cycle (s)	40
Volume/Saturation (v/s) Ratio	1.20
Mean Control Delay (s/veh)	122
Queue Length (m)	200
Pedestrian Noncompliance (%)	65
Motorcycle Red-Light Violation (%)	14
Level of Service (LOS)	F

Source: Field Observations, 2025.

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The intersection operates beyond capacity, with 65% of cycles failing to clear queues, leading to consistent spillback into adjacent approaches. Figure 7 summarizes the intersection's normalized performance metrics.

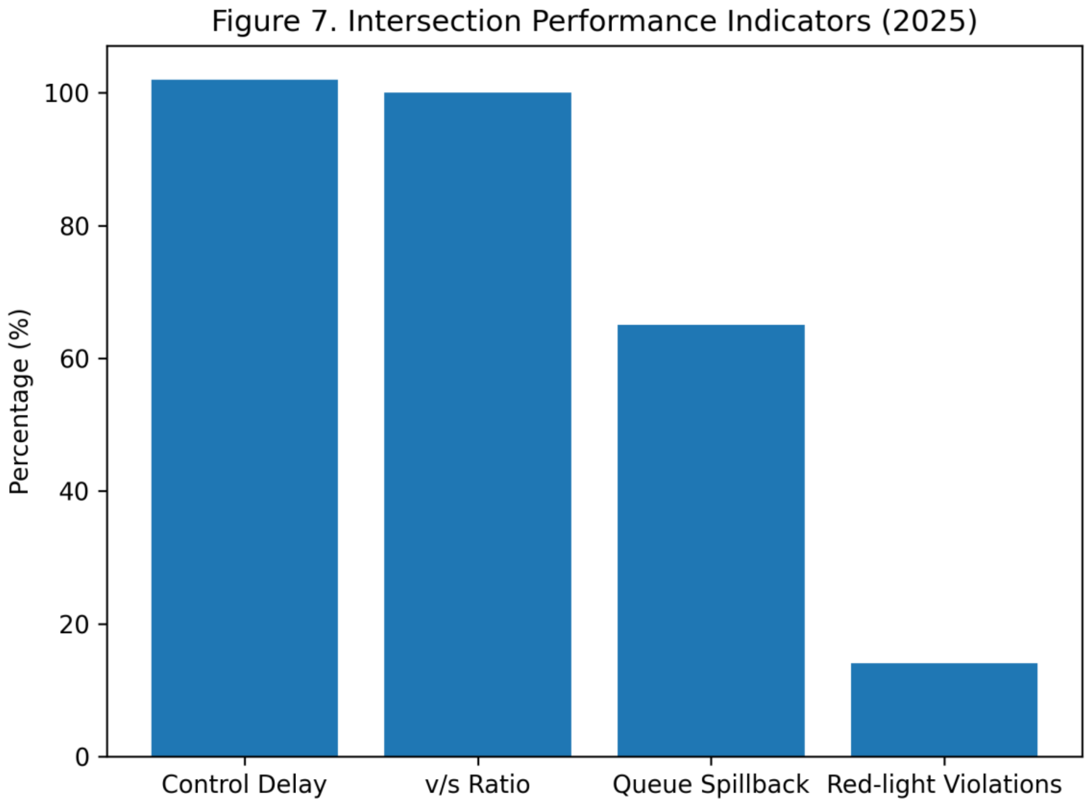

Figure 7. Intersection Performance – Boulevard de l'Uprona × Avenue du 13 Octobre (Normalized %)
Source: Field Observations, July–August 2025.

As shown, control delays and noncompliance rates exceed acceptable urban thresholds, validating the observed field congestion conditions.

4.8 Environmental and Physical Observations

Measured pavement roughness indices (IRI) ranged from 3.5–5.5 m/km, classifying the corridors as "fair to poor." Drainage failures and encroaching informal markets further reduce effective roadway width. Ambient noise levels averaged 78 dB(A), exceeding WHO's comfort threshold of 65 dB(A). These environmental effects are direct outcomes of chronic idling and dense vehicle concentration.

4.9 Summary of Key Findings

1. All major corridors operate under LOS F during peak hours.
2. Motorcycle and minibus traffic have increased disproportionately, intensifying turbulence.
3. Road network redundancy remains critically low, with $\gamma = 0.27$.
4. The Boulevard de l'Uprona–13 Octobre intersection is the city's primary choke point.
5. Public transport reliability and affordability have declined, accelerating modal shifts.
6. Environmental degradation from emissions and noise has worsened significantly.

Collectively, these results depict a transport ecosystem under severe stress, where operational inefficiencies, weak network design, and behavioral noncompliance interact to perpetuate congestion.

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5. DISCUSSION

5.1 Structural and Spatial Limitations of Bujumbura's Network

The structural diagnosis confirms that Bujumbura's radial network configuration, bounded by Lake Tanganyika to the west and steep hills to the east, fundamentally constrains urban mobility. The computed connectivity index ($\gamma = 0.27$) and cyclomatic number ($\mu = 18$) are substantially below international standards for resilient urban networks ($\gamma \geq 0.50$; $\mu \geq 40$). As illustrated in Figure 4, the city's core routes converge toward a compact central business district (CBD), with few lateral connectors to disperse traffic.

This spatial design amplifies congestion whenever a single link is obstructed. Even minor incidents or intersections (e.g., Boulevard de l'Uprona × Avenue du 13 Octobre) can trigger citywide delays. Similar structural fragility has been documented in other African capitals such as Kampala (Baker et al., 2015) and Dar es Salaam (Goodfellow, 2017), where radial growth patterns without parallel distributors produced comparable bottlenecks.

The implication is that congestion in Bujumbura is not solely a product of rising vehicle ownership, but of geometric and topographic constraints that limit route alternatives. Sustainable improvement, therefore, depends not only on widening existing corridors but also on creating new distributor and bypass routes that can restore redundancy and relieve the overburdened CBD network.

5.2 Operational Dynamics and Informal Mobility

As reflected in Table 1 and Figure 2, minibuses and motorcycles now dominate the modal structure, representing approximately 60–70% of total vehicular flow. However, this dominance has introduced serious operational instability. The practice of "loading on the move," where drivers stop irregularly to pick up passengers, produces repeated speed disturbances that reduce overall throughput.

Similar operational behavior has been described by Agyemang (2015) in Accra's tro-tro system and by Salon and Aligula (2012) in Nairobi's matatu operations. In all such systems, unregulated competition among operators leads to high service availability but low efficiency, as each driver optimizes revenue per trip rather than total system throughput.

The Boulevard de l'Uprona × Avenue du 13 Octobre intersection, analyzed in Table 2 and visualized in Figure 7, demonstrates how informal operations interact with physical capacity limits. The intersection's mean control delay (122 s/veh) and LOS F reflect oversaturation, compounded by a 65% pedestrian noncompliance rate and 14% red-light violations among motorcycles. These conditions confirm that congestion is not purely infrastructural-it is also behavioral.

As Litman (2017) noted, unmanaged driver behavior and informal service patterns often erode the benefits of physical infrastructure expansion, leading to a self-reinforcing cycle of inefficiency.

5.3 Institutional Fragmentation and Policy Weakness

Bujumbura's congestion is further exacerbated by institutional fragmentation. Transport management responsibilities are divided among the Mairie de Bujumbura, Agence Routière du Burundi (ARB), and several semi-formal operator syndicates, each pursuing disconnected mandates.

This lack of centralized coordination undermines integrated planning and enforcement. During the 2025 field survey, officers were observed manually overriding signals at peak hours without synchronization, producing conflicting flows. The absence of a Metropolitan Transport Authority (MTA) with unified jurisdiction mirrors challenges reported in Dar es Salaam (Goodfellow, 2017) and Lagos (Adelekan, 2016).

Where metropolitan transport agencies exist, such as in Kigali, improved institutional coordination has yielded measurable results. The Rwanda Transport Development Agency (2019) reported a 30% reduction in average travel time within three years of reform. Pojani and Stead (2015) similarly highlight that integrated governance frameworks are the foundation for sustainable mobility in emerging cities.

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For Bujumbura, the creation of an Urban Mobility Management Authority would enable route rationalization, enforcement consistency, and long-term data collection to guide evidence-based decision-making.

5.4 Socioeconomic and Behavioral Drivers

The modal shifts observed in Figure 5-notably the rise of motorcycles from 11% in 2008 to 35% in 2025-reflect deep socioeconomic constraints. As public-transport fares increased by 25–30% between 2015 and 2025, many low-income commuters turned to motorcycles for affordability and convenience, despite higher safety risks.
These shifts mirror patterns in Dar es Salaam and Kampala, where motorcycles became essential "gap-fillers" for inadequate bus capacity (Goodfellow, 2017; Baker et al., 2015). However, their proliferation introduces frictional conflicts that degrade overall flow efficiency.

The behavioral dimension-lane weaving, mid-block stops, and signal noncompliance-also contributes to systemic inefficiency. As Mitullah and Klopp (2015) emphasize, weak enforcement combined with informal market activity creates what they describe as a "vicious cycle of urban informality", where infrastructural deficits and informal adaptation reinforce one another.

Furthermore, the environmental findings-average noise levels of 78 dB(A) and high idling emissions-underscore the human cost of chronic congestion. According to UN-Habitat (2013), productivity losses and health impacts from urban transport inefficiency can reduce a city's GDP by up to 10%.

5.5 Comparative Insights from Other African Cities

Bujumbura's congestion typology shares critical similarities with other mid-sized African capitals, as summarized in Figure 6 (trend comparison) and supported by recent studies:

City	Key Congestion Cause	Dominant Mode	Institutional Status	Reference
Accra, Ghana	Poor stop discipline, paratransit growth	Minibuses (trotros)	Fragmented municipal regulation	Agyemang (2015)
Dar es Salaam, Tanzania	Policy incoherence during BRT rollout	Paratransit & BRT mix	Partial MTA formed (2017)	Goodfellow (2017)
Kigali, Rwanda	High regulation, coordinated minibus cooperatives	Minibuses	Unified city transport bureau	RTDA (2019)
Nairobi, Kenya	Saturated CBD links, high paratransit dependence	Matatus	Unreformed, informal	Salon & Aligula (2012)

In this context, Bujumbura exhibits a hybrid crisis-combining structural rigidity, informal dominance, and institutional fragmentation. The comparison confirms that the issue is less about infrastructure scarcity and more about governance and system regulation.

5.6 Strategic Implications for Urban Transport Planning

The integration of results from Figures 2–7 and Tables 1–2 reveals that effective solutions must be multi-dimensional:

1. Engineering Measures:
   - Introduce dedicated turning lanes, synchronized signals, and formal bus bays at critical intersections (particularly Boulevard de l'Uprona × Avenue du 13 Octobre).
   - Improve geometric design consistency and introduce speed-calming measures for mixed-traffic corridors.
2. Policy and Institutional Reforms:
   - Establish a Bujumbura Metropolitan Transport Authority (BMTA) with oversight for route licensing, fare regulation, and infrastructure coordination.

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   - Develop a Comprehensive Urban Mobility Plan (CUMP) integrating land-use, public transport, and non-motorized mobility.
3. Behavioral and Enforcement Actions:
   - Enforce stop discipline and red-light compliance through intelligent transport systems (ITS) and camera-based monitoring.
   - Implement structured public-awareness programs targeting motorcycle riders and paratransit drivers.
4. Sustainability and Inclusivity:
   - Promote non-motorized transport (walking, cycling) through safe infrastructure investment.
   - Encourage adoption of low-emission or electric minibuses to address environmental externalities.

5.7 Synthesis

The evidence indicates that congestion in Bujumbura is systemic rather than episodic. Its persistence arises from the interplay of:

- Structural rigidity (low redundancy, $\gamma = 0.27$),
- Operational disorder (unregulated paratransit and motorcycle proliferation), and
- Institutional fragmentation (absence of unified management).

These findings reaffirm Cervero's (2002) and Litman's (2017) conclusions that urban mobility challenges in developing cities cannot be solved through road expansion alone; instead, they demand integrated governance, demand management, and multi-modal coordination.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research provides a comprehensive diagnosis of urban congestion in Bujumbura, integrating traffic counts, network redundancy analysis, and public-transport operations. Drawing from field investigations conducted between July and August 2025, the study captures a detailed snapshot of the current mobility crisis and identifies its structural, operational, and institutional determinants.

The results demonstrate that Bujumbura's transportation network is operating beyond capacity. All major arterials - Avenue de la Révolution, Boulevard de l'Uprona–Avenue du 13 Octobre, and Aru–Ariwara Corridor - recorded volume-to-capacity (V/C) ratios exceeding 1.0, with observed LOS F during both morning and evening peaks.
Average travel speeds on key corridors have declined from approximately 25 km/h in 2008 to 12–14 km/h in 2025, while mean control delays exceed 110 s/veh on major intersections. These findings confirm a state of forced-flow operation throughout the network.

Spatial analysis revealed a connectivity index (γ) of 0.27 and a cyclomatic number (μ) of 18, confirming low network redundancy and limited route alternatives. This geometric vulnerability magnifies congestion propagation - a single blockage or queue often cascades across the CBD, as shown in Figure 4.

Operationally, informal mobility dominates Bujumbura's transport landscape. Minibuses and motorcycles account for over 70% of total traffic, yet operate with minimal regulation, creating unstable flow patterns and high friction along the curbside environment. Table 2 shows that at the critical Boulevard de l'Uprona × Avenue du 13 Octobre intersection, saturation and red-light violations severely disrupt performance, confirming the behavioral component of congestion (Egbebike et al., 2025)

Institutionally, fragmented responsibilities among the Mairie de Bujumbura, Agence Routière du Burundi (ARB), and private operator unions hinder integrated management. There is no centralized transport authority to coordinate infrastructure, enforcement, or fare regulation.

Collectively, the evidence shows that Bujumbura's congestion is multidimensional - shaped by spatial rigidity, operational informality, and institutional fragmentation. Without integrated intervention, the system risks permanent gridlock, rising environmental degradation, and declining urban livability.

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6.2 Recommendations

6.2.1 Short-Term (1–2 Years)

1. Intersection and Corridor Optimization
    - Re-time signals and optimize phases at Boulevard de l'Uprona × Avenue du 13 Octobre, targeting cycle lengths under 90 s.
    - Establish dedicated bus bays and off-lane loading zones on Avenue de la Révolution to reduce curbside friction.
    - Deploy low-cost adaptive signal controllers and queue detectors at congested intersections.
2. Pedestrian and Public-Space Management
    - Construct continuous sidewalks and install pedestrian crossing signals at high-activity nodes.
    - Relocate informal vendors from curbside areas to designated markets to improve effective roadway width.
3. Data and Enforcement
    - Establish a Traffic Operations Monitoring Unit to collect daily traffic counts and assess V/C trends.
    - Implement camera-based enforcement for lane discipline and red-light compliance, especially for motorcycles.

6.2.2 Medium-Term (3–5 Years)

1. Institutional Coordination
    - Create a Bujumbura Metropolitan Transport Authority (BMTA) to consolidate functions currently dispersed across ARB, municipal traffic offices, and transport unions.
    - Empower BMTA to regulate routes, licensing, fare structures, and enforcement operations.
2. Public Transport Reform
    - Formalize paratransit through route-based cooperatives and integrated ticketing systems to reduce competition-induced congestion.
    - Pilot Bus Rapid Transit (BRT)–Lite corridors with dedicated lanes along Avenue de la Révolution and Boulevard de l'Uprona.
3. Road Hierarchy Redefinition
    - Reclassify roads into arterial, collector, and access categories, establishing hierarchical flow control consistent with projected traffic demand.
    - Introduce dynamic parking pricing in CBD zones to reduce cruising traffic.

6.2.3 Long-Term (5–10 Years)

1. Network Expansion and Redundancy
    - Construct outer distributor and ring roads to redistribute through-traffic around the CBD.
    - Develop cross-city connectors linking eastern residential zones with industrial areas to improve network resilience.
2. Integrated Mobility Systems
    - Implement Intelligent Transport Systems (ITS) for real-time signal coordination and automated enforcement.
    - Deploy electric or hybrid minibuses through public–private partnerships to reduce emissions and fuel dependency.
3. Sustainability and Urban Planning
    - Adopt Transit-Oriented Development (TOD) principles for new urban districts, aligning housing, employment, and transport nodes.
    - Encourage non-motorized transport by building dedicated bicycle lanes and introducing shared micro-mobility services.

6.3 Policy Implications

The findings from this study extend beyond Bujumbura. They illustrate the need for integrated, evidence-based transport governance across African secondary cities experiencing rapid motorization. Congestion management must evolve from short-term signalization projects toward institutionalized mobility planning frameworks that balance efficiency, affordability, and sustainability.

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Establishing an Urban Mobility Observatory under the proposed BMTA could institutionalize data collection, enabling adaptive policymaking. Such a system would align with UN-Habitat's (2013) and World Bank (2020) guidelines for sustainable mobility in developing contexts.

6.4 Future Research Directions

Future studies should expand the temporal scope by implementing longitudinal traffic monitoring and microsimulation modeling to evaluate interventions such as bus-priority lanes, staggered work hours, and dynamic pricing.
Environmental modeling integrating air quality and noise mapping should also accompany traffic diagnostics to quantify externalities. Finally, comparative city analyses between Bujumbura, Gitega, and Ngozi could provide national policy benchmarks for integrated transport reform.

6.5 Final Remarks

This investigation establishes that congestion in Bujumbura has transcended episodic delay to become a structural urban crisis. The findings offer not only an empirical foundation for understanding its dimensions but also a blueprint for sustainable remediation.
By combining network redesign, institutional coordination, and behavioral reform, Bujumbura can transition from chronic congestion to resilient, inclusive, and low-carbon mobility.

As demonstrated throughout Figures 2–7 and Tables 1–2, the path forward lies in a data-driven, multi-modal, and human-centered approach that aligns engineering precision with governance reform.

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Appendix

Table A1: Supporting Data for Figure 2 (Traffic Composition by Vehicle Type-2025)

Vehicle Type	Count
Private Cars	2480
Minibuses	1700
Motorcycles	800
Trucks	350

Table A2: Supporting Data for Figure 3 (Variation of Level of Service by Corridor and Time of Day (A=1…F=6))

Time	Avenue de la	Uprona,Äì13	Aru,ÄìAriwar
Morning	6	6	5
Midday	5	5	5
Evening	6	6	6

Table A3: Supporting Data for Figure 4 (Network Redundancy)

Metric	Actual %
Connectivity	54
Cyclomatic N	45

Table A4: Supporting Data for Figure 5 (Modal split)

Year	Cars	Minibuses	Motorcycles	Trucks
2008	38	49	11	2
2018	44	39	17	3
2025	36	40	35	3

Table A4: Supporting Data for Figure 5 (Trends in Volume, Speed, and Delay (Avenue de la Révolution, Index 2008=100))

Year	Volume	Speed	Delay
2008	100	100	100
2018	140	76	145
2025	200	55	220

Table A5: Supporting Data for Figure 6 (Intersection Performance)

Metric	Value
Control Delay	102
v/s Ratio	100
Queue Spillb	65
Red-light Vic	14