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A comprehensive approach to evaluating and predicting level of service for two-lane rural highways

Ahmed Hadi
University Sains Malaysia, School of Civil Engineering Campus, 14320 Nibong Tebal, Penang, Malaysia, ahmedhadi@student.usm.my
Farid Ezanee Mohamed Ghazali
University Sains Malaysia, School of Civil Engineering Campus, 14320, Nibong Tebal, Penang, Malaysia, cefarid@usm.my (corresponding author)
Basim Jrew
Isra University, Civil Engineering Department, P.O. Box 22, Amman 11622, Jordan, basim_jrew@yahoo.com
Ali Hassoon
University Sains Malaysia, School of Civil Engineering Campus, 14320, Nibong Tebal, Penang, Malaysia, ali.s.hassoon@gmail.com
Saad Ismael Ibrahim
Al-Iraqia University, College of Media, Unit of Rehabilitation Employment and Follow-Up, Baghdad 10001, Iraq, saad.i.ibrahim@aliraqia.edu.iq

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Abstract: Highways are vital to national transportation, especially in developing countries where infrastructure challenges are common. This study evaluates and predicts the Level of Service (LOS) for a rural two-lane, two-way highway in Iraq that connects Salah al-Din and Kirkuk governorates. The road suffers from high traffic volumes, including 15% heavy vehicles, frequent accidents, and poor geometric design. It is divided into seven segments covering diverse land uses such as urban, industrial, and residential zones. Using Highway Capacity Software (HCS-2024) and methodologies from the HCM 7th Edition, the current LOS was found to range between E and F, indicating critical congestion and safety issues. These conditions negatively affect economic productivity, road safety, and quality of life. To address these challenges, the study proposes lane expansion, geometric improvements, and speed adjustments. These measures are expected to raise LOS to A and B under current conditions, and to B, C, and D in future growth scenarios. The study highlights the value of applying modern analytical tools to rural highways and provides a framework for improving traffic performance and logistics efficiency in similar contexts.

1 Introduction

One of the most important aspects of the transport system is the presence of road networks in the country, as they facilitate travel by people and goods to different areas [1]. By the development of the country, the urbanization is also increasing, and the population is also significantly increasing, making it difficult to maintain and enhance the performance of highway systems as it has great pressure from the increasing number of road networks [2]. The highways primarily serve as a means of transporting people from one place to another, and their performance varies depending on factors such as the volume of traffic using the road, the speed at which it moves, and the level of congestion on the streets. All of that is crucial to determining the degree of efficiency of road systems [3]. In recent times, technology has advanced rapidly. Climate change has a significant impact on human life, prompting a transformation of rural highways in the current era of high complexity and rapid technological advancements [4]. The potential requirements for highways increase as cities' populations, economies, and urban areas expand. The performance of highways also reflects their ability to handle traffic, which encompasses the following factors: Traffic Volume: How many vehicles can use a road at one time? Traffic speed refers to the speed at which vehicles can travel on various sections of the highway. Traffic congestion refers to the volume of traffic that a road can accommodate without necessitating slowing down due to the high density of vehicles on it. Anticipation of service levels helps the growth of infrastructure, improving traffic flow, technical elements of logistics, and the incorporation of new technologies, which can assist in maintaining the highest level of effectiveness of transportation [5].

Various factors, including traffic volume, road design, environmental factors, traffic conditions, and basic infrastructure, influence the LOS for two-lane, two-way rural highways [6]. Several studies have focused on evaluating and improving the LOS using various analytical methods and tools, particularly Highway Capacity Software (HCS) and Highway Capacity Manual (HCM). The studies identified key factors influencing LOS, such as the percentage of heavy vehicles [7], lane width, and

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design speed [8,9], and the influence of road geometry [10]. The majority of these factors directly affect the LOS and the number of head-on collisions, especially during peak traffic hours [11].

There are many challenges associated with the transport system in developing countries, especially in Iraq. These include congestion, reliable, and safe public transportation; accidents on the road; and difficulty when it comes to non-motorized modes of transportation [12]. The congestion generates high levels of air pollution and noise pollution, as well as greenhouse gas emissions. As a developing nation, Iraq has seen many of its transportation networks and highway infrastructure deteriorate due to wars. Additionally, there seems to be a lack of plans in place to upgrade the transportation system to meet demands [13]. Improving any system like transportation involves a process that bridges the gap between the public and the government [14]. To enhance a highway system in the future, it's crucial to comprehend its requirements, scrutinize and assess them, and chart out the future services it will necessitate. Based on the growing population in Iraq, this study identifies key factors that will shape the future service levels of the country's highway system, utilizing the HCM and HCS methodologies.

Most of Iraq's highway networks are two-lane, two-way highways [15]. The highway connecting Salah al-Din and Kirkuk governorates in Iraq is one such vital link, serving not only as a conduit for local traffic but also as a strategic route for commercial and logistical movements. This paper evaluates and analyses the main concerns. Included in that challenge is the fact many of these highways are often congested, have higher accident rates, and have limited passing opportunities. In addition to the congestion, these highways suffer from inadequate maintenance and insufficient signage [16,17]. Another significant issue is finding appropriate improvement techniques for each highway. In order to better understand this issue, you need to address how road geometrics and traffic characteristics impact the level of service [18-22]. Geometric characteristics include lane width, shoulder width, and sight distance. These characteristics aid in maintaining driver safety on the highway, regulating vehicle speed due to limited space for maneuvering, and enabling the driver to see potential obstacles ahead [23-26]. Narrow lanes and sharp curves will increase the chance of an accident because a driver does not have enough time to react if another vehicle crosses the centerline or makes another type of non-diverse maneuver. A properly designed road with adequate sight distances will provide a vehicle with enough time to see the hazard ahead and react accordingly to the situation.

One of the core parts of transportation engineering is the highway capacity evaluation, which determines the efficiency, safety, and LOS of a highway. The HCM provides a most widely accepted planning and design standard framework to evaluate the performance of highways. HCM takes into consideration factors such as traffic volume, speed, lane width, environmental conditions, etc. Therefore, HCM's methodologies are regarded as most accurate and applicable therefore, as they provide the groundwork for the transportation planning and design [27]. The Highway Capacity Software (HCS) provides the computational application of HCM's methodologies. The HCS significantly outperforms the HCM by enabling detailed analysis of various scenarios, facilitating the evaluation of current conditions and the assessment of future performance based on various traffic growth models and enhancements. The integration of HCM and HCS is evolving a smart methodology for highway evaluation, which ultimately relies on analysis and the most credible prediction [28].

This study considers evaluating the existing LOS for a two-lane, two-way rural highway in the governorates of Salah al-Din and Kirkuk in Iraq. Rural highways are essential for supporting traffic flow and logistics in developing countries like Iraq. However, the literature shows a clear gap in using modern tools such as HCS to assess the technical aspects of traffic and logistics management. Few previous works have combined LOS evaluation with detailed segment-based analysis, particularly on rural highways. This study addresses that gap by evaluating the existing and future LOS of a two-lane, two-way rural highway using HCS-2024 and HCM 2022. The road was divided into seven segments for detailed analysis. A structured, step-by-step approach was adopted to ensure accurate problem identification, systematic evaluation, and the effective development of logistics and traffic management strategies. This method is particularly suitable for handling infrastructure challenges by combining technical assessment with forward-looking planning.

2 Methodology

A significant component of this study involves the use of real two-lane highway data and growth rates in order to predict future traffic volumes. This will be followed by the application of HCM 7th and HCS 2024 to analyze and evaluate the LOS on the selected highway under existing and future conditions. In addition to being very useful, this data gives an accurate picture of how traffic is and is struggling on these highways in real time. It will be possible to assess the service level more accurately and identify improvements that need to be made, aiming to increase the efficiency and safety of the chosen highway. Analyzing the real data for segments was accomplished with the HCM 7th, followed by the HCS-2024 in order to validate the results and analyze the data in detail. In this program, every effort has been made to portray reality as accurately as possible. Through the new highway design, it will be possible to improve segment quality, reduce risks, and increase safety, both in the existing conditions and in the future.

2.1 Description of the site

The two-way highway that connects Salah al-Din Governorate and Kirkuk Governorate in Iraq is a crucial transportation route, characterized by high traffic volumes, numerous heavy vehicles, and a high rate of traffic accidents. Every day, approximately 15% of the road is occupied by heavy vehicles. This highway can be divided into seven segments: the southern access, which faces congestion from local and agricultural traffic; the urban interface; the industrial zone; a mid-segment that faces congestion from agricultural traffic; residential areas; and the northern segment leading into Kirkuk, which continues to experience heavy traffic, as indicated in Figure 1.

As one of the most important international highways, the road is of immense economic and cultural significance. The highway connects Baghdad's major agricultural, recreational, and religious areas with the south of the country. Additionally, a significant number of heavy vehicles transporting goods on the chosen highway contribute to serious congestion at various times of the day. The highway is also plagued by poor geometric conditions and heavy traffic. Furthermore, the traffic volume and accidents on the selected highway within AADT and PHV are very high, and in the past two decades, there have been numerous deaths, injuries, and property damages. A comprehensive evaluation of these highways is imperative in order to identify key improvements that can enhance safety, efficiency, and overall service levels on this vital road.

Figure 1 The study area from an aerial photograph [29]

2.2 Data collection

Data collected for the highway can be categorized into three categories: highway geometric, traffic volume, and vehicle speed data. The primary method for data collection in this study was observation. Video recording was performed daily during peak hours for one hour over a period of two weeks using a camera-type video recorder. Both vehicle types (passenger cars and heavy trucks) and movement directions were counted for all segments. Furthermore, geometric data was collected at the site. This evaluation included measurements of lane width, lanes, access points, and lateral clearances. The data provided in this paper was vital in understanding current traffic conditions, making sure the analysis was accurate, and planning for future improvements. Based on existing conditions, Figure 2 shows traffic volume data. Moreover, the growth rate will be used in order to predict the LOS for future traffic conditions in the selected study area. Additionally, the directorate of transportation and communications registrations compiled by the Ministry of Planning [30] in Iraq showed an annual growth rate of three percent (3%) consistent with the number of vehicles registered over the past few years. Figures 3 and Figure 4 show predicted traffic volume data.

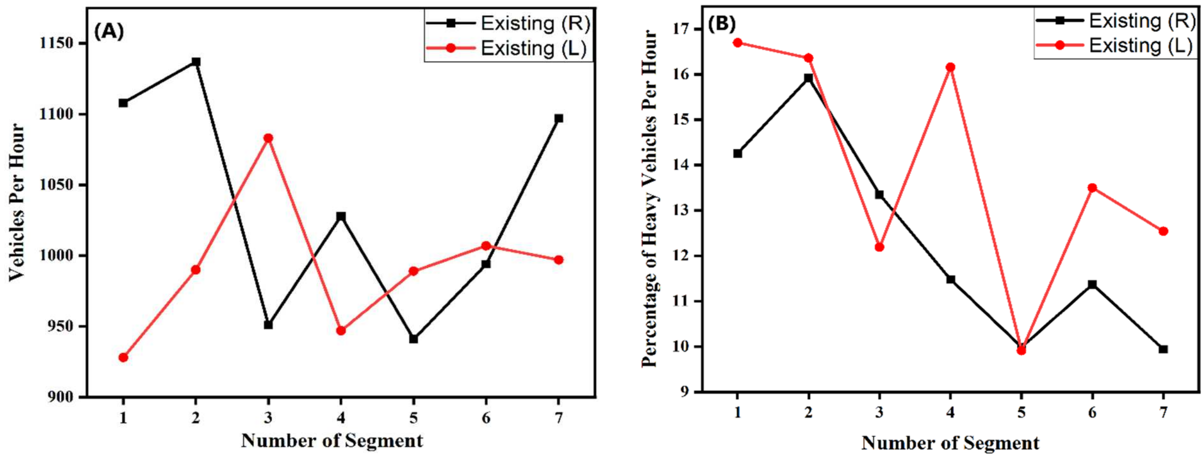

Figure 2 (A) The number of passenger cars per hour for the seven segments (B) The percentage of heavy vehicles per hour for the seven segments under existing conditions

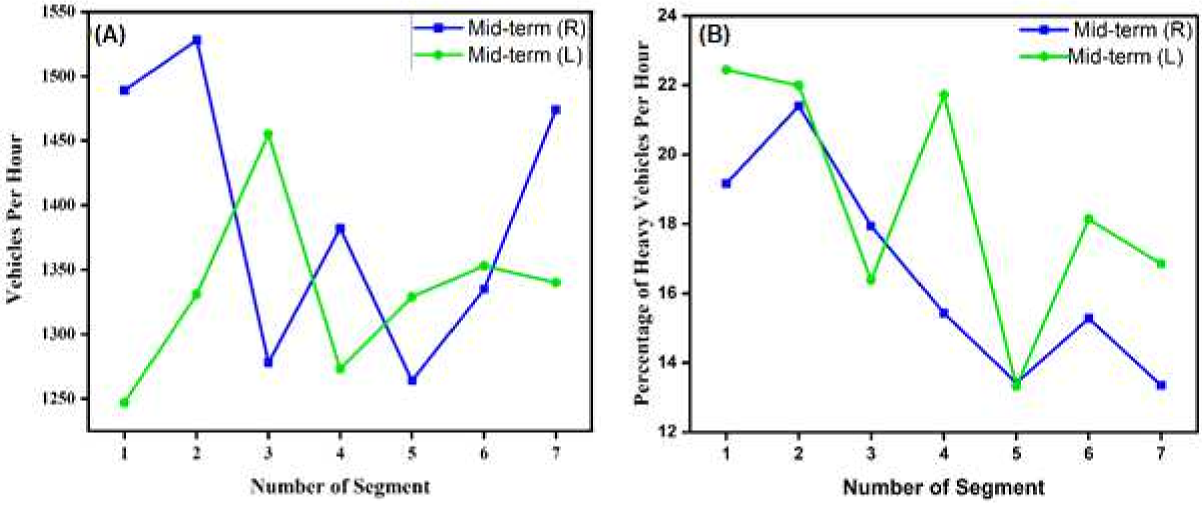

Figure 3 (A) The number of passenger cars per hour for the seven segments (B) The percentage of heavy vehicles per hour for the seven segments under mid-term conditions

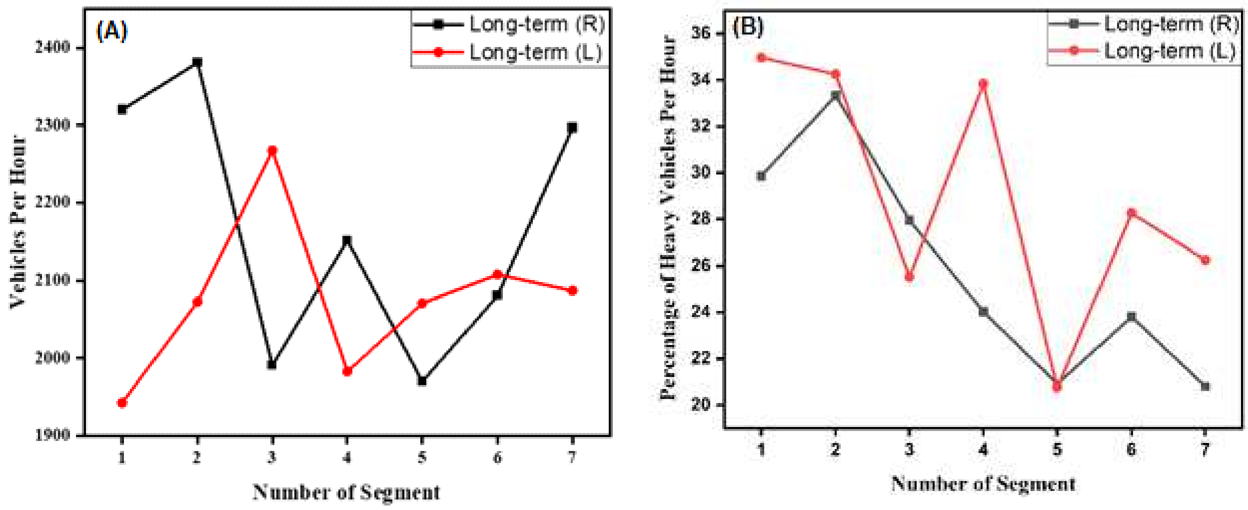

Figure 4 (A) The number of passenger cars per hour for the seven segments (B) The percentage of heavy vehicles per hour for the seven segments under long-term conditions

2.3 Analysis software

The Highway Capacity Software (HCS-2024), based on the methodologies outlined in the 7th edition of the HCM, evaluates the capacity, performance, and Level of Service (LOS) of different types of roadways. With the updated HCS 2024, transportation management professionals will have an enhanced tool for analyzing and assessing highway performance and LOS, incorporating the most recent guidelines from the 7th edition of the HCM. Transportation planners and highway designers use this tool to analyze traffic flow, congestion, and capacity, thus enabling better highway designs, traffic management, and transportation planning. It helps identify traffic flow improvements and mitigation strategies, including changing incident management and access management policies. It helps in identifying highway maintenance needs and provides an in-depth analysis of the highway system.

2.4 Analysis

There have been numerous field investigations in the study area, which aimed at verification of geometric and traffic data, segmentation, and collection of data necessary for analyses. The collected data included traffic counts, speeds, volumes, and crash data. Field investigations were conducted using field surveys, interviews, and observations of the highway. All data was processed and analyzed using standard software programs. According to observations made for each segment, the posted speed limit is 62 mi/h (100 km). Based on Equation (1), the base free flow speed (BFFS) will be estimated using HCM 7th.

$$BFFS = 1.14 \times Spl \qquad (1)$$

Where SpI represents the posted speed limit (mi/h), each lane has a width of 11 feet (3.35 meters), and in each direction, the shoulder width and lateral clearance are zero. Furthermore, in order to evaluate the LOS for each segment, it is necessary to estimate the demand volume under prevailing conditions (V) and convert it to the demand flow rate under equivalent base conditions (Vp). According to the traffic volume, the maximum peak hour volume (PHV) has been determined for each segment. The following information is provided for each of the seven highway segments under existing circumstances. The data not only aids in future LOS predictions, but also aids in highway improvements like lane widening and multilane route conversion. For future highway improvements, the posted speed limit is 60 mph (97 kph), and BFFS on multilane highways is approximately five miles per hour (8 kph) above the posted speed under base conditions when the speed limit is higher than 50 mph (80 kph) or seven miles per hour (11 kph) when the speed limit is less than 50 mph (80 kph). There is 12 ft (3.6 m) of lane width for each lane, while shoulder width and lateral clearance in each direction are 6 ft (1.8 m). The Ministry of Planning, Central Statistical Organization of Iraq (MPCSO) estimates that the peak hour volume (PHV) and the percentage of trucks (HV%) will increase by 3% annually for the mid-term and long-term period. In order to perform a mid-term and long-term analysis, it is necessary to convert the present demand volume to the future peak-hour demand volume (PHV), using Equation (2):

$$PHV(Future) = PHV(Present) \times (1+g)^n \qquad (2)$$

In this case, PHV represents peak hour volume, g represents growth rate, and n represents the number of years. Finally, a new feature of this system is the reduction in the number of access points in each segment to two.

3 Results and discussion

The road performance analysis was conducted using HCS-2024 and HCM 7th edition. The results of the analyses showed that the 'current LOS' of the highway is significantly poor because of increased volume of traffic, the presence of heavy vehicles, and interruptions caused by inadequate road design. The results of the analyses also revealed that the free flow speed is relatively low due to road conditions and vehicle interactions. The analysis also reveals a higher delay time and frequency of stops, both of which negatively impact service quality and traffic safety. The analysis of the present road condition has been carried out by considering four types of performance indicators, such as density of vehicles, vehicle speed, delay, and LOS. Additionally, the LOSs for the mid-term and long-term in 2034, 2049, respectively, are predicted. The LOS values for the two scenarios fell within the range of F to E. This indicates an urgent need for improvements in the overall performance and traffic safety of the road. Additionally, the potential for improvement in each segment is important for decision making to give clear overview about the traffic conditions and to identify the segments that needs to be improved in order to enhance the expected transportation and to smooth & safe the traffic flow. Some of the improvements are to be performed as per the optimization of the roads such as widen. Repair. Upgrade the existing infrastructure, introduce some technology features such as traffic signals and automatic traffic control systems, and rely on regular inspections and regular maintenance of the road performance.

The current Policy on Geometric Design of Highways and Streets 2018 states that LOS-A is for rural highways that are free flow, LOS-B is for rural highways when there is reasonably free flow, and LOS-C is for rural highways when there is stable flow. Some highway agencies treat the LOS-D (approaching unstable flow) as the highest LOS of the others. There are two types of LOS: LOS-E, indicating an unsteady flow or traffic at maximum capacity, and LOS-F, indicating a forced flow or unacceptable traffic conditions. These segments of the highway require improvement to achieve a better LOS [31].

There are numerous ways in which low infrastructure can negatively impact different types of highway users. For example, a traffic collision can result in a human accident, potentially resulting in fatalities, financial hardships, business losses, or job insecurity. As well as having a significant impact on the environment, it also has a significant impact on the people living near the highway [32]. Additionally, this increases for individuals, affecting their budgets and financial well-being. Poor LOS can hinder productivity and economic growth in surrounding areas, exacerbating the problems for highway users. In this study, each segment of the highway was analyzed using HCS-2024 to determine the existing LOS and predict the LOS for both the mid-term and long-term conditions from both directions of the highway. Table 1 presents the results of HCS-2024's analysis of the selected highway under the current conditions.

Table 1 Evaluation of the highway's existing conditions in 2023

No. of Segment	Direction	FFS mi/h	Average speed mi/h	VMT Veh-mi/AP	VHD Veh-h/P	Follower Density, Follower/mi/ln	LOS
1	Right	63.9	59.8	551	0.60	14.4	E
	Left	63.1	58.9	461	0.52	15.6	E
2	Right	62.9	58.6	565	0.65	16.6	E
	Left	63.3	59.0	492	0.57	16.9	E
3	Right	63.7	59.4	473	0.54	16.4	E
	Left	63.5	59.4	538	0.59	14.3	E
4	Right	63.2	59.2	511	0.55	13.8	E
	Left	63.6	59.6	471	0.49	13.1	E
5	Right	63.0	59.2	468	0.49	12.5	E
	Left	62.8	58.9	492	0.52	12.9	E
6	Right	63.5	59.6	494	0.52	12.8	E
	Left	63.4	59.5	501	0.52	12.8	E
7	Right	62.5	58.5	545	0.60	14.5	E
	Left	63.7	59.8	496	0.51	12.6	E

Based on a detailed assessment of the current condition of the highway connecting Salah Al-Din and Kirkuk Governorates, and utilizing real-world data analyzed through the HCS-2024 software and the HCM, 7th Edition, the study revealed that the LOS across all seven segments of the highway existing ranges between LOS E and F. This reflects severely poor operational performance, characterized by high traffic congestion, increased travel delays, significantly reduced user comfort, and elevated traffic safety risks, largely due to the high proportion of heavy vehicles and substandard geometric design.

Furthermore, the future projections under medium- and long-term scenarios indicate continued deterioration levels of service unless comprehensive improvement measures are implemented. Based on these findings, the study concludes that it is imperative to undertake a package of proposed enhancements, the most critical of which is converting the highway from a two-lane, two-way rural highway to a multilane highway. Other proposed improvements include geometric design enhancements, such as widening shoulders and increasing speed limits in alignment with the new design standards while maintaining safety considerations.

The methodology adopted in this study is distinguished by its accuracy and comprehensiveness, as it integrates actual traffic data analysis with LOS forecasting models while considering local highway conditions in Iraq. This context-specific and efficient approach is particularly valuable in addressing the challenges of rural highways suffering from inadequate infrastructure and lack of sustainable planning, especially in regions experiencing rapid traffic growth and a high percentage of heavy vehicles.

This study contributes a scientific and practical model that can be utilized by academic researchers, policy makers, and field engineers by highlighting the direct relationship between technical assessment outcomes and development options. It provides a solid knowledge base to support effective decision-making aimed at enhancing the efficiency and safety of the highway network. Moreover, the study emphasizes the importance of employing advanced standard analytical tools such as HCS and HCM to support infrastructure-related decisions and to guide resources toward interventions with tangible impacts on performance, service levels, and safety. Table 2, Table 3, and Table 4 present HCS-2024 analysis results under existing, mid-term, and long-term conditions.

Table 2 Evaluation of the highway's existing conditions in 2023 post-enhancements

No. of Segment	Direction	FFS mi/h	Flow rate pc/h/ln	Average speed mi/h	Density pc/mi/ln	No. of lane	LOS
1	Right	59.5	652	59.5	11.0	2	A
	Left	59.5	694	59.5	11.7	2	B
2	Right	59.5	724	59.5	12.2	2	B
	Left	59.5	739	59.5	12.4	2	B
3	Right	59.5	710	59.5	11.9	2	B
	Left	59.5	633	59.5	10.6	2	A
4	Right	59.5	610	59.5	10.3	2	A
	Left	59.5	618	59.5	10.4	2	A
5	Right	59.5	556	59.5	9.3	2	A
	Left	59.5	572	59.5	9.6	2	A
6	Right	59.5	582	59.5	9.8	2	A
	Left	59.5	596	59.5	10.0	2	A
7	Right	59.5	622	59.5	10.5	2	A
	Left	59.5	584	59.5	9.8	2	A

Table 3 Evaluation of the mid-term condition of multilane highways in 2049 post-enhancement

No. of Segment	Direction	FFS mi/h	Flow rate pc/h/ln	Average speed mi/h	Density pc/mi/ln	No. of lane	LOS
1	Right	59.5	915	59.5	15.4	2	B
	Left	59.5	978	59.5	16.4	2	B
2	Right	59.5	1019	59.5	17.1	2	B
	Left	59.5	1040	59.5	17.5	2	B
3	Right	59.5	992	59.5	16.7	2	B
	Left	59.5	882	59.5	14.8	2	B
4	Right	59.5	849	59.5	14.3	2	B
	Left	59.5	870	59.5	14.6	2	B
5	Right	59.5	770	59.5	12.9	2	B
	Left	59.5	793	59.5	13.3	2	B
6	Right	59.5	810	59.5	13.6	2	B
	Left	59.5	833	59.5	14.0	2	B
7	Right	59.5	862	59.5	14.5	2	B
	Left	59.5	816	59.5	13.7	2	B

Table 4 Evaluation of the long-term condition of multilane highways in 2049 post-enhancement

No. of Segment	Direction	FFS mi/h	Flow rate pc/h/ln	Average speed mi/h	Density pc/mi/ln	No. of lane	LOS
1	Right	59.5	1553	58.2	26.7	2	D
	Left	59.5	1681	56.7	29.6	2	D
2	Right	59.5	1744	55.9	31.2	2	D
	Left	59.5	1784	55.3	32.3	2	D
3	Right	59.5	1675	56.8	29.5	2	D
	Left	59.5	1482	58.9	25.2	2	C
4	Right	59.5	1420	59.4	23.9	2	C
	Left	59.5	1492	58.9	25.3	2	C
5	Right	59.5	1280	59.5	21.5	2	C
	Left	59.5	1316	59.5	22.1	2	C
6	Right	59.5	1356	59.5	22.8	2	C
	Left	59.5	1408	59.5	23.7	2	C
7	Right	59.5	1430	59.4	24.1	2	C
	Left	59.5	1372	59.5	23.1	2	C

4 Conclusion

The analysis of the results highlights the significant and detrimental impact of inadequate infrastructure and low LOS on highway users. These issues manifest in various ways, including an increase in traffic collisions, reduced productivity, and hindered economic growth in surrounding areas, further compounding the challenges for highway users. Additionally, the problems extend to environmental degradation, adversely affecting residents living near the highway. Increasing traffic volumes and congestion under both current and projected conditions are straining the highway segments, which are unable to accommodate high traffic levels. Currently the LOS for all 7 segments is at E and F. However, after the implementation of an improved management program, all segments will operate under LOS-A and B. For future scenarios, all segments will be operating at LOS-B, C, and D. These improvements will enhance operational efficiency, improve user experience, reduce negative environmental impacts such as gas emissions, noise, etc., and streamline the movement of goods along the highway. The improvements involve transforming a two-lane highway into a divided multilane highway by creating two lanes for each direction. By increasing the number of lanes, a highway transitions from a one-lane highway to a multi-lane highway. Another modification involves raising the speed limit to alleviate congestion, enabling users to navigate with sufficient time to commute alongside other users and under optimal geometric conditions. These improvements will result in a safer mode of transportation, stimulate socioeconomic development, and enhance the quality of life for all users.

5 Recommendation

In the planning process, the priority should be to increase the number of lanes and their width, as well as to improve geometric conditions to ideal levels, particularly for segments operating at LOS-E. In addition to the segments included in this study, it is recommended that all segments of Iraq's two-lane, two-way highways be analyzed. A cost-benefit analysis could be conducted if traffic congestion was reduced and LOS was improved. Furthermore, the reduction of accidents, delays, and stops will contribute to reduced fuel consumption. This study did not include cost estimates, but future studies should incorporate them once data becomes available. Finally, it is recommended to explore the relationship between road geometric characteristics, heavy vehicle movements, LOS, and capacity for two-lane, two-way highways in Iraq.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Review process

Single-blind peer review process.