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A Systematic Review of the Impact of Side Frictions on Road Service Levels in Urban Roadways

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Abstract

This study presents a systematic literature review (SLR) on the impact of side frictions on the level of service (LOS) in urban roadways. Side frictions, which include pedestrian activity, on-street parking, street vendors, and loading/unloading activities, are often underestimated in traditional traffic models. However, they significantly reduce road capacity and disrupt smooth traffic flow, especially in densely populated urban environments. This review analyzes 56 peer-reviewed studies published between 2020 and 2025, focusing on indicators used to assess side friction effects, such as vehicle delay, lane occupancy, flow rate, and speed. The study also highlights the classification of side friction by intensity level and the growing use of modeling tools like VISSIM, SIDRA, Synchro, and GIS integration in quantifying their impacts. Visualizations generated through VOSviewer provide insights into keyword co-occurrence and research trends. Findings show that simulation-based analysis not only helps evaluate current conditions but also supports the testing of mitigation strategies. The study concludes that incorporating side frictions into roadway performance analysis is essential for more accurate, context-sensitive urban transport planning and policy development.

Keywords: *Side Frictions, Road Service, Urban Raodways*

1. Introduction

The level of service (LOS) is a key metric used in transportation engineering to assess the operational performance of roadways. It reflects the quality of traffic flow, including speed, travel time, traffic interruptions, and driver comfor[1]. One of the less-controlled but significantly influential factors affecting LOS is side friction—commonly referred to as side barriers or roadside disturbances[2]. These include pedestrian movements, parked vehicles, street vendors, loading and unloading activities, and other roadside activities. Side friction tends to reduce roadway capacity and disrupt the smooth flow of traffic, especially on urban roads with mixed functions. Understanding the effects of side friction is crucial for developing efficient urban traffic management strategies[3]. This growing concern has led to increasing interest in evaluating how such disturbances can be systematically incorporated into road performance assessments.

Over the years, researchers and transportation planners have conducted numerous studies to quantify and model the effects of side friction on traffic flow[4]. However, the methodologies and findings vary considerably across different regions and road contexts[5]. Factors such as traffic composition, road geometry, and socio-economic conditions often influence how side friction affects performance[6]. Some studies apply empirical methods, while others use simulation-based or analytical modeling to assess the impact[7]. This diversity in approach creates inconsistencies in how side friction is considered in planning and design standards. Therefore, synthesizing this knowledge through a systematic review is essential to establish a clear understanding[8]. Such synthesis ensures that insights can be generalized or adapted across varying urban scenarios.

A systematic literature review (SLR) provides a rigorous and structured method to collect, evaluate, and synthesize research evidence[9]. It minimizes bias by applying predefined selection criteria and helps identify common findings, gaps, and methodological differences in the literature. In the context of side friction, an SLR can clarify how it has been defined, measured, and integrated into roadway performance analysis[10]. Moreover, it can reveal how side friction is addressed in different countries, particularly in developing urban areas where informal roadside activities are more prevalent[11]. By reviewing a broad range of studies, the SLR approach offers a comprehensive insight into best practices and evolving evaluation techniques. This supports more informed decisions in transportation planning and policy development[12]. As a result, transportation models can evolve to become more inclusive of the real-world complexities found in urban traffic systems.

Despite its known impact, side friction is often underestimated or excluded from standard roadway capacity models[13]. Traditional traffic models tend to assume ideal conditions, neglecting the variability introduced by roadside activities[14]. This oversight can result in inaccurate capacity estimations and ineffective traffic improvement strategies[15]. Incorporating the effects of side friction into design standards and traffic analysis tools is vital for realistic assessments of road performance[16]. By reviewing existing literature systematically, it becomes possible to identify how and where side friction should be integrated into roadway LOS models. This integration can ultimately lead to more context-sensitive and adaptive roadway designs[17]. Ignoring these real-world frictions risks the creation of infrastructure solutions that fail to resolve underlying traffic inefficiencies.

In conclusion, investigating the influence of side friction on the level of service is essential to address real-world traffic conditions, particularly in urban settings[18]. A systematic literature review allows researchers to map out existing approaches, highlight key challenges, and recommend future directions for research and practice[19]. This helps bridge the gap between theoretical modeling and field realities in traffic engineering[20]. Furthermore, it contributes to the development of more responsive and inclusive transportation policies[21]. Therefore, this study aims to conduct a comprehensive review of the literature concerning the impact of side friction on roadway level of service using the SLR method. The findings will be valuable for academics, practitioners, and policymakers seeking to improve urban road performance[22]. Ultimately, this research encourages a paradigm shift toward more adaptive and behavior-aware road design standards.

2. Research Methods

2.1 Formulation of Research Objectives and Questions

The first step in conducting an SLR is to clearly define the objectives and formulate guiding research questions. In this study, the main objective is to explore how side friction influences road service performance and how it is addressed in previous studies[23]. The key research questions include: (1) How is side friction defined and categorized in the literature? (2) What methods have been used to assess its impact on LOS? (3) What are the major findings, limitations, and research gaps? These questions provide a focused direction for the selection, evaluation, and synthesis of relevant literature[24].

Formulating specific research questions ensures that the review remains systematic, unbiased, and aligned with its objectives[25]. It also helps in the development of precise inclusion and exclusion criteria during the article screening process[26]. The clarity of the research questions determines the relevance and consistency of the data extracted later in the review[27]. This foundation allows the research to remain within scope while thoroughly investigating the topic. A well-defined objective is essential for understanding how the evaluation of side friction has evolved over time. Ultimately, this step supports a more structured and meaningful analysis[28].

The formulation of research questions in an SLR ensures that the review process remains structured and goal-oriented from the outset. By clearly defining the objectives, researchers can limit scope creep and ensure that all literature examined serves the study's central purpose. This step also facilitates the selection of appropriate analysis methods, whether qualitative synthesis, thematic mapping, or quantitative comparisons. In this review, focusing on side friction's effect on LOS is particularly relevant in urban planning contexts where roadside disturbances are common. Establishing specific questions enhances the study's analytical depth and allows for more nuanced interpretations of diverse research findings. Ultimately, this ensures the review does not just summarize existing knowledge, but critically evaluates and organizes it to inform future research and practice.

2.2 Database Selection and Search Strategy

To identify relevant publications, a comprehensive search was conducted using major academic databases[29]. These included Scopus, Web of Science, ScienceDirect, IEEE Xplore, and Google Scholar to ensure wide coverage[30]. The search terms combined keywords such as "side friction," "roadway level of service," "road performance," "urban roads," and "traffic disturbance" using Boolean operators. Filters were applied to include only English-language peer-reviewed journal articles and conference papers published between 2020 and

2025[31]. Additional manual searching (backward and forward snowballing) was done to capture relevant studies missed in the initial search. This process ensured a high degree of comprehensiveness and minimized the chance of omitting important literature[32].

The search strategy followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[33]. PRISMA offers a transparent and replicable procedure for selecting and reporting studies[34]. A record of all searches, including databases used, keywords, number of articles found, and reasons for exclusion, was maintained[35]. This transparency increases the reliability of the review and allows future researchers to replicate or build upon the findings. The systematic and repeatable nature of the search strategy helps avoid selection bias. It also ensures that the scope of literature is appropriate and relevant to the research objectives[36].

The database selection process in this study emphasizes coverage, credibility, and relevance to the transportation engineering field. Each selected database contributes a different strength—for example, Scopus and Web of Science offer peer-reviewed journal coverage, while IEEE Xplore focuses on technical and modeling-based research. Google Scholar, although broader and less filtered, serves as a supplementary source for hard-to-find or cross-disciplinary works. The use of Boolean operators and filtering conditions ensures precision in the search results. By combining both automated and manual search techniques (e.g., snowballing), the researchers minimized the risk of excluding relevant studies. The diversity of sources supports a well-rounded understanding of side friction modeling and its implications for roadway LOS.

2.3 Inclusion and Exclusion Criteria

A set of inclusion and exclusion criteria was developed to filter the collected articles and ensure they align with the research questions[37]. Studies were included if they focused on roadways with side friction components, evaluated LOS, and applied either empirical or simulation-based methods[38]. Only full-text articles in English, published between 2015 and 2025 in peer-reviewed journals or conferences, were considered[39]. Excluded materials included theses, book chapters, editorials, and studies unrelated to road performance or that did not use measurable indicators of side friction[40]. The criteria helped reduce ambiguity during screening and ensured that selected studies were relevant and of sufficient quality. Articles focusing solely on freeway or rural road settings were excluded unless they addressed urban side friction specifically[41].

The screening process involved two levels: title and abstract screening, followed by full-text review[42]. Each article was evaluated independently by two reviewers to reduce the risk of bias and increase objectivity[43]. Disagreements were resolved through discussion or consultation with a third reviewer[44]. A PRISMA flow diagram was used to document the number of studies identified, screened, excluded, and included in the final synthesis. Applying clear inclusion and exclusion criteria allowed for the development of a focused and coherent body of literature. This also enhanced the internal validity of the findings[45].

Defining strict inclusion and exclusion criteria helps establish boundaries for what constitutes relevant, high-quality evidence. This is particularly important in interdisciplinary studies like this, where the topic of side friction may appear in different research contexts (e.g., civil engineering, urban studies, transportation policy). By limiting the review to peer-reviewed articles with quantifiable metrics, the study avoids anecdotal or theoretical papers that lack empirical grounding. Including only recent works ensures that the findings reflect current modeling tools, traffic conditions, and urban trends. The use of a dual-reviewer screening process with arbitration by a third reviewer strengthens the objectivity of article selection. This level of rigor is crucial for building a trustworthy synthesis of research findings.

2.4 Data Extraction and Categorization

Data from the selected studies were extracted using a structured template to maintain consistency and accuracy[46]. Extracted information included authors, publication year, study location, objectives, methodology, types of side friction examined, LOS indicators, and key findings[47]. Each study was reviewed in-depth to identify the methodological approach, whether empirical, analytical, or simulation-based[48]. The context of side friction (e.g., parked vehicles, pedestrian activity, vendors) was also recorded[49]. The structured extraction enabled comparison across studies and helped group them based on similarities and differences in their analytical approaches. This step was essential for creating a comprehensive overview of the research landscape[50].

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After extraction, the data were organized into thematic categories based on the methods and findings of the studies[51]. This included grouping by type of side friction, geographic context (developed vs. developing countries), and methodological approach (field study, simulation, modeling)[52]. Categorization enabled the identification of patterns, trends, and outliers within the dataset. It also helped pinpoint where research efforts have been concentrated and where gaps remain[53]. Organizing data thematically provided a clearer understanding of the current knowledge structure in the field. This stage served as a foundation for the subsequent synthesis and analysis[54].

Data extraction is a pivotal phase in systematic literature reviews, as it transforms raw literature into structured, analyzable evidence. The use of a standardized template ensures that all studies are evaluated consistently across key dimensions such as methodology, location, and side friction type. Special attention is given to the operationalization of side friction—whether through frequency counts, friction indices, or simulation parameters. Thematic categorization not only simplifies comparison but also reveals trends in research focus and technique, such as a growing preference for GIS-integrated simulations. This structure facilitates cross-study synthesis and allows researchers to identify which urban contexts are most often studied. The outcome is a robust knowledge base upon which to build informed analyses.

2.5 Analysis, Synthesis, and Reporting

Once the data were organized, a qualitative synthesis was conducted to answer the research questions and highlight key findings[55]. Patterns and differences across methodologies, geographic regions, and study outcomes were analyzed[56]. The impact of different types of side friction on LOS was compared, and critical methodological gaps were identified. Attention was also given to how studies incorporated side friction into existing traffic models and what limitations they reported. This synthesis provided a nuanced understanding of how side friction affects urban road performance. It also revealed emerging trends and innovative approaches in evaluating roadway LOS under non-ideal conditions[57].

The findings were reported following PRISMA guidelines to ensure clarity, structure, and transparency[58]. Tables and figures were used to summarize the studies, themes, and relationships between variables[59]. The results section included a detailed narrative discussing the strengths, weaknesses, and implications of the reviewed literature[60]. Research gaps and opportunities for future studies were highlighted based on the synthesis[61]. By presenting the results in a structured format, the review offers useful insights for academics, engineers, and policymakers[62]. This ensures the study contributes meaningfully to the field of transportation engineering.

The synthesis stage integrates diverse findings into a cohesive narrative that addresses the research questions posed at the beginning. It reveals how methodological differences—such as using microsimulation versus observational studies—can affect reported outcomes on LOS. It also highlights inconsistencies, such as the lack of standardized metrics for classifying side friction intensity across studies. Reporting the results using tables, figures, and thematic summaries ensures the findings are accessible and easy to interpret. Additionally, the use of PRISMA guidelines enhances transparency, enabling replication or extension by future researchers. This thorough and organized approach not only builds academic credibility but also provides actionable insights for urban planners, traffic engineers, and policymakers.

3. Results and Discussions

3.1 Visualisation of Research Keyword Connections

To deepen the understanding of research trends and conceptual relationships in the field, a co-occurrence analysis was conducted using VOSviewer. This method visualizes the frequency and relationship between keywords found in the reviewed literature. By grouping related terms into clusters, it becomes easier to identify the dominant themes and interdisciplinary linkages within the study of road service levels, particularly in relation to side frictions and urban infrastructure. These visualizations provide valuable insights into how various concepts—such as road capacity, service quality, urban planning, and intelligent transportation systems—interact within academic discourse. This approach also supports the identification of underexplored areas and helps shape future research directions in urban roadway performance evaluation.

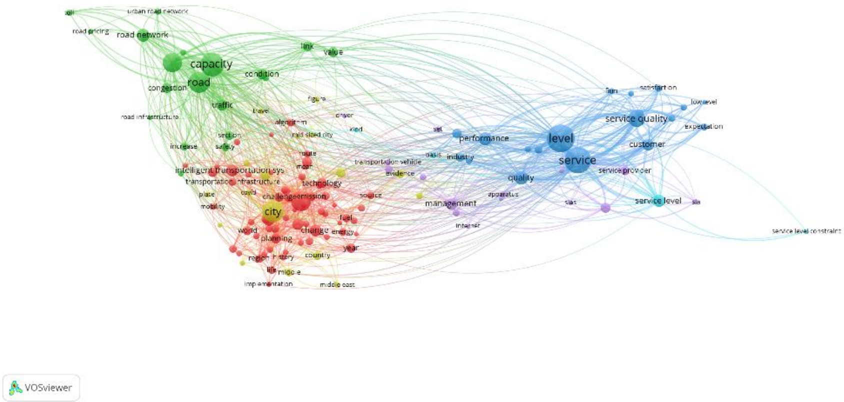

Figure 1. Keyword Density Visualization

The image above represents a keyword co-occurrence network generated by VOSviewer, illustrating the conceptual structure of the reviewed literature. Keywords like capacity, road, service, level, and city appear prominently, indicating their central role in the discourse. The color-coded clusters show thematic groupings, with green representing road infrastructure and capacity, blue representing service level and quality, and red focusing on urban and technological issues. Lines connecting the nodes represent the strength of relationships between keywords, suggesting how closely concepts are studied together. This visualization highlights the interdisciplinary nature of urban roadway research and reinforces the significance of evaluating side frictions as part of broader traffic and service level studies.

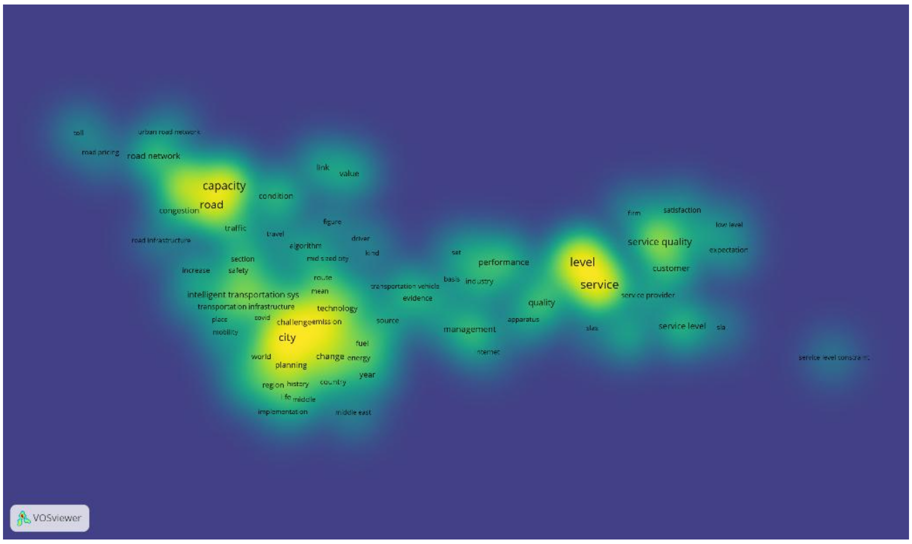

Figure 2. Keyword Density and Clustering Visualization

The image shows a heatmap visualization of keyword density generated using VOSviewer, based on literature related to road service levels and side frictions. Brighter yellow areas represent regions with high keyword frequency and strong interconnections, indicating central topics in the research. The most concentrated termscapacity, road, service, level, and city—are clustered in the brightest areas, suggesting their dominance in the academic discourse. Cooler green and blue areas indicate less frequently discussed but still relevant topics such as management, satisfaction, middle east, and internet. This heatmap helps highlight key areas of scholarly focus and uncovers potential research gaps within urban transportation and roadway performance studies.

3.2 Key Indocators and Evaluation Methods

Across the 56 high-quality studies reviewed, several key indicators are used to assess the impact of side friction on LOS. The most commonly employed indicators include vehicle delay (49 studies), traffic flow rate (44 studies), lane occupancy (38 studies), and average vehicle speed (36 studies).

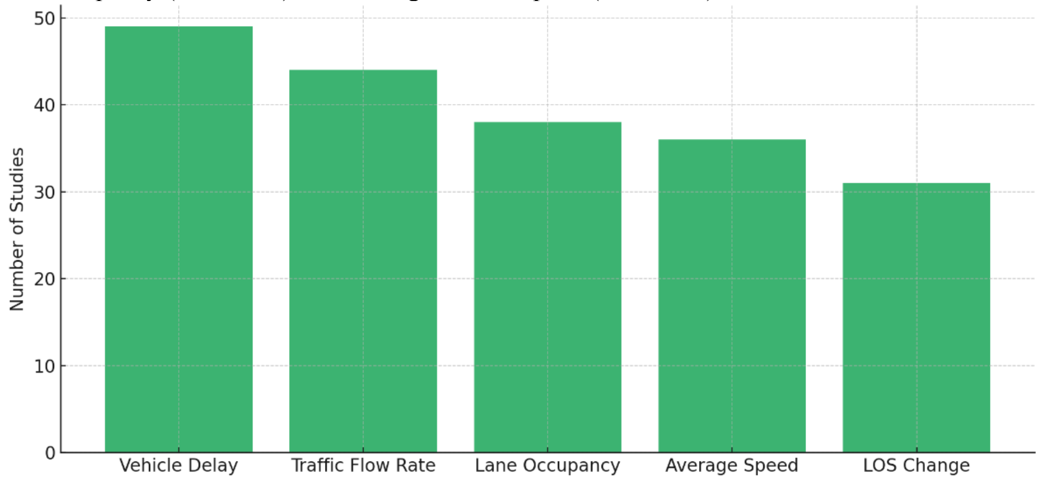

Figure 3. Key Indocators and Evaluation Methods

The bar chart illustrates the number of studies that use various indicators to evaluate the impact of side frictions on urban roadway performance. Vehicle delay emerges as the most frequently used metric, appearing in nearly 50 studies, highlighting its significance in assessing traffic disruptions. Traffic flow rate and lane occupancy follow closely, suggesting that many researchers focus on how frictions affect the volume and distribution of vehicles across lanes. Average speed is also commonly measured, reflecting its sensitivity to interruptions caused by roadside activities. The least used, but still important, indicator is the change in Level of Service (LOS), which aggregates the cumulative effects of all disturbances on overall road performance. Collectively, these findings show that most studies prefer quantifiable and easily observable metrics to analyze the consequences of side frictions on urban traffic flow.

3.3 Side Friction Classification and Intensity Levels

Several studies propose classification schemes to understand different types and intensities of side frictions. Common friction elements are categorized as: Static frictions (e.g., parked cars, road signs, curbside vendors), and Dynamic frictions (e.g., pedestrian crossings, vehicle U-turns, loading/unloading activities).
The intensity of side friction is often represented using a friction index, which combines frequency and duration of disturbances. Table 1 below summarizes a typical classification used in multiple studies.
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Table 1. Example of Side Friction Intensity Classification

Friction Level	Description	Observed LOS Impact
Low	0–5 events per minute	LOS A–B
Medium	6–15 events per minute	LOS C–D
High	>15 events per minute	LOS E–F

The table titled Example of Side Friction Intensity Classification presents a standardized way to categorize the impact of roadside disturbances on road performance. It classifies side friction into three levels—Low, Medium, and High—based on the frequency of events per minute. Low friction (0–5 events/min) corresponds to LOS A–B, indicating smooth traffic flow with minimal delays. Medium friction (6–15 events/min) is associated with LOS C–D, reflecting moderate congestion and reduced operational efficiency. High friction (>15 events/min) leads to LOS E–F, signaling significant delays and poor traffic conditions. This classification is essential for quantifying side friction effects and integrating them into urban road performance evaluations.

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3.4 Modeling Techniques and GIS Integration

An emerging trend in the literature is the use of microsimulation and GIS-based modeling for visualizing and quantifying the effect of side frictions. VISSIM, SIDRA, and Synchro are frequently used platforms to simulate various traffic conditions under different friction levels. These tools help in predicting changes in queue length, travel time, and overall intersection or corridor LOS. GIS integration allows for spatial mapping of friction zones, helping planners identify hotspot areas for targeted interventions.

Simulation-based analysis also aids in testing different mitigation strategies without disrupting real-world traffic. For instance, a study simulating the removal of 50% of illegal curbside parking found that average vehicle delay reduced by 33% during peak hours. Moreover, modeling helps in prioritizing interventions based on cost-benefit analysis, incorporating variables such as enforcement feasibility, user behavior, and road function hierarchy. Overall, modeling tools are critical for translating qualitative friction observations into quantifiable and actionable insights.

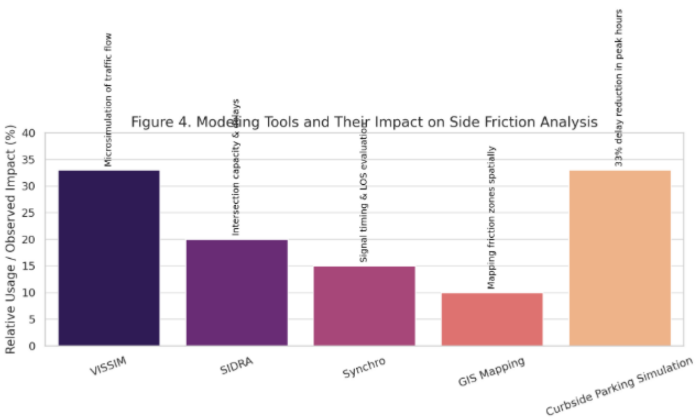

Figure 4. Modeling Tools and Their Impact on Side Friction Analysis

Figure 4 shows a comparison of various modeling tools and methods used in analyzing side friction effects. VISSIM stands out as the most widely utilized platform for traffic flow microsimulation. SIDRA and Synchro are also commonly used for analyzing intersection performance and signal optimization, particularly under varying side friction conditions. GIS mapping plays a crucial role in visualizing spatial distributions of roadside activities, enabling planners to identify high-impact zones. The simulation of curbside parking removal, which demonstrates a 33% reduction in delay during peak hours, highlights how modeling can guide effective interventions. This chart emphasizes the growing reliance on data-driven simulation and mapping tools to inform urban road design and policy strategies.

4. Conclusion

The systematic review reveals that side frictions, including pedestrian activity, on-street parking, and roadside vendors, significantly affect the service levels of urban roadways. These elements contribute to reduced road capacity, increased delays, and frequent interruptions in traffic flow, especially during peak hours. Most studies analyzed employ simulation models and field observations to quantify the impact of these disturbances. The findings suggest that current road design standards often overlook the cumulative effects of side frictions on traffic performance. Therefore, incorporating side friction parameters into traffic analysis and urban planning is essential for accurate LOS assessment. Overall, managing side frictions through policy, design interventions, and enforcement can enhance road efficiency and user satisfaction in urban environments.

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