Multilane Highway Performance and Infrastructure Investment- A Field Evaluation of Level of Service Against Malaysian Highway Guidelines

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DOI: https://doi.org/10.47772/IJRISS.2026.100700528

Received: 24 July 2026; Accepted: 30 July 2026; Published: 06 August 2026

ABSTRACT

Assessing highway performance is essential not only for managing traffic flow, but also for ensuring that infrastructure investments yield optimal operational benefits. Level of Service (LOS) is the standard measure for evaluating operational traffic quality, ranging from LOS A (free-flowing) to LOS F (heavily congested). Although the Malaysian Highway Capacity Manual (MHCM) provides guidelines for estimating LOS, empirical verification against real-world traffic conditions remains limited—a gap that directly impacts investment and planning decisions. This study evaluated the LOS of four multilane highway segments along Jalan Kuala Selangor–Kapar and Jalan Kapar–Kuala Selangor, comparing sites with and without physical medians. Field traffic data were collected using tally counters over two days per location, combined with geometric road measurements, and analyzed using Minitab software. The findings indicated that all four sites currently operate at LOS A or LOS B, reflecting smooth traffic flow, minimal delays, and high driver comfort. These results confirm the ongoing validity of the MHCM framework under present conditions while establishing an empirical baseline for highway authorities to time and target future infrastructure spending, such as lane widening, as demand increases.

Keywords: Level of Service, multilane highways, infrastructure investment, traffic flow, Malaysian Highway Capacity Manual

INTRODUCTION

Highway performance had been widely studied as a technical concern; however, it also directly shapes how efficiently people and goods move across a region, and how well public investment in roads is actually paying off. Level of Service (LOS) is the standard measure used to assess this performance, especially on multilane highways where traffic flow, vehicle dynamics, and infrastructure design collectively influence the overall user experience (Salam et al., 2022). Malaysian Highway Guidelines consist of a series of criteria for Level of Service (LOS) evaluation on multilane highways, but there is a demand to compare the performance of this framework against conditions in the real world.

Multilane roads play a major role in Malaysia's road network, providing mobility for people and commodities across the country. Maintaining the maximum level of service on these roadways is critical to meeting levels of efficiency, safety, and user quality, and, by extension, ensuring a strong return on the investments made in these corridors.

While the Malaysian Highway Capacity Manual (MHCM) provides a theoretical framework for highway evaluation, several factors complicate its practical application, such as varying road environments, user behaviors, and complex interactions between vehicles. In view of these challenges, measuring the LOS of multilane highways using real data and comparing the results with MHCM standards is of great importance. Such empirical evaluations help identify inconsistencies, formulate performance improvement recommendations, and guarantee that design and investment decisions align with current and future traffic needs.

The rise of multilane highways in Malaysia has led to specific user-centric problems that may not be predicted by current guidelines. Although the Malaysian Highway Capacity Manual provides guidelines for assessing highway performance, traffic congestion and unsmooth traffic flow—which often differ from theoretical outcomes—are frequently encountered. These operational discrepancies stem from limitations in the MHCM, which primarily measures rural and suburban highways (Khoo et al., 2024). As a result, these problems affect user comfort, safety, and general highway operational efficiency, directly impacting the effectiveness of related investment decisions.

Level of Service (LOS) serves as a critical performance metric that shapes highway design, traffic control, and infrastructure resource allocation. While the Malaysian Highway Capacity Manual (MHCM) offers a consistent method for estimating LOS, it lacks recent empirical verification against field conditions (Rahmat et al., 2023). Without continuous validation, planning recommendations risk becoming outdated, leading to inefficient operations and misaligned capital investments.

To address these gaps, this study evaluates the current Level of Service across four selected multilane highway segments along Jalan Kuala Selangor–Kapar and Jalan Kapar–Kuala Selangor using MHCM guidelines. By analyzing empirical traffic parameters—including traffic volume, flow rate, speed, and density—across both divided and undivided configurations, this research validates the MHCM framework under present field conditions and provides evidence-based recommendations to guide future infrastructure planning and asset management.

LITERATURE REVIEW

Multilane Highway

A multilane highway is one that has two lanes or more for the exclusive purpose of carrying traffic in each direction. Access is either completely or partially uncontrolled, and there may be sporadic halts in traffic because of signalized intersections that are more than three kilometres away (Vien et al., 2019). In Malaysia, multilane highways are extremely prevalent. These roads may be divided or undivided. A rigid or flexible barrier separates divided roadways. These obstacles, which divide each route, could be paved or a landscape median. Multilane highways are frequently seen in suburban areas that connect to major cities.

Guidelines for managing and assessing capacity and service quality for different highway facilities are found in the Highway Capacity Manual (HCM). Based on a research study, a comparison had been made between the US Highway Capacity Manual and the Malaysian Highway Capacity Manual for the evaluation of multilane highways (Adnan et al., 2023). According to the data analysis done, MHCM 2011 measures the density of multilane highways more accurately than HCM 2010, which tends to underestimate the density during peak hours when the flow rate is significantly higher. It was found that MHCM 2011 better accurately depicts the state of traffic flow on Malaysian roads, as HCM 2010 was created without accounting for the geometrical, geographical, driver behaviour, and data collection characteristics of Malaysian highways.

Level of Service

According to HCM 2011, the Level of Service is characterized as a qualitative assessment of operational conditions in a traffic flow, determined by measures such as travel flow, speed, ability to manoeuvre safely, and overall driver comfort and convenience. Levels of service range from "A" to "F," indicating the complete variety of traffic operating conditions from optimal to poor. Conditions where traffic volumes are below the facility's capacity are often represented by levels of service "A" through "E," whereas conditions where capacity is exceeded or forced conditions exist are represented by level of service "F".

Level of Service (LOS) is determined by analyzing three interrelated traffic parameters, namely flow rate, speed, and density. These parameters work together to characterize the operational performance of a road segment, thus helping engineers evaluate its efficiency and capacity. The relationship among these three parameters is normally read off a reference chart that combines the speed-flow curve with the density-flow curve into a single diagram: as flow rate rises along the horizontal axis, a family of curves for different free-flow speeds (ranging from 60 to 110 km/h) shows how average travel speed responds, while diagonal density lines cutting across the chart (from roughly 7 to 31 passenger cars per kilometre per lane) divide the space into six bands labelled LOS A through LOS F. A road segment's measured flow rate, speed, and density can be plotted directly onto this chart to read off which LOS band it falls into, and this is the reference used throughout the present study to classify each site's measured parameters against the A-F scale.

Flow Rate and Density

Flow rate is commonly expressed in terms of vehicles per hour (veh/hr), and is an important performance and capacity parameter for roadway evaluation. Flow rate is affected by a number of different influences, such as road geometry and traffic control, environmental conditions, and driver behaviour. Specifically, in practical scenarios, flow rate plays a significant role in the assessment of Level of Service (LOS) of a road. It was found that the road cross-section parameter and the posted speed limit greatly affect the speed-flow relationship of the road in an area (Naser, 2021). Meanwhile, it was found that the density-flow relationship is highly sensitive to aggressive drivers and a high number of heavy vehicles (Kockelman, 1998).

Density illustrates the flexibility of movement within the flow of traffic. Density of road systems is critical for analysis and management purposes. It also serves as a basis on which to assess the performance of transportation infrastructure, specifically in urban environments with high road traffic. Traffic density is influenced by road capacity, driver actions, vehicle types, and, more indirectly, external factors like weather or traffic accidents. According to HCM 2011, as flow rate increases from zero, density will also increase from zero as there are more vehicles on the highway. Apart from that, it was said that density changes uniformly across the free-flow speed range. Understanding the relationship between flow rate, density, and speed is important for improving road design and traffic management.

Speed

Speed is a crucial factor in traffic engineering that can characterize the dynamic relationship among road users, road design, and traffic control systems. It serves a crucial role in evaluating the effectiveness, safety, and capacity of roadway infrastructure. Velocity influences not just the duration of travel, but also Level of Service (LOS), fuel usage, and vehicle emissions. Traffic evaluation had well-defined several distinct types of speed used for this purpose: free-flow speed, which describes how fast a vehicle travels when it is essentially alone on the road with no interaction from other vehicles or control devices; running speed, which is the average speed maintained while a vehicle is actually in motion, excluding any stopped time; and travel speed, which is the overall average speed over a trip including any stops or delays along the way. Each of these captures a different aspect of how a vehicle moves along a segment, and together they give a fuller picture than a single average speed figure would. Research indicated that on a multilane highway, lane width, median width, and access points along the road segment emerged as the key factors affecting operating speed (Semeida, 2013). Furthermore, it was found that the operating speed is hardly affected by the posted speed limit. This highlights the significance of speed, as it is a factor that directly influences the assessment of the highway's Level of Service.

Highway Asset Management and Investment Decisions

Level of Service had also been found to carry relevance beyond the traditional engineering domain, as it also functions as an input into how infrastructure agencies decide where and when to invest limited resources. It has been proposed that LOS can be formally incorporated into infrastructure investment decision-making as a performance indicator, helping agencies produce resource allocation plans that remain compliant with service standards while directing funding toward the segments most in need of improvement (Sharma et al., 2008). This phenomenon shows that an LOS evaluation such as the one conducted in this study is not simply a compliance check against the MHCM, but a decision-support exercise that tells infrastructure authorities where a corridor is performing well and where it may warrant future capital investment, such as lane widening or the addition of auxiliary lanes.

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

Research Gap

Based on the studies reviewed, it had been found that LOS is shaped by a well-established set of parameters, namely flow rate, density, and speed, and that the MHCM offers a locally calibrated alternative to international frameworks such as the HCM. However, empirical verification of the MHCM against current, real-world traffic conditions on Malaysian multilane highways remains limited (Rahmat et al., 2023), and existing studies rarely connect LOS findings explicitly to infrastructure investment decision-making. This gap, namely a current, field-based evaluation of MHCM performance that also considers its implications for investment and asset management, is what the present study aims to address.

METHODOLOGY

Methodological Framework

The study followed a structured sequence of six stages, illustrated in Figure 1. It began by defining the study objectives, conducting a preliminary site survey to shortlist candidate locations along Jalan Kuala Selangor-Kapar and Jalan Kapar-Kuala Selangor, and carrying out a detailed site survey to confirm the potential traffic pavements to be selected. The second stage involved obtaining the necessary approvals and setting up the equipment strategy, including the entry into the site location and the readiness of the tally counter, measuring wheel, and stopwatch. This was followed by a pilot test run to determine the sampling approach and test the instruments and data collection method. The fourth stage was the main data analysis, covering free-flow speed, flow rate, average travel speed, density, and Level of Service. The fifth stage was a validity check, where the archived data was compared with published findings to confirm it was reasonable. The process concluded with the sixth stage of results, discussion, conclusion, and report writing. As shown in the figure, each stage feeds directly into the next in a linear sequence, meaning any issue caught at the validity-check stage would require revisiting the data analysis stage before the study could proceed to write-up.

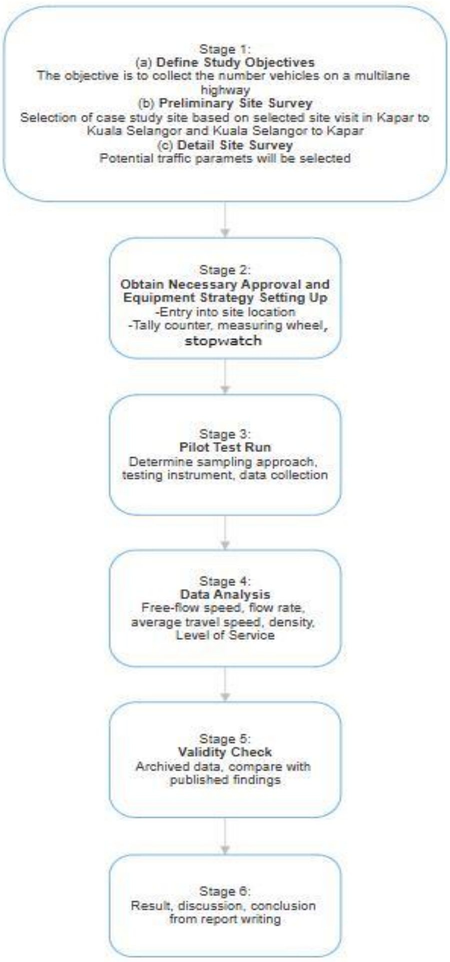

Figure 1. Flowchart of study

Location

The study locations that were selected for the collection of data were Jalan Kuala Selangor-Kapar and Jalan Kapar-Kuala Selangor, which are located on the West Coast Expressway highway in Selangor, as shown in Figure 2. The type of road is a divided multilane highway of 4 lanes, with 2 lanes in each direction. Other than that, the design standard is R5, and the geometric topography of these study areas is flat terrain. The locations were chosen according to the geometric design, which is with and without a physical median. As the map shows, the four study sites sit along these two connecting highway stretches, positioned so that two of the sites capture a segment with a physical median separating opposing traffic flows, while the other two capture a segment without one, allowing the effect of the median itself to be compared directly alongside the other traffic parameters measured at each site.

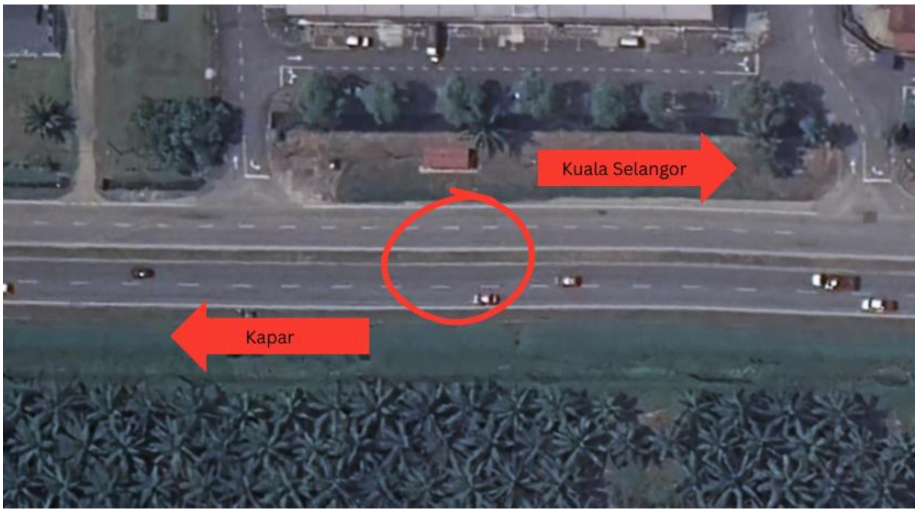

Figure 2. Location of study (Source: Google Earth)

Instrumentation

The total traffic volume that is used for the calculation of the flow rate was recorded using the tally counter instrument. A tally counter is a simple mechanical or electronic device used to manually count the number of vehicles during traffic volume studies. In this study, manual tally counters were used as they are particularly useful for short-duration manual counts and for tracking and classifying vehicles. The vehicle classes were divided into five classes based on the Malaysia Highway Capacity Manual (2011): Class 1 (cars and small vans/utilities), Class 2 (lorries with two axles or large vans), Class 3 (large lorries, trailers, and heavy vehicles with three axles or more), Class 4 (buses), and Class 5 (motorcycles). Other instruments that were used during the data collection were a measuring wheel and a stopwatch. The measuring wheel was used to measure the geometric data of each lane, while the stopwatch was used to measure the recording time of the study.

Geometric Data

Other than the traffic volume data, the geometric data of the road at the study locations were also measured. Elements like lane width, shoulder width, sight distance, curve radius, and superelevation significantly influence accident rates; particularly, short sight distances and sharp curves can lead to higher accident frequencies (Mohammed, 2019). Four geometric measurements were recorded at each of the four study locations: lane width, shoulder width, number of lanes, and the presence or absence of a physical median, allowing each site's geometric profile to be compared directly against its measured Level of Service.

Study Limitations

Several methodological limitations of this study should be noted. First, field data collection was restricted to four specific sites along the Jalan Kuala Selangor–Kapar and Jalan Kapar–Kuala Selangor corridors. While these locations allowed for a direct comparison between divided and undivided multilane configurations, the sample size limits the direct generalizability of the findings across the entire Malaysian multilane highway network.

Second, traffic data were gathered during a two-hour morning window (8:30 a.m. to 10:30 a.m.) across one weekday and one weekend day per site. Although this window captured active morning travel conditions, it does not reflect peak evening surges, full-day traffic fluctuations, seasonal volume shifts, or Annual Average Daily Traffic (AADT) profiles. Additionally, environmental factors such as adverse weather conditions and varying heavy vehicle compositions were not isolated during data collection. Future research expanding the geographical scope, extending the observation window, and incorporating long-term continuous traffic counts would further validate and extend these operational findings.

DATA ANALYSIS AND FINDINGS

Traffic Volume and Flow Rate Characteristics

Descriptive statistical analysis was carried out separately for the slow lane (SL) and the fast lane (FL). It resulted that for flow rate, the fast lane shows a greater mean (536.75 pc/h/ln) than the slow lane (429.69 pc/h/ln), suggesting more vehicles preferred the fast lane during the observed period. Average travel speed followed the same pattern, at 76.31 km/h in the fast lane against 62.66 km/h in the slow lane, while density was only marginally higher in the fast lane (7.061 pc/km/ln) than the slow lane (6.851 pc/km/ln). The standard deviations for all parameters are nearly identical between lanes, indicating consistent variability. Skewness values are positive in both lanes, with the fast lane showing higher skewness, implying more values above the mean, especially for speed and density. Negative kurtosis in both lanes suggests relatively flat data distributions, with fewer extreme outliers. These patterns collectively highlight that the fast lane experiences more intense, yet stable and predictable, traffic conditions. Histogram plots generated for flow rate, average travel speed, and density in both lanes illustrate this same difference visually: the fast lane's distributions show more noticeable skewness and multimodal tendencies, indicating greater variation in speed and flow, while the slow lane's distributions cluster more tightly around the mean, reflecting steadier, more uniform conditions.

Speed and Density Relationship

The average travel speed is higher in the fast lane at 76.31 km/h compared to 62.66 km/h in the slow lane, which aligns with typical driver behaviour. Traffic density also reflects a slight increase in the fast lane (7.061 pc/km/ln) versus the slow lane (6.851 pc/km/ln), likely due to the higher flow despite higher speeds.

Three-dimensional scatterplots relating flow rate, average travel speed, and density were generated separately for each lane to visualize how the three parameters move together. In the slow lane (SL), the flow rate is about 300 to 530 pc/h/ln, while density fluctuates from 5 to 9 pc/km/ln, and average travel speed lies between 55 and 70 km/h. The pattern indicates a moderate-to-strong positive correlation between flow rate and density at low to moderate levels, implying that an increase in vehicles within the lane leads to an enhanced total flow. An evident strong inverse correlation exists between average travel speed and density, indicating that increased traffic leads to decreased travel speed. The most effective flow in the slow lane seems to take place when density is average and speed stays between 62–68 km/h, consistent with traditional traffic flow theory.

Conversely, the fast lane (FL) exhibits greater overall flow rates, varying from 460 to more than 660 pc/h/ln, with density between 6 and 9 pc/km/ln but with notably higher travel speeds, ranging from 72 to 85 km/h. The pattern for the fast lane is similar, where flow rate rises with density up to a certain point, but begins to plateau at higher limits, accompanied by a statistically significant inverse speed–density relationship. In contrast to the slow lane, the fast lane can sustain greater speeds even when density increases, reflecting a more effective flow pattern. Overall, through the evaluation of Level of Service, these relationships can help inform strategies for lane management, traffic regulation, and infrastructure planning to optimize flow and safety across all lanes.

Level of Service by Site

The analysis of the multilane highway sites along Jalan Kuala Selangor-Kapar and Jalan Kapar-Kuala Selangor revealed that traffic conditions are generally smooth and efficient. On weekends, Jalan Kuala Selangor-Kapar showed Level of Service (LOS) ratings of both LOS A and B, indicating free-flowing traffic with varying levels of manoeuvrability. However, on weekdays, the LOS for most locations along this route was LOS A, suggesting very little interference from other vehicles and smooth travel conditions. For Jalan Kapar-Kuala Selangor, weekend results showed all locations at LOS B, while weekday results were mixed, with some locations at LOS A and others at LOS B, indicating slightly more variability in traffic conditions but still within an acceptable performance range. These ratings were derived from MHCM evaluation worksheets completed separately for each of the four locations on both a weekday and a weekend, working through the standard MHCM procedure of converting measured traffic volume into flow rate, comparing it against the free-flow speed of the segment, and reading off the corresponding LOS band. Overall, the assessment of all four of these multilane highway sites showed that all locations function at LOS A and LOS B, signifying effective traffic movement with slight delays and great driver comfort. These findings indicate that the present road design and traffic situation are operating effectively within the current demand. While no urgent enhancements are necessary, it is advisable to keep monitoring in order to uphold these service levels as traffic increases.

Evaluation Against MHCM Parameters

The alignment of the parameters with the MHCM can be evaluated against the LOS criteria for multilane highways stated in the manual. Under a Base Free-Flow Speed of 100 km/h, the MHCM's reference chart sets out six LOS bands: LOS A applies where density stays at or below roughly 6 pc/km/ln, corresponding to free-flowing conditions with maximum service flow rates around 700 pc/h/ln; density bands rise progressively through LOS B, C, and D as traffic thickens and maximum service flow rates climb toward roughly 1,100, 1,550, and 1,980 pc/h/ln respectively, while average speed gradually falls; LOS E represents conditions approaching capacity, with density up to roughly 34 pc/km/ln and flow rates topping out near 2,170 pc/h/ln; and LOS F represents breakdown conditions beyond this threshold, where flow becomes unstable and unpredictable. Measured against this scale, none of the parameters recorded at any of the four study sites exceeded the maximum capacity for either lane. This indicates that current MHCM theoretical standards remain accurate and valid for multilane highways in Malaysia under present conditions, though their applicability to other countries may differ.

Implications for Highway Asset Management and Investment Priorities

Read through an asset-management lens, it can be said that these results carry a clear practical message. All four sites currently operate at LOS A or B, which means no urgent capital investment is required at present. However, the results also give infrastructure agencies something more useful than a pass/fail reading, namely a baseline against which future degradation can be measured. Since LOS can be formally incorporated into infrastructure investment decision-making as a performance indicator (Sharma et al., 2008), these findings can serve as a monitoring benchmark, signalling early if traffic growth begins pushing any site toward LOS C or below, at which point the geometric interventions already identified in this study, such as wider lanes, additional lanes, or auxiliary lanes at key points, would become priority candidates for capital investment rather than precautionary suggestions. Thus, this explains why the value of this evaluation lies not only in confirming that the MHCM holds up under current conditions, but in establishing a reference point that highway authorities can use to time and target future infrastructure spending.

CONCLUSION AND RECOMMENDATIONS

Increasing the Level of Service (LOS) on a multilane highway requires a combination of infrastructure modification, traffic management measures, and policy actions. Adding lanes or auxiliary lanes at critical points can mitigate bottlenecks and support greater traffic volume in the future. Based on the study results of Msallam (2019), by modifying geometric and traffic conditions, such as increasing lane width, adding lanes, and optimizing geometric design, the LOS for critical segments can be improved. This was proven by Msallam, as the enhancements enabled segments operating at LOS E or F to achieve acceptable LOS, such as LOS C (stable flow) and LOS D (approaching unstable flow). Therefore, in this study, this can be applied to both Jalan Kuala Selangor-Kapar and Jalan Kapar-Kuala Selangor, where some of the locations operate at LOS B.

More broadly, it can be said that since LOS results can serve directly as an input into infrastructure investment decisions (Sharma et al., 2008), these findings give infrastructure agencies a practical basis for two things at once: confirming that no urgent capital spending is required today, while identifying exactly where future investment should be directed first if conditions change. Hence, this kind of evidence-based prioritization allows limited infrastructure budgets to be allocated where they will have the greatest effect, rather than spread evenly or reactively across the network.

As for recommendations, future studies can be applied with different variables, new and uncommon in the field of study, such as heavy vehicle composition. Another recommendation also can be conducted with a longer observation period across a wider range of sites, and by incorporating variation in weather conditions. Considering the current stage of multilane highway development in Malaysia, research can be conducted to compare these findings against other regions where road standards and driver behaviour may differ.

In conclusion, this study effectively achieved its objectives by evaluating the Level of Service (LOS) of multilane highways using MHCM guidelines, analyzing traffic parameters, and providing improvement recommendations. The findings revealed an inverse relationship between average travel speed and traffic density, and a direct relationship between density and flow rate, indicating that higher traffic volumes reduce speed and increase density. The fast lane was found to maintain higher speeds under increased density compared to the slow lane, reflecting a more efficient flow. Additionally, all four highway sites operated within LOS A and B, suggesting smooth traffic flow, minimal delays, and high driver comfort. Importantly, none of the measured parameters exceeded the maximum allowable limits, indicating that current road designs are sufficient for present traffic conditions. These results validate the existing theoretical models for multilane highway performance in Malaysia, though their applicability to other countries may differ. Therefore, every infrastructure agency needs to take care of continued research and monitoring to ensure ongoing safety and efficiency, and to help direct investment where it is needed most on multilane highways.

ACKNOWLEDGEMENT

The author would like to express sincere gratitude to the Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), Shah Alam, for the facilities and technical support provided throughout this study. Appreciation is also extended to the Department of Technology and Supply Chain Management, Faculty of Business Management, Universiti Teknologi MARA (UiTM), Puncak Alam, for their support and guidance in facilitating the business and management framing of this research.

Author's Declaration

The author declares that this manuscript was prepared with the assistance of an AI language tool, used for language editing and reframing the presentation and writing style of the research. All data collection, field measurements, statistical analysis, and research findings reported in this paper are the original work of the researcher, and were not generated or altered by AI.

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