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Impact of On-Street Parking Space Placement on Through Traffic

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Abstract. On-street parking significantly impacts urban traffic flow. Existing research has primarily focused on pricing policies as a method to mitigate the congestion caused by parking. However, the specific influence of spatial parking configurations on through traffic remains underexplored. This study investigates how the placement of on-street parking spaces affects through traffic, using microscopic simulation to analyse travel time disruptions across a range of scenarios. A simulated urban road network serves as the test environment, allowing for systematic variations in traffic and parking demand at all the potential parking locations. Results indicate that certain parking locations cause significant disruptions to through traffic, with increased delays correlating with higher through and local traffic volumes. Notably, spillover effects from cruising for parking cause delays even at locations away from primary through traffic routes. In contrast, some parking locations near throughways had minimal impact due to available alternative routes. These findings highlight that parking placement impacts are shaped by the interaction of traffic flow and parking demand rather than proximity alone. The results underscore the need for strategic parking placement in urban areas to minimize disruptions to through traffic, suggesting that parking management strategies could reduce adverse impacts on urban mobility.

Submission Type. Model, Analysis.

BoK Concepts. Agent-based modelling, Network Analysis, Users in infrastructure & transport.

Keywords. parking, through traffic, SUMO, microscopic simulation

1 Introduction

Parking, a ubiquitous aspect of urban transportation, has profound implications for both individual drivers and society as a whole. On-street parking, in particular, significantly influences driving behaviour and traffic flow. The decision of where to park often involves a trade-off between convenience and availability. While parking farther away from the destination may increase the likelihood of finding an empty parking space, it necessitates additional walking. On the other hand, parking closer to the destination minimises walking time but decreases the chances of finding a vacant parking space, often leading to a time-consuming and frustrating search, referred to as "cruising for parking" (Shoup, 2006). The phenomenon of cruising is inherently tied to the spatial placement of parking facilities. Poorly allocated or limited on-street parking leads to extended periods of cruising, which not only exacerbates congestion but also disrupts the flow of through traffic, resulting in additional delays, higher emissions, and increased fuel consumption. Therefore, the consequences of on-street parking placement extend far beyond the individual driver.

The existing literature has extensively investigated the economic impact of parking using the cost of parking (Inci, 2015; Anderson and de Palma, 2004). Gillen (1977) noted that, in major urban areas, the time spent searching for a parking spot and walking to one's destination could account for a significant portion of overall travel time. Most studies have sought to mitigate the adverse effects of parking by addressing cruising for parking, predominantly through pricing policies (Fosgerau and de Palma, 2013; Calthrop et al., 2000). In contrast, the impact of the placement of on-street parking on through traffic remains underexplored.

Existing studies have three key limitations. Firstly, they focus solely on off-street parking spaces (Wang et al., 2022; Shen et al., 2019). Secondly, although works such as Ceylan et al. (2014) and Gkini et al. (2018) have explored the optimal on-street parking locations, these studies overlook the differentiation between costs to through and local traffic. Through traffic comprises vehicles passing through without a destination in the locality and primarily considering costs related to their travel times through the locality (Ye et al., 2020; Cao et al., 2017; Guo et al., 2012). In contrast, local traffic, which has immediate destinations and requires parking within the locality, places greater emphasis on search time and walk time (Rybarsch et al., 2017). Although these factors are interrelated, a clear distinction is vital due to their varying impacts on each traffic type. Thirdly, these studies typically assume the spatial distribution of parking spaces as fixed and fail to consider the direct implications of parking space placement on through traffic. Assuming a fixed spatial distribution of parking spaces overlooks real-world variability, especially in low- and middle-income countries where parking locations are often unplanned and responsive to immediate demand (Parmar et al., 2020). This flexible parking placement can directly impact the flow of through traffic by adjusting to changing conditions and local needs.

This study, therefore, seeks to address this gap by examining the impact of the spatial distribution of on-street parking spaces on through traffic within a specified locality, as the distinction between through and local traffic is most meaningful within localized urban areas rather than across a city. Our research question is: *How does the placement of on-street parking spaces within a locality affect the through traffic?* We employ a microscopic simulation-based approach to assess the impact on through traffic at different potential parking locations. This study presents a structured methodology for assessing parking placement strategies in urban networks, providing a valuable decision-support tool for urban policymaking. The approach is adaptable to any city's road network by tailoring the input parameters to reflect local traffic and parking conditions. Moreover, it has the potential to be extended to address issues such as dynamic on-street parking space legality, variable parking pricing, and parking algorithms for autonomous vehicles.

In the following, Section 2 outlines the proposed methodology to assess the impact of spatial parking placement on through traffic. Section 3 demonstrates the methodology on a test network, followed by a discussion of the results in Section 4. The findings are summarised and discussed in Section 5.

2 Proposed Methodology

The impact of on-street parking is perceived differently by through traffic and local traffic, as each faces distinct costs: through traffic primarily values uninterrupted flow to minimize their travel time, while local traffic is more concerned with parking availability near destinations. In urban areas, the allocation of sections of a road or designated lanes for on-street parking introduces potential points of disruption for the continuous flow of through traffic, particularly from vehicles manoeuvring into parking spaces or cruising for parking. Locations that force through traffic to either decelerate or navigate around parked or parking vehicles are hypothesized to have a more significant negative impact. This study assesses the degree of disruption caused by different parking placement configurations by analysing their impact on through traffic travel times.

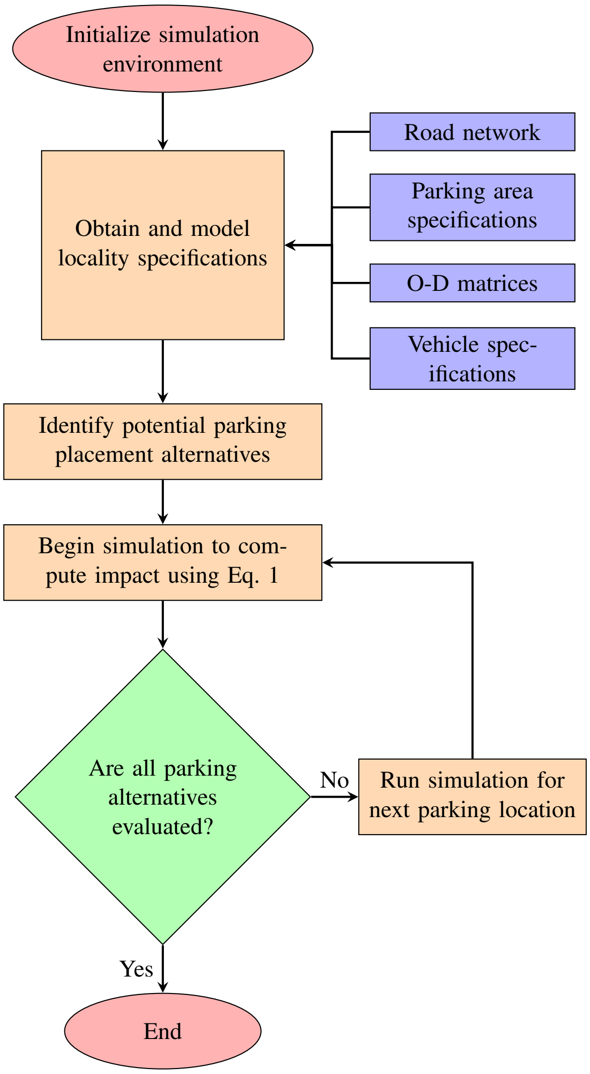

Figure 1. Flowchart illustrating the simulation-based methodology for assessing the impact of parking space placement on through traffic flow.

To achieve this, we employ a simulation-based approach. First, we obtain the road network for the locality under consideration, along with determining traffic and parking demand patterns. These data may be collected through field measurements or by simulating a comprehensive spectrum of scenarios. A baseline scenario is then established, simulating the initial or current conditions to obtain travel times for all the through traffic vehicles. Subsequently, we identify all potential parking locations within the road network. Notably, these locations extend beyond officially designated parking areas to include spaces not typically marked for parking, whether they are proposed sites or locations being evaluated for their suitability as parking spaces.

To assess the impact of parking on through traffic, we use increased travel times as a primary performance metric. For each parking location, we compute the change in travel time for every vehicle that does not have a destination within the network, comparing these values to the baseline scenario. Any disruption to the steady flow of through traffic caused by parking space placement leads to increased congestion, which is reflected in longer travel times. The cumulative impact of parking placement on through traffic is quantified by calculating the average change in travel times across the entire simulation period for the through traffic demand. Eq. (1) quantifies the impact on through traffic.

$$\Delta TT_{\text{avg}}^{\text{scenario}} = \frac{1}{N}\sum_{i=1}^{N}\left(tt_i^{\text{scenario}} - tt_i^{\text{baseline}}\right) \tag{1}$$

where $\Delta TT_{\text{avg}}^{\text{scenario}}$ is the average change in travel time for through traffic in a given scenario, tt_i^{scenario} denotes the travel time for each vehicle i in a given scenario, $tt_{free}^{\text{baseline}}$ refers to the travel time for the same vehicle i in the baseline scenario, and N denotes the total number of vehicles contributing to the through traffic demand. This computation yields an impact, in terms of travel times, associated with each potential parking location under varying traffic and parking demand scenarios.

This methodology is summarized in the flowchart shown in Fig. 1, which outlines the sequential steps from initializing the simulation environment to evaluating each parking alternative.

3 Experiment Design

To demonstrate the proposed methodology, we apply it to a hypothetical road network using SUMO (Simulation of Urban Mobility), an open-source microscopic traffic simulator (Lopez et al., 2018). SUMO incorporates well-established car-following and lane-changing models grounded in traffic flow theory (Erdmann, 2015). The microscopic nature of the simulation explicitly captures vehicle interactions, including those influenced by parking manoeuvres, rather than approximating them through aggregate flow equations.

We use a complex and non-symmetrical, randomly generated, broken grid-type road network. The hypothetical network spans 2 km by 1.5 km and consists of 114 edges. The total length of all edges combined is 32.25 km, with each link representing a bidirectional two-lane road, as shown in Fig. 2, excluding highways and arterials, where on-street parking is generally prohibited. Out of these 114 edges, eight serve as entry and exit points for traffic, resulting in a total of 64 origin-destination (O-D) pairs, as indicated by the green-coloured edges in Fig. 2. Parking is permitted only on the remaining 106 edges, with both lanes available for parking. This configuration yields a total of 212 potential parking locations, each comprising eight on-street parking spaces measuring 6 meters in length and 3 meters in width. A simulated street network was chosen to ensure a controlled environment for evaluation without the constraints of real-world data availability. While empirical traffic data could be used, such data is

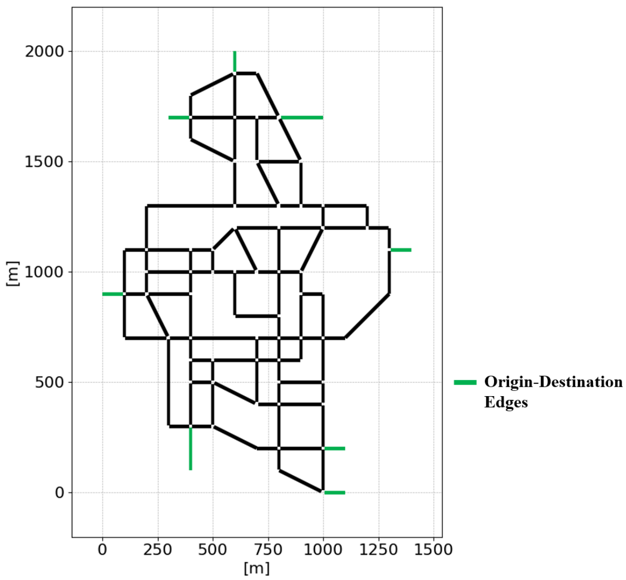

Figure 2. The road network used for demonstration.

often macroscopic in nature and lacks microscopic vehicle interactions. Moreover, the framework can be applied to real-world networks by adjusting input parameters such as traffic demand, parking demand, and network structure accordingly.

The traffic demands, both through and local, are assumed to be uniformly distributed for simplicity, with vehicles entering at equal intervals and exhibiting the same demand for each O-D pair. Although this study assumes uniformly distributed demand, alternative distributions could be incorporated without altering the methodology. Vehicles follow dynamic routing, selecting the shortest path based on current travel times and traffic conditions in the network. Parking manoeuvres may temporarily disrupt through traffic; if a lane change is possible, vehicles adapt, otherwise, following vehicles must wait. Similarly, drivers do not make probabilistic parking decisions but adhere to SUMO's default behaviour, selecting parking spaces based on proximity to their intended destination and travel time to the parking spot. The simulation duration is set to 4 hours or 14,400 time-steps, as results stabilize beyond this period. All vehicles in the simulation are uniform, each with a length of 5 meters and a maximum speed of 70 km/h. Vehicles spend an extra 20 seconds entering and 10 seconds when leaving an on-street parking area, accounting for additional time spent on the road during manoeuvres.

The network reaches its maximum capacity at a through traffic flow of 3,840 vehicles per hour, beyond which an insertion backlog occurs. Consequently, four distinct through traffic flow scenarios and six local traffic demand scenarios, where significant changes in behaviour occurred during sensitivity analysis, were chosen for analysis, as shown in Table 1. The baseline scenario, where no

Table 1. Summary of through traffic and local traffic scenarios, detailing through traffic demand (vehicles/hour), parking demand (vehicle-hours), parking occupancy (%), and parking duration (minutes)

Through Traffic Scenario Name	Traffic Demand	Parking Demand	Parking Occupancy	Parking Duration
Low Traffic	640	64	100	15
Moderate Traffic	1,280	64	100	15
High Traffic	2,560	64	100	15
Max Capacity	3,840	64	100	15
Local Traffic Scenario Name	Traffic Demand	Parking Demand	Parking Occupancy	Parking Duration
High Demand, Long Duration	2,560	64.00	100	15
High Demand, Moderate Duration	2,560	64.00	100	10
High Demand, Short Duration	2,560	64.00	100	5
Moderate Demand, Moderate Duration	2,560	42.33	100	10
Low Demand, Short Duration	2,560	32.00	100	5
Minimal Demand, Short Duration	2,560	21.33	66	5

parking is allowed, serves as a reference to isolate the impact of different parking configurations.

In all through traffic flow scenarios, local traffic demand is fixed at 64 vehicles per hour for 15-minute intervals, representing typical short-term parking in city centres. Similarly, parking occupancy is set to 100% (64 vehicle-hours) to simulate conditions where cruising for parking is prominent. Sensitivity analysis indicates that occupancy below 85% has minimal cruising while exceeding 100% leads to standstill conditions. Although such extremities are not entirely realistic, the behaviour is constrained by the capabilities of SUMO. While these values represent plausible urban conditions, they can be adjusted for different contexts without altering the methodology. Parking demand is quantified in vehicle-hours, which can also be interpreted as the number of vehicles parked per hour multiplied by their average parking duration.

4 Results and Discussion

We ran simulations across four distinct through traffic flow scenarios and six local traffic or parking demand scenarios. For each of these scenarios, we evaluated the impact of placing parking spaces at each of the 212 potential locations.

4.1 Impact of Parking Placement Across Different Through Traffic Flows

As explained in Section 3, local traffic demand is fixed at 64 vehicle-hours, while through traffic flow is varied to conduct simulations under four traffic scenarios. Table 2 presents key statistics for each scenario. The results reveal that parking placement has a varied impact on travel times, with certain locations causing more significant disruptions than others. The disparity between the mean and median values reflects the skewed nature of disruptions, where most parking placements cause minimal delays, but a few highly disruptive locations significantly raise the mean.

Table 2. Statistics of average absolute changes in travel times (in seconds) under four through traffic flow scenarios (640, 1,280, 2,560, and 3,840 vehicles per hour). The data highlights that the mean and maximum travel time increases as traffic flow increases.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Minimum	0.125	0.070	0.629	0.451
Maximum	787.292	896.763	1624.059	2221.854
Mean	51.655	56.405	84.520	172.329
Median	7.797	8.990	11.320	20.208
Variance	120.597	133.424	208.700	381.569

As the heatmaps in Fig. 3 illustrate, even at low traffic flow levels, the edges utilized by through traffic are significantly influenced by on-street parking placement. For instance, parking placement at edge ID 23 (Fig. A1) caused a significant increase in travel time, with a change as high as 787 seconds. Conversely, the impact of parking placement diminishes as one moves toward the centre of the road network, an area less utilized by through traffic at lower flow rates. For instance, parking placement at edge ID 183 (Fig. A1) resulted in the smallest average change in travel time. When the through traffic flow is increased from 640 to 1280 vehicles per hour, the overall distribution of impact remains relatively consistent; however, there is a slight increase in the magnitude of the impact. This observation suggests that at lower flow rates, the effects of parking placement are predominantly confined to the edges actively used by through traffic. As through traffic demand continues to increase toward the road network's capacity, the heatmaps reveal a growing impact on travel times across both outer and inner edges. At these higher flow levels, even inner sections of the network begin to experience notable disruptions due to parking placement, highlighting the strain on through traffic as congestion intensifies across the network.

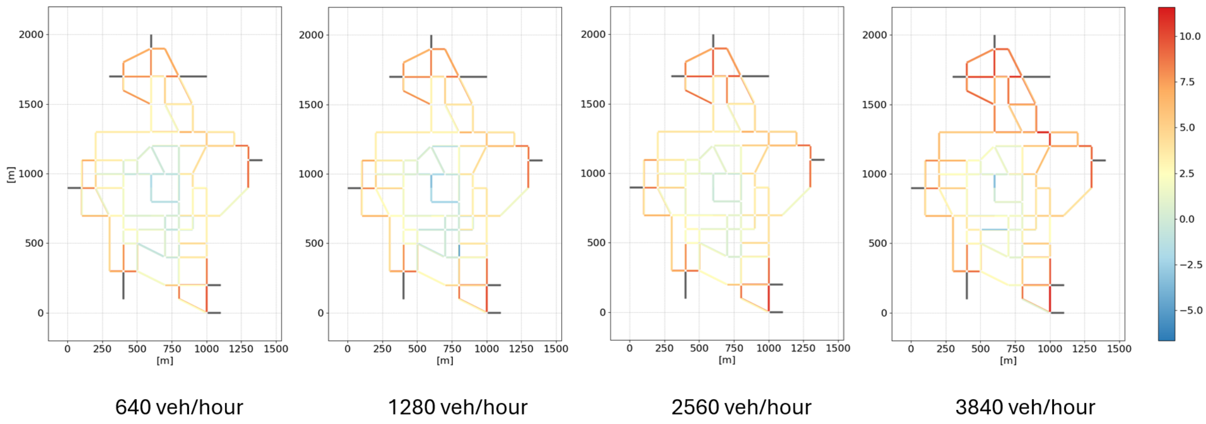

Figure 3. Impact of on-street parking placement on through traffic across four through traffic flow scenarios. Each road section, or edge, is colour-coded based on the average change in travel time experienced by through traffic vehicles as a result of on-street parking placement on that specific edge. The colour scale is plotted on a logarithmic scale to represent the extensive range of observed values effectively.

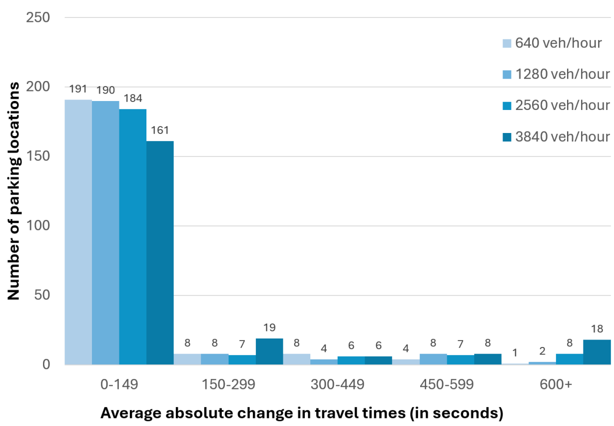

Figure 4. Distribution of average absolute changes in travel time across different through traffic flow scenarios. The X-axis represents the average absolute change in travel time (in seconds), while the Y-axis shows the number of parking placement alternatives that result in that level of disruption.

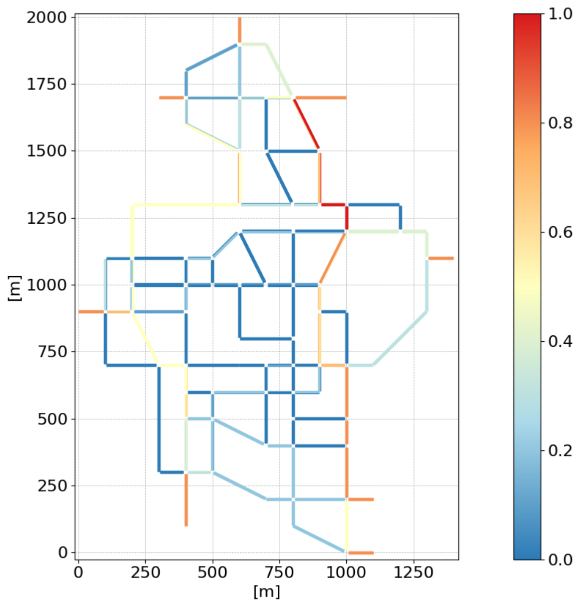

Figure 5. Heatmap illustrating the betweenness centrality of the road network. This represents the relative importance of each edge in connecting the network.

The bar chart in Fig. 4 categorizes the parking locations by the magnitude of their impact on through traffic. In each scenario, the majority of parking locations result in a relatively small increase in travel time (0–149 seconds). As the traffic flow increases, the number of parking locations inducing significant delays also rises, as evidenced by the larger number of locations in the higher time categories. For instance, at the highest traffic flow of 3,840 vehicles/hour, 18 parking locations lead to average travel time changes exceeding 600 seconds, while no such locations exist in the very low capacity scenario. The presence of the 600+ second category in Fig. 4 indicates that certain parking placements lead to significant disruptions in travel time, though this does not imply that vehicles are stacked in the system.

Although traffic flows at arrival are known, dynamic routing prevents exact link-level flows from being precomputed. Therefore, we incorporate betweenness centrality, Fig. 5, to identify structurally important roads. This analysis shows that parking disruptions are not strictly correlated with centrality. Contrary to intuitive assumptions, the impact of parking placement was not confined to the most central edges. Although high-centrality edges often exhibited significant delays, several edges with lower centrality also demonstrated notable impacts. This suggests that factors beyond centrality, such as local traffic patterns and alternative routing options, are critical in determining parking placement impacts. Furthermore, the high disruption observed near exits in this study is primarily due to the specific network geometry rather than centrality. Here, exit edges lack alternative cruising paths, causing parking manoeuvres to directly interfere with through traffic, leading to significant delays. In a different road network with multiple alternative routes, the impact of exit-adjacent parking may differ.

4.2 Impact of Parking Placement Across Different Local Traffic Demands

Next, we fix the through traffic flow and vary the local traffic demand to evaluate how different levels of parking occupancy affect the impact of parking placement.

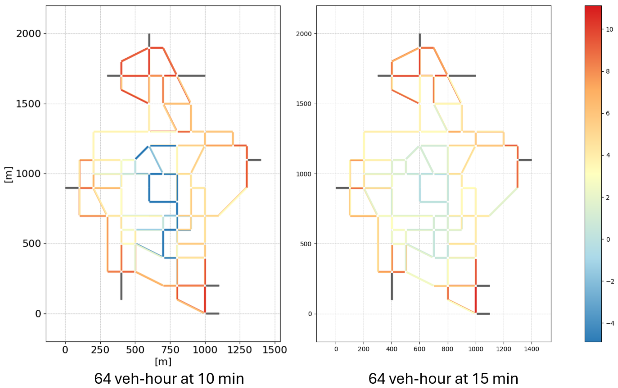

Figure 6. Heatmap illustrating the travel time impact of on-street parking with varying parking durations. Shorter durations generally reduce congestion, especially for roads less used by through traffic.

The heatmaps in Fig. 6 demonstrate that when the parking duration is reduced from 15 minutes to 10 minutes, the impact on the inner edges, which are typically not utilized by through traffic, decreases significantly. This reduction in impact occurs because shorter parking durations reduce the time vehicles spend searching for parking. However, as shown in Fig. 7, further reducing the parking duration while keeping the parking demand constant increases the impact on through traffic. This is because more vehicles are now circulating and cruising for parking, leading to more significant interference with the flow of through traffic.

As we reduce the parking occupancy from 100% to 66%, as illustrated in Fig. 7, the impact of parking on through traffic decreases considerably, regardless of the parking placement. This suggests that cruising for parking plays a significant role in disrupting the flow of through traffic. A further decrease in parking occupancy, as shown in Fig. 8, results in even less impact at each parking placement alternative, reinforcing the notion that lower occupancy levels mitigate the effect of parking-related traffic disruptions.

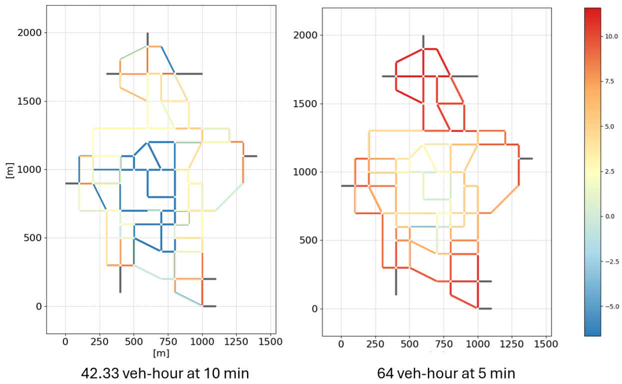

Figure 7. Heatmap illustrating the travel time impact of on-street parking with varying parking durations and demand levels, showing decreased disruptions to through traffic across all roads as occupancy levels decrease.

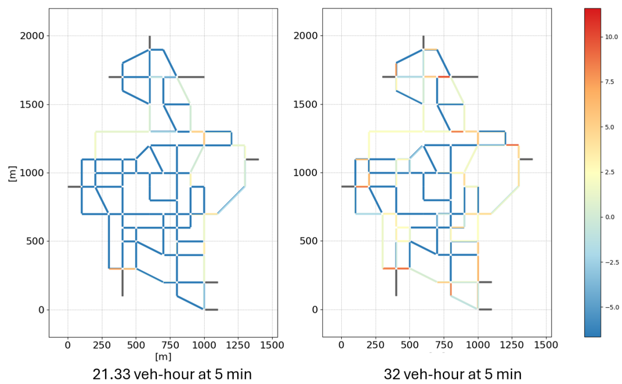

Figure 8. Heatmap demonstrating the minimal travel time impact of parking across all roads at low occupancy levels.

Comparing the results across both through traffic and local traffic demand scenarios, it becomes evident that higher through traffic flows amplify the impact of parking placement, while lower parking occupancies reduce it. These findings also emphasize that the extent of disruptions is not solely dependent on the proximity of parking locations to through traffic routes but is shaped by a complex interaction of traffic flow patterns and local parking demand. This dual influence underscores the need for strategic parking placement tailored to both through traffic and local parking demand patterns to minimize disruptions. Urban planners can use these findings to reduce through traffic disruptions by strategically placing parking. Approaches like dynamic pricing or placing parking in low-impact areas can mitigate the negative effects of cruising for parking.

5 Conclusions

This study presents a framework to analyse the impact of on-street parking placement on through traffic, revealing how specific on-street parking locations can significantly disrupt the travel time of through traffic. The findings indicate that higher traffic volumes and parking demand amplify the disruptive effect of parking placement. Notably, the impact of parking placement is influenced not solely by proximity to central through traffic routes but also by the interaction between through and local traffic and the availability of alternative routes. Crucially, avoiding high-centrality edges alone does not minimize the impact of parking placement, and relying solely on link flow to predict parking-induced delays can be misleading. Instead, a more comprehensive approach that accounts for dynamic routing, cruising effects, and localized interactions is necessary to accurately assess the impacts of parking placement on through traffic. Parking placement strategies must consider a combination of network centrality metrics, local traffic patterns, and alternative routing options to mitigate disruptions effectively.

However, several limitations in this study present opportunities for future work. First, we assumed uniform traffic and parking demand, though real-world demand is often spatially and temporally varied. Incorporating non-uniform demand distributions could improve the accuracy of the simulation framework. Secondly, we only considered the impact of parking placement at individual locations one at a time. Exploring the effects of combinations of parking locations could provide further insights, as multiple parking spaces may collectively influence traffic flow differently. Thirdly, while demonstrated on a hypothetical network, the same model can be applied to any real city and its traffic patterns. Lastly, the study does not account for heterogeneity in vehicles (e.g., different vehicle sizes or types), which could introduce more variability in the impact of parking. Addressing these limitations in future research could help refine our understanding of parking placement's impact on through traffic. By optimizing parking space placement, urban planners can significantly alleviate traffic congestion, thereby enhancing mobility and reducing travel delays for urban commuters.

6 Data and Software Availability Section

The simulations in this study were conducted using SUMO (Lopez et al., 2018), available at SUMO's official website.

To facilitate reproducibility, the input files for all simulation scenarios, including network definitions, traffic demand files, and configuration settings, have been made publicly available in a dedicated repository at https://github.com/prashweb/AGILE-Simulation-Scenarios-Parking-Study-2024.git.

7 Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to improve language and readability. After using this tool, we reviewed and edited the content as needed and took full responsibility for the content of the publication.

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Appendix A

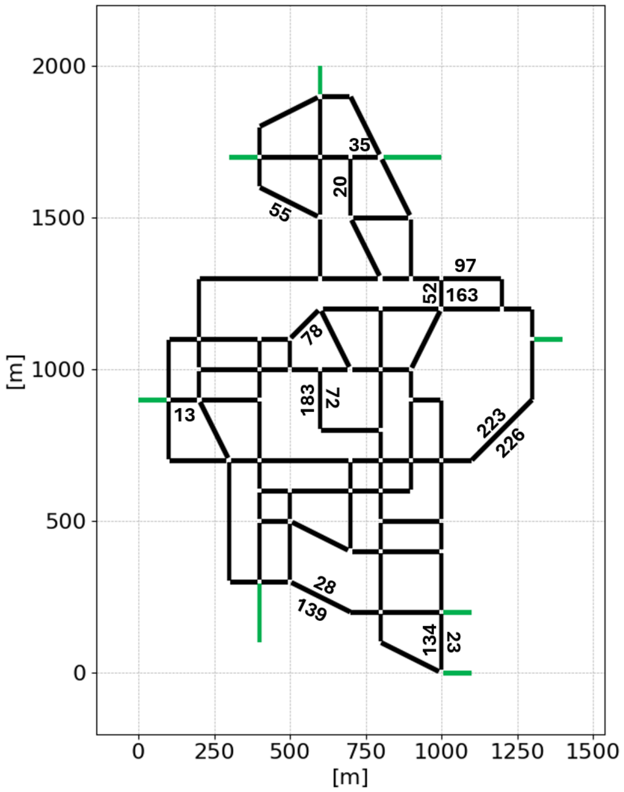

Figure A1. The Road Network showcasing various Edge IDs (shown as numerical).