Optimizing Urban Road Networks: A Systematic Review of Design, Control, and Multimodal Integration

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ABSTRACT

Urban areas worldwide are grappling with the pervasive challenge of traffic congestion, which impedes economic productivity, degrades environmental quality, and diminishes the quality of life for residents. The design and management of road networks are fundamental determinants of urban mobility. This systematic review presents a comprehensive analysis and proposes a new conceptual framework for optimizing road networks to enhance traffic flow. The critical interdependencies between network topology, smart traffic management systems, and multimodal integration are examined. Through a structured review of 82 selected studies, this paper synthesizes the evidence on various interventions, from hierarchical network forms to adaptive traffic control and Bus Rapid Transit (BRT). Case studies from Singapore, Curitiba, and Amsterdam illustrate that success is contingent not only on technical solutions but also on specific governance models. The review highlights the powerful synergy between physical infrastructure and intelligent control systems, but also identifies an emerging conflict between centralized planning and decentralized, user-led optimization through modern navigation applications. We conclude that moving beyond isolated fixes requires an integrated decision-making framework that acknowledges these complex interactions. This paper provides a comprehensive resource for researchers, transportation engineers, and urban planners seeking to develop more efficient, sustainable, and resilient urban transportation systems.

Keywords: Urban Mobility, Traffic Congestion, Road Network Design, Traffic Flow, Intelligent Transportation Systems, Sustainable Transportation, Multimodal Integration

1. INTRODUCTION

The 21st century is unequivocally the urban century. Cities are absorbing the vast majority of global population growth, with projections indicating that over two-thirds of humanity will reside in urban areas by 2050 (United Nations, 2018). This unprecedented wave of urbanization places immense, often unsustainable, strain on foundational urban systems, none more so than transportation infrastructure (World Bank, 2019). The ability to move people and goods efficiently, safely, and with minimal environmental impact has become a defining challenge for urban governance and a critical determinant of a city's economic competitiveness and quality of life (Hickman et al., 2013). Yet, despite decades of investment and technological advancement, the problem of urban traffic congestion remains stubbornly pervasive. In the United States alone, the annual costs of delay and wasted fuel are measured in the hundreds of billions of dollars (Texas A&M Transportation Institute, 2019), a scenario mirrored in the megacities of Europe and Asia where congestion acts as a major brake on economic productivity and public health (ITF, 2019).

For much of the 20th century, the prevailing response to congestion was a straightforward, supply-side approach: build more roads. This paradigm, however, has been fundamentally challenged by the consistent observation of induced demand. The expansion of road capacity often generates new traffic that quickly consumes any initial gains in speed or flow, a phenomenon famously described as the fundamental law of road congestion (Duranton and Turner, 2011). This self-defeating cycle of construction and congestion, coupled with growing awareness of the profound environmental and social costs of car-centric development, has catalyzed a shift in the paradigm. The focus of leading-edge research and practice has moved decisively from network expansion to network optimization, seeking to unlock the latent capacity of existing infrastructure through smarter design, dynamic management, and a more equitable allocation of street space.

The performance of an urban road network is not a simple function of its physical dimensions but emerges from the complex interplay of three core domains: physical structure, operational control, and demand management (Vickrey, 1969). The network's physical structure, or topology, has been a subject of intense study within network science, which analyses its properties of connectivity, redundancy, and resilience (Barthélemy, 2011). Empirical research in transport geography has demonstrated how different layouts, such as traditional grids, suburban hierarchical patterns, or hybrid forms, profoundly influence travel behavior, energy consumption, and vulnerability to disruptions (Xie and Levinson, 2009). Yet, an optimal physical design is a necessary but not sufficient condition for efficiency. Even well-connected networks perform poorly under the static, pre-timed signal controls of the past. This has motivated decades of investment in Intelligent Transportation Systems (ITS), particularly adaptive traffic signal control technologies that respond to real-time conditions (FHWA, 2021; Genders & Razavi, 2016). Recent advancements leverage artificial intelligence (AI) and machine learning (ML) to create predictive control systems that anticipate traffic patterns, further enhancing efficiency (Alizadeh Shabestary & Abdulhai, 2022).

Beyond managing vehicular flow, a third and increasingly critical dimension of optimization involves the strategic reallocation of road space to favor more space-efficient modes of transport. This reflects a broader shift in planning philosophy, away from simply maximizing vehicle throughput and towards a more holistic goal of sustainable mobility (Banister, 2008). The implementation of high-capacity public transport, such as Bus Rapid Transit (BRT), has been shown to deliver significant gains in corridor efficiency and travel time reliability (Cervero, 2013; Hensher & Mulley, 2022). Simultaneously, integrating this trunk infrastructure with feeder networks for active transportation (walking and cycling) is critical for solving the first- and last-mile problems and is strongly linked to reduced car dependency, particularly when coupled with supportive land-use policies, such as Transit-Oriented Development (TOD) (Cervero & Kockelman, 1997).

Despite a vast and growing body of literature across these domains, a significant gap persists in synthesizing this knowledge into a coherent, actionable framework for policymakers and practitioners. Findings on network topology, traffic control, and multimodal planning often exist in separate intellectual silos, studied by different academic communities with distinct methods and priorities. This fragmentation obscures the powerful synergies and potential conflicts that exist between interventions. This systematic review aims to bridge that gap by assembling and critically appraising the empirical record across these three core strands. A key puzzle this review helps unravel is the emerging tension between the top-down, centralized logic of traditional urban planning and the bottom-up, decentralized, real-time optimization now being driven by ubiquitous consumer technologies. By clarifying these interdependencies, this paper seeks to move the discourse from a focus on isolated fixes to a more integrated, strategic, and ultimately more effective approach to optimizing urban road networks for the challenges of the 21st century.

2. METHODOLOGY

2.1 Review Design

To ensure a structured, transparent, and reproducible process, this study adopted a systematic review design. The methodology was developed and executed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, which provides an evidence-based checklist of items for reporting in systematic reviews and meta-analyses (Page et al., 2021). A review protocol was established prior to the commencement of the search, specifying the research questions, search strategy, eligibility criteria, and methods for synthesis to minimize bias and promote methodological rigor.

2.2 Data Sources and Search Strategy

A comprehensive and systematic search of the international academic literature was conducted to identify all relevant studies published between 2000 and 2024. Four major electronic databases were queried, chosen for their extensive coverage of transportation engineering, urban planning, geography, and related interdisciplinary fields: Scopus, Web of Science, TRID (Transport Research International Documentation Database), and Google Scholar. The search strategy was designed to be highly sensitive, combining keywords from three core conceptual pillars: (1) Network and Infrastructure (e.g., "road network," "street network," "topology"); (2) Traffic and Mobility (e.g., "traffic flow," "urban mobility," "congestion," "accessibility"); and (3) Outcomes and Interventions (e.g., "optimize," "efficient," "design," "adaptive control," "multimodal"). Boolean operators (AND, OR) were used to construct detailed search strings tailored to the syntax of each database. For example, a representative full search string for the Scopus database was: (TITLE-ABS-KEY ("road network" OR "street network") AND TITLE-ABS-KEY ("traffic flow" OR "urban mobility" OR "congestion") AND TITLE-ABS-KEY ("optimize" OR "efficient" OR "design")). To ensure comprehensiveness, the reference lists of previously published relevant review articles were also manually scanned to identify any studies missed by the database search.

2.3 Eligibility criteria

Studies were deemed eligible for inclusion based on a pre-defined set of PICOs (Population, Intervention, Comparison, and Outcome) study design criteria. The population was defined as urban road networks at any scale (for example, corridor, sub-network, and city-wide). Interventions of interest included any structural, operational, or policy-based change related to network design, traffic control, or multimodal integration. Comparators were required, meaning studies had to compare the intervention against a baseline (or another alternative. Outcomes had to include at least one quantifiable metric of network performance, such as travel time, vehicle delay, throughput, emissions, or mode share. All empirical study designs were considered, including simulation studies, observational before-and-after studies, and comparative case studies. Only peer-reviewed journal articles and major conference papers published in English were included.

2.4 Screening and study selection

The study selection process was conducted in two phases. First, the titles and abstracts of all records retrieved from the database search were independently screened by two reviewers against the eligibility criteria. Any disagreements between the reviewers were resolved through discussion. In the second phase, the full texts of all potentially eligible articles were retrieved and assessed in detail against the same inclusion criteria to determine the final selection. The reasons for excluding articles at the full-text stage were documented. The entire screening and selection process, including the number of records identified, included, and excluded, is summarized in a PRISMA flow diagram.

2.5 Data Extraction and Items

A standardized data extraction form was developed and pre-tested to systematically collect key information from each included study. The extracted data items included: (1) bibliographic details (author, year, title); (2) study context (city, country, city characteristics like population and income level); (3) study design and methodology; (4) details of the intervention being evaluated; (5) the specific outcome measures reported; and (6) the key quantitative findings and conclusions of the study. This structured approach ensured consistency in data collection across all studies and facilitated subsequent synthesis and comparison.

2.6 Risk of Bias and Study Quality Assessment

To evaluate the methodological quality and risk of bias of the included studies, a modified version of the well-established Downs and Black (1998) checklist was used. This tool is designed to assess the quality of both randomized and non-randomized studies. The checklist was adapted for the specific context of transport studies, with items evaluating four key domains: (1) clarity of aims and reporting quality; (2) internal validity (addressing issues of bias and confounding); (3) external validity (generalizability of the findings); and (4) statistical power. Based on their score, each study was qualitatively rated as "strong," "moderate," or "weak." This quality assessment was not used to exclude studies but rather to inform the narrative synthesis, allowing for a weighting of the evidence. For instance, in cases of conflicting results, findings from studies rated as "strong" were given greater precedence.

2.7 Synthesis Approach

Given the significant heterogeneity across the included studies in terms of interventions, outcome measures, and contexts, a quantitative meta-analysis was not feasible or appropriate. Therefore, a narrative synthesis approach was undertaken. The findings were first organized into logical thematic domains based on the primary type of intervention: Network Topology and Design, Smart Traffic Management and Control, and Multimodal Integration. Within each theme, the results from individual studies were summarized and tabulated to allow for transparent comparison. The narrative then focused on identifying cross-study patterns, regularities, and divergences in the evidence, paying close attention to how the quality of a study might influence its findings. This approach allowed for a comprehensive and nuanced interpretation of a diverse body of literature.

3. RESULTS

3.1 Study Selection and Characteristics

The systematic search of the four databases yielded an initial 4,328 records. After removing 1,226 duplicates, the titles and abstracts of 3,102 unique articles were screened. This initial screening led to the exclusion of 2,881 records that were clearly not relevant to the review's objectives. The full texts of the remaining 251 articles were retrieved for detailed assessment. Of these, 169 were excluded for various reasons, most commonly due to the absence of quantifiable outcome data (n=78) or a focus on non-urban contexts, such as inter-city highways (n=45). Ultimately, a final set of 82 studies met all inclusion criteria and were included in the qualitative synthesis. The full process is detailed in the PRISMA diagram (Fig. 1).

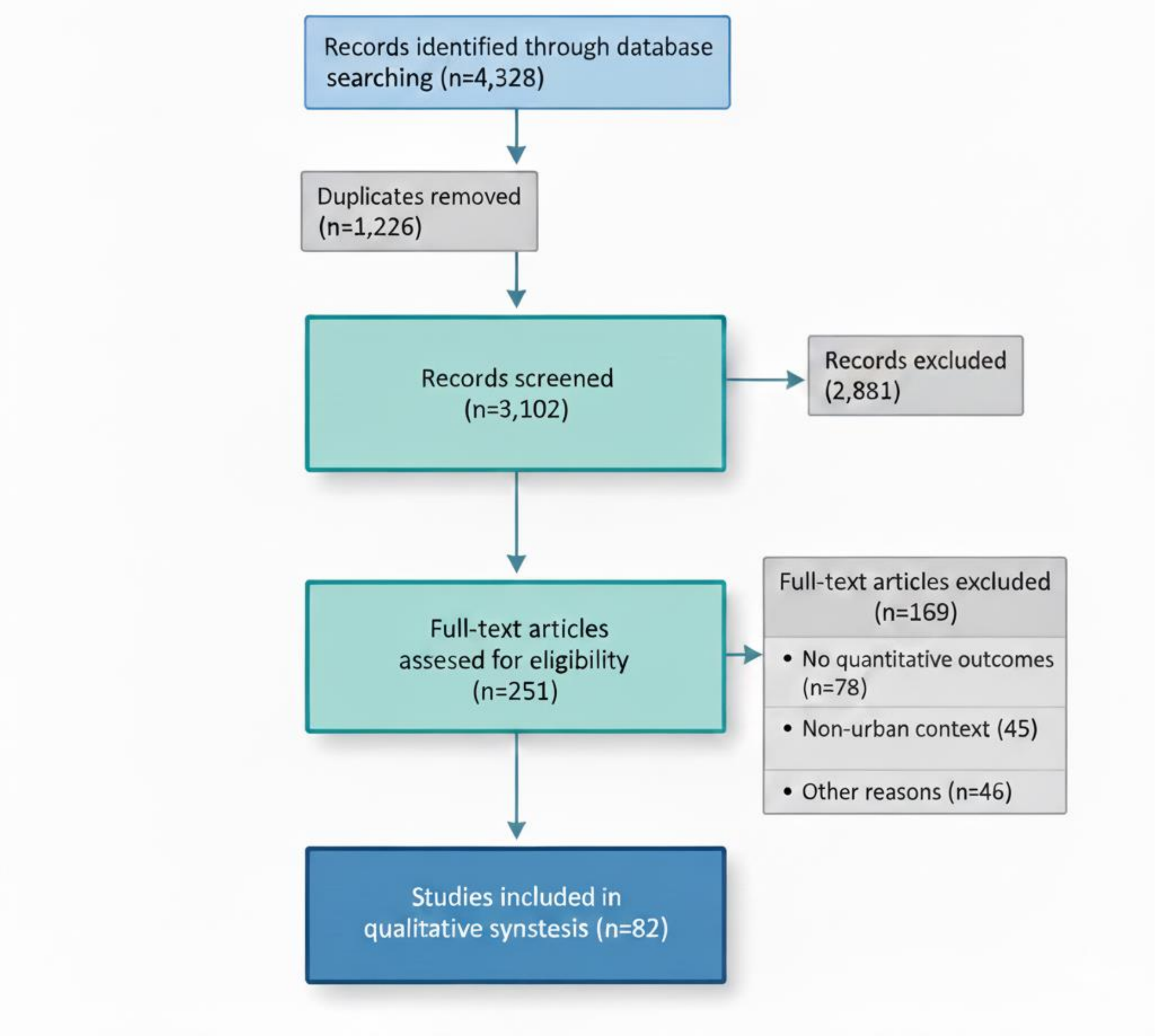

Fig. 1. PRISMA Flow Diagram

Across the 82 included studies, evidence is concentrated in high-income contexts. The largest shares come from the United States (n = 21), China (n = 14), and the United Kingdom (n = 10). Additional contributions include Germany (n = 8), Canada and Singapore (each n = 6), India (n = 5), the Netherlands (n = 4), Brazil (n = 3), Portugal (n = 2), and Colombia (n = 2) (Fig. 2). This skew has implications for generalizability and highlights the need for more evaluations in middle- and lower-income urban settings.

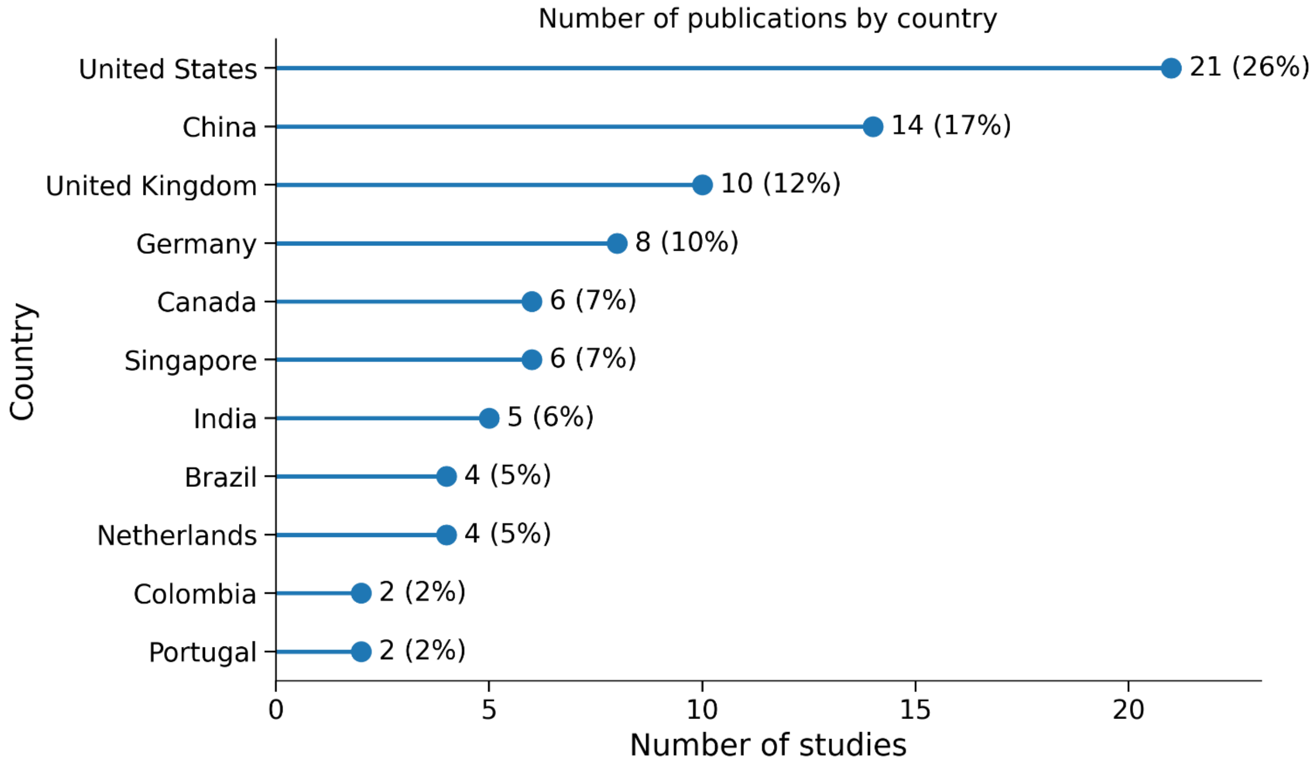

Fig. 2. Publications by Country

Annual publication activity increases over the 2000–2024 period (as shown in Fig. 3), reflecting growing attention to integrated design, adaptive control, and multimodal strategies. This trend supports the field's maturation and motivates the thematic synthesis in Sections 3.2–3.4.

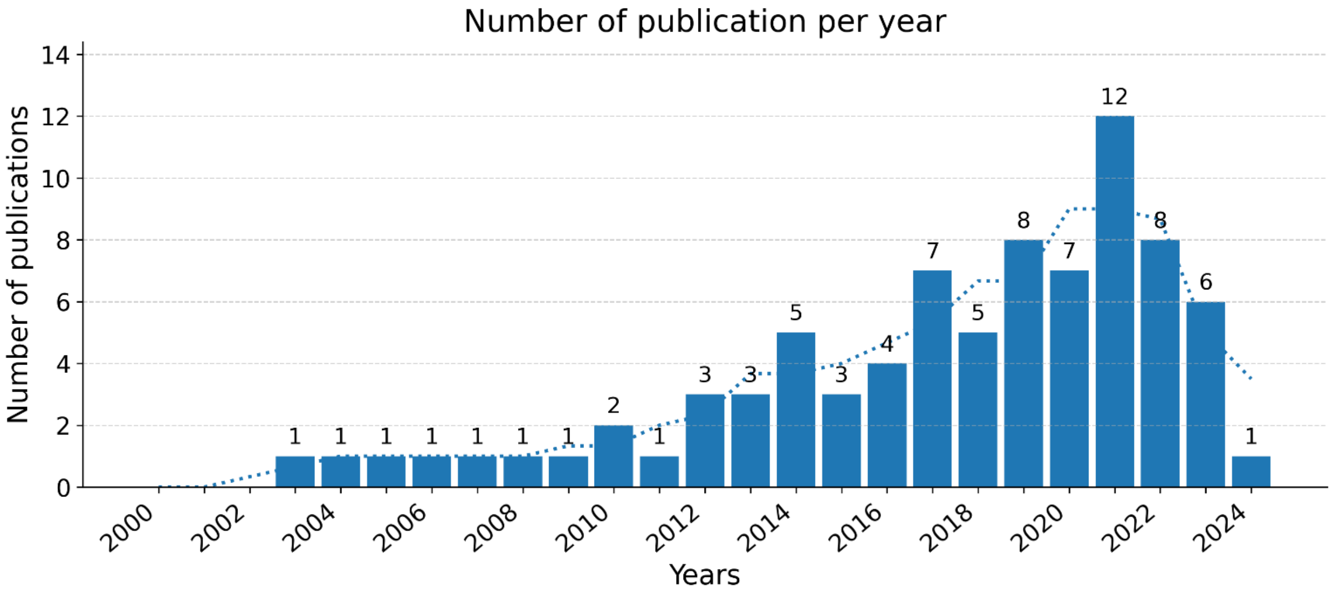

Fig. 3 Annual Publication Trend.

Methodologically, simulation studies dominate (n = 61; 74%), followed by experimental designs (n = 15; 18%) and empirical studies (n = 6; 7%) (as shown in Fig. 4). This mix is useful for mechanism testing but underscores the need for more before–after and comparative case studies to strengthen external validity.

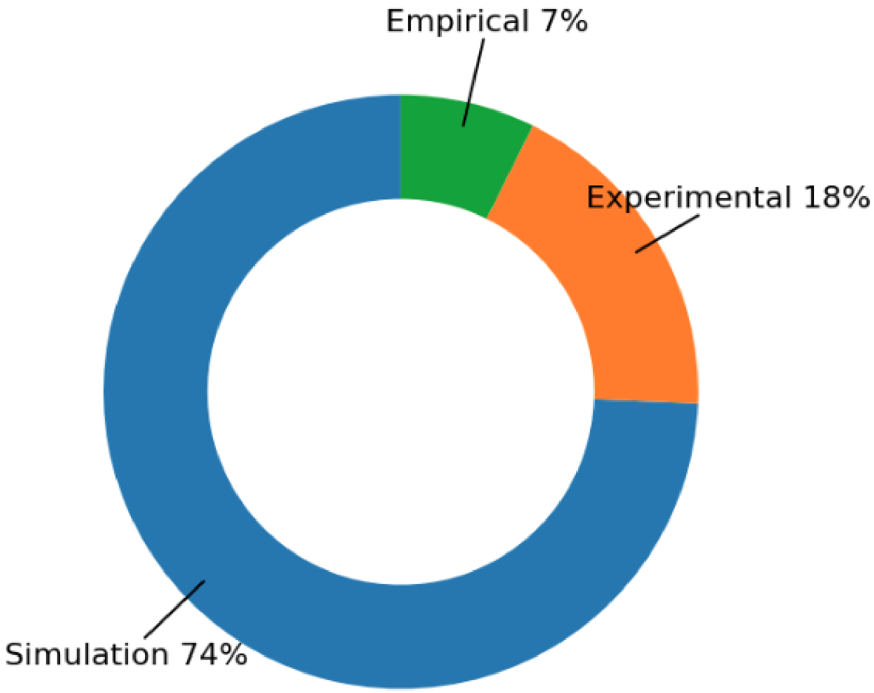

Figure 4. Study design composition of the included studies

A representative subset of study attributes and key outcomes is presented in Table 1 to support a quick comparison of contexts, interventions, designs, and quantitative effects.

Table 1. Characteristics of selected included studies

Author(s), Year	Location	City Context	Intervention(s)	Study Design	Key Quantitative Finding
Carvalho & El-Geneidy, 2025	Montréal, Canada	High-income, large	New BRT corridor	Empirical	BRT cut average trip time by ≈4 minutes
Tang, Lin, Fan, Yu & Lu, 2022	Beijing, China	Middle-income, large	Epidemic spread on road network under two mechanisms	Simulation	Trajectory-based spread produces worse resilience than sporadic..

			(sporadic vs. trajectory)		
Qin, Mei, & Xiao, 2021	Beijing, China	High-income, large.	Traffic flow network built from taxi GPS to identify congestion areas	Empirical	817,462 morning-peak taxi trajectories inside the Fifth Ring Road confirm the network's congestion hot-spot detection
Wang, Sun, Hu, & Boukerche, 2023	England, UK	High-income, large.	Hybrid traffic-flow prediction fusing historical data with road-network features	Experimental	The model demonstrated an excellent fit with a low prediction error, and the equal-weighting scheme yielded the best overall performance.
Bari et al., 2022	Surat, India	Middle-income, large.	Congestion mitigation, measures in mixed traffic	Simulation	Simulation identified optimized signal timing as most effective for reducing delays in mixed traffic.
OECD/ITF, 2018	Lisbon, Portugal	High-income, medium.	Integrated mobility pricing & public transport.	Simulation	22% reduction in VKT; 15% drop in emissions.

3.2 Network Topology and Design

Early work comparing street forms showed why grid-like networks typically yield higher accessibility and more routing options, whereas hierarchical layouts concentrate flows onto arterials and are prone to bottlenecks (Sevtsuk, 2014; Tsigdinos, Nikitas, & Bakogiannis, 2024). This literature evolved into formal, comparable measures of connectivity, centrality, circuity, and intersection composition, enabling precise quantification of accessibility–flow trade-offs across cities. By the late 2010s, city-scale extraction of topology from OpenStreetMap standardized cross-city benchmarking of network orientation, node degree, four-way intersection share, and related metrics linked to redundancy and potential resilience (Boeing, 2017; Boeing, 2019).

Since 2020, resilience under disruption and climate risk has moved to the foreground. New frameworks fuse topological robustness with spatial exposure (for example, flood or heat risk) to identify vulnerable subnetworks and prioritize interventions. Complementary studies assess accessibility degradation under link removals and shock scenarios and propose design responses that harden critical connectors while preserving overall redundancy (Serdar et al., 2022; Azargoshasbi et al., 2025). This shift reframes “good topology” as not only efficient under recurrent demand, but also robust to non-recurrent shocks and climate stressors.

3.3 Smart Traffic Management

From the early 2000s to the 2010s, field deployments demonstrated the efficacy of adaptive signal control (SCOOT and SCATS) and transit signal priority (TSP), resulting in consistent corridor-level reductions in delay and improved reliability compared to fixed-time or actuated coordination (Radin et al., 2018; National Academies of Sciences, Engineering, and Medicine [NASEM], 2020). Practice syntheses and corridor evaluations reported double-digit percentage improvements in travel time and delay under real-world conditions, while documenting manageable impacts on cross-street operations when designs were calibrated carefully. These results provided the operational baseline against which newer data-driven approaches are judged.

In the late 2010s and the 2020s, probe-vehicle and connected-vehicle data enabled learning-based control. Reinforcement-learning signal control has progressed from single-junction prototypes to multi-agent corridor and network coordination, with recent reviews consolidating best practices and highlighting deployment gaps, including safety constraints, simulation-to-field transfer, and benchmarking (Noaeen et al., 2022; Mei et al., 2023). In parallel, CAV-aware strategies such as platooning and dynamic lane management, including reversible or flexible tidal lanes, emerged as complementary levers to increase capacity and stabilize flows, supported by microsimulation and early operational studies (Qin et al., 2024; Zhang et al., 2024).

3.4 Multimodal Integration

During the 2000s, bus rapid transit (BRT) systems demonstrated that surface transit can deliver rapid-transit-like performance when supported by dedicated right-of-way, off-board fare collection, high-quality stations, and frequent service. The technical playbook, which prioritizes signals, median alignment, and robust operations management, has produced repeatable travel-time and reliability gains across diverse urban contexts, serving as a template for corridor redesign (ITDP, 2017; ITDP, 2024).

Throughout the 2010s and into the 2020s, cities expanded protected cycling networks and aligned pricing, bus priority, and street reallocation to increase person throughput and safety (Pucher et al., 2010; Buehler & Pucher, 2011). Post-pandemic initiatives expanded low-emission and low-traffic zones while integrating micromobility. Multiple evaluations now report measurable pollutant reductions, as well as reliability and health benefits, when such policies are paired with strong transit supply. The policy and design environment for small-wheeled devices has also become more standardized (Shi, 2024; ITF, 2022).

4. DISCUSSION

This synthesis of evidence moves beyond a simple catalog of interventions to reveal the deeper, often interdependent, forces that shape the performance of urban road networks. What emerges is a compelling picture of synergy, conflict, and context. Our discussion is organized around the critical themes that surfaced from the review: the interplay between design, control, and mode; the disruptive influence of new technologies; the vital role of governance; and the inherent limitations of the current body of evidence.

4.1 The Integrated Framework: A Synergy of Design, Control, and Mode

A central finding is that physical design, technological control, and modal allocation are not independent variables but deeply interconnected. An ATCS will yield far greater returns on a well-connected grid network than on a brittle, hierarchical one because the grid's redundancy provides the flexibility that the control system can exploit. This synergy creates a virtuous cycle: a well-designed network makes smart controls more effective, and effective controls, in turn, make the network more efficient for all users, including those using public transportation. This enhanced efficiency can, in turn, make modal shifts away from private cars more attractive, further reducing overall congestion.

This highlights a systemic weakness in urban planning: the frequent separation of network designers, traffic operations engineers, and public transportation planners into professional silos. These divisions are often institutionalized through separate funding streams, distinct departmental goals, and specialized professional training, creating barriers to the kind of integrated approach this review finds is most effective. The proposed integrated framework (Table 2) is therefore not just an analytical tool but a call for more collaborative planning processes where infrastructure decisions are made in concert with operational and modal strategies. Such an approach is fundamental to achieving broader urban goals, from the "complete streets" concept, which serves all users, to the "15-minute city" model, which prioritizes accessibility over automobility.

Table 2. An integrated framework of network interventions and their interdependencies

Intervention Domain	Interaction with Physical Topology	Interaction with Operational Control	Interaction with Modal Allocation
Physical Topology	Foundational grid networks enhance resilience; hierarchical networks create	A connected topology provides routing alternatives that ATCS can leverage. A	Street design (e.g., width) enables or constrains the reallocation of space for bus lanes or cycle tracks.

	bottlenecks.	disconnected topology limits the effectiveness of smart control.	
Operational Control	Control systems, such as ATCS, optimize flow on the existing physical network.	Synergistic ATCS and ramp metering are core control strategies.	Transit Signal Priority (TSP) is a control strategy that directly supports a specific mode.
Modal Allocation	Reallocating a lane for a BRT system is a physical change to the network topology.	This reallocation changes traffic dynamics, requiring signal retiming and new control strategies for the remaining lanes.	Prioritizing one mode (e.g., buses) often comes at the expense of another (e.g., private cars).
Demand Management	Congestion pricing zones are defined by physical street boundaries.	Pricing levels can be adjusted dynamically in response to real-time traffic data from control systems.	The goal of pricing is to influence modal choice, shifting travellers to more space-efficient modes like public transport.

4.2 Emerging Paradigms: The Conflict Between Centralized and Decentralized Control

The rise of ubiquitous navigation applications represents a paradigm shift from top-down, planner-led optimization to a bottom-up, decentralized model driven by individual users. This creates a critical and growing conflict. For decades, urban planning has relied on hierarchical networks to channel traffic onto major arterials, a form of static, centralized control embedded in physical design to protect residential streets. Navigation apps, however, are agnostic to a street's intended function; their algorithms seek only to minimize individual travel time, routing users through any available path. This rat-running has tangible consequences, degrading the quality of life in residential areas through increased traffic, noise, and safety risks, particularly for children and pedestrians. It imposes wear and tear on local streets not designed for high traffic volumes.

This tension highlights a fundamental challenge for contemporary urban governance. Planners are exploring potential mitigation strategies, such as using geofencing to discourage routing through sensitive areas or implementing digital curb management systems that dynamically price or restrict access. However, these solutions themselves raise complex questions about data privacy, corporate responsibility, and regulatory authority. Furthermore, the equity implications are significant. The benefits of this decentralized optimization primarily accrue to tech-savvy drivers, while the negative externalities are often borne by residents of neighbourhoods used as shortcuts, who may have less political power to advocate for traffic calming or other protective measures. Effectively managing this conflict requires a new kind of digital age planning that is as attuned to algorithmic behaviour as it is to traffic engineering.

4.3 Case studies (Translating evidence into practice)

This section examines three city cases (Singapore, Curitiba, and Amsterdam) that translate the review's synthesized trends into practice.These cases operationalize the trends identified in Section 3. Singapore combines sustained demand management with high-capacity public transport, reflecting the multimodal integration logic. Curitiba's BRT and corridor design embody the surface-metro approach documented in the 2000s and refined in the 2010s. Amsterdam's long-term shift towards protected cycling, along with safety guidance for small-wheeled devices, anticipates the development of micromobility standards. Across all three contexts, governance capacity and policy continuity are the enabling factors that convert the technical potential documented in the previous section into durable, measured outcomes.

4.3.1 Singapore (Pricing integrated with high-capacity transit)

Singapore's strategy combines electronic road pricing with an extensive metro and bus network. The pricing instruments regulate peak-period car access, while frequent and reliable public transport provides a viable alternative for most trips. Land-use planning reinforces this bundle by concentrating growth along transit-served corridors. Over multiple decades, authorities have calibrated charge levels, spatial coverage, and public transport services to maintain stable person-throughput while moderating private vehicle demand. Reported outcomes include sustained corridor reliability, predictable travel times, and environmental gains consistent with low-emission zone practices. The pattern aligns with earlier discussions that access management, paired with strong transit supply, can improve system performance without requiring continuous roadway expansion.

4.3.2 Curitiba (Surface-metro logic through BRT corridor design)

Curitiba's network is organized around trunk-and-feeder bus rapid transit corridors with median stations, off-board fare collection, and high service frequencies. The design emulates rapid-transit performance on surface streets by reallocating space and prioritizing buses at intersections. Corridor treatments include median running, platform-level boarding, and operations management that reduces dwell time and irregularity. Evaluations report consistent travel-time savings and improved reliability relative to mixed-traffic operations. The approach reflects the BRT playbook, consolidated in the 2000s and 2010s, with an emphasis on corridor-level person-throughput, as described in Section 3.4. Recent updates focus on station design, network integration, and data-informed headway management, aligning with the smart management trend.

4.3.3 Amsterdam (Protected cycling networks and safety-first standards)

Amsterdam has pursued a long-term strategy to expand protected cycling networks, implement traffic calming measures on local streets, and integrate micromobility with public transportation. The city emphasizes protected infrastructure, safe intersection design, and clear rules for small-wheeled devices. Network build-out prioritizes continuous and comfortable routes and intersection treatments that reduce conflict points. Reported outcomes include higher cycling mode share, improved safety, and reliable local accessibility. The approach aligns with the 2020s micromobility guidance, which treats infrastructure protection and device-specific standards as prerequisites for safe growth in non-car modes.

Table 3. Case studies and thematic alignment

Case city	Intervention focus	Time frame	Key outcomes	Thematic alignment
Singapore	Congestion pricing integrated with high-frequency metro and bus networks	1990s–2020s	Managed congestion with stable person-throughput and reliability	Pricing with high-capacity transit; continuity with low-emission zone (LEZ) and ultra low emission zone (ULEZ) logic
Curitiba	BRT trunk-and-feeder network, median stations, off-board fare collection	2000s–2020s	Corridor travel-time and reliability improvements	Surface-metro BRT corridor design; operations and headway management
Amsterdam	Protected cycling network, traffic calming, street reallocation	2010s–2020s	Safety and mode-share gains; improved local access	Protected cycling network and micromobility safety standards

4.4 Limitations of the Evidence and this Review

A critical look at the evidence base reveals important limitations. There is a clear preponderance of simulation-based studies. While valuable for isolating variables, they may not fully capture the complex behavioural responses of real-world road users. Furthermore, there is a notable scarcity of high-quality empirical studies from cities in the Global South, where challenges of rapid urbanization, informal transport systems, and resource constraints differ significantly. This geographical bias limits the global applicability of many findings and overlooks potentially innovative, context-specific solutions emerging from these regions.

This review also finds that the literature has historically been dominated by a narrow focus on traffic flow metrics like speed and delay. Such measures fail to capture the ultimate purpose of a transportation system, which is to provide access to opportunities. A more holistic evaluation framework is needed, prioritizing metrics like accessibility, which connects transport to jobs, healthcare, and education; equity, which examines who benefits and who is burdened by a transport system; and reliability, which affects the stress and predictability of daily life. Finally, this review is constrained by its reliance on published, English-language literature and may be subject to a degree of publication bias. These limitations should temper the direct application of these findings and highlight the urgent need for future research.

5. CONCLUSION

The challenge of urban congestion is not a simple problem of capacity but a complex issue of design, technology, and human behaviour. This systematic review confirms that the path to creating efficient, sustainable, and liveable cities does not lie in the costly and often counterproductive expansion of road infrastructure. Instead, the evidence suggests a multifaceted strategy based on the intelligent optimization of existing networks. The most successful approaches do not seek a single panacea, but rather weave together sophisticated network topologies, advanced technological management, and a firm commitment to multimodal transportation. This requires a fundamental shift in perspective, from moving cars to moving people.

The core contribution of this work is the emphasis on integration. The interdependence between physical design, operational control, and the allocation of road space demands that we dismantle the professional silos that have long separated transport planners from traffic engineers and land-use experts. A holistic, collaborative approach is no longer a recommendation but a requirement for meaningful progress. This review also highlights a growing tension between the centralized logic of traditional urban planning and the decentralized, real-time optimization enabled by modern technology. Navigating this tension is a defining challenge for the next generation of urban governance, requiring tools and mindsets that are as much about managing data and algorithms as they are about managing concrete and asphalt.

In synthesizing evidence from 2000 to 2024, the analysis brings recency to the forefront and organizes developments into a clear narrative over time. Early foundations laid the groundwork for methodological consolidation in the 2010s and for implementation-focused evaluations in the 2020s. The case studies of Singapore, Curitiba, and Amsterdam illustrate how the reviewed trends are translated into practice, including pricing aligned with high-capacity transit, surface-metro bus rapid transit corridor design, and protected cycling supported by device-specific safety standards. Across these settings, durable gains arise when design choices, adaptive management, and space reallocation are implemented as a coherent package rather than as isolated projects, and when institutions have the capacity to monitor outcomes and iteratively adjust pricing, service levels, and designs.

Looking ahead, evaluation priorities should shift from simulation-heavy studies toward rigorous field assessments that use appropriate counterfactuals and report a broader set of outcomes, including accessibility, equity, reliability, and emissions. Cities adopting data-driven optimization must also address local externalities, such as unwanted diversion onto minor streets, by pairing algorithmic routing and signal coordination with access management and neighborhood traffic calming. Finally, transferability depends on aligning policy bundles with local demand patterns, right-of-way constraints, and governance capacity. The thematic alignment across the cases provides a practical guide for adaptation, linking observed outcomes to the underlying mechanisms that produced them.

Ultimately, an optimized, multimodal transport system is not only more efficient but also more equitable, more conducive to public health, and essential for climate mitigation. By embracing an integrated, evidence-based, and politically informed approach, cities can transform urban road networks from sources of delay and emissions into arteries of thriving, sustainable, and equitable communities.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript were used during the writing and editing of this manuscript.

COMPETING INTERESTS

Author has declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ABBREVIATIONS

ITS: Intelligent Transportation Systems

ATCS: Adaptive Traffic Control Systems
TOD: Transit-Oriented Development

ATCS: Adaptive Traffic Control Systems
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

SCATS: Sydney Coordinated Adaptive Traffic System
TRID: Transport Research International Documentation Database

ATCS: Adaptive Traffic Control Systems
PICO: Population, Interventions, Comparison, and Outcomes
SCOOT: Split Cycle and Offset Optimisation Technique
SP: Signal Priority
NMT: Non-Motorized Transport
LEZ: Low Emission Zone
ULEZ: Ultra Low Emission Zone