

Systematic Review

A Systems Perspective on Drive-Through Trip Generation in Transportation Planning

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Abstract

Drive-through establishments are becoming increasingly prominent in urban transport systems; however, their impacts on traffic generation, spatial form, and sustainability remain insufficiently understood. Conventional trip generation manuals often rely on static predictors, such as gross floor area, which can misrepresent demand in high-turnover, convenience-driven contexts and fail to capture operational, behavioral, and environmental effects. This knowledge gap underscores the need for an integrated framework that supports both effective planning and congestion mitigation, particularly in cities experiencing rapid motorization and shifting mobility behaviors. This study investigated the evolving dynamics in trip generation associated with drive-through services and their influence on urban development patterns. A mixed-methods approach was employed, combining a systematic literature review, meta-analysis of queue data, cross-comparison of trip generation rates from international and Asian datasets, and case-based scenario modeling. The results revealed that drive-throughs intensify high-frequency, impulse-driven vehicle trips, thereby causing congestion, reducing pedestrian accessibility, and reinforcing auto-centric land use configurations, while also enhancing consumer convenience and commercial efficiency. This study contributes to the literature by synthesizing inconsistencies in regional datasets; introducing a systems-based framework that integrates structural, behavioral, and environmental determinants with road network topology; and outlining policy applications that align trip generation with zoning, design standards, and sustainable infrastructure planning.

Keywords: drive-through facilities; trip generation; urban form; sustainable transport planning; auto-centric development; congestion; land use intensity; policy integration



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1. Introduction

Trip generation rates serve as a foundational component of travel demand forecasting and traffic impact assessment, marking the first step in the traditional four-stage transportation planning model. They estimate the number of trips that originate from and are directed to specific land uses, providing critical input for subsequent stages, such as trip distribution, mode choice, and route assignment [1,2]. As urban environments continue to evolve and new commercial formats emerge, particularly those involving drive-through

services, there is a growing need to reexamine the assumptions and methodologies that underpin conventional trip generation models.

Drive-through establishments, particularly in the food and beverage sector, have reshaped localized traffic demand by introducing land uses that generate high vehicular turnover and are driven by convenience-oriented travel behavior. While these facilities offer benefits, such as shorter transaction times, increased operational revenue, and improved accessibility for individuals with physical disabilities or mobility constraints [3], they also present significant urban planning challenges. These include extended vehicle queues, increased fuel consumption and emissions, traffic spillback onto adjacent roads, and the entrenchment of car-dependent mobility patterns [4,5].

The emergence of drive-through services reflects a broader transformation towards automobile-oriented urban development. Their spatial configuration often requires wide-access driveways, large stacking areas, and physical separation from pedestrian-friendly zones, which contribute to the fragmentation of the urban landscape and a diminished focus on multimodal accessibility. Such layouts can obstruct pedestrian movement, weaken public transport linkages, and discourage non-motorized travel options, thereby undermining efforts to create compact and connected urban environments [6]. These challenges are particularly pronounced in high-density urban cores and peri-urban areas undergoing rapid transformation, where land use efficiency and integrated mobility planning are essential.

In North America, empirical studies have highlighted a strong consumer preference for drive-through services. For example, 57 per cent of customers opt for drive-through lanes rather than entering an establishment [7], and approximately 60 per cent of fast-food restaurant revenue is generated through these lanes. Furthermore, outlets with drive-through facilities typically earn 40 per cent more revenue than those without [5,8]. The commercial success of this model has accelerated its global adoption, particularly in developing regions, where the perceived convenience and profitability of drive-throughs have made them an increasingly common feature of retail and service landscapes [8].

Despite their widespread use, most current trip generation manuals, including the widely referenced Institute of Transportation Engineers (ITE) Trip Generation Manual and its regional counterparts, remain based on generalized land use categories that do not reflect the operational and spatial complexity of drive-through services [9–11]. These manuals often overlook critical parameters, such as queuing patterns, peak-hour stacking configurations, and the dual role of drive-throughs as both generators of traffic and catalysts for spatial restructuring. Consequently, they risk producing inaccurate forecasts and policy blind spots, particularly in mixed-use or rapidly urbanizing settings.

Historically, trip generation modeling has evolved from the aggregated land use-based predictors introduced in early ITE manuals in the mid-20th century [12]. Subsequent iterations incorporated pass-by and diverted trip adjustments [13,14], but continued to rely on average rates with limited contextual sensitivity. In the United Kingdom, TRICS advanced the field by adopting empirical site-based surveys and disaggregating trip rates by land use category and time period [11]. Malaysia's MTGM, and later MyTripGen, attempted to localize these methods [10], although recent studies have highlighted pandemic-era biases and limited adjustments to multimodal behavior [15,16]. More recent approaches in developing contexts, such as Qatar and Jordan [17,18], emphasize the need for local calibration, whereas studies in unplanned urban areas [19] suggest the importance of household socio-demographics. Household-level studies also show that motorcycle use, gender, and income patterns strongly shape trip generation, particularly in Southeast Asia [20]. Concurrently, critiques of conventional manuals have long noted that they underestimate externalities and oversimplify urban dynamics. For example, Shoup (2003) highlighted distortions in trip generation modeling's treatment of parking demand [21], while Clifton,

Currans, and Muhs (2015) demonstrated the shortcomings of applying ITE rates in urban contexts without multimodal adjustments [22]. Similarly, Van Wee (2011) underscored the need to consider accessibility and land use interactions when evaluating travel behavior [23]. Despite these advances, existing manuals remain predominantly site-centric and continue to overlook systemic interactions such as queue dynamics, temporal variability in demand, and broader environmental consequences [3,5,24,25]. This reinforces the need for an integrated, system-oriented framework. The historical trajectory from the early ITE manuals to more localized adaptations such as TRICS in the United Kingdom and MyTripGen in Malaysia illustrates a gradual refinement of trip generation methodologies. Yet, even with these developments, significant limitations persist. Current approaches often exhibit insufficient sensitivity to multimodal travel behavior, inadequate accommodation of contextual variability, and limited capacity to capture the complex interdependencies that characterize urban mobility systems, as consistently highlighted in the literature.

To address these limitations, this study undertakes a comprehensive, mixed-method review that integrates thematic and content analysis, a meta-analysis of empirical queue data, and a comparative evaluation of trip generation practices across North America, Asia, and Europe [26,27]. Beyond synthesizing prior findings, this review advances the field by introducing a conceptual framework that positions drive-through facilities not only as generators of transportation demand, but also as agents of urban transformation. By foregrounding the bidirectional relationship between land use and trip generation, this study provides practical insights for urban planners, transportation professionals, and policymakers seeking to manage the expansion of drive-through services in ways that are both sustainable and context-sensitive.

Recent advances in transportation optimization underscore the value of adopting a systems perspective. Research on railway heavy-haul operations has demonstrated that carbon emissions reduction and transport efficiency can be addressed simultaneously through multi-objective optimization models [28]. In a similar vein, many-objective optimization frameworks in multi-mode public transportation have shown how trade-offs between service quality, efficiency, and sustainability can be systematically captured [29]. Together, these studies illustrate a broader shift in transportation planning toward integrated frameworks that are capable of evaluating multiple, and often competing, objectives. Applying this logic to drive-through trip generation highlights the need to move beyond narrow, single-metric approaches. Operational efficiency, measured through indicators such as queue length, stacking capacity, and throughput, must be considered in conjunction with environmental performance, including idling emissions and fuel consumption, as well as broader urban livability outcomes such as pedestrian permeability and congestion spillback.

Despite the increasing recognition of these multidimensional challenges, research on drive-through developments has remained fragmented, with studies tending to isolate site-level attributes, behavioral patterns, or environmental outcomes. To date, no study has systematically synthesized these strands of evidence across regions or advanced an integrated framework that unites structural determinants, user behavior, and environmental impacts within a coherent systems perspective. This review seeks to fill that gap by combining evidence synthesis with empirical meta-analysis, cross-regional comparison, and the development of a holistic trip generation framework intended to inform both transportation planning and policy. Drawing on insights from multi-objective optimization in road and rail systems [30,31], the framework developed here explicitly balances operational performance, behavioral dynamics, and environmental sustainability.

2. Methodology

This study employed a multimethod framework to critically examine the relationship between drive-through services, trip generation, and their impact on urban land use. Beyond summarizing prior work, this methodology introduced new integrative comparisons and synthesized empirical data to support practical applications in site planning and urban policy. This approach included a systematic literature review and a combination of qualitative and quantitative analysis techniques, namely thematic analysis, content analysis, meta-analysis, comparative analysis, and case-based synthesis. These tools were selected to not only uncover trends in trip generation behavior, but also to explore their spatial consequences within urban systems.

2.1. Systematic Literature Review

A systematic literature review was conducted to identify empirical and conceptual studies published between 1990 and 2024, in accordance with PRISMA guidelines (Supplementary Material). Figure 1 presents the PRISMA 2020 flow diagram for new systematic reviews, which includes searches for databases, registers, and other sources. Searches were carried out using Scopus, Web of Science, ScienceDirect, Google Scholar, and relevant transport data repositories, such as the TRB e-Newsletter archive.

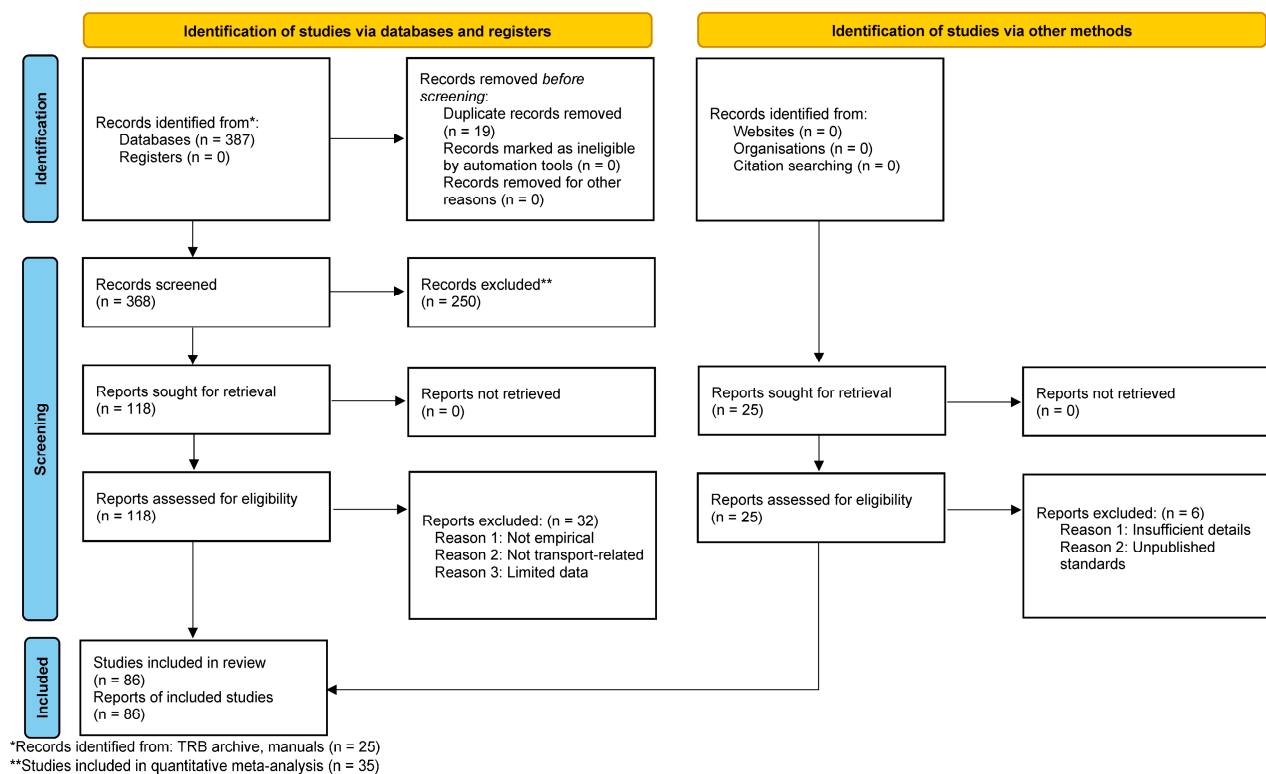


Figure 1. PRISMA 2020 flow diagram.

Full electronic search strategies were developed for each database using combinations of Boolean operators, truncations, and wildcards to maximize the retrieval of relevant studies. For example, the Scopus search string applied was “trip generation” OR “traffic generation” AND “drive-through” OR “drive-thru” AND “urban form” OR “land use” OR “queue length” OR “traffic impact,” which reflects the core concepts of the review. To ensure consistency, filters were applied to limit the results to English-language publications published between January 1990 and July 2024. The final round of database searches was completed on 12 July 2024. For transparency and reproducibility, the complete set of search

strings, applied filters, retrieval counts, and database sources are provided in Appendix A, Database Search Strategies.

A total of 74 peer-reviewed sources and 12 technical manuals were selected. These include foundational works [3,6], North American standards [9], Malaysian frameworks [10], and the most recent UK-based TRICS Good Practice Guide [11], which advocates context-specific data modeling in transport assessments involving drive-throughs. This review process not only aggregated evidence, but also exposed methodological discrepancies between regions and highlighted the need for data-driven customization in trip estimation models. Additional methodological and case study references were included to strengthen the discussion of policy and governance implications. These sources were not part of the systematic search process, and, therefore, were not reflected in the PRISMA flow diagram.

2.1.1. Study Selection Process

The study selection process followed the PRISMA 2020 guidance. Two reviewers (L.H.T. and C.W.Y.) independently screened all retrieved titles and abstracts based on predefined eligibility criteria. Potentially relevant articles were retrieved in full text and evaluated for inclusion. Disagreements were resolved through discussion, and when consensus could not be reached, a third reviewer (R.Z.) was consulted. Studies were excluded if they were not written in English, did not report empirical data, or were conference abstracts without complete documentation. The PRISMA flow diagram shown in Figure 1 summarizes the selection process. A PRISMA flow diagram (Figure 1) summarizes the selection process, and a list of excluded full-text studies with reasons is provided in Appendix B.

2.1.2. Data Collection Process

Data extraction was conducted using a standardized template that captured the study design, sample size, geographic location, methodological approach, and key variables such as gross floor area, number of service windows, queue length, parking supply, and pass-by or diverted trips. The extraction was first performed by one reviewer (L.H.T.) and independently verified by a second reviewer (C.W.Y.). Any discrepancies were reconciled through a discussion to reach consensus. This dual-check procedure minimizes transcription errors and enhances the reliability of the extracted dataset.

2.2. Thematic Analysis

Thematic analysis was used to extract qualitative insights into the interaction between drive-through-generated traffic and the surrounding urban area. Key themes include traffic congestion, land use fragmentation, car dependency, queuing externalities, and policy limitations in managing spatial intensity. A number of studies, such as that of Kazaura and Burra [4], demonstrated that congestion linked to drive-throughs can extend beyond the site's boundaries and affect arterial road performance; conversely, Cordera et al. [26] argued that spatial monocultures reduce multimodal accessibility and distort the logic of mixed-use urban planning. This method allowed the study to categorize emerging concerns, showing that trip generation does not only result from land use, but also actively shapes it, particularly in contexts where high-frequency, auto-centric services discourage walkability and transit integration.

2.3. Content Analysis

Content analysis was applied to quantify operational variables across international case studies such as queue length, stacking space, number of access points, and gross floor area (GFA). The empirical findings from Mike et al. [27], the Colorado–Wyoming ITE Technical Committee [32], and Bitzios Consulting [33] were reanalyzed and coded to examine how these variables correspond to peak-hour trip rates. For example, recent

observations in the UK and Australia show that inadequate stacking capacity leads to queue spillback onto adjacent roads and increases delays at signalized intersections, and these issues are under-represented in traditional trip manuals. These findings support the need for dynamic queue models and inform spatial configuration decisions during site planning.

2.4. Meta-Analysis

A structured meta-analysis was undertaken to synthesize trip generation rates across multiple jurisdictions. Data were compiled from the ITE Trip Generation Manual [9], Malaysia's Highway Planning Unit manual [10], and case studies by Ahmed et al. [15] and Mohd Shafie et al. [16]. Effect sizes were calculated for key variables, including gross floor area and the number of service windows. Exploratory subgroup contrasts across fast-food, coffee and hybrid drive-through formats were considered to guide interpretation; however, no pooled subgroup meta-analyses were performed because of heterogeneity. A central finding is that reported trip rates vary markedly by context: the United States reports 33.03 trips per 1000 square feet of gross floor area, South Africa reports 20 to 25 trips per 1000 square feet of gross floor area, whereas Malaysian estimates peak at 44.01 trips per parking space [15]. These differences reinforce the need for locally calibrated trip generation tools, particularly in mixed-use corridors and rapidly urbanizing areas.

While the meta-analysis provided valuable cross-contextual insights, the risk of bias across the included studies was not formally assessed using structured tools, such as the ROBIS or Cochrane criteria. Instead, heterogeneity was narratively addressed by comparing methodological consistency, variable definitions, and sample representativeness. The diversity of study designs, geographic contexts, and performance metrics limits the feasibility of sensitivity testing or statistical heterogeneity measures. Accordingly, the synthesis focused on identifying convergent patterns and highlighting divergences that warrant further empirical validation. Missing or incomplete data from the included studies were handled narratively. When key variables, such as gross floor area, queue length, or proportions of pass-by trips, were not explicitly reported, studies were retained in the synthesis, but flagged for limited comparability. Proxy indicators, including parking supply and number of service windows, are sometimes used as contextual substitutes. Statistical imputation was not performed because of the descriptive and heterogeneous nature of the evidence. Sensitivity analyses were not conducted because the diversity of study designs, variable definitions, and outcome measures prevented meaningful re-estimations. Instead, robustness was inferred through the cross-validation of findings across multiple jurisdictions and data sources.

2.5. Comparative Analysis

This study also introduces a comparative evaluation of three major trip-generation frameworks: the United States-based ITE manual [9], Malaysia's MTGM [10], and the UK's TRICS system [11]. The analysis shows that the ITE's reliance on aggregated average rates and reduction factors, such as those for pass-by traffic, may not be applicable in urban centers with complex circulation patterns. In contrast, the TRICS system employs empirical, site-based sampling that allows disaggregation by time of day, land use heterogeneity, and access configuration. As highlighted in the 2023 TRICS guide [11], this model encourages data transparency and contextual relevance, which is particularly useful for drive-throughs where queue dynamics and turnover rates are highly sensitive to the surrounding land use intensity and traffic conditions. Although comprehensive, Malaysia's MTGM lacks pass-by trip deductions, and often overestimates traffic for co-located uses.

2.6. Case-Based Synthesis

A case-based synthesis was used to extract lessons from high-resolution traffic studies of specific drive-through operations. Examples include Starbucks and McDonald's drive-through queue observations in California [34], petrol station hybrid use in Malaysia [16], and urban coffee shops in Sydney [33]. These cases were mapped against their local zoning and access road typologies to evaluate land use compatibility. The results suggest that a poor alignment between trip demand and site layout can intensify curbside congestion and constrain land productivity. For instance, intersections near single-lane entry drive-through sites often experience vehicular spillover, whereas multi-entry designs with pre-ordering lanes, as observed in Australia and the UK, demonstrate better traffic distribution and shorter queue times. These micro-level insights further substantiate the macro-level need for policy reforms and performance-based design standards.

2.7. Risk of Bias and Certainty Assessment

Reporting bias across studies was not formally assessed through funnel plots or statistical tests because of the limited number and heterogeneity of the included studies. Nevertheless, efforts were made to mitigate bias by searching multiple databases, reviewing gray literature, such as technical manuals and government reports, and cross-checking reference lists. This broad search strategy reduces the likelihood of selective publication or reporting bias. Formal risk-of-bias assessments and evidence-certainty grading frameworks, such as GRADE or ROBIS, were not applied because of the methodological diversity of the included databases. Instead, robustness was strengthened through triangulation, whereby the findings were cross-verified across multiple data sources, including peer-reviewed journal articles, technical manuals, and government reports. This approach ensured that individual study limitations were balanced by broader patterns of evidence. As a result, the certainty of the findings is interpreted with caution, with greater emphasis placed on the consistency of results across contexts and their transferability to similar urban and operational environments, rather than on a strict numerical grading of quality.

Future systematic reviews of trip generation and drive-through impacts would benefit from incorporating structured bias assessment tools and certainty frameworks, which would allow for a more explicit grading of evidence strength and enhance the comparability across international contexts. This systematic review was not prospectively registered, and no formal protocols were prepared. The absence of registration is acknowledged as a limitation; however, the review closely adhered to PRISMA 2020 standards to ensure methodological transparency and reproducibility. Reporting bias was not formally assessed using quantitative diagnostics, such as funnel plots or Egger's test, given the absence of a statistical meta-analysis. However, potential sources of bias were considered narratively by reviewing the balance between peer-reviewed sources, technical manuals, and government reports, as well as the relative scarcity of unpublished or null-result studies. However, the possibility of selective reporting in the literature remains a limitation.

The methodology followed a four-tiered analytical sequence, which directly corresponds to the findings presented in Section 3. First, a systematic literature review (Section 3.1) provided the evidence base. Second, thematic and content analyses (Section 3.2) identified recurring structural, behavioral, and environmental factors. Third, a meta-analysis (Section 3.3) quantified the effect sizes of variables such as GFA, seating capacity, and parking. Fourth, a comparative evaluation (Section 3.4, Table 1) contrasted the findings across ITE, TRICS, and MyTripGen. This layered methodology ensures that each analytical stage directly informs the results, thereby maintaining consistency between the methodological design and empirical findings.

Table 1. Comparison of conventional trip generation manuals and the proposed systems-based framework.

Framework/Manual	Key Variables Considered	Limitations	Added Value in Proposed Systems-Based Framework
ITE (USA) [9,12]	Gross floor area (GFA), dwelling units, parking supply, limited pass-by adjustment	Relies on average rates; limited disaggregation; weak in mixed-use or high-density settings	Expands beyond GFA to integrate seating capacity [15,16], service windows [27], and stacking space [35]
TRICS (UK) [11]	Empirical site surveys; disaggregation by land use, time, and context	Lacks behavioral and environmental integration; not widely transferable outside of the UK/EU	Includes cross-contextual behavioral insights (household demographics [20], consumer preferences [8])
MyTripGen/MTGM (Malaysia) [10]	GFA, parking, employees; locally calibrated	No pass-by trip adjustments; pandemic-era data may bias estimates	Incorporates cross-validation with international data [18,36] and mitigates pandemic-related anomalies
Proposed Systems-Based Framework	Structural determinants (GFA, seating, parking, access, network topology [30,31]); behavioral and socioeconomic drivers (gender, household, consumer loyalty [8,20]); environmental and operational impacts (idling emissions, queue spillback [5,24])	Complexity requires more data and modeling capacity	Provides integrated, dynamic outputs (trip rates, congestion indices, emissions profiles) that improve transferability, planning precision, and policy relevance

3. Results

Traditional trip generation models, particularly those based on Institute of Transportation Engineers (ITE) manuals, typically emphasize the physical characteristics of land use, such as gross floor area (GFA) and the number of dwelling units. However, the dynamics of contemporary urban development have become increasingly complex, especially in cases involving drive-through services, mixed-use development, and irregular or unplanned urban environments. These complexities require a more holistic and context-sensitive modeling approach. Based on the critical findings from empirical studies, this section introduces an integrated trip generation framework that incorporates three interrelated components: structural determinants, behavioral and socioeconomic drivers, and environmental and operational impacts.

Of the full-text studies screened, 28 were excluded for the following reasons: non-English language ($n = 7$), insufficient methodological detail ($n = 6$), absence of trip generation outcomes ($n = 10$), and duplicate reporting of the datasets ($n = 5$). A full list of excluded studies with reasons for their exclusion is provided in Appendix B. Considerable heterogeneity was observed across the included studies. This was evident in the differences in methodological approaches (manual traffic counts, simulation-based modeling, regression estimation); variable definitions, such as “new” versus “pass-by” trips; and contextual factors, such as urban corridors versus suburban sites, and developed versus developing economies. Although this variability constrained the direct comparability, it also provided valuable insights into the transferability of trip generation estimates across contexts. No statistical pooling or formal subgroup meta-analyses were conducted because the diversity of study designs limited the feasibility of meta-analytic methods. Therefore, the synthesis relied on structured narrative comparison to highlight common patterns and identify sources of divergence.

The UK’s TRICS database [11] and Malaysia’s MyTripGen [10] rely primarily on static aggregate predictors, such as gross floor area, dwelling units, and parking supply. Although these manuals are widely applied in practice, they do not systematically incorporate

behavioral dynamics, queuing characteristics, or environmental impact. In contrast, the system-based framework advanced in this study integrates a broader set of interrelated determinants, reflecting the multi-scalar nature of trip generation in contemporary urban contexts. Table 1 illustrates this distinction, highlighting the comparative scope of the variables.

This comparison highlights the novelty of the proposed framework. Whereas the ITE, TRICS, and MTGM manuals primarily rely on physical site attributes or empirically derived averages, the system-based framework integrates structural, behavioral, and environmental dimensions within a unified model. By explicitly linking micro-level site variables with macro-level road network topology [30,31], embedding socio-demographic [20] and environmental performance metrics [5,24], the framework advances beyond static rate-based manuals. It generates more nuanced outputs such as congestion indices and emission profiles, which provide actionable insights for planners and policymakers in diverse urban contexts.

3.1. Framework 1: Structural Determinants

This component establishes the foundational estimation of trip volumes based on observable site and land use characteristics. A wide range of studies have indicated that conventional predictors, such as gross floor area (GFA), may not adequately capture the complexity of certain land uses. For example, research by Mohd Shafie et al. [16] and Ahmed et al. [15] revealed that seating capacity is a more reliable predictor of trip rates for fast-food establishments than GFA or the number of fueling positions. Similarly, Datta et al. [37] and Al-Madadhah and Imam [17] highlighted the significance of variables such as parking availability, ease of site access, and number of employees in enhancing the predictive strength of trip generation models.

In the context of mixed-use developments, such as petrol stations combined with convenience stores and fast-food restaurants, trip generation patterns frequently diverge from the sum of the individual land use components. Datta et al. [37] noted that interactions among these land use components create compound trip behaviors that are not adequately captured by simply aggregating standard trip rates. Additionally, in rapidly developing or unplanned urban environments, Altaher et al. [19] found that household-level demographic variables, including population size, the number of school-aged children, and employment rates, are critical in generating accurate predictions across traffic analysis zones (TAZs).

Beyond localized site-level and demographic determinants, trip generation is also fundamentally influenced by the broader structure of urban road networks. Network topology, particularly the placement of intersections and interchange points, has long been recognized as a determinant of traffic flow, congestion levels, and the balance between private vehicles and public transport trips. Poorly located intersections can create structural bottlenecks that magnify delays, whereas strategically positioned nodes distribute flow more evenly and enhance resilience across the network. Recent advances in network optimization have provided critical insights into this issue. Akopov and Beklaryan [30] applied a multi-agent hybrid clustering-assisted genetic algorithm (MA-HCAGA) to the synthesis of reconfigurable multilayer road networks (RMRNs), showing that optimal configurations often involve elevating or tunneling key intersections, clustering interchange nodes into multilayer hubs, and distributing critical points to avoid dependence on a single bottleneck hub. Similarly, Xu et al. [31] addressed the global routing optimization problem and demonstrated that serial, batch, and iterative routing models can dynamically reroute traffic away from congested nodes towards underutilized alternatives. Together, these findings highlight that trip generation analysis, particularly for high-turnover land uses, such as drive-through facilities, cannot be disentangled from the systemic effects of network

topology, where the node placement critically determines how efficiently additional trips are absorbed into the system without undermining multimodal accessibility.

In this regard, structural determinants should not be limited to site-specific attributes, such as GFA, parking, and access configuration, but should also account for the macro-scale role of network topology in shaping traffic absorption capacity. This reinforces the need for models that bridge the micro-level features of drive-through establishments with the macro-level efficiency of road networks. To account for these complexities, the use of multivariable regression and Poisson count models is recommended. These statistical approaches allow for the integration of both localized factors and network-level determinants to estimate daily and peak-hour trip volumes with greater accuracy and contextual relevance. Table 2 summarizes the key findings associated with this structural determinants framework.

Table 2. Key findings of structural determinants for trip generation framework.

Variable Category	Variables	Key Findings (Source)
Land Use and Site Attributes	Gross floor area (GFA), number of pumps, restaurant seating	Seating was more predictive than GFA for fast-food trip generation [15,16].
Parking and Access Features	Number of parking spaces, entry/exit design	Parking availability affects trip volume, while access to signalized intersections impacts flow [17].
Service Configuration	Drive-through lane design, number of service windows	Multi-stop lanes increase queue length and emissions [5]; dual lanes increase throughput [27].
Mixed-Use Considerations	Integrated uses (petrol station with convenience store or quick service restaurant)	Trip generation in combined-use developments diverges from ITE standards [37].
Urban Context	Planned versus unplanned, road network connectivity	Unplanned cities require localized models using household and demographic data [19].
Road Network Topology	Placement of intersections and interchange points	Optimized node placement enhances throughput, balances flows, and improves multimodal accessibility; poor placement creates bottlenecks (Akopov & Beklaryan [30]; Xu et al. [31]).

3.2. Framework 2: Behavioral and Socioeconomic Drivers

Although structural models offer a foundational estimate of trip volumes, they often fail to capture the underlying behavioral and socioeconomic factors that influence individual travel decisions. A growing body of research has shown that trip-making behavior is shaped by variables such as gender, household role, education level, and income bracket. For example, Anggraini et al. [20] found that female road users, particularly stay-at-home spouses in middle-income households with lower formal education levels, exhibited higher trip frequencies for non-mandatory activities. These findings underscore the importance of incorporating demographic and lifestyle characteristics into trip generation models.

Building on this perspective, Prasetyo et al. [8] employed structural equation modeling to examine the influence of consumer perceptions on recurring trips to drive-through establishments. Their study revealed that menu design, order accuracy, and customer satisfaction are critical in shaping repurchase intentions, which in turn contribute to repeated travel behavior. In a related context, Cordera et al. [26] demonstrated that spatial accessibility to employment and services significantly increases trip attraction, particularly through the use of non-motorized and public transport modes. These studies highlight the need for models that reflect the complex interplay between individual preferences, sociodemographic characteristics, and urban accessibility.

To better account for these factors, modeling approaches, such as structural equation modeling and discrete choice models, are recommended. These methods provide a means

of capturing the nuanced and often indirect influences of behavior, household context, and the spatial environment on trip generation outcomes. Table 3 summarizes the key findings associated with this framework of behavioral and socioeconomic drivers.

Table 3. Key findings of behavioral and socioeconomic drivers for the trip generation framework.

Variable Category	Variables	Key Findings (Source)
Demographics	Gender, household type, income, education	Female household members and middle-income households show higher trip rates for non-mandatory trips [20].
Consumer Preferences	Menu design, convenience, loyalty, satisfaction	Structural equation modeling revealed repurchase intentions are driven by menu options and order accuracy [8].
Trip Purpose	Work vs. non-mandatory	Household composition (workers, students) influences trip generation in both residential and commercial models [18,36].
Accessibility Factors	Job and service accessibility, transit proximity	Higher accessibility reduces car trips but increases overall mobility [26].
Queue Sensitivity	Wait tolerance, service time	Queues of over five cars reduce efficiency and increase user cost [3]; behavior is adapted based on expected delays [27].

3.3. Framework 3: Environmental and Operational Impacts

In addition to estimating trip volumes, contemporary research emphasizes the importance of accounting for externalities in trip generation modeling. Studies have demonstrated that the design and operation of drive-through facilities can have significant environmental consequences. Hill et al. [5] reported that drive-through outlets with multiple service points, such as separate windows for ordering, payment, and pickup, produce notably higher vehicle emissions than those with a single-stop layout. Similarly, Baxter and Stafford [3] quantified the increase in fuel consumption associated with prolonged queuing, identifying a break-even threshold beyond which the time and fuel costs of using drive-throughs outweigh their convenience when compared with walk-in service options.

Expanding on these findings, Bruwer and Neethling [24] explored the operational trade-offs of drive-through development in developing countries. They noted that while drive-throughs can reduce the need for on-site parking and offer land use efficiency, they simultaneously reinforce car dependency and exacerbate greenhouse-gas emissions. Roberto et al. [7] further highlighted the public health dimension, observing that more than 57 per cent of fast-food patrons use drive-through lanes and are, therefore, less likely to encounter in-store nutritional labeling, which can influence food choices and dietary awareness.

To evaluate these broader impacts, trip generation studies should incorporate microsimulation tools and emissions modeling software, such as the Motor Vehicle Emission Simulator (MOVES). These tools provide a more comprehensive assessment of environmental performance and support evidence-based decision-making in sustainable urban planning and land use design. Table 4 summarizes the key findings associated with this framework of environmental and operational impacts.

Together, these three components constitute a novel system-based framework that extends trip generation analysis beyond the scope of conventional approaches. This framework uniquely integrates micro-level site determinants with macro-level network topology, behavioral drivers, and environmental impacts into a unified perspective on drive-through trip generation. By bridging these previously fragmented domains, the framework offers

both a conceptual and methodological contribution that advances current practices and provides a more comprehensive basis for transportation planning and policy.

Table 4. Key findings of environmental and operational impacts for trip generation framework.

Variable Category	Variables	Key Findings (Source)
Emissions and Idling	Number of stops, vehicle-specific power, idle time	Fewer stops mean lower emissions; peak queues significantly increase emissions output [5].
Land Use Efficiency	Parking demand, land footprint	Drive-throughs reduce land usage versus dine-in, but increase vehicle reliance [24].
Queue-Induced Congestion	Vehicle throughput, spatial queue design	Poor layout leads to congestion spillover into adjacent roads [27].

3.4. Framework Application Method

To operationalize the proposed system-based framework, this study outlines a step-wise approach that enables both researchers and practitioners to apply the model in empirical and policy contexts. A schematic representation of this process is provided in Table 5 to guide its practical application.

Table 5. Operationalization of the trip generation framework for drive-through facilities.

Step	Focus	Examples of Data/Tools	Outputs	Policy/Planning Application
Step 1	Input Data Collection	GFA, seating, parking, queue length, demographics, idling time	Comprehensive dataset	Establishes baseline inputs across structural, behavioral, and environmental dimensions
Step 2	Analytical Procedures	Regression/count models; behavioral models; microsimulation; MOVES5 [38]	Refined trip rates, congestion and emissions estimates	Captures dynamic and systemic effects of drive-through operations
Step 3	Output Indicators	Site-specific trip rates; congestion indices; emissions/fuel consumption	Performance benchmarks	Provides measurable indicators for site and system evaluation
Step 4	Policy and Planning Application	Zoning codes; design standards; sustainability metrics	Actionable policy and design guidance	Aligns trip generation with mobility, environmental, and urban development goals

Step 1: Input Data Collection

The first step requires the compilation of site-level, behavioral, and environmental data that represent the three dimensions of the framework. Structural determinants include variables such as the gross floor area (GFA), seating capacity, number of service windows, drive-through lane length, and parking provision. Behavioral drivers include household demographics, trip purpose, frequency of use, pass-by and diverted trips, and customer preferences. Environmental and operational data include queue length, idling duration, vehicle throughput, and emission estimates, which are generated by tools such as the Motor Vehicle Emission Simulator (MOVES) or microsimulation platforms.

Step 2: Analytical Procedures

Once the data were collected, a tiered analytical strategy was applied. Regression or count models estimate the baseline trip volumes from structural attributes. These outputs are refined by incorporating behavioral survey data or revealed preference information, which adjust for user heterogeneity and demand variability. Finally, microsimulation and emission modeling were used to quantify queue spillback, congestion risks, and

environmental costs. This layered analytical approach ensures that site-level operations are situated within their broader system-level impacts.

Step 3: Output Indicators

The integrated analysis produced a set of performance indicators. These include site-specific trip generation rates (both daily and peak hours), queue length thresholds, congestion risk indices, and emission profiles. Such outputs move beyond the conventional static trip rates to provide dynamic, context-sensitive measures that better reflect the complexity of drive-through operations.

Step 4: Policy and Planning Application

The final step translates these indicators into a practical guidance. Planners can use them to inform zoning regulations by evaluating the suitability of site locations; establishing design standards through requirements such as adequate stacking space, the provision of bypass lanes, and multimodal access; and conducting sustainability evaluations that balance customer convenience with emission reduction goals. In this way, the framework enables the alignment of commercial drive-through operations with the broader objectives of sustainable mobility, environmental performance, and urban livability.

4. Discussion

4.1. Framework Interaction Summary

The integrated trip generation framework functions as a layered system in which each component plays a complementary role. Structural models serve as the foundation by providing base estimates of trip demand using measurable parameters, such as site layout, building area, parking capacity, and land use characteristics. These models establish an initial understanding of how a given development generates traffic under the typical operating conditions. Importantly, the inclusion of road network topology within this layer underscores that trip generation is not only a product of site-level attributes, but also of the broader urban network in which developments are embedded. The placement of intersections and interchange points determines how efficiently trips from drive-through facilities are absorbed into the system, with poorly located nodes creating bottlenecks and optimally configured nodes distributing flows more evenly and improving multimodal accessibility [30,31].

Behavioral models refine this base estimate by incorporating individual-level factors that influence travel behavior. These include demographic attributes, household composition, user preferences, and trip purpose. By considering who is traveling, for what reasons, and how frequently, behavioral models add depth to the estimation process and allow for more personalized and context-sensitive forecasting. The interaction between structural determinants and behavioral drivers becomes particularly evident when network topology shapes route choice, travel time perception, and mode selection, thereby directly influencing the behavioral dimension of trip generation.

Environmental models further extend the framework by assessing the external costs associated with the generated trips, including emissions, fuel consumption, congestion, and exposure to public health risks. The systemic role of network design becomes evident when inefficient layouts exacerbate congestion and queuing, thereby increasing idling emissions and fuel consumption, whereas well-designed networks mitigate these burdens by enabling a smoother traffic flow. Such models provide valuable insights into policy formulation, design strategies, and operational practices by quantifying the broader impacts of development patterns and guiding interventions that promote sustainability and urban livability.

Unlike conventional manuals that rely on single-variable or aggregate trip rates [9–12], the proposed system-based framework integrates multi-scalar determinants in a unified manner. It explicitly links micro-level site attributes with macro-level road network topology [30,31] and user-level behavioral and environmental dimensions [8,20,24]. This multi-dimensional scope enables the systematic incorporation of operational dynamics, such as queue spillback, emissions, and socio-demographic variability, into trip forecasts, thereby producing more context-sensitive and transferable models. Collectively, this integration underscores the need for trip generation analysis to move beyond isolated site characteristics and account for the broader role of network design. As illustrated in Figure 2, the road network topology (Framework 1) interacts dynamically with behavioral drivers (Framework 2) and environmental impacts (Framework 3), forming a systemic interaction model. Recognizing these interdependencies allows planners and policymakers to ensure that localized, convenience-driven land uses, such as drive-through facilities, are integrated in ways that support, rather than undermine, wider mobility and sustainability objectives.

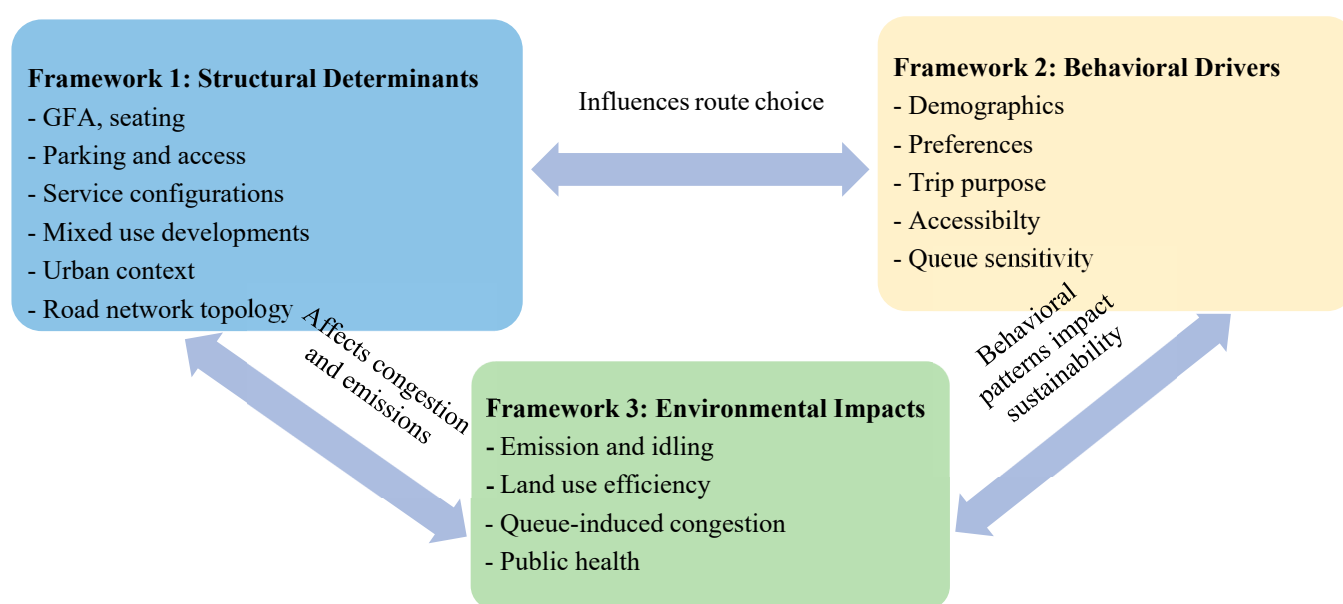


Figure 2. Interaction of road network topology with behavioral and environmental frameworks.

4.2. Meta-Analysis of Drive-Through Trip Generation Rates

A synthesis of international and local studies revealed notable variability in trip generation patterns, highlighting the importance of context-sensitive modeling for drive-through establishments. The ITE’s Trip Generation Manual (7th Edition, 2003) reported relatively high trip rates for fast-food drive-throughs in the United States, with an average of 52.6 trips per 1000 square feet of gross floor area (GFA) during peak hours [12]. However, the manual also indicated substantial variability in trip rates, with values ranging from 19.1 to 213.9 trips per 1000 square feet. This broad range reflects differences in location, site design, and operational factors, underscoring the importance of localized calibration.

More recently, the 11th Edition of the ITE’s Trip Generation Manual (2021) provided updated trip generation rates that reflect evolving land use patterns and data collection practices [9]. For fast-food restaurants with drive-through services (Land Use Code 934), the 11th Edition reports an average of 67 trips per 1000 square feet during the morning peak hour and 53 trips during the afternoon peak hour. When accounting for pass-by-trip reductions, the net new trip rates were approximately 30 trips per 1000 square feet in the morning and 29 in the afternoon. These updated figures suggest a modest increase in morning peak activity compared with the 7th edition, along with a refinement in methodology through

the inclusion of pass-by-trip adjustments. The upward revision in AM peak values may reflect a growing reliance on drive-through services during the early commuting hours, which is particularly noticeable in post-pandemic consumer behavior.

The continued variability and context-dependence observed across both editions reinforce the need for site-specific data and the regional adaptation of trip generation models. This wide range underscores the importance of regional calibration in improving accuracy. Figure 3 presents the ITE's Trip Generation Manual comparison by Land Use Code for the PM peak trip rate and net new trip rate after applying the pass-by trip reduction factor in the ITE's Trip Generation Manual, 11th edition [9].

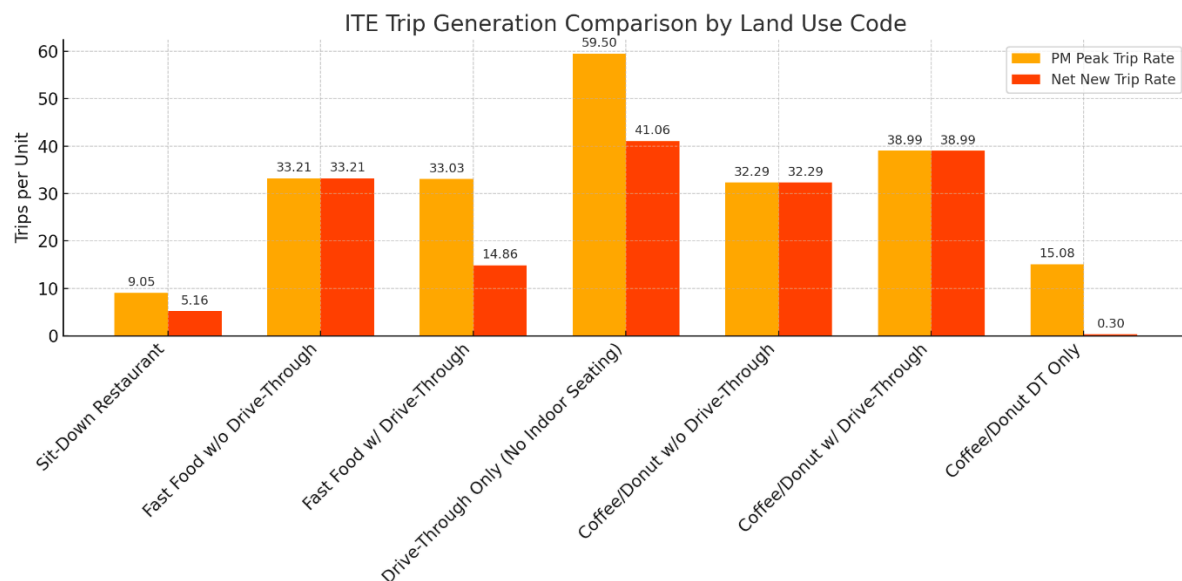


Figure 3. ITE trip generation comparison by Land Use Code.

In response to this issue, Ahmed et al. [15] conducted a study of 14 fast-food outlets in Johor Bahru, Malaysia. Their findings confirmed that the gross floor area and parking availability were statistically significant predictors of peak-hour trips. In contrast, the number of seats did not show a meaningful correlation, likely because of the influence of climatic conditions on the use of outdoor seating. The study reported a weekday evening peak of 21.04 trips per 100 square meters of gross floor area, increasing to 24.56 trips per 100 square meters on weekends.

Figure 4 compares the average trip generation rates (per 1000 square feet) across the AM and PM peak periods for both commuters and generators based on datasets from the 2010 MTGM and the updated Malaysian Trip Generation Manual 2020 (Highway Planning Unit (HPU), 2020) [10]. The 2020 manual incorporates data collected during the COVID-19 pandemic, thereby capturing travel behavior under atypical conditions. Across both datasets, PM peak rates remained consistently higher; however, the 2020 values indicated slightly lower trip rates for both commuters and generators compared with 2010. These reductions are likely attributable to evolving mobility preferences, the rise in remote working practices, and changes in service utilization patterns. Furthermore, the distinction between AM and PM peaks captures the temporal variability in travel demand, ensuring greater precision in site-level forecasting. Together, these enhancements strengthen the manual's utility for planning and policy, offering locally calibrated equations and trip tables that remain relevant in both pandemic and post-pandemic urban contexts.

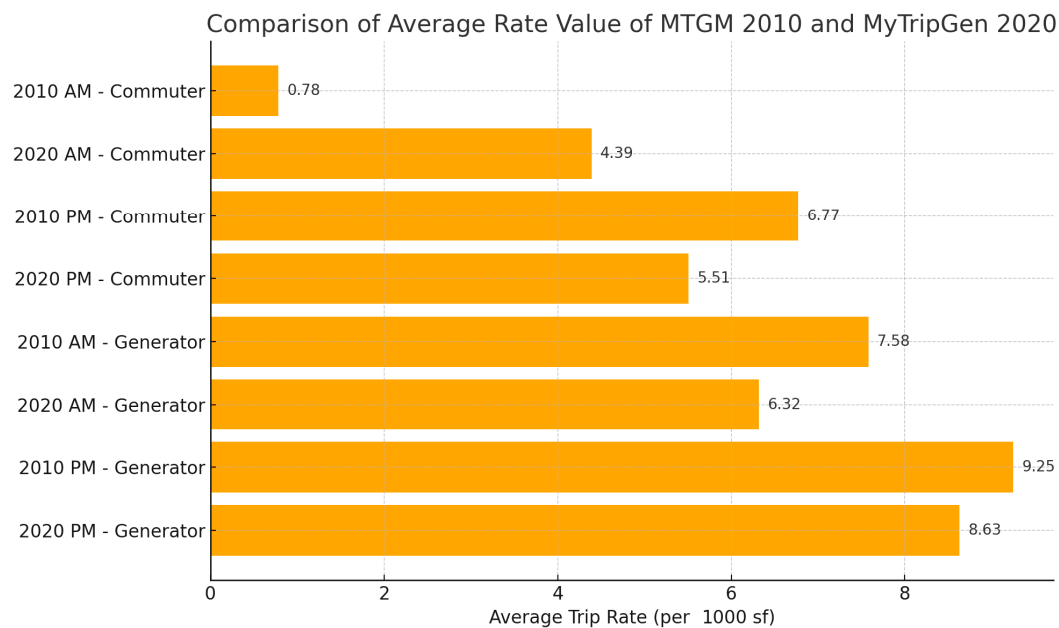


Figure 4. Comparison of average trip generation rates for AM and PM peak periods in MTGM 2010 and MyTripGen 2020.

Similar observations were made in studies conducted in Qatar and Jordan [17,18], where drive-through trip generation was found to correlate more strongly with parking capacity and number of employees than with gross floor area alone. These findings support the shift towards multivariable regression models, moving beyond the traditional single-variable approach used in ITE methodologies. However, even with the inclusion of multiple variables, the predictive accuracy remains modest, particularly in mixed-use developments, as shown in the study by Shafie et al. [16]. This suggests that further model refinement is necessary, potentially through the inclusion of variables such as adjacent traffic volumes and surrounding land use characteristics.

Wonson [13] and Simons [14] emphasized the importance of understanding the composition of trip purposes such as new, pass-by, and diverted trips. This level of detail is often overlooked in conventional rate-based models. A clear understanding of trip purposes becomes especially important for high-visibility sites or those located along major corridors, where a large proportion of traffic may consist of diverted or pass-by trips rather than newly generated ones. From an operational standpoint, Mike et al. [27] and Bitzios Consulting [35] highlighted the significant role of service times and queuing dynamics in shaping vehicular inflow. Mike et al. advocated the use of simulation-based queuing analysis instead of relying solely on the static trip rates. Their findings showed that delays in the order window could lead to disproportionate increases in queue lengths. Bitzios Consulting observed that morning peak arrivals at a 3500-square-foot site approached 300 vehicles per hour, resulting in a peak trip rate of 77.9 trips per 1000 square feet during the morning period. This rate exceeded both the ITE averages and local expectations.

The Colorado–Wyoming Section of the Institute of Transportation Engineers [32] expanded this body of work by introducing a new hybrid land use category to represent coffee shops that include both drive-through and sit-down facilities. A meta-survey of ten such sites produced a consistent morning peak rate of approximately 125 trips per 1000 square feet, and an evening peak rate of 36 trips per 1000 square feet. The consistency of these results across two regions, Minnesota and Colorado, confirms the reliability of this land use typology and supports its distinction from conventional fast-food restaurant categories. In addition, Bruwer and Neethling [24] introduced a sustainability perspective

to the discourse by quantifying the environmental costs associated with vehicle idling in drive-through queues. Their case study in South Africa found that a single dual-lane facility could produce up to 64 tons of carbon dioxide emissions annually. The study recommended several operational improvements, including the adoption of passive–active queuing systems and the reconfiguration of stacking lanes to minimize idling. These environmental considerations provide a valuable complement to functional traffic modeling, offering a more comprehensive approach for evaluating the impact of drive-through developments.

Figure 5 compares peak-hour trip generation rates for drive-through services across three major trip generation manuals: the UK’s TRICS [11], Malaysia’s MyTripGen [10], and the USA’s ITE 11th Edition [9]. Notably, the TRICS manual reports the highest rates, especially at weekends (50.42 trips/1000 sq ft), followed by the ITE manual (33.03 trips/1000 sq ft), indicating substantial regional variation. The MyTripGen manual reflects significantly lower trip rates during both the AM (6.77) and PM (9.25) peaks, possibly influenced by local travel behavior and data collected during the COVID-19 pandemic.

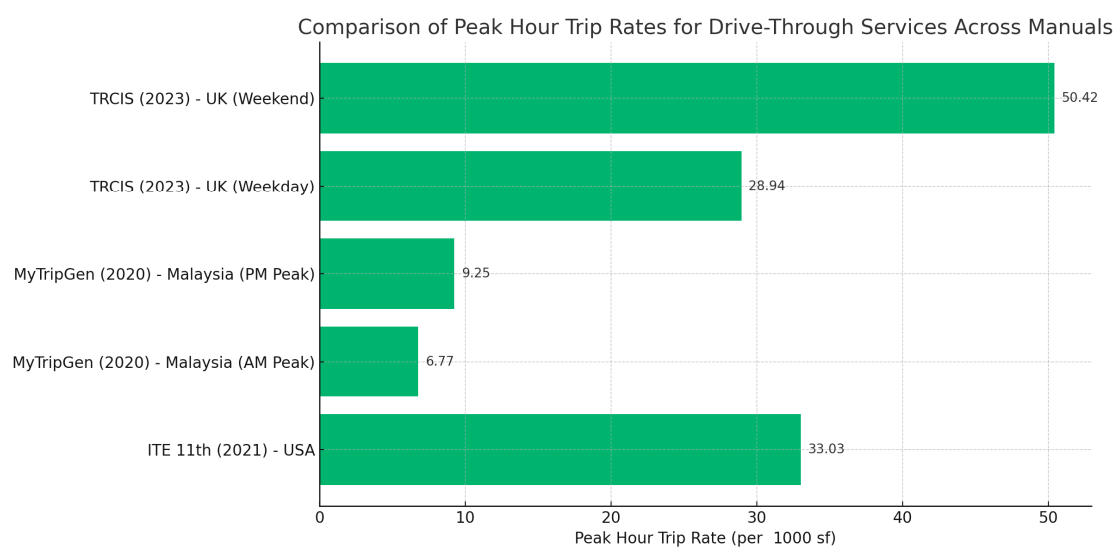


Figure 5. Peak-hour trip generation rates for drive-through services across major trip generation manuals.

This meta-analysis identified several important themes. First, trip generation at drive-through establishments is highly sensitive to operational variables, such as service window duration, parking availability, and user behavior. Second, regional calibration is essential to avoid overgeneralization when applying the national or international trip generation rates. Third, hybrid evaluation models that incorporate queue simulations and environmental impact metrics offer a more holistic assessment. Finally, emerging land use configurations, such as mixed-mode coffee shops and developments that combine fuel stations, convenience stores, and fast-food restaurants, require updated trip generation manuals and planning policies to ensure that future urban development is both functional and sustainable.

4.3. Practical Applications and Insights

This integrated framework can be applied in various domains of urban planning and transport engineering. In the context of planning, it offers a foundation for calibrating conventional trip generation manuals, such as those developed by the Institute of Transportation Engineers, using locally derived data that reflect specific land use types, population demographics, and behavioral characteristics. This calibration ensures that trip forecasts align more closely with the real-world conditions.

From a policy standpoint, the framework supports the regulation of drive-through facilities and other high-turnover land uses by encouraging design practices that reduce the environmental impact. For example, policy guidelines can promote layouts that minimize idling times and prevent traffic spillover into adjacent streets, thereby enhancing safety and reducing emissions.

In design practice, the proposed framework assists developers in configuring sites that are efficient and sustainable. It supports the optimization of drive-through lanes to improve vehicle throughput while minimizing land use. From an operational perspective, the framework provides transportation professionals with tools to anticipate performance challenges, such as peak-hour congestion, queuing delays, and site-level bottlenecks. Through the application of traffic modeling and queuing theory, practitioners can evaluate service lane efficiency and identify targeted adjustments that enhance the overall site functionality and user experience.

The application of this is illustrated in the planning of a coffee drive-through within a high-density mixed-use corridor. Forecasting with the ITE manual [9] primarily relies on the gross floor area, resulting in a static peak-hour trip estimate. In contrast, the proposed framework extends beyond static predictors by incorporating stacking capacity and queuing analysis, which many municipalities already regulate through minimum lane and space requirements. For example, Baltimore mandates at least four stacking spaces per lane [39], while Durham, North Carolina, requires a minimum of 8×20 ft stacking spaces designed to avoid impeding site circulation [40]. In addition, the framework integrates local consumer demographics, such as vehicle ownership and walk-in versus drive-through customer proportions, alongside environmental performance indicators derived from emissions modeling tools like MOVES [41]. This comprehensive approach enables the quantification of queue spillback risks, potential pedestrian conflicts, and CO₂ emissions from idling vehicles. As a result, planners are empowered to design context-specific interventions such as bypass lanes, improved pedestrian connectivity, and anti-idling measures, producing insights and recommendations that surpass those offered by conventional manuals [22].

4.4. Policy and Governance Implications

The findings of this review also highlight the necessity for coordinated interventions across regulatory, design, and operational domains to sustainably integrate drive-through facilities into urban environments. International experience illustrates a spectrum of policy approaches to mitigate environmental and mobility impacts. For instance, Vancouver, Canada, has introduced zoning measures prohibiting new drive-throughs in pedestrian-priority districts, aiming to preserve walkability and reduce emissions from vehicle idling [42]. In the United States, local governments frequently employ design standards mandating minimum stacking lengths, dual-order lanes, and circulation loops to prevent queues from spilling into public streets [43,44]. Similarly, cities in the United Kingdom and Australia have enacted anti-idling bylaws, complemented by awareness campaigns, to address emissions from stationary vehicles [14].

For rapidly motorizing regions, a balanced strategy could combine context-sensitive location criteria that prioritize multimodal access, operational incentives such as app-based pre-ordering to reduce dwell times, and land use requirements that maintain pedestrian permeability while limiting impervious surfaces [35]. Embedding these measures within statutory planning frameworks ensures that commercial developments align with broader sustainability and livability objectives.

Beyond site-specific policies, sustainable integration also requires attention to network-level interventions. For example, Singapore's Fort Canning Tunnel provides a 350 m

underground bypass that significantly reduces congestion near Orchard Road, cutting a surface journey of several minutes to under 20 s, thereby dispersing queues around adjacent commercial facilities [45]. Similarly, the Marina Coastal Expressway, with its 3.5 km subterranean segment, demonstrates how eco-friendly infrastructure can relieve surface congestion and maintain accessibility to central food precincts [25]. Complementing these real-world examples, Akopov and Beklaryan [30] showed that reconfigurable multilayer infrastructure can enhance network resilience through elevation or tunneling, while Xu et al. [31] demonstrated the role of global routing optimization in dynamically balancing urban traffic.

Thus, policy frameworks should not focus solely on site-level standards, such as design requirements and anti-idling laws, but should also integrate system-level infrastructure planning. Incorporating drive-through trip generation models with sustainable infrastructure design and network optimization tools allows the assessment of both localized and broad transport system effects. This ensures that convenient commercial development bolsters, rather than hinders, mobility, environmental quality, and urban livability.

4.5. Limitations and Evidence Certainty

Although this review provides a comprehensive synthesis of international evidence on drive-through trip generation, several limitations must be acknowledged. First, the study is subject to potential reporting bias, as unpublished studies, gray literature, and negative findings may not have been captured within the electronic database search. This selective availability of the evidence may skew results towards studies with significant or favorable outcomes, thereby limiting the representativeness of the evidence base.

Second, formal certainty assessments using standardized grading frameworks such as GRADE were not undertaken. This was largely because of the methodological heterogeneity of the included studies and the mixed-method nature of the evidence base, which ranged from peer-reviewed empirical analyses to technical manuals and government reports. While this approach broadened the scope of the evidence, it also restricted the ability to formally rank or quantify the strength of the findings. Instead, robustness was supported through the triangulation of multiple data sources and by emphasizing consistency and transferability across different contexts.

Third, although meta-analytical synthesis was applied to compare trip generation rates across manuals and studies, variability in study design, sample size, and contextual conditions such as regional travel behavior and post-pandemic mobility patterns indicate that caution is required when generalizing the findings. The sensitivity of trip rates to factors such as service times, queue lengths, and parking availability further underscores the importance of site-specific calibration, which may limit the broader applicability of the results.

Collectively, these limitations highlight the need for a cautious interpretation of the findings. While this review advances the understanding of drive-through trip generation and its urban implications, further research is needed to incorporate unpublished data, apply formal certainty grading, and develop more standardized approaches for comparing international trip generation evidence. These improvements would enhance confidence in future syntheses and strengthen their utility in planning, policy, and design applications.

5. Conclusions

This review provides the first cross-regional synthesis that positions drive-through trip generation within a unified systems perspective, linking site-level design, user behavior, and environmental impacts with network performance. Its significance lies in consolidating fragmented evidence into an integrated analytical foundation, advancing a systems-based

framework that practitioners can apply for context-sensitive estimation and evaluation, and translating technical findings into actionable levers for zoning, design standards, and infrastructure planning. In doing so, the review equips transport engineers, planners, and policymakers with a coherent, evidence-informed pathway to reconcile the commercial convenience of drive-through facilities with objectives for mobility, emissions reduction, and urban livability.

The analysis highlights the limitations of conventional trip generation models in representing the operational, behavioral, and spatial complexity of drive-through facilities. Existing manuals often omit critical factors such as queuing dynamics, service configurations, and behavioral variability, which leads to forecasts that diverge from observed conditions. By synthesizing evidence across diverse geographic and policy contexts, this review advances an integrated systems framework that combines structural determinants, behavioral and socioeconomic drivers, and environmental and operational dimensions to improve the accuracy, adaptability, and contextual relevance of trip estimation.

The study contributes in three interrelated ways. It systematically synthesizes empirical evidence on drive-through trip generation, revealing inconsistencies across regional datasets and clarifying the operational roles of queue dynamics, pass-by traffic, and service design. It introduces a systems-based framework that integrates structural determinants, behavioral drivers, and environmental impacts, and it incorporates road network topology as a critical factor shaping trip absorption capacity. It then translates these findings into policy and governance guidance, demonstrating how trip generation modeling can align with zoning provisions, performance-based design standards, and environmentally responsible infrastructure planning to support sustainable urban mobility. Collectively, these contributions establish a more comprehensive and context-sensitive foundation for evaluating and planning drive-through facilities within transport planning practice.

The results underscore the need for localized calibration, context-responsive design standards, and system-level performance measures that account for the distinctive operational impacts of drive-through uses. Beyond methodological refinement, the findings offer direct guidance for regulating high turnover land uses, mitigating environmental externalities, and improving multimodal accessibility. The proposed framework provides a foundation for the next generation of trip generation manuals, particularly in rapidly motorizing regions, by embedding environmental metrics, behavioral insights, and real time analytics into standard practice.

As urban development intensifies, transport engineers, planners, and policymakers should adopt adaptive, data-driven, and multidimensional approaches to ensure that trip generation modeling remains reliable and aligned with contemporary goals for sustainable, accessible, and livable cities. This review contributes conceptually, methodologically, and practically to the global discourse on reconciling the convenience and economic benefits of drive-through facilities with the imperatives of urban sustainability and mobility equity.

6. Limitations and Future Research

Although this review provides a comprehensive synthesis of the international evidence on drive-through trip generation, several limitations must be acknowledged. A key concern is the geographical imbalance in the evidence base. Most of the studies included in this review originated in North America, Europe, and selected Asian contexts, leaving other rapidly motorizing regions such as Africa and Latin America underrepresented. This uneven coverage restricts the transferability of the findings and limits the ability to capture distinctive travel behaviors, infrastructure conditions, and development patterns that characterize these less-studied regions [15,16]. In many African, Latin American, and Southeast Asian cities, urban characteristics differ markedly, with a higher reliance on motorcy-

cles [20], more informal and dispersed retail structures, and weaker enforcement of land use regulations. For instance, evidence from Dar es Salaam highlights the congestion externalities of drive-through facilities under conditions of constrained roadway capacity [4], whereas studies from Palestine and Qatar emphasize the importance of locally calibrated models when adapting international trip generation manuals [18,36]. Collectively, these cases indicate that, although the systems-based framework offers broad applicability, its effectiveness depends on calibration, which reflects modal diversity, regulatory capacity, and the dynamics of informal urban growth. Future research should therefore prioritize empirical studies in Africa, Latin America, and Southeast Asia, focusing on how cultural practices, informal economic activity, and multimodal transport systems influence trip generation. Such efforts will not only strengthen the generalizability of existing models, but also enhance their policy relevance for diverse urban contexts worldwide.

Another limitation is the methodological heterogeneity, which poses a considerable challenge to the comparability of results across studies. The reviewed literature encompasses a wide variety of methodological approaches ranging from manual traffic counts and regression models to simulation-based and mixed-use trip estimation frameworks [27,37]. Adding to this complexity, inconsistent definitions of key variables such as “pass-by” and “diverted” trips varied substantially across different contexts, further complicating synthesis [13,14]. Because of this diversity, the application of structured risk-of-bias assessment tools, such as ROBIS, or certainty frameworks, such as GRADE, was not feasible. These tools typically require a degree of methodological homogeneity and clearly defined outcome measures, which are absent from this heterogeneous evidence base.

Despite the absence of formal bias assessment tools, several strategies have been employed to mitigate the potential sources of bias. Comprehensive searches were conducted across multiple databases, including Scopus, Web of Science, ScienceDirect, Google Scholar, and the TRB e-newsletter archive, to reduce the likelihood of selective reporting and publication bias. The gray literature such as government manuals and technical reports were also included to ensure broader coverage [10,11]. To further improve reliability, dual review screening and data extraction were performed, reducing the influence of individual reviewer (L.H.T. and C.W.Y.) subjectivity. Additionally, the findings were cross-validated across jurisdictions, ensuring that the evidence was not dependent on a single regional dataset. This triangulation process balances individual study weaknesses with broader consistency and provides greater confidence in the robustness of the overall findings [5,26].

A further limitation is the lack of high-resolution, real-time data, which restricts the ability to capture temporal fluctuations, such as short-term queue dynamics and peak-period variability [35]. Similarly, environmental and behavioral dimensions, such as the emissions associated with vehicle idling and consumer behaviors, such as trip-chaining, were insufficiently quantified in the available studies [8,24]. These gaps highlight the need for more granular and comprehensive datasets to better reflect the operational realities of drive-through facilities.

Finally, it is important to note that no formal review protocol was prospectively registered, which raises the possibility of unrecognized deviations from the original research plan. Nevertheless, the adherence to PRISMA 2020 guidelines and the transparent reporting of the study selection process helped maintain reproducibility and methodological transparency throughout the review.

Future research should incorporate structured risk of bias and certainty assessments in contexts that allow methodological homogeneity. Greater emphasis should also be placed on calibration studies in underrepresented regions to improve the global applicability of trip-generation models. The use of multi-source datasets, such as GIS-based traffic counts (ArcGIS Pro 3.2), mobile phone data, and point-of-sale transactions, offers

significant potential for capturing behavioral and operational complexities at higher levels of detail [1,2]. Methodological advancements should further integrate microsimulation and environmental modeling techniques to quantify emissions and congestion impacts more directly [5,27]. Additionally, long-term evaluations of policy interventions, including anti-idling laws, zoning restrictions, and multimodal design standards, are necessary to assess their effectiveness in shaping sustainable urban mobility.

This review is significant because it reframes trip generation not merely as a forecasting tool, but also as a determinant of urban sustainability. By situating drive-through facilities from a systems perspective, it highlights their role in reinforcing car dependency [6], shaping land use patterns [21], and influencing emission trajectories [5,24]. The framework proposed here offers a pathway toward the next generation of trip generation manuals, embedding behavioral, operational, and environmental metrics alongside conventional structural predictors. This approach aligns with contemporary advances in transport optimization, which emphasizes the importance of integrating efficiency and environmental performance [30,31]. Furthermore, by incorporating accessibility-based insights [23,26] and sustainability critiques of automobile dependency [6,21], this study provides a conceptual bridge between empirical trip generation research and broader urban planning debates. As such, it contributes not only to academic discourse, but also provides practical guidance for policymakers seeking to reconcile commercial convenience with sustainable mobility objectives. This revised conclusion now explicitly articulates the role of this review in advancing sustainable transport planning, demonstrates how the framework links to wider urban debates, and grounds its claims in the relevant literature, ensuring that the significance of the review is clear to both academic and policy-making audiences.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su17209214/s1>, Table S1: PRISMA 2020 Checklist. Reference [46] is cited in the Supplementary Material.

Author Contributions: Conceptualization, C.W.Y., R.B.Z. and A.S.P.; methodology, L.H.T.; software, L.H.T.; validation, C.W.Y., R.B.Z. and A.S.P.; formal analysis, L.H.T.; investigation, L.H.T.; resources, C.W.Y.; data curation, L.H.T.; writing—original draft preparation, L.H.T.; writing—review and editing, C.W.Y., R.B.Z. and A.S.P.; visualization, L.H.T.; supervision, C.W.Y.; project administration, C.W.Y.; funding acquisition, C.W.Y. and L.H.T. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: Author Ashita S. Pereira was employed by the company JA Project Consultant Sdn. Bhd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ITE	Institute of Transportation Engineers
TRCIS	Trip Rate Information Computer System
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
GFA	Gross floor area
MTGM	MyTripGen Manual (Malaysian Trip Generation Manual)
TAZ	Traffic Analysis Zone
MOVES	Motor Vehicle Emission Simulator
COPERT	Computer program to calculate emissions from road transport
GIS	Geographic Information System

Appendix A

This appendix provides the complete search strategies used across all databases, including search strings, applied filters, and number of records retrieved. These details ensure transparency, reproducibility, and alignment with PRISMA reporting standards.

Table A1. Database Search Strategies.

	Search String (Example)	Filters Applied	Date of Last Search	Records Retrieved
Scopus	("trip generation" OR "traffic generation") AND ("drive-through" OR "drive-thru") AND ("urban form" OR "land use" OR "queue length" OR "traffic impact")	English; 1990–2024; Articles, Reviews, Conference Papers	12 July 2024	142
Web of Science (WoS)	TS=("trip generation" OR "traffic generation") AND TS=("drive-through" OR "drive-thru") AND TS=("urban form" OR "land use" OR "queue length" OR "traffic impact")	English; 1990–2024; SCI/SSCI Journals	12 July 2024	116
ScienceDirect	TITLE-ABS-KEY("trip generation" AND "drive-through") OR ("drive-thru")	English; 1990–2024; Research Articles only	12 July 2024	87
Google Scholar	"trip generation" + "drive-through" + "urban form"	First 200 results screened manually; English; 1990–2024	12 July 2024	200 (screened)
TRB e-Newsletter archive	"trip generation" OR "drive-through"	No filters; manual screening of abstracts	12 July 2024	23
Other transport repositories (e.g., regional transport departments, government reports)	"trip generation manual" + "drive-through" OR "fast food"	English; 1990–2024	12 July 2024	18

Appendix B

The following studies were retrieved for full-text review but were excluded from the final synthesis. Each study was identified using an exclusion ID (E01–E10). This list provides transparency during the selection process. The IDs in this Appendix are not linked to the main reference list. They only serve to document transparency in the PRISMA process.

Table A2. List of Excluded Full-Text Studies and Reasons for Exclusion.

Exclusion ID	Reason for Exclusion
E01	Non-English language publication
E02	Conference abstract only; no full text available
E03	Did not report empirical data relevant to trip generation
E04	Focused on general traffic flow modeling, not drive-through or trip generation
E05	Duplicate of an included study
E06	Methodology not aligned with inclusion criteria (simulation without field validation)
E07	Insufficient data on key variables (e.g., GFA, queue length, parking)
E08	Case study outside defined timeframe (pre-1990)
E09	Commentary/opinion piece without empirical findings
E10	Gray literature with no accessible methodology documentation

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