**Edelweiss Applied Science and Technology**
*ISSN: 2576-8484*
*Vol. 9, No. 5, 43-52*
*2025*
*Publisher: Learning Gate*
*DOI: 10.55214/25768484.v9i5.6775*


# Sustainable development strategies for improving the efficiency and safety of a highway in Iraq

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**Abstract:** The performance of two-lane, two-way highways in Iraq, especially in rural areas, is often hindered by high traffic volumes, inadequate infrastructure, and safety concerns. This research focuses on evaluating and improving the performance of the highway connecting Salah al-Din Governorate to Kirkuk Governorate, which faces significant congestion and safety challenges. Using the Highway Capacity Software (HCS 2024) and the Highway Capacity Manual (HCM 7th edition), the study aims to assess the current and short-term future conditions of the highway, particularly in terms of traffic flow and service levels. The study discusses prominent factors influencing the highway's operational performance, including traffic composition, geometric design, and safety considerations, and proposes specific improvements for service quality enhancement and congestion relief. Proposed measures include lane widening and speed limit adjustments. The research addresses the creation of predictive models to estimate future traffic volume and levels of service, thereby providing valuable information on possible improvements that would make highways both safer and more efficient. The research plays a critical role in informing future planning and highway infrastructure development in Iraq, especially in areas with similar issues.

***Keywords:*** *Highway performance, Infrastructure improvement traffic flow, Level of service (LOS), Road safety.*

## 1. Introduction

Transportation infrastructure, such as roads and highways, plays a role in fostering growth and enhancing local communities worldwide, particularly in Iraq [1, 2]. To ensure the functioning and safety of these facilities on a day-to-day basis, it is imperative to deliver top-notch services [3]. The rising population in Iraq has sparked a surge in demand across all spheres of life, leading to a correlation between increased usage and the need for vehicles and highway capacity. Consequently, this surge has resulted in heightened traffic congestion and accidents, posing challenges for residents' mobility. These issues have only worsened the hardships as transportation costs continue to escalate [4].

Most road systems around the world mainly comprise two-lane roads found in both urban and suburban regions. These types of roads are widely prevalent globally, not just in the United States [5, 6]. The two-lane highways were the main concern discussed and analysed in this paper, since they make up the majority of highway networks in Iraq [7]. According to a report by the Iraq Central Statistical Organization (CSO), approximately 80% of Iraq's road network consists of arterials and rural, mostly two-lane, two-way highways [8]. In general, two-lane highways have lower speed limits and fewer technical parameters than motorways. There are two-lane highways that are used both for short- and long-distance. It is important to determine the extent to which a road's geometric and traffic characteristics impact the level of service in order to determine suitable improvements for the highway [9].


**History:** Received: 21 February 2025; Revised: 18 April 2025; Accepted: 21 April 2025; Published: 2 May 2025
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Prior studies on two-lane highways have primarily focused on three key aspects: evaluation, Level of Service (LOS), and improvement. There have been several studies published on the first group of studies, investigating the influence of several parameters, such as the quality and reliability of highways [5, 7, 8, 10]. The performance measures[11-14]. Heavy vehicles [15, 16]. And the geometric features of the highway (number of lanes, lane width, shoulder width, access point, and lateral clearance) [17]. The conditions outlined in the passage assist in maintaining safety and maximizing the performance of two-lane, two-way highways. Road quality and reliability as well as characteristics like lane number and shoulder width can influence both traffic volume and traffic flow. Moreover, vehicular presence on these roads generates stability, maneuverability, and overall traffic dynamics, like speed, volume, and flow rate, issues that point to the necessity of meticulous studies and enhancement schemes. There have been studies conducted to compare the parameters of two-lane, two-way road networks to other kinds of roadway classifications [9, 18]. Some of the reasons why such roads are less safe include the absence of dividers or medians. Additionally, the presence of some of the design features typical of highways, such as trees, poles, heights, walls, or other objects to delineate lanes, control access, and beautify the layout of the roads, is largely absent [19]. The previous stipulation declares two-way, two-lane roads to be quite unsafe relative to other roads because of their weak design principles [12-14, 20]. On these roads, there is no barrier separating opposite directions of traffic, which may increase the risk of head-on collisions and run-off accidents [15, 21, 22]. Furthermore, a lack of separation between the two traffic flows may make passing more hazardous, especially on two-way roads with higher traffic volumes [15].

In the aforementioned second research category, a few studies concentrate on examining traffic's overall properties, including traffic flow speeds, maximum permissible speed limits, traffic volumes, and geometrical parameters influencing two-lane, two-way highways. The aim is to enhance highways and road safety, or to reduce the risk associated with these roadways [22]. Speed limits are a critical factor in evaluating highways and road safety, with many benefits. The regulations set by law enforcement for the average speed of travel help to control traffic flow and avoid unnecessary conditions or accidents. It also creates better traffic characteristics, such as less constricted roadways and, overall, a better-running and safer highway [23]. The procedures evaluate these highways based on their performance, and the overall progress rating aids in making necessary updates and improvements. These highways are evaluated based on performance measures that closely align with their performance determinants. In the past two to three decades, performance measures for two-lane highways have been an area of focus for several research efforts due to the well-perceived limitations of the current HCM measures for this type of highway [11]. Compared to other types of highways, performance measures for two-lane highways often pose unique challenges [24, 25]. Due to the limited passing opportunities and generally low capacity of two-lane highways, performance measures typically focus on the LOS, travel time reliability, and safety. As it is, specific analysis will guarantee that the strategies for upgrading and enhancing two-lane roads will appropriately consider the varying needs of weekday, weekend, and annual peak periods, in addition to the overall objectives concerning such highways. The rural road network in Iraq has undergone dramatic challenges in the past decades with an enormous upsurge in volume of car traffic, thereby witnessing a decline in service quality and operational performance [3, 26-28]. The apparent consequences of traffic congestion, accidents, and increased air pollution are evidence of this issue. Other issues that afflict the rural regions of Iraq are the low quality and lack of coordination in the construction and upkeep of infrastructure projects, which have greatly hindered economic development and growth in these regions [29].

The new HCM-2022 and HCS-2024 present new measures and criteria for the performance analysis of transportation facilities. These measures encompass traffic congestion and future population growth. Moreover, policymakers are able to implement new technologies and solutions that aim at optimizing the use of transportation resources and system performance as a whole. Lastly, the new HCM-2022 and HCS-2024 offer a definitive guide to ongoing improvement in transportation [30].

Every aspect of performance measurement is included in the computation of the LOS of a dual-lane highway [18, 31]. The peak hour volume (PHV) computes the traffic flow during the peak hour,

*Edelweiss Applied Science and Technology*
*ISSN: 2576-8484*
*Vol. 9, No. 5: 43-52, 2025*
*DOI: 10.55214/25768484.v9i5.6775*

whereas the percentage of heavy vehicles (HV%) computes the effect of heavy vehicles on traffic congestion [15]. The peak hour factor (PHF) considers the variation of traffic flow within the peak hour interval [16, 32]. The speed limit assigned is the maximum permitted speed on the road, and the access point (AP) examines intersections or entry points that may affect traffic flow [17]. These are fundamental variables in the analysis and computation of LOS for two-lane, two-way roads [11].

The present research is intended to analyze and enhance the two-lane highway's operational performance between Salah El-Din Governorate and Kirkuk Governorate in Iraq based on the LOS as per current conditions, short-term traffic projections, and geometric features. The highway is segmented into seven various sections, each of which is analyzed by the HCS 2024 method to find its equivalent LOS. Collected data was processed by HCM 2022 in order to provide insights into conditions and to fairly evaluate the LOS for every segment. The study assisted in determining strategies for increasing LOS and overcoming any problems currently present, helping decision-makers achieve a clear insight into the condition of the road. The results of this study can inform policy, providing the basis for targeted enhancement and strategic intervention to enhance highway performance and ensure sustainable development.

## 2. Methodology

One of the most significant aspects of this study is the use of real two-lane highway data from Iraq, along with the use of HCM and HCS in determining the LOS of the selected highway. Such data is crucial as it presents a real reflection of the current traffic condition and problems on such highways. Through the utilization of this data set, there can be a more accurate determination of the service level along with the critical improvements that will make the highway safer and more efficient. The HCM 7th Edition was utilized to compute the data in each segment, then the HCS in validating and analyzing the results. The program provided an accurate representation of current conditions to enable the making of improvements in highway design that minimize hazards and promote safety.

### *2.1. Description of the Site*

The purpose of this study is to analyze a major two-lane highway connecting the northern region of Iraq to the multi-lane arterial system of Baghdad. These segments were selected for evaluation and improvement due to their high traffic density and frequent accident locations, as shown in Figure 1. The highway, being a key international route, holds significant economic and cultural importance. It plays a crucial role in linking Baghdad with the southern regions of the country, including vital agricultural, recreational, and religious areas. Additionally, a considerable portion of the traffic consists of heavy vehicles that transport goods, contributing to significant congestion at various times throughout the day. The highway also faces challenges related to its poor geometric design and heavy traffic load. The traffic volume, as measured by AADT and PHV, is extremely high, leading to frequent accidents. Over the past two decades, this has resulted in numerous fatalities, injuries, and property damage.

*Edelweiss Applied Science and Technology*
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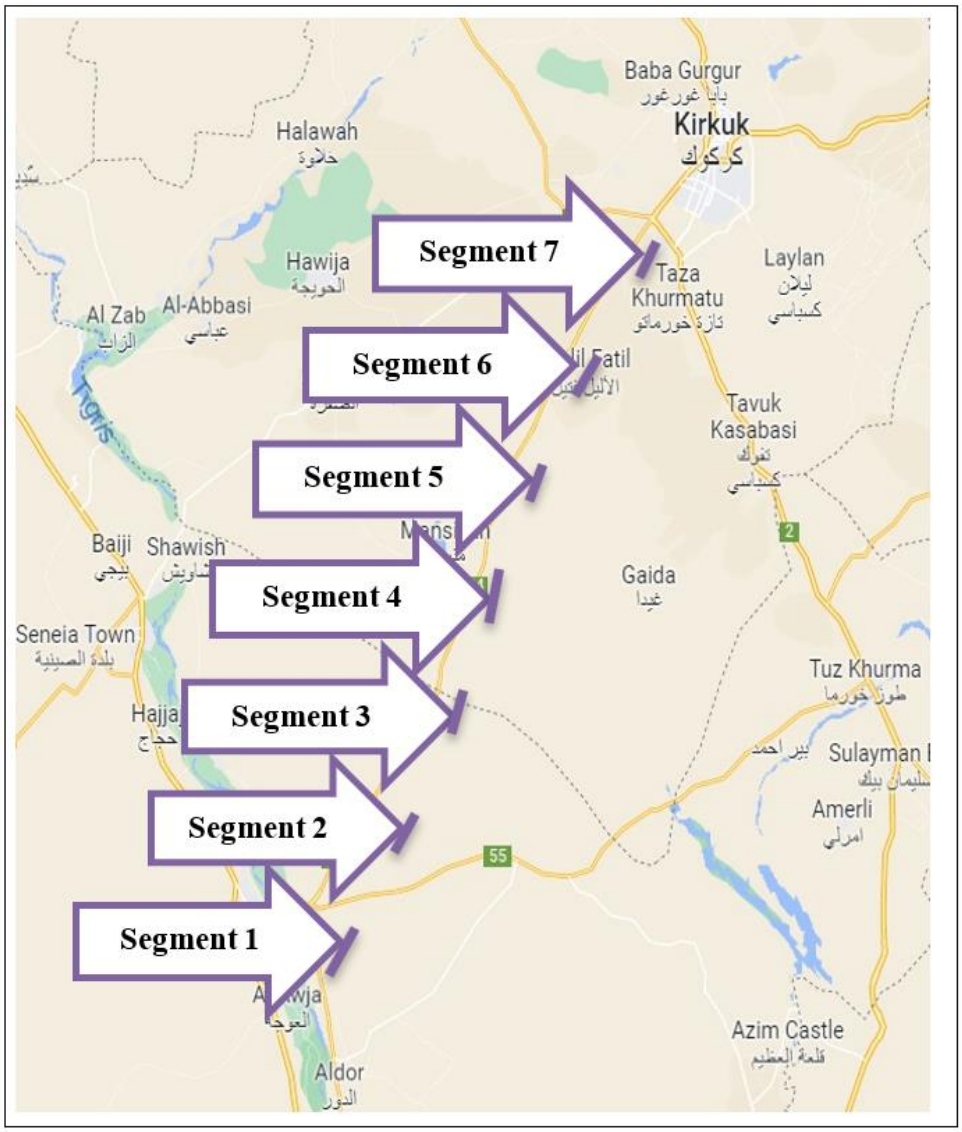


**Figure 1.**
Aerial Photograph of the study area ("Google Maps," 2024).

*2.2. Data Collection*

The data collected for the highway was categorized into three main types: highway geometric data, vehicle speed data, and traffic volume data. Traffic data was gathered through direct observation, serving as the primary data source for this study. Recordings were conducted daily for one hour during peak periods, spanning from Thursday, December 15, 2022, to Wednesday, December 21, 2023, using a network video recorder (NVR) system. The recordings in question recorded the vehicle types, i.e., passenger cars and heavy trucks, and directions of travel. The recorded data underwent an exhaustive hand review and verification process by means of video recordings to determine its accuracy and reliability. In addition, geometric data were also gathered in the field, which included measurements with respect to lane width, number of lanes, entry points, and lateral clearance. These data gave useful indications of the then-prevailing traffic conditions, allowing an accurate assessment to be made and a foundation for planning for the improvements wanted. Figure 2 shows the traffic volume data representative of the prevailing conditions.

*Edelweiss Applied Science and Technology*
*ISSN: 2576-8484*
*Vol. 9, No. 5: 43-52, 2025*
*DOI: 10.55214/25768484.v9i5.6775*

In order to project future traffic conditions, a growth rate was included in the analysis. From the records of vehicle registration at the Traffic Department of the Ministry of Interior in Iraq, a growth rate of three percent (3%) per year was used, which is representative of the historical trend of traffic volume for the last several years. In this way, future traffic demands can be realistically estimated, thereby facilitating the formulation of efficient highway improvement strategies.

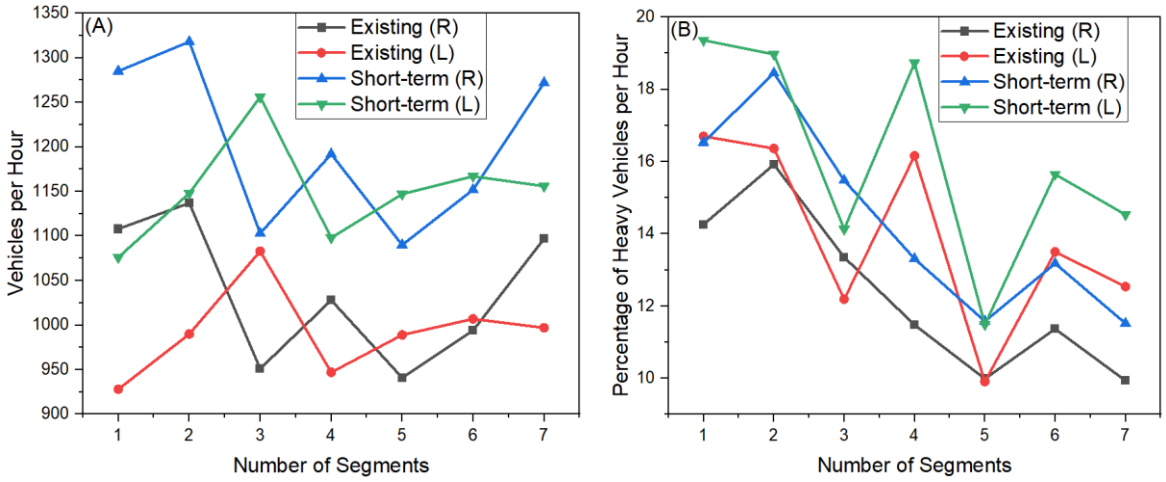


**Figure 2.**
(A) represents the number of passenger cars per hour for the seven segments, and (B) represents the percentage of heavy vehicles per hour for the seven segments (existing, and short-term conditions).

*2.3. Analysis Tool*

The Highway Capacity Software (HCS) initially materialized due to the efforts of the Federal Highway Administration (FHWA) in 1986 as "Center for Microcomputers in Transportation" (McTrans) HCS 2024. Today, it is a comprehensive software support center affiliated with the University of Florida that provides service to the transportation professionals globally. HCS is Windows-based software backed by a robust support system coupled with thorough technical support and offers a sound traffic analysis system. The updated Highway Capacity Software 2024 is widely used by transportation management professionals as an improved analytical tool to evaluate the performance of highways and roadways. It provides holistic judgments of vital factors such as traffic flow, congestion, capacity, and safety. With the use of HCS, practitioners can make well-informed, data-driven decisions to improve highway design, traffic management strategies, and the overall framework of transportation planning. Significantly, HCS 2024 introduces valuable enhancements, including improved accuracy in analysis, new modeling capabilities for dynamic traffic conditions, and compatibility with future transportation technologies. Its usability as well as high level of customization make it an essential tool in streamlining transportation infrastructure, ultimately resulting in safer, more efficient highways worldwide.

*2.4. Analysis*

A series of field reconnaissance was made in the study area on a number of occasions to validate the geometric and traffic data related to the highway, delineate the sections of the highway, and gather the necessary data for analysis. The highway from Salah El-Din Governorate to Kirkuk Governorate is a rural two-lane, two-way highway with one lane allocated for traffic flow in each direction. The observed posted speed is 62.13 mi/h (100 km/h), which has been observed for each segment. In accordance with Eq. (1), the estimated base free flow speed (BFFS) will be drawn from the HCM 7th.

$$\text{BFFS} = 1.14 \times \text{Spl} \quad (1)$$

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Where SpI represents the posted speed limit (mi/h), Each lane has a width of 11.48 ft (3.49 m), and in each direction, the shoulder width and lateral clearance are zero. Additionally, to define the LOS for each segment, we must estimate the demand volume under prevailing conditions (V) for the selected segments and convert it into the demand flow rate under equivalent base conditions (Vp). The maximum peak hour volume (PHV) for each segment has been obtained from traffic volume. Given the current circumstances, we provide the following details for each of the seven highway segments. The data was also used to identify future improvements to the highway, such as widening lanes or changing it to a multi-lane highway. As for future improvements for highways, the posted speed limit is 60 mi/h (97 km/h), and the BFFS on multi-lane highways under base conditions is approximately the posted speed plus 5 mi/h (8 km/h) for a speed limit of 50 mi/h (80 km/h) or higher and the posted speed plus 7 mi/h (11 km/h) for speed limits less than 50 mi/h (80 km/h). Each lane has a width of 12 feet (3.6 meters), while the shoulder width and lateral clearance are 6 feet (1.8 meters) in each direction. The Ministry of Planning, Central Statistical Organization of Iraq (MPCSO) expects the peak hour volume (PHV) and percent of trucks (HV%) to grow by a percentage of 3% per year for the short-term analysis. The short-term analysis begins by converting the present demand volume to the future peak-hour demand volume (PHV) using Eq. (2), which is as follows:

$$\mathrm{PHV}_{(\mathrm{Future})} = \mathrm{PHV}_{(\mathrm{Present})} \times (1 + \mathrm{g})^{\mathrm{n}} \quad (2)$$

Where PHV is peak hour volume, g is the growth rate, and n is the number of years. It is worth noting that the number of access points in each segment has been reduced to two access points per segment.

## 3. Findings and Analysis Results

This study aimed to assess the current traffic conditions on the selected highway (Salah El-Din Governorate to Kirkuk Governorate) to determine the highway's LOS, efficiency, and effectiveness. Identifying potential improvements for each segment is crucial for decision-makers, as it provides valuable insights into the current traffic conditions and highlights the areas in need of enhancement to improve transportation quality and ensure safe, uninterrupted traffic flow. In addition to the updated HCM-2022 analysis, a future scenario was evaluated using short-term forecasting for 2028. The study utilized HCS-2024 software to verify the evaluation's validity and accuracy, comparing the results with other validation methods, including surveys and hand sample analysis. This multi-validation approach enabled a comprehensive and reliable assessment, which enhanced the credibility of the findings.

As per the 2018 Policy on Geometric Design of Highways and Streets, the desirable LOS of rural highways comprises LOS-A (free flow), LOS-B (reasonably free flow), and LOS-C (stable flow). Although there are some highway authorities who accept LOS-D (approaching unstable flow) as satisfactory, LOS-E (unstable flow or maximum capacity) and LOS-F (forced or breakdown flow) are viewed as unacceptable, which would signal the requirement for improvement [33]. Low LOS can have a severe effect on highway users, leading to crashes that result in fatalities, economic losses, and adverse effects on local economies. Poor LOS can also limit access to essential services, impacting the quality of life for local communities [34]. Moreover, the environmental effects of poor LOS can cause health issues and loss of economic benefits [35]. Added travel time, fuel consumption, and lost productivity enhance the negative impacts. The evaluation of each segment of the highway was conducted for both existing and future conditions by HCS-2024, considering each direction of travel. Existing condition analysis results are presented in Table 1.

*Edelweiss Applied Science and Technology*
*ISSN: 2576-8484*
*Vol. 9, No. 5: 43-52, 2025*
*DOI: 10.55214/25768484.v9i5.6775*

**Table 1.**
Result of an analysis of the existing conditions of the highway 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 |

After evaluating the existing conditions, which revealed unfavorable outcomes for the highway, the initial proposal was analyzed, and the geometric design was enhanced to achieve an optimal state. Table 2 presents the results of the HCS-2024 analysis of the selected highway following the first improvement under existing conditions.

**Table 2.**
Results of the first improvement of the highway in the existing condition 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 | 68.5 | 64.1 | 551 | 0.55 | 13.2 | E |
| | Left | 65.6 | 61.3 | 461 | 0.49 | 14.8 | E |
| 2 | Right | 67.4 | 62.9 | 565 | 0.60 | 15.3 | E |
| | Left | 65.9 | 61.4 | 492 | 0.54 | 16.0 | E |
| 3 | Right | 68.5 | 63.9 | 473 | 0.49 | 15.0 | E |
| | Left | 66.0 | 61.8 | 538 | 0.56 | 13.6 | E |
| 4 | Right | 68.0 | 63.8 | 511 | 0.50 | 12.5 | E |
| | Left | 66.1 | 62.0 | 471 | 0.47 | 12.5 | E |
| 5 | Right | 67.8 | 63.7 | 468 | 0.45 | 11.4 | D |
| | Left | 65.3 | 61.3 | 492 | 0.50 | 12.3 | E |
| 6 | Right | 68.3 | 64.1 | 494 | 0.47 | 11.7 | D |
| | Left | 66.0 | 61.9 | 501 | 0.50 | 12.3 | E |
| 7 | Right | 67.3 | 63.0 | 545 | 0.55 | 13.3 | E |
| | Left | 66.2 | 62.1 | 496 | 0.49 | 12.1 | E |

Given the unsatisfactory results of the first improvement, it is recommended to implement the second proposal, which involves upgrading the highway from a two-lane, two-way configuration to a multi-lane highway. Tables 3 and 4 present the results of the HCS-2024 analysis for the selected highway under both existing and short-term forecast conditions.

*Edelweiss Applied Science and Technology*
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*Vol. 9, No. 5: 43-52, 2025*
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**Table 3.**
Results of the second improvement of the highway in the existing condition in 2023.

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

**Table 4.**
Results of the second improvement of the highway in the short-term condition in 2028.

| No. of Segment | Direction | Flow rate Pc/h/ln | FFS mi/h | Average travel speed mi/h | Density Pc/mi/ln | LOS |
|---|---|---|---|---|---|---|
| 1 | Right | 772 | 59.5 | 59.5 | 13.0 | B |
| | Left | 823 | 59.5 | 59.5 | 13.8 | B |
| 2 | Right | 858 | 59.5 | 59.5 | 14.4 | B |
| | Left | 875 | 59.5 | 59.5 | 14.7 | B |
| 3 | Right | 838 | 59.5 | 59.5 | 14.1 | B |
| | Left | 747 | 59.5 | 59.5 | 12.6 | B |
| 4 | Right | 718 | 59.5 | 59.5 | 12.1 | B |
| | Left | 732 | 59.5 | 59.5 | 12.3 | B |
| 5 | Right | 654 | 59.5 | 59.5 | 11.0 | A |
| | Left | 673 | 59.5 | 59.5 | 11.3 | B |
| 6 | Right | 686 | 59.5 | 59.5 | 11.5 | B |
| | Left | 702 | 59.5 | 59.5 | 11.8 | B |
| 7 | Right | 731 | 59.5 | 59.5 | 12.3 | B |
| | Left | 690 | 59.5 | 59.5 | 11.6 | B |

## 4. Conclusion

The analysis of the results indicates that increased traffic volumes and congestion, under both existing conditions and short-term forecast conditions, significantly impact highway segments. The highway is currently unable to accommodate this high traffic volume, resulting in a LOS of E for all seven segments. However, in the short-term forecast, two segments show a slight improvement, operating at LOS-D. With the implementation of improvements in the management program, all segments are expected to achieve LOS-A and LOS-B, which will enhance operational efficiency and provide better service to users. Furthermore, these changes will help reduce the environmental impact. Segments that previously operated at LOS-E showed improvements in LOS as a result of modified geometric and traffic conditions. These modifications include increasing the number of lanes to two in each direction, converting the highway from a two-lane two-way road to a divided multi-lane highway, reducing access points, and raising the posted speed limit, all of which work to reduce congestion and improve geometric conditions to optimal levels.

*Edelweiss Applied Science and Technology*
*ISSN: 2576-8484*
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*DOI: 10.55214/25768484.v9i5.6775*

## 5. Recommendation

As a general recommendation, all major urban and rural highways in Iraq should be designed and planned according to the methodology outlined in HCM 2022. Future improvement efforts should focus on increasing the number of lanes, expanding lane widths, and enhancing geometric conditions to optimal levels, especially for segments currently operating at LOS-E. In addition to the segments analyzed in this study, it is recommended that all two-lane, two-way highway segments across Iraq be evaluated. Reducing traffic congestion and improving the LOS could be beneficial for a cost-benefit analysis. Furthermore, reducing accidents, stops, and delays will contribute to lower fuel consumption and improved environmental outcomes. While this study does not include cost estimations, it is strongly recommended that future studies incorporate them once sufficient data becomes available. Lastly, for two-lane, two-way highways in Iraq, it is also advised to explore the relationship between road geometric characteristics, Heavy Vehicles (HVs), LOS, and capacity to gain a deeper understanding of the factors influencing highway performance.

## Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

## Copyright:



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*Edelweiss Applied Science and Technology*
*ISSN: 2576-8484*
*Vol. 9, No. 5: 43-52, 2025*
*DOI: 10.55214/25768484.v9i5.6775*