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Analyzing the Impact of Side Friction on Vehicle Operating Costs and Urban Traffic Performance

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ABSTRACT

On-street parking activities along Merdeka Barat Street in Lhokseumawe City have disrupted traffic flow. This study aims to determine the magnitude of Vehicle Operating Costs (VOC) resulting from on-street parking activities and to compare the VOC with parking fees (retributions). The study was conducted over a 7-day period, from 07:00 to 19:00 WIB. Traffic and parking characteristics were analyzed using the 2023 PKJI method, the VOC analysis employed the 2005 method from the Department of Public Works, and parking retribution was calculated based on Lhokseumawe City Qanun No. 1 of 2024. The analysis revealed that the highest average traffic volume occurred on Tuesday with 1,328 PCU/hour and a Level of Service (LOS) of D. The highest volume of light vehicle parking occurred on Wednesday, totaling 469 vehicles. The average vehicle speeds on Merdeka Barat Street were 51.92 km/h for motorcycles, 29.02 km/h for light vehicles, and 19.26 km/h for heavy vehicles. The total Vehicle Operating Cost (VOC) on Merdeka Barat Street amounted to Rp 21,305,163.94, while the total parking retribution reached Rp 6,164,000. The comparison between the VOC and parking retribution over the 12-hour observation period showed a significant difference of Rp 15,141,239.31.

Keywords: On-Street Parking; Parking Retribution; Traffic Flow; Vehicle Operating Cost (VOC); Vehicle Speed

INTRODUCTION

Transportation is the movement of people or goods from one place to another using vehicles powered either manually or by machines. As time progresses, population growth continues to rise, leading to greater movement of people and goods. This surge in mobility significantly impacts traffic volume, often resulting in congestion along road segments and increased travel costs (Rizki, 2023). Parking is defined as the condition in which a motor vehicle remains stationary for a certain period of time according to its needs, requiring a designated stopping area provided by the government, individuals, or private entities (Hong & Jayahkudy, 2024). Parking problems arise when the demand for parking exceeds the available capacity. Vehicles that cannot be accommodated in designated parking areas often resort to using the roadway (on-street parking), which interferes with traffic flow and reduces the level of service, eventually leading to congestion.

Congestion refers to a condition in which the traffic volume on a road segment exceeds its designed capacity, resulting in vehicle speeds approaching 0 km/h and causing long queues. One of the main causes of traffic congestion is the rapid increase in the number of vehicles each year. Without adequate infrastructure development, this situation leads to new problems, such as the use of road space for parking. This issue is common in densely populated cities with limited parking space due to the large number of commercial buildings and shops (Firadusi et al., 2022). A low level of road service has direct consequences on user costs. The higher the average speed of vehicles on a road segment, the lower the operational costs incurred. Conversely, lower speeds result in higher Vehicle Operating Costs (VOC), primarily due to increased fuel consumption and longer travel times (Sriharyani & Mardiansyah, 2019).

In Lhokseumawe City, the population continues to grow each year. According to data from the Statistics Indonesia of Lhokseumawe Municipality (Badan Pusat Statistik Kota Lhokseumawe/BPS, 2024), the average annual population increase in 2024 is approximately 2,500 people. This population growth contributes to the rising number of vehicles in the city, thereby affecting traffic volumes on urban roads, including Merdeka Barat Street. Merdeka Barat Street in Lhokseumawe is a commercial area with relatively high traffic volume and noticeable on-street parking activity. The imbalance between increasing traffic volume and the road's capacity and performance has led to several issues, such as vehicle queues, travel delays, and a decline in the level of service. These problems directly impact Vehicle Operating Costs (VOC) and contribute to increased travel expenses for road users. On-street parking activities along Merdeka Barat Street, particularly during peak hours, exacerbate traffic congestion and further reduce the road's service level.

Furthermore, urban transport challenges related to on-street parking are not limited to Lhokseumawe but are also prevalent in many Indonesian cities experiencing rapid urbanization. Poorly managed roadside parking contributes not only to traffic inefficiency but also to environmental impacts such as higher fuel emissions and noise pollution. Similar studies in major cities like Surabaya, Yogyakarta, and Medan have demonstrated that unregulated parking zones can reduce road capacity by up to 30%, emphasizing the urgent need for better parking management systems. These challenges underline the importance of understanding how side friction, as a cumulative effect of roadside activities, influences both traffic performance and operating costs.

Therefore, understanding the relationship between on-street parking, traffic performance, and VOC is crucial for developing sustainable traffic management

strategies in Lhokseumawe City. The findings of this study are expected to provide valuable insights for local governments and urban planners in improving parking management, optimizing road capacity, and minimizing transportation costs for the community. In addition, this research can serve as a reference for future studies focused on evaluating the economic impact of side friction factors on urban transport systems, supporting evidence-based policy formulation for more efficient and sustainable city planning.

LITERATURE REVIEW

Fundamentals of Transportation and Traffic

Transportation is a system that enables the movement of people and goods from one location to another using various modes, including motorized and non-motorized vehicles. It plays a vital role in supporting social and economic activities, particularly in urban areas. As population and vehicle ownership grow, urban traffic systems become increasingly congested, leading to reduced travel efficiency and higher transportation costs. The interrelationship between vehicles, roads, and human behavior defines traffic dynamics, where even small disruptions can significantly impact overall traffic performance (Directorate of Urban Traffic and Transportation System Development [Direktorat Bina Sistem Lalu Lintas dan Angkutan Kota], 1998).

Traffic Flow Characteristics

Traffic flow refers to the interaction among drivers, vehicles, and the road. No two traffic flows are exactly the same, even under similar conditions, meaning that the flow on a particular road segment always varies (Marza et al., 2023). Nevertheless, certain parameters are required to represent the condition of a road segment or to be used for design and analysis purposes. These parameters include volume, speed, density, level of service (LOS), and degree of saturation.

Side Friction

Side friction refers to various roadside activities and disturbances that influence the performance of urban roadways. These include on-street parking, pedestrian crossings, loading and unloading activities, vehicles entering or exiting driveways, and street vendors operating along the roadside. According to the Indonesian Road Capacity Manual, side friction is one of the main factors contributing to the decline in traffic flow quality, particularly in urban areas where land use is intensive and the right-of-way is limited (Ministry of Public Works [Departemen Pekerjaan Umum/DPU], 2023). Higher levels of side friction typically result in more frequent interruptions to traffic flow, increasing travel time and reducing average speeds (Rosalia et al., 2023). Numerous studies have shown that side friction significantly affects urban traffic performance indicators such as speed, capacity, and level of service (LOS). Side friction can reduce effective lane width, force lane changes, and create unexpected stops, all of which lead to reduced road capacity and increased vehicle queuing (Srivastava & Kumar, 2023). As a result, roads with high side friction often operate at a lower LOS, particularly during peak hours. The Highway Capacity Manual (Transportation Research Board, 2016) suggests that side friction should be considered when assessing operational efficiency in urban road segments, especially in developing countries with high levels of informal roadside activity.

Vehicle Operating Cost

Vehicle Operating Cost (VOC), as defined by the DPU (2005), refers to the total cost required to operate a vehicle under specific traffic and road conditions for a particular type of vehicle per kilometer of travel distance (Rp/km). VOC consists of various cost

components incurred during vehicle operation under particular conditions. The main components of VOC include fuel costs, engine oil and lubricant expenses, tire wear and replacement, routine maintenance and repair, and vehicle depreciation due to travel distance. Additionally, in the case of commercial or freight vehicles, VOC may also include driver wages and the value of time lost due to delays. These components are interrelated and significantly influenced by factors such as vehicle speed, road surface condition, and side friction caused by on-street parking or other roadside activities (Widari et al., 2023).

The Impact of On-Street Parking on Vehicle Operating Cost

On-street parking is a major issue contributing to congestion in urban areas due to the reduction in road capacity caused by the use of part of the roadway for parking spaces. Transportation problems in urban areas arise from the high demand for movement, which cannot be balanced by the availability of adequate road networks. As a result, on-street parking activities often lead to traffic congestion, which in turn generates external costs that must be borne by road users. According to Firdausi et al. (2022), the impact of on-street parking on Vehicle Operating Costs (VOC) generally includes the following: a decrease in average speed, increased traffic congestion, time-loss costs, higher fuel consumption, elevated maintenance and repair costs, and potential vehicle damage.

RESEARCH METHOD

Research Design

This study employs a quantitative method with a case study approach on Jalan Merdeka Barat, Lhokseumawe City. The analysis is based on primary data obtained from field surveys and secondary data collected from relevant agencies. The quantitative method was selected because this research requires numerical measurement of traffic variables and the calculation of Vehicle Operating Costs (VOC) to produce objective and measurable results.

Research Location and Time

This study was conducted along the Merdeka Barat road section in Lhokseumawe City, specifically between AN Coffee and Pizza Hut, where on-street parking activities were observed. Data collection was carried out over seven consecutive days, from Monday to Sunday, between 07:00 and 19:00 WIB.

Primary Data

Primary data refers to information obtained directly from the source, which requires processing before it can be analyzed. This type of data is often termed original or new, as it reflects current and site-specific conditions. Researchers must collect primary data firsthand through methods such as surveys, experiments, or observations to ensure accuracy and relevance. The collection methods for primary data vary according to the research objectives. Surveys were conducted to assess road geometry, traffic volume, vehicle speed, and parking characteristics, with each dataset serving a distinct analytical purpose. These measurements allow researchers to evaluate infrastructure conditions, identify traffic patterns, and observe behavioral trends, forming the basis for evidence-based decision-making in transportation studies.

Secondary Data

Secondary data consist of information obtained from existing sources, with researchers serving as secondary collectors rather than the original producers of the material. This type of data is readily accessible and can be sourced from government agencies,

institutional publications such as the *Statistics Indonesia of Lhokseumawe Municipality* (BPS, 2024), academic journals, official reports, and digital platforms. Its availability allows researchers to efficiently incorporate external datasets into their analyses without conducting new field observations.

The secondary data used in this study include location maps obtained from Google Earth, demographic statistics from municipal records, regional parking regulations, and Vehicle Operating Cost (VOC) component prices derived from official publications and verified websites. These datasets serve various purposes, including geographical identification, demographic analysis, policy evaluation, and economic assessment.

Research Implementation Stages

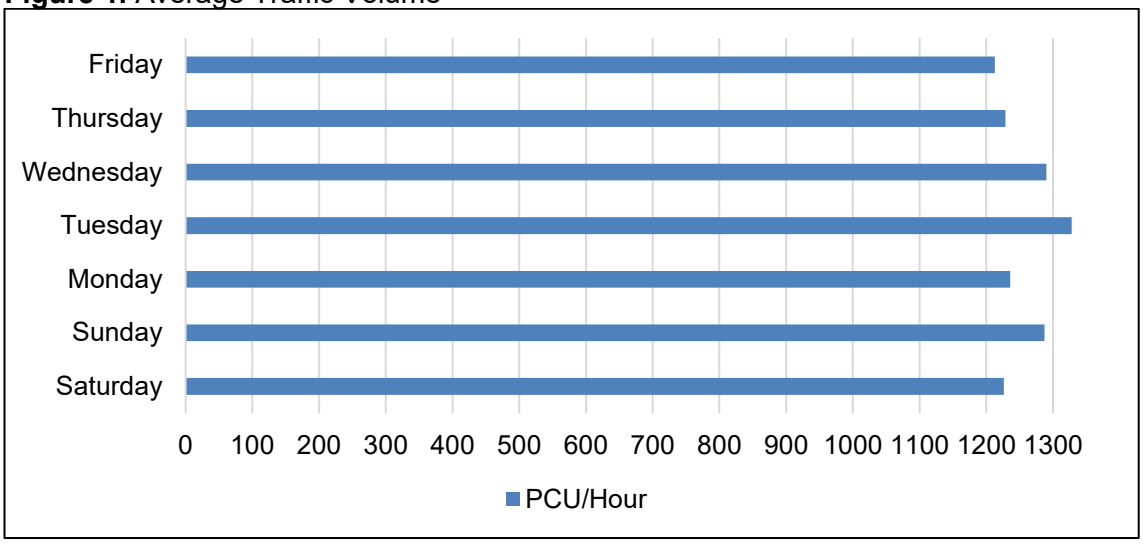
The research implementation follows a systematic process that begins with problem formulation, literature review, and preliminary surveys. Data collection encompasses both primary measurements (road geometry, traffic volume, speed, and parking characteristics) and secondary sources (location maps, cost components, and parking regulations). The analysis employs the *Indonesian Road Capacity Manual* (DPU, 2023) as the primary reference for traffic and parking evaluation, alongside the DPU (2005) methodology for calculating vehicle operating costs (Hilman et al., 2023). The process concludes with the interpretation of results, formulation of conclusions, and development of recommendations. This structured and methodical approach ensures consistency with established analytical frameworks in transportation research and upholds empirical validity through standardized evaluation techniques.

RESULTS

Traffic Volume

Traffic volume data were collected through a seven-day field survey conducted from November 2 to 8, 2024, at 15-minute intervals between 07:00 and 19:00 WIB, using vehicle classifications based on the *Indonesian Road Capacity Manual* (DPU, 2023).

Figure 1. Average Traffic Volume



Based on the traffic volume data analysis table above, the highest average traffic volume occurred on Tuesday, with 1,328 PCU/hour.

Vehicle Speed

A speed survey was conducted to measure the velocities of three vehicle categories: motorcycles (MC), light vehicles (LV), and heavy vehicles (HV). The recorded average speeds were 51.92 km/h for motorcycles, 29.02 km/h for light vehicles, and 19.26 km/h for heavy vehicles. These findings demonstrate significant variations in speed patterns across different vehicle types, reflecting their distinct operational characteristics. Motorcycles exhibited the highest average speed, while heavy vehicles maintained the lowest, consistent with typical traffic behavior.

Degree of Saturation

The degree of saturation serves as the primary indicator for assessing the performance of a road segment, with its value determining potential capacity issues. A capacity of 3,060 PCU/hour serves as the benchmark for evaluation.

Table 1. Degree of Saturation

Observation Days	Peak Hour Volume (PCU/Hour)	Degree of Saturation (DS)
Saturday	2340.9	0.765
Sunday	1990.1	0.650
Monday	1576.1	0.515
Tuesday	1581.9	0.517
Wednesday	1467	0.479
Thursday	1403.1	0.459
Friday	1404.1	0.459

Level of Service

The level of service (LOS) for a road segment is determined by its degree of saturation (DS), which reflects traffic flow conditions. The observed DS values ranged from 0.459 to 0.765 across different days, corresponding to LOS categories C and D. A DS value of 0.765 on Saturday resulted in LOS D, indicating unstable traffic flow with reduced speeds and volumes approaching road capacity. All other observation days exhibited DS values below 0.650, consistently yielding LOS C. This classification represents stable traffic flow conditions where vehicle speeds remain controllable. The data demonstrates that weekend traffic, particularly on Saturdays, experiences greater congestion compared to weekdays, suggesting periodic variations in road usage patterns that may inform traffic management strategies.

Parking Volume

Parking volume refers to the number of vehicles occupying parking spaces within a designated area over a specified time period. This metric serves as a key indicator of parking demand and infrastructure utilization. The data presented in Table 1 demonstrates fluctuations in light vehicle parking volumes across different days, with values ranging from 392 on Thursday to 469 on Saturday. The weekly parking volume for light vehicles totals 3082, as recorded over seven consecutive days of observation.

Parking Accumulation

Figure 2. Parking Accumulation

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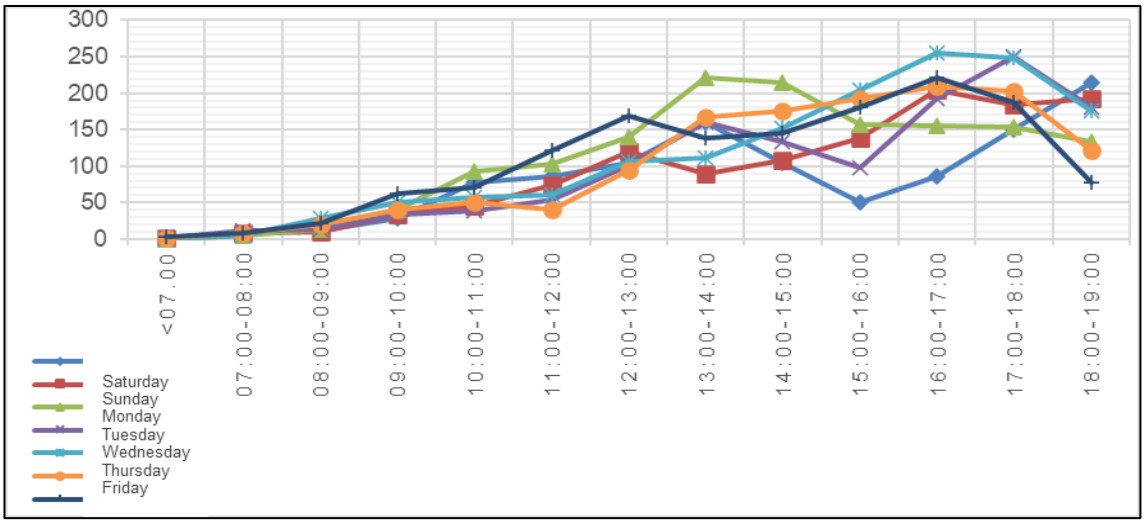
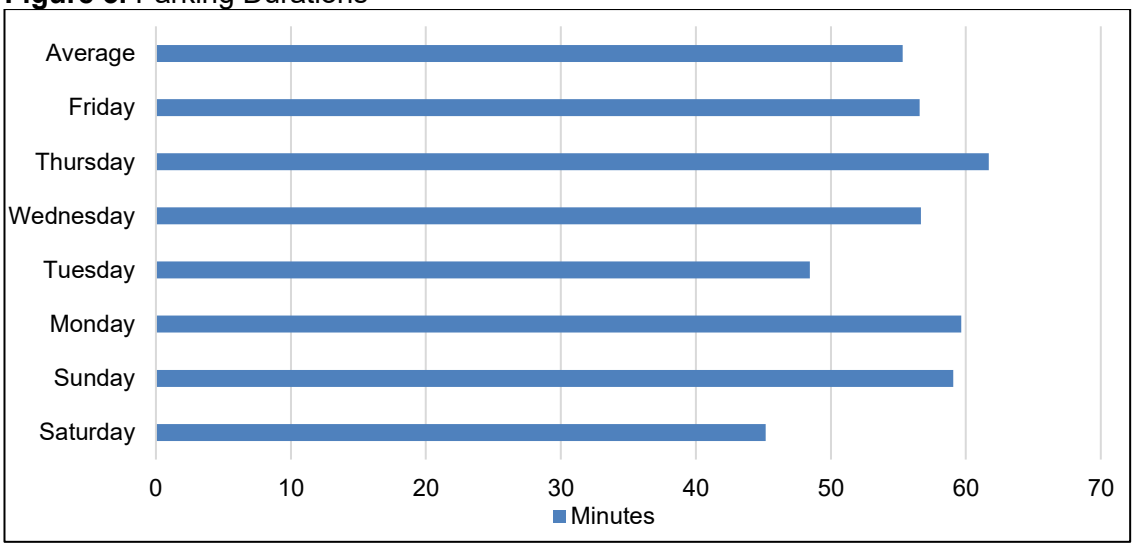


Parking Duration

Parking duration refers to the length of time a vehicle remains parked in a parking location within a specific time interval. The observed data reveal variations in duration across different days, with the highest average value of 61.71 minutes recorded on Thursday and the lowest value of 45.17 minutes on Saturday. The weekly average duration was 55.33 minutes, indicating relatively consistent measurements overall, although weekend values tended to be lower compared to weekdays. These fluctuations may reflect differences in daily activity patterns or operational conditions that influenced the recorded durations.

Figure 3. Parking Durations



Parking Space Requirement

Parking space requirement is the number of spaces needed for vehicles to park. Based on a seven-day survey with 12 hours of observation per day, the parking space requirement for the Merdeka Barat road section is as follows.

Table 2. Parking Space Requirement

Days	Number of parked vehicles (veh) (Y)	Average parking duration (hours/veh) (D)	Required parking spaces Z = Y x D/T
Saturday	469	0.777	30.35
Sunday	400	0.984	32.81
Monday	465	0.994	38.53
Tuesday	453	0.807	30.48
Wednesday	466	0.944	36.68
Thursday	392	1.028	33.60
Friday	437	0.943	34.34
Average Parking space requiment			33.83

Parking Disruption Level

Parking disruption level refers to the impact of parking activities on the smooth flow of traffic, which includes the number of vehicles causing disruption, the number of vehicles affected, the length of the disruption area, and the duration of the disruption time.

Table 3. Parking Disruption level

Days	Disruptions	Queues		Queue length (Meters)	Queue Duration (minutes)
		MC	LV		
Saturday	7	24	24	126	26
Sunday	6	17	15	88	18
Monday	5	12	17	78	19
Tuesday	6	13	15	67	18
Wednesday	8	18	16	88	21
Thursday	6	12	7	47	10
Friday	5	12	11	59	17

Items Consumption

Items consumption on the Merdeka Barat road section, obtained from the analysis of observation data using the DPU (2005) method for each type of vehicle, is as follows:

Table 4. Total Items Consumption Costs

Vehicle Type	Fuel (Rp)	Lubricating Oil (Rp)	Spare Parts (Rp)	Tire (Rp)
Sedan	6,674,781.76	1,298,791.43	1,195,941.58	1,470.38
Utility	2,829,075.27	652,865.74	836,172.26	1,239.53
Small Bus	411,141.57	73,003.22	108,773.58	237.46
Large Bus	18,840.77	11,937.36	1,089.19	4.29
Small Truck	2,539,363.30	203,201.13	9,642.01	550.13
Medium Truck	64,433.05	21,377.39	5,293.34	13.41
Large Truck	106,380.37	10,593.72	64.45	11.92
Total	12,644,016.09	2,271,769.99	2,156,976.41	3,527.12

Table 5. Total Maintenance Labor and Vehicle Operating Cost

Vehicle Type	Maintenance (Rp)	VOC (Rp)
Sedan	2,251,628.20	11,422,613.35
Utility	1,430,766.87	5,750,119.67
Small Bus	388,788.32	981,944.14
Large Bus	4,689.28	36,556.60
Small Truck	126,261.37	2,879,017.95

Medium Truck	26,463.42	117,580.60
Large Truck	281.15	117,331.62
Total	4,228,878.61	21,305,163.94

Parking Retribution

Based on *Lhokseumawe City Qanun No. 1 of 2024* concerning parking service retributions on public roads and in special parking areas, the parking fee rate on public roads in Lhokseumawe City for four-wheeled vehicles is Rp 2,000 (Lhokseumawe City Government [Pemerintah Kota Lhokseumawe], 2024). The amount of parking retribution on the Merdeka Barat road section (Km 1.8–Km 2.3) can be analyzed based on the number of vehicles parked along that section during the observation period.

Table 6. Parking Retribution

Days	Parked Vehicles (units)	Total Retribution (Rp)
Saturday	469	938,000
Sunday	400	800,000
Monday	465	930,000
Tuesday	453	906,000
Wednesday	466	932,000
Thursday	392	784,000
Friday	437	874,000
Total parking retribution		6,164,000

DISCUSSION

The results of this study indicate that side friction significantly increases vehicle operating costs by reducing average travel speeds and causing frequent stop-and-go conditions. These findings are consistent with Firdausi et al. (2022), who observed that roadside parking and informal loading activities increase fuel consumption and reduce overall road performance. Similarly, Hilman et al. (2023) emphasized that the presence of side friction along urban corridors leads to delays, reduced travel speed, and elevated fuel usage, conditions that are also evident in the case of Merdeka Barat Street. The increase in operating costs observed in this study can thus be attributed primarily to higher fuel consumption, vehicle wear due to repeated acceleration and braking, and increased maintenance frequency under congested conditions.

Moreover, the findings reveal a clear deterioration in traffic performance, as shown by the decline in the Level of Service (LOS) from C to D, and in some cases approaching E during peak hours. This result supports the conclusions of Putra and Hidayah (2019), who found that on-street parking significantly reduces effective lane capacity and leads to unstable traffic flow. The current study strengthens that evidence by quantifying the economic implications through Vehicle Operating Cost (VOC) calculations. The total VOC of IDR 21,305,239.31 compared to total parking retribution of IDR 6,164,000 demonstrates a substantial cost imbalance borne by road users. This discrepancy highlights the hidden externalities of poorly managed on-street parking, where individual convenience results in collective economic loss.

From a policy perspective, these results suggest that effective management of side friction can play a critical role in improving traffic efficiency and reducing unnecessary vehicle operating costs. Strategies such as restricting roadside parking during peak hours, designating loading and unloading zones, and developing off-street parking facilities could mitigate the adverse impacts of side friction. These approaches are

supported by Marza et al. (2023) and Rosalia et al. (2023), who both found that physical and regulatory improvements to road space allocation can significantly enhance traffic flow and reduce congestion-related expenses. Local governments should therefore consider integrating dynamic parking policies, periodic traffic monitoring, and enforcement mechanisms to optimize road performance in dense commercial areas such as Merdeka Barat Street.

In addition, the results demonstrate that high side friction not only affects operational costs but also contributes to broader urban inefficiencies, including lost time and productivity. These findings align with international studies such as Nooh et al. (2018) and Widari et al. (2023), who noted that friction-induced slowdowns result in substantial economic losses in urban environments. Hence, addressing side friction is essential not only for technical traffic management but also for promoting urban economic efficiency and sustainability.

However, this study is limited by its focus on a single urban corridor and does not account for variations in land use intensity, pedestrian activity, or signalized intersection effects. Future research should extend this analysis to multiple urban road types and integrate simulation-based modeling to capture the dynamic interactions between side friction, traffic composition, and urban land use. Incorporating behavioral variables such as driver compliance and enforcement effectiveness would also enrich understanding of friction management strategies in Indonesian urban contexts.

CONCLUSION

Based on the calculations and analysis of the impact of on-street parking on Vehicle Operating Costs (VOC) along Merdeka Barat Street, Lhokseumawe City, several conclusions can be drawn. The highest traffic volume reached 1,328 PCU/hour, with average speeds of 51.92 km/h for motorcycles, 29.02 km/h for light vehicles, and 19.26 km/h for heavy vehicles. The road's level of service was classified as Level D, indicating unstable traffic flow approaching capacity, which may lead to congestion. During the seven-day observation period, the total on-street parking volume reached 3,082 vehicles, with an average parking duration of 55.33 minutes and a peak occupancy index of 92%, showing near-full utilization during peak hours. Although the available parking space could still accommodate demand, it was operating close to maximum capacity. The total Vehicle Operating Costs generated by on-street parking activities over the seven-day, 12-hour observation period amounted to IDR 21,305,239.31, with the highest cost recorded on Sunday (IDR 3,253,950.34) and the lowest on Thursday (IDR 2,719,940.40). Meanwhile, the total parking fees collected during the same period amounted to IDR 6,164,000, with the highest revenue on Saturday (IDR 938,000) and the lowest on Thursday (IDR 784,000). The comparison between Vehicle Operating Costs and parking fee revenues revealed a significant difference of IDR 15,141,239.31, indicating that the economic burden borne by road users due to on-street parking is substantially higher than the parking revenue collected by the authorities.

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DECLARATION OF CONFLICTING INTERESTS

The authors have declared no potential conflicts of interest concerning the study, authorship, and/or publication of this article.

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