Evaluation of Flexible Pavement Friction Coefficients: A Case Study of East-West Highway Near Mahendranagar City, Nepal

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Abstract

Friction is a crucial factor in highway engineering, as it affects the traction between a vehicle's wheels and the road surface. This traction significantly influences the movement, speed, and efficiency of vehicles on highways. The coefficient of friction depends on various factors, such as pavement materials, traffic volume, road age, temperature, and weather conditions. The Skid Resistance Test Method is adopted for the study, which involves using a Portable Skid Resistance Tester to measure the British Pendulum Number (BPN) and then calculating the coefficient of friction by dividing the BPN by 10. An evaluation of a 5 km stretch of the East-West highway near Mahendranagar Bazaar revealed a longitudinal coefficient of friction of 0.354 and a lateral coefficient of friction of 0.184 under both dry and wet conditions. These findings were relevant for design speeds ranging from 60 to 80 km/h and considered an Annual Average Daily Traffic (AADT) of 10,321 Passenger Car Units (PCU) during the year 2023/2024. The assessment also indicated a variance of 0.19% and a poor International Roughness Index (IRI) value of 2.05. These aggregates had specific gravities ranging from 2.6 to 2.67 and were sized at 13.2 mm. The application rate for the aggregates ranged from 12 to 15 kg per square meter. It is important to note that a higher coefficient of friction leads to reduced vehicle efficiency. Thus, it is crucial to carefully consider the coefficient of friction values and detailed specifications to ensure traffic safety and road integrity.

Keywords: *AADT, Friction, IRI, Skid Resistance Test, Surface dressing*

Introduction

A country's roads are its foundation, essential to its entire growth. Any country's level of development may be determined by its road network, as roads are essential for trade and transportation. They promote economic growth and connection both inside and beyond borders by facilitating the flow of people and products. Safe roads are a major worldwide transportation problem. The safety of both drivers and pedestrians is directly impacted by the state of the road surface. Friction between the tyre and the road surface is one of the numerous variables affecting road safety. The amount of traction that a vehicle has impacts its maneuverability and braking capacity, and the friction coefficient is a key factor in determining this. In terms of structure and surface, roads can be classified into flexible and rigid pavements. 95% of the whole world's highways are flexible pavement (Zaid et al., 2019). Typically, a flexible pavement is constructed in stages, starting with the sub-grade and going up to the base course, sub-base, and surface layer. The surface layer consists of two components: the wearing course and the binder course. As the topmost visible surface of the road, the wearing course is essential to ensuring a secure, comfortable, and well-fractioned driving experience.

The assessment of a road's skid resistance, or frictional properties, is an essential factor in determining its propensity for failure and long-term serviceability. In Nepal, where road networks serve as the mainstay of the transportation infrastructure, determining the friction coefficients of flexible pavements becomes an important field of study. Given the heterogeneous climate and fluctuating traffic volumes in Nepal, the effectiveness of flexible pavements can have a major influence on road safety. The International Roughness Index (IRI), in addition to friction coefficients, is a crucial indicator of pavement quality. Together with friction coefficients, IRI provides a thorough knowledge of pavement performance by reflecting ride quality and smoothness of road surfaces. This helps transportation authorities' priorities maintenance and rehabilitation projects to improve traffic safety. Road friction coefficient is a powerful means to improve vehicle driving safety and stability performances via active safety systems such as emergency collision avoidance (ECA), active front steering (AFS), anti-lock braking system (ABS), direct yaw moment control (DYC) and traction control system (TCS) (Zhao et al., 2017). The performance of these systems is directly tied to the operating range of tire forces, which remain within the limitations imposed by the road friction coefficient. Understanding this coefficient can significantly enhance system effectiveness.

Depending on the aggregate type, condition, and surface roughness, flexible pavements made of asphalt layers have different frictional characteristics. Aggregate characteristics such as texture, angularity, form, and abrasion resistance affect pavement surface friction variations(Zhan et al., 2021). In especially during bad weather, high coefficients of friction are necessary to prevent sliding and provide sufficient grip. These characteristics have a direct impact on stopping distances, vehicle stability, and general road safety. Maintaining high friction levels requires careful planning, routine maintenance, and the right aggregate selection and surface treatments. For the purpose of improving commuter efficiency and road safety, it is imperative to comprehend and optimize this relationship.

Objectives

The study aims to evaluate the condition of the flexible pavement along the East-West (National) highway near Mahendranagar City, Nepal. This study aims to quantify the longitudinal and lateral coefficients of friction (CoF) and figure out the International Roughness Index (IRI) connected to these CoF values. In addition, the study looks at the effects of pavement ageing, traffic volume, surface material degradation, and meteorological variables on coefficients of friction (CoF).

Literature Review

Efficient highway transportation stands as a pivotal determinant for ensuring traffic safety (Kalašová & Stacho, 2006). Various factors influence this, including pavement type, traffic volume, vehicle speed, braking characteristics, pavement aging, and the efficacy of highway management and planning systems. Within the Context of flexible pavement systems (FPS), assessing surface friction characteristics through skid resistance measurement (Abdallah et al., 2019)stands as a primary method among numerous direct and indirect tire-road friction coefficient (TRFC) estimation approaches (Wang et al., 2022). The features of surface friction are greatly influenced by the materials used for surface wearing, especially when it comes to variations in vehicle speed. Beketov and Khalimova extensively studied the dependence of the adhesion coefficient on road surface type and vehicle speed across surfaces with varying roughness, yielding an empirical dependence reflecting the relationship between traffic speed, flow density, and load factor under diverse traffic conditions (Beketov & Khalimova, 2023). Nemchinov's work underscores the significance of surface roughness in generating friction force, with variations in friction coefficients in different directions impacting vehicle movement (Beketov & Khalimova, 2023).

Azizov's findings suggest that pavement roughness is consistently worse at the edge of the carriageway compared to the middle part, based on assessments conducted along the vehicle track and carriageway edge (Beketov & Khalimova, 2023). Surface aging directly influences skid resistance, exhibiting higher skid resistance during initial application phases and reduced resistance due to aggregate polishing, leading to increased slipperiness over time (Kumar & Gupta, 2021). Under wet conditions, the evolution of friction coefficients contribute significantly to total theoretical values, whereas dry adhesion has a minimal impact (Singh et al., 2019). Hence, annual pavement condition evaluation is imperative, correlating with changes in traffic volume to effectively plan and manage traffic flows, maintenance, and reconstruction. Accurate prediction of pavement performance, especially regarding the International Roughness Index (IRI), hinges upon substantial changes in friction coefficients. Sigdel and Pradhananga devised an IRI prediction model tailored for Nepal's national highways (Sigdel & Pradhananga, 2021). Traffic volume serves as a pivotal factor influencing road surface conditions, with heavy vehicle Average Annual Daily Traffic (AADT) significantly impacting IRI values (Siregar & Sumabrata, 2023). Regular examination of pavement surface problems is essential due to the diversity of flow entities on national roads. Recommendations for appropriate restoration based on vehicle attributes, road materials, and weather conditions are therefore necessary.

After reviewing previous literature, it was decided that an appropriate case study would be to assess flexible pavement friction coefficients and how they affect traffic safety along the East-West route close to Mahendranagar City.

Methodology

Pavement, as the uppermost layer of roads, serves as the primary interface with road vehicles, influencing significantly on-road usability and functionality. The compacted thickness and materials of pavement play a crucial role in determining its performance and durability. Factors such as traffic volume, quality of materials used in construction and environmental conditions (viz. climatic conditions and hydro-geological conditions) contribute to the degradation of pavement roughness over time. The study of pavement roughness is addressed by longitudinal and lateral coefficients of friction, which govern vehicle movement. Adequate friction between tires and road surfaces ensures optimal traction, facilitating safe deceleration. Conversely, insufficient friction can lead to increased stopping distances and the risk of skidding, compromising road safety.

Bitumen, a primary binding material used in Nepal's national highways, exhibits specific friction characteristics, resulting in higher skid resistance compared to other pavement types such as concrete or Water Bound Macadam (WBM) pavements. Additionally, the frictional properties of a road are influenced by the type of aggregates used, with greater resistance to polishing indicative of higher frictional characteristics. The application of Single Bituminous Surface Dressing (SBSD), a thin surface layer for resealing, is common in the study section of the East-West highway. The BPN values were corrected to account for the temperature-dependent stiffness of the rubber slider. This was achieved by applying the TRRL and ARRB correction equation to bring the BPN values to a standardized temperature of 20ºC (Msallam et al., 2017) as below:

$$\text{BPN 20} = \frac{BPN\ at\ t,\ \ test\ temperature}{1-\left(0.00525\,(t-20)\right)}$$

Road conditions can be classified by evaluating the International Roughness Index (IRI) based on British Pendulum Number (BPN) values. This categorization helps determine the necessary maintenance levels to maintain the highest standards of safety and driving comfort. IRI is discovered and assessed below their thresholds by using the model for evaluating the Friction of Flexible Pavement and the correlation between PCI, IRI, and Skid Number (Obando et al., 2022).

$IRI=18.844PCI^{-0.642}$
Where:
IRI= International Roughness Index (m/Km)
PCI=Pavement Condition Index (0-100)
$Fn= 30.251e^{0.005PCI}$
Where:
Fn= Friction Number(Skid Resistance Number)

Data validation involved comparing observed/calculated data with field measurements and referencing specifications from NRS 2078 (2nd amendment). Secondary data provided by the Department of Roads, Kanchanpur branch, included information on surface resealing aging, laboratory test results of aggregates, and spray rates of coarse aggregates used in SBSD work. Traffic accident data from different fiscal years were obtained from the District Traffic Office, Kanchanpur. Secondary data from various sources were cross-referenced with primary data collected through observations and calculations to assess traffic safety. Average Annual Daily Traffic (AADT) and International Roughness Index (IRI) values were sourced from the official website of the Department of Roads, Nepal.

The comprehensive analysis of both primary and secondary data is summarized in the conclusion of the case study. Key findings highlighted the impacts of pavement surface materials, average vehicle speed (considered under design speed), and traffic volume on the friction coefficient increase postconstruction period. These insights contribute to the understanding of pavement performance and the formulation of effective maintenance and traffic management strategies to enhance road safety. To assess the current state of the study area, a 5 km stretch of the East-West highway near Mahendranagar city in Nepal was selected for analysis. British Pendulum Number (BPN) values, representing skid resistance, were measured at 19 intermediate sections using the Stanley British Pendulum Skid Resistance Tester (Munro Instruments, 2019), focusing on sections with intersections and changes in gradients.

Figure 1: Location map of the study area

Results and Discussion

The analysis of data from the evaluation of friction coefficients for flexible pavements on the East-West Highway near Mahendranagar City, Nepal, provides valuable insights. The use of a British Pendulum Tester (BPT) allowed for the quantification of friction coefficients. The results, presented in detailed tables and graphs, effectively demonstrate the frictional behavior of the pavement under different conditions. A comprehensive analysis of variance was conducted, considering factors such as temperature and surface moisture (dry vs. wet conditions). The specific material properties of the pavement under investigation, which features a Single Bituminous Surface Dressing (SBSD) with an average cross-section of 12 meters, greatly influenced the friction coefficients. Although no accident data related to pavement defects were identified from secondary sources, the study highlights the highway's smooth operational performance. This performance indicates that the pavement is adequately maintaining safety and functionality. The findings emphasize the significance of surface dressing type, temperature, and moisture conditions in influencing pavement friction, which are crucial for developing effective traffic safety measures and pavement maintenance strategies.

Determination of Longitudinal and Lateral coefficients of Friction

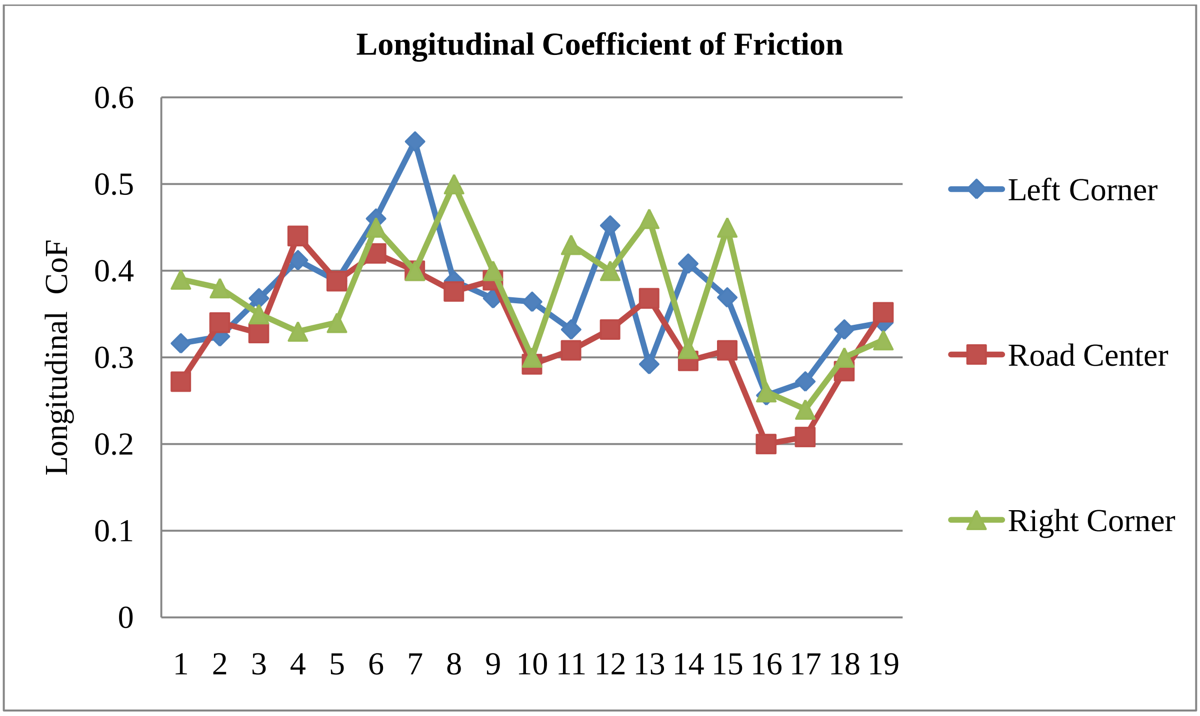

Figure 2: Longitudinal coefficient of friction

The supplied graphs show differences at the left edge, centerline, and right edge along the alignment for the longitudinal and lateral coefficient of friction (CoF) in various highway sections. The centerline often shows the lowest CoF values, according to the data, which points to a continuous trend. This suggests that most cars mostly drive on the centerline, which leads to less friction and smoother wear. The left and right corners, on the other hand, have greater CoF values, which suggests less frequent vehicle passage and, as a result, less wear and tear. Different friction characteristics are produced throughout the road surface as a result of this unequal traffic load distribution. Points 5, 7, and 10 in particular show notable peaks in CoF near the corners, highlighting the variation in vehicle distribution even more.

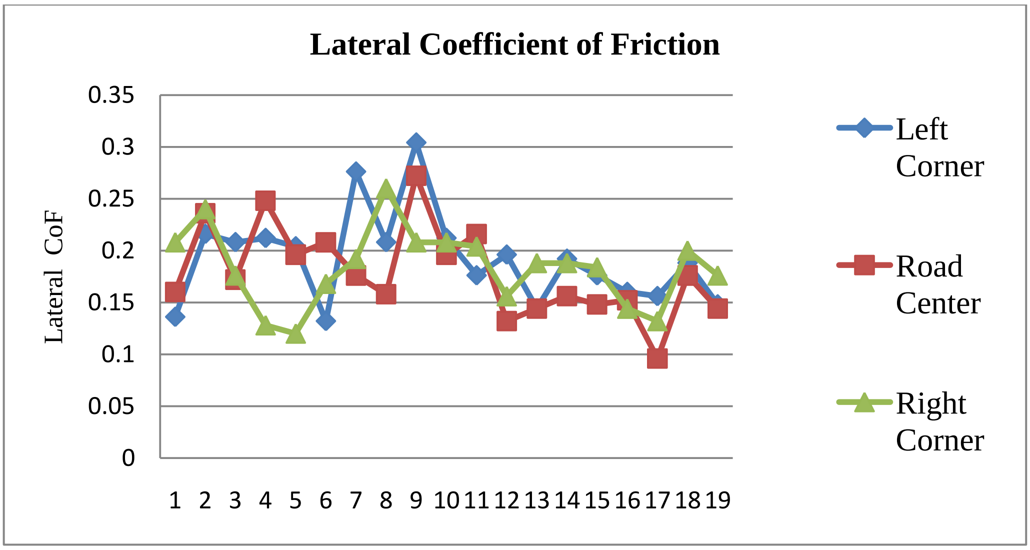

Figure 3: Lateral coefficient of friction

The analysis reveals that the minimum CoF values on the centerline, particularly around sections 3, 7, and 14, may be attributed to the compounding effect of traffic concentration. On the other hand, the elevated CoF at the edges can be linked to the accumulation of debris, less frequent traffic, and potential edge effects such as water retention and weaker pavement support. Understanding these variations is crucial for optimizing pavement design and maintenance strategies. Ensuring a more uniform CoF across the highway can enhance vehicle safety, improve driving comfort, and prolong the lifespan of the pavement. Future research should focus on mitigating wear on the centerline and enhancing edge support to achieve a balanced distribution of traffic-induced stresses.

Coefficient of Friction in Dry and Wet Conditions

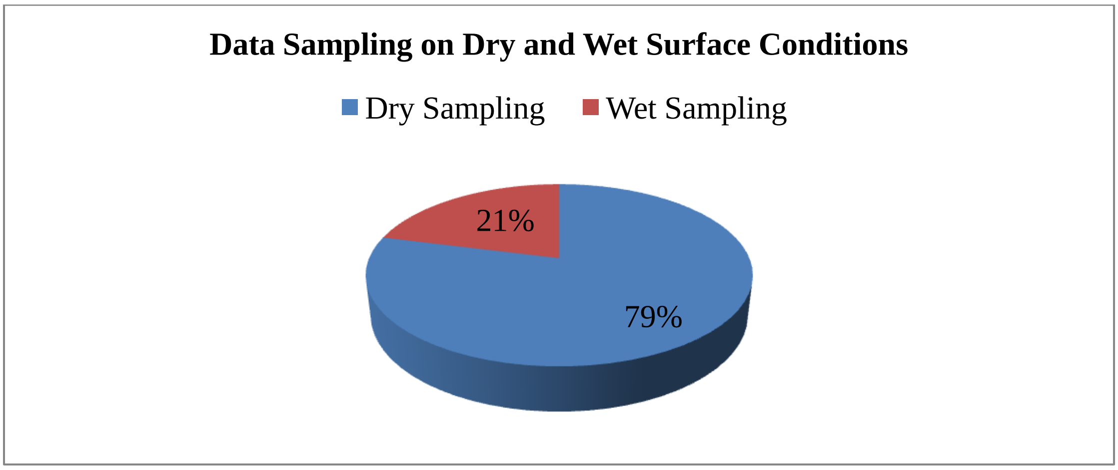

Figure 4: Data sampling on dry and wet surface conditions

The distribution of sampling on dry and wet portions of the highway to evaluate skid resistance is represented in the pie chart. Wet surface sampling made up a notably smaller percentage of the data collection, which was conducted on dry surfaces for the most part.

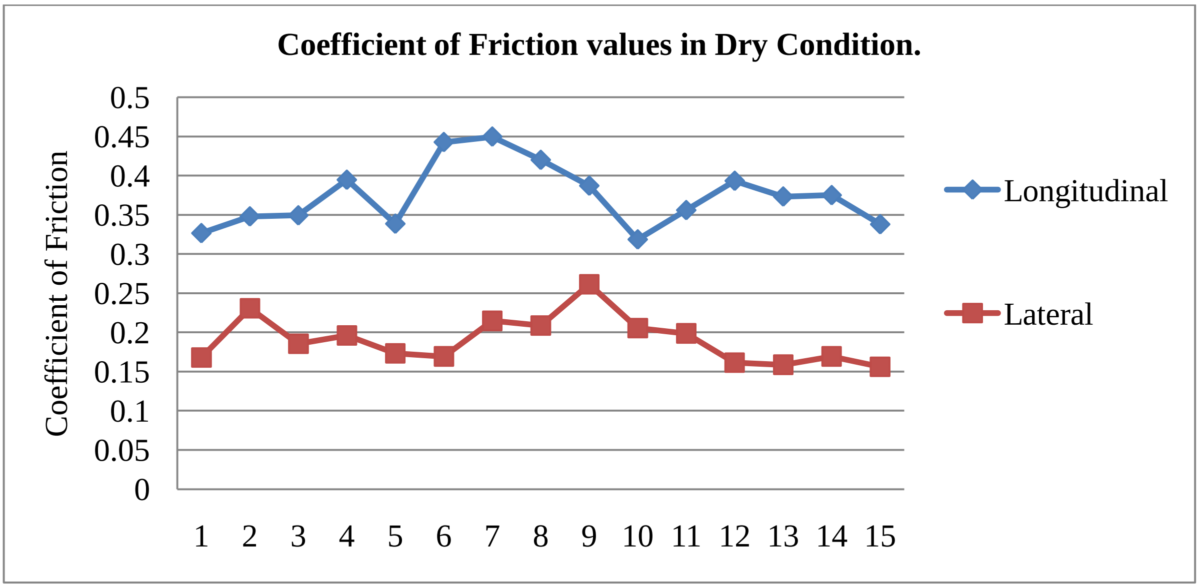

Figure 5: Coefficient of friction values in dry condition

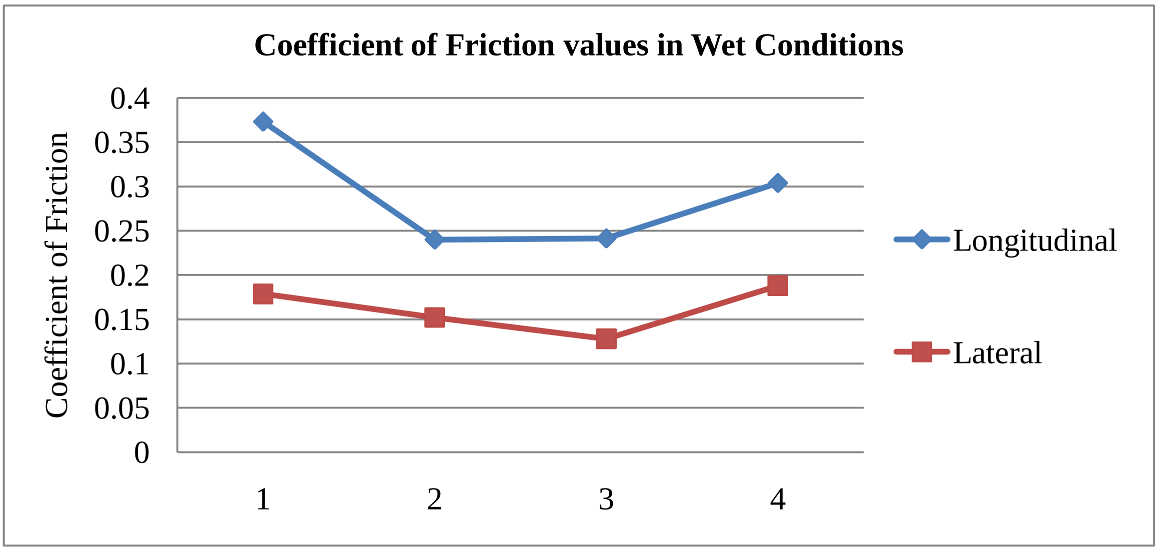

Figure 6: Coefficient of friction values in wet condition

The examination of skid resistance in both dry and wet surface conditions demonstrates different patterns in the behavior of friction. Higher longitudinal CoF values, ranging between 0.3 and 0.45, are seen in the first graph, which represents 15 sections in dry conditions. This indicates more stable and advantageous friction levels. Less variability but reduced friction is seen in the lateral CoF values, which range from 0.15 to 0.25. This suggests that lateral movement patterns may face a safety risk in dry conditions. Along the entire length of the highway, the longitudinal CoF consistency indicates dependable traction for vehicle movement; however, the lower lateral CoF needs attention for side-to-side stability.

On the other hand, the second graph, which shows four sections in wet conditions, emphasizes lower overall CoF values. The range of values for longitudinal CoF is 0.25 to 0.35, whereas the range for lateral CoF is 0.1 to 0.2. The higher chances of hydroplaning and decreased vehicle control are highlighted by the lower CoF in rainy conditions. While the overall lower friction values highlight the need for better drainage and surface treatments to improve safety, the consistency in the lateral CoF values, despite being lower, indicates uniformity in surface response under wet conditions. The data from both wet and dry conditions show how important it is to perform targeted maintenance and surface treatments to improve skid resistance, especially in adverse weather, so that drivers are as safe as possible.

Study of International Roughness Coefficient (IRI)

The Department of Roads Nepal's 2022–2023(*DOR: SSRN*, n.d.)Study period's International Roughness Index (IRI) plot for the NH01-070 chainage shows notable variations in surface roughness, with values ranging from 6.84 to 10.10. These variations highlight areas that need maintenance to ensure consistent ride quality and vehicular safety.

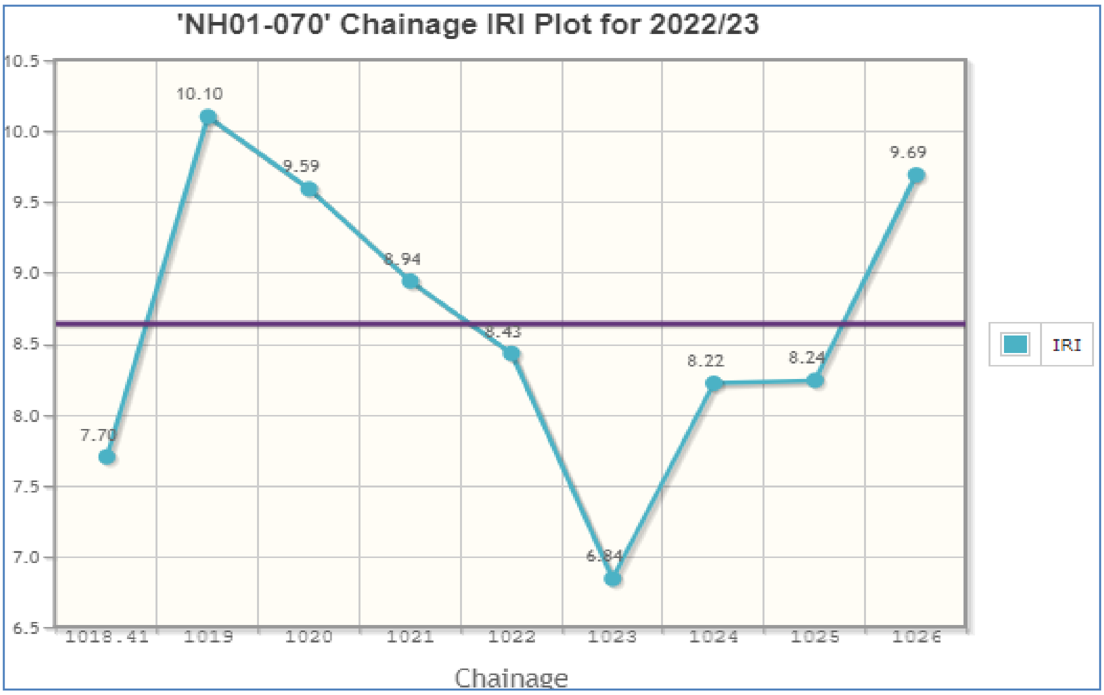

Figure 7: IRI plot for the year 2022/23 of the study area

Based on Obando et al.'s threshold, our study's IRI value of 2.05 m/Km denotes poor road condition. It denotes a rougher ride, which affects passenger comfort and may result in higher maintenance expenses because of accelerated wear and tear.

Other Factors Affecting Coefficient of Friction

a) AADT study

The graph from 2011–12 to 2023–24 showing Annual Average Daily Traffic (AADT) in Passenger Car Units (PCUs) shows a notable upward trend that peaks in 2018–19. This increase in AADT exacerbates wear on the road surface, which has a negative effect on friction coefficients and raises concerns for traffic safety. Because of this, in order to reduce accident rates and assure the best possible performance of the highway, strict maintenance and improved friction management techniques are required.

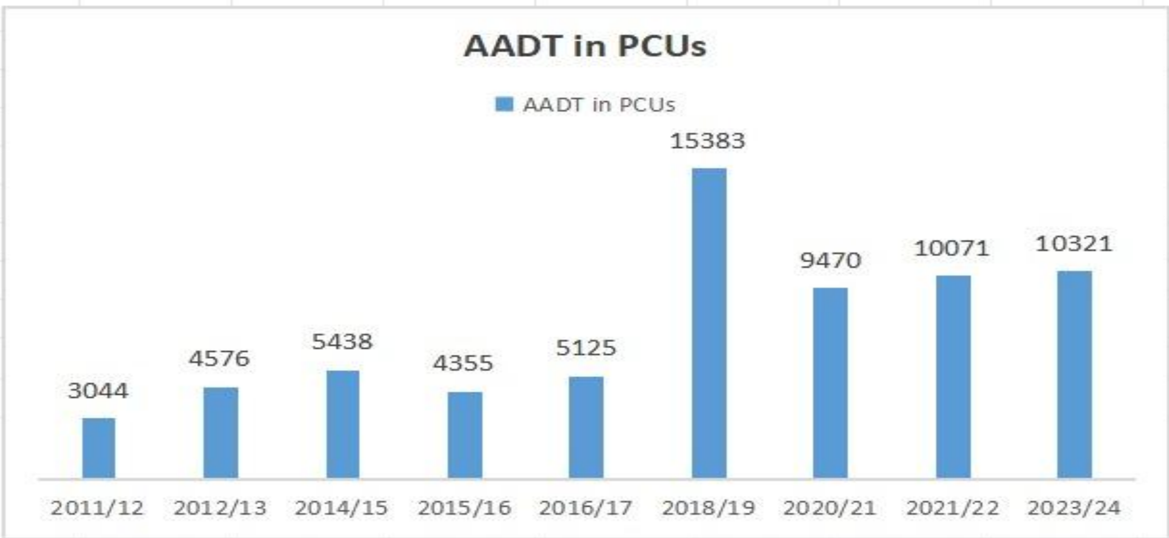

Figure 8: AADT in PCUs of different year of the study area.

From the data available on the AADT of previous years, the AADT of the survey year has been forecasted using the Geometrical Increase Method:

$P_n = P(1+I_g/100)^n$

Where:

n =No. of years between the last data available year to the survey year

I_g = Average Increase in AADT of previous years.

b) *Study of Surface Material Properties*

The material properties shown in the table below represent all characteristics of Single Bituminous Surface Dressing (SBSD) on the East-West Highway in Mahendranagar. The aggregates are carried from Mahakali River. These are irregularly shaped, uncrushed materials, mostly composed of quartzite and meta-quartzite. High density materials correlate with increased friction, as indicated by the specific gravity range. Reliability of materials to wear is indicated by low Los Angeles Abrasion values, which preserve the surface roughness necessary for friction. A balance in particle shape is reflected in the combined flakiness and elongation indices, which promote stability and ideal interlock, both of which raise the level of friction sustainably. Reduced porosity, which results from low water absorption, keeps the surface texture intact even when wet. Surface integrity is preserved in the face of abrupt impacts when the aggregate impact value is moderate. The results of the soundness test show resilience to weathering, assuring continuous friction over time. The weight of the material per square meter affects the pavement surface's frictional behavior by ensuring proper coverage and application.

Table 1: Characteristics of Wearing Course of the study area

Single Bituminous Surface Dressing(SBSD)/Resealing on East West Highway ,Mahendranagar	
Date	2078/12/01-2079/03/20
Chainage	997+000 to 1018+410
Source	100% natural river bed from Mahakali River.
Type	Quartzite and Meta Quartzite.
Shape	Uncrushed Irregular Shape including all Oval, Cubical, Round, Angular, Semi Angular.
Nominal Size of Aggregate for SBSD (Used)	13.2 mm
Specific Gravity	2.6-2.67
Los Angeles Abrasion Value	13-16
Combine Flakiness and Elongation Indices	20-27%
Water Absorption	0.2-0.6%
Aggregate Impact Value	09-Nov
Soundness Test for Ductility Under NaSO4	4-6%
Weight per square meter for SBSD	12-15 Kg per sq .m..
Note: Referenced on the basis of Table 13.13 of NRS 2073, 2nd Amendment 2078.	

Conclusion

The analysis of flexible pavement friction coefficients near Mahendranagar, Nepal, along the East-West Highway emphasizes how crucial it is to keep friction levels at a sufficient level to ensure traffic safety. The research, which included data from 2023 and 2024, examined both wet and dry pavement conditions and found that the average longitudinal and lateral friction coefficients were, respectively, 0.354 and 0.184. With an Annual Average Daily Traffic (AADT) of 10,321 Passenger

Car Units (PCU) and design speeds of 60–80 km/h, this investigation revealed a minimal variation of 0.19% and an International Roughness Index (IRI) of 2.05.The results highlight how important friction coefficients are for maintaining vehicle stability and stopping effectiveness—two essential elements of accident prevention and road safety. Adequate friction values must be provided within predetermined limits; too little friction can cause skidding and loss of control, while too much friction can reduce vehicle efficiency and adversely impact safety. The results indicate that the application of 0.88 l/m³ of bitumen tack and 12.07 kg/m³ of coarse aggregates three years ago produced friction values within acceptable ranges, and that the current states of friction coefficients on this section of the East-West Highway appear to conform to design criteria and international standards. In order to improve traffic flow conditions and increase highway safety, this study emphasizes the significance of continuous monitoring and adherence to friction specifications in pavement design and maintenance practices.

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Conflict of Interest

Authors declare that no conflict of interest.

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