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Development of IRI Prediction Model for National Highways of Nepal

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Abstract
Reliable prediction of pavement performance is essential for transportation agencies to effectively plan and manage maintenance, rehabilitation, and reconstruction of roads. Currently, the maintenance needs of national highways in Nepal are decided based on Surface Distress Index (SDI) and International Roughness Index (IRI). SDI is a subjective rating but IRI considers the interaction between pavement and vehicles, and is a globally accepted pavement performance indicator. Therefore, to support with a convenient yet reliable prediction of pavement condition, this study develops an IRI prediction model for pavements of national highways in Nepal using multiple linear regression technique. IRI, traffic and climatic database of and around 1745 highway sections of Nepal were used for the development of the model. The results of regression and validation shows that the model can predict future IRI as a function of initial IRI of the road, commercial vehicle traffic, rainfall and accumulated low and high temperature days the road is subjected to, with a reasonable degree of accuracy. The model shows a good fit to the observed values with R square value of 0.761.

Keywords
IRI, pavement performance, multiple linear regression, pavement maintenance.

1. Introduction

Pavement surface roughness is an important pavement performance indicator. Prediction of roughness that may occur in the future gives the idea about pavement performance at future, and can assists engineers, planners and the concerned authorities to develop rational plans for maintenance and rehabilitation. Roughness represents not just the condition of the pavement, but also the rider's comfort and the quality of the surface. A newly constructed pavement may have some initial roughness, which increases over time as the pavement deteriorates due to vehicle movement and environmental factors. It reduces vehicle efficiency and raises fuel consumption, maintenance and repair costs, and greenhouse gas emissions.

ASTM E867 defines pavement roughness as "the deviation of the pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality dynamic load and drainage." In the 1970s, the World Bank sponsored several large-scale research programs aimed at developing cost-effective maintenance alternatives for roadway pavements and developed the concept of International Roughness Index (IRI). IRI was an output of International Road Roughness experiment conducted in Brazil in 1982 by the World Bank [1]. It is defined as "the accumulated suspension vertical motion divided by the distance travelled as obtained from a mathematical model of a simulated quarter-car traversing a measured profile at 80 km/hr" [2]. The pavement roughness or smoothness values are comprehensive pavement evaluation indicator that takes into account not only comfort and ride quality but also the presence of distress. The condition of pavement can be evaluated by thoroughly observing the type and severity of distress presence in pavement. But this method is time consuming and costly for both project level and network level.

Highway infrastructure is a backbone of economic development of a nation. However, for developing countries like Nepal, maintaining road pavements in smooth condition is one of the major challenges. Huge amount of fund is spent every year for the maintenance works. Currently, Department of Roads (DoR), Nepal is using Surface Distress Index (SDI) and IRI values to prioritize the roads for the maintenance interventions. SDI is another pavement performance rating, but it is primarily based on subjective evaluation. IRI is based on vehicle response due to the interaction between pavement and vehicle and is a better performance indicator [3]. Therefore, development of pavement performance model with IRI as an index parameter and relating it to the major factors causing pavement distress is essential for development of efficient pavement management system with optimum utilization of the available resources.

In context of Nepal, there have been a few studies on pavement performance indicators. SDI model was developed to predict the periodic maintenance period of bituminous road in Nepal [4]. However, this model took only time into account as an independent variable. Incorporating climate and traffic parameters is highly recommended to improve model reliability. IRI is one of the major performance indicator used by DoR for performance based maintenance contract [5]. However, to the knowledge of authors, none of the studies has made attempts towards development of IRI model as a pavement performance indicator. Therefore, this study is an initial step towards this direction and aims to develop an IRI prediction model for flexible pavements of national highways in Nepal. The model has significant potential to assist engineers, planners and concerned authorities in formulating plans and strategies for pavement maintenance and rehabilitation and reconstruction.

2. Relevent Literature

All pavements deteriorate over time irrespective of their design and construction standards. The factors that affect pavement performance are pavement type, structural strength of pavement, traffic load, sub -grade type, environmental and regional effects[6]. Hot temperatures make asphalt binder soft, resulting in shear failure in flexible pavements under heavy traffic and leading to rutting or permanent deformation [7]. Thermal fatigue cracks are induced in asphalt pavement in relatively low temperature range. This significantly decreases the rideability of the pavement [8]. Pavement performance models play an important role in pavement management system. An important feature of a pavement management system is to determine the current condition of a pavement network and to predict its future condition by using pavement performance model [9].

Both deterministic and stochastic models have been developed to estimate pavement performance measures such as IRI. Shabanpour [10] presents an extensive survey of state of arts of literature in pavement performance modeling. A majority of the studies in this field has developed IRI models using Multiple Linear Regression (MLR) models. A reason behind could be the easier interpretability of MLR models in comparison to their counterparts [11]. Therefore, the IRI prediction model in this study is developed using MLR approach and some of the relevant works in this direction are discussed below.

Nassiri [12] developed IRI model using distress data stored in Alberta's Pavement Management System database. Correlation and regression analysis showed variable such as age, AADT, Freezing Index, Plasticity index of subgrade, rutting, base and overlay thickness were linearly correlated with IRI and significant for IRI progression. Sandra [13] developed IRI model using distress data by adopting multiple linear regression approach. It is highly desirable to develop separate models for different pavement types, traffic volumes, and traffic composition. Makendra [14] developed IRI model by using Multiple Linear Regression (MLR) technique. Age, modified structural number, commercial vehicle and rainfall are the independent variables considered in the study. Rainfall parameter was found insignificant for the prediction of IRI. Abdelaziz [15] developed roughness model for flexible pavement based on long term pavement performance database. Initial IRI, age and standard deviation of rut depth were found most significant variables for the IRI progression. Climate factors were not considered in this study which have significant role on pavement deterioration. Author claimed that reliable IRI prediction model can be developed by considering traffic factors and pavement age [16].

Review of literature studies shows that accuracy of database and appropriate choice of independent variables are major tasks while modeling the IRI. Most studies shows traffic and climate parameters are crucial for the prediction of IRI. In context of Nepal, SDI model was developed in past but only time was used as an independent variable. To the knowledge of authors, there are no studies on development of IRI prediction models. Therefore, this study attempts to fill in this gap in literature and presents an IRI prediction model specific to Nepalese context.

3. Methodology

The research methodology in this study follows reviewing relevant literature, appropriate choice of the modeling approach, identification of the crucial variables in Nepalese context and collection of relevant databases. As discussed earlier in Section 2, multiple linear regression approach has been chosen for modeling IRI in this study because of its simplicity in understanding and interpretation. The MLR approach, variables defined and the data sources used in this study are detailed discussed in the following subsections.

3.1 A multiple linear regression model for IRI prediction

Regression analysis is a method to find a functional relationship between dependent variables and independent variables. A regression analysis that has more than one regressor variable or independent variable is called Multiple Linear Regression (MLR). MLR relates the dependent variable Y to the n independent variables X_1 to X_n as a linear function of unknown parameters β_0, β_1 ... β_n called the regression coefficients. β_0 is the intercept and the β_1 ... β_n are the partial regression coefficients that measures the expected change in Y per unit change in X_1 to X_n.

For the IRI prediction model, five independent variables as discussed in the following are defined based on literature review and considering the traffic and climatic specificities that the Nepalese pavements are exposed to.

Initial IRI (IRI_0): Newly constructed pavement also has some initial IRI. IRI values which is obtained just after the effective maintenance work measured in m/km is considered in this study.

Commercial Vehicles (CV): Road pavement failure is mainly due to the traffic movement from both magnitudes of individual axle load and the number of load repetitions. Total number of heavy truck, light weight truck and multi axle trucks are considered in this study.

Rainfall (RF): Amount of rainfall that occurs in given pavement section during analysis period measured in mm.

Accumulated low and high temperature days (TD_l, TD_h): Although some literature of other studies mention effect of temperature is crucial but most of these literature considered single temperature related parameter i.e. average annual temperature. But since Nepalese highways are subjected to a wide range of temperature variation, two temperature specific independent parameters TD_l and TD_h have been introduced here. To include the cumulative effect of temperature, It is defined TD_h as accumulated high temperature days that are total days in a year with temperature higher than 25°C and TD_l as accumulated low temperature days that are total days in a year with temperature lower than 25°C and both expressed as °C days.

Therefore, the multiple linear regression model in specific to this study for prediction of IRI of pavements of national highways in Nepal can be expressed as given in equation 1.

The regression coefficients β_1 ... β_5 can be obtained through least square approach.

$$IRI = \beta_0 + \beta_1 IRI_0 + \beta_2 CV + \beta_3 RF + \beta_4 TD_l + \beta_5 TD_h \quad (1)$$

3.2 Data collection and processing

The required data for the study were collected from different secondary sources. The IRI and commercial vehicle traffic information were obtained from Department of Roads (DoR) Nepal, Highway Management Information System (HMIS) unit database [17]. In Nepal, there are altogether 80 national highways that make a total length of 14,913 km [18]. Among them, thirteen national highways were considered in this study. The measurement of IRI value by DoR started from FY 1995/96, but the systematic web based online database system was initiated only after FY 2012/13. The IRI database of DoR HMIS units covers about 3,397 km length of roadway of national highways. The online database provides annual IRI measurements for the four years period from 2012 to 2017. The HMIS database also provides other detail information of the associated highway section such as the highway name (code), number of link with starting and ending chainage, length, average annual daily traffic and the number of commercial vehicles.

To enrich the data quality, preprocessing of the DoR's IRI data was carried out by crosschecking the IRI measurements based on the road maintenance, rehabilitation and intervention records from Roads Board Nepal [19]. The RBN report provides detailed information about last surface activities, date of construction, and the age since last surface activity. A few sections show decline of IRI in DoR's database but no records on maintenance, rehabilitation, interventions are found in RBN's report. These unusual records can be misleading and may cause error in the model development. Therefore, the road link which have unexplained decline in IRI values were eliminated and were not used for model development. Traffic data for the road sections were obtained based on the traffic data collected at the corresponding survey stations. The number of commercial vehicle was obtained by adding number of multi axle truck, heavy truck and light truck.

The environmental data on average annual rainfall, and daily maximum, minimum and average temperature required for this study was obtained from Department of Hydrology and Meteorology (DHM), Nepal. Annual rainfall in mm collected in the gauge station was distributed in the roadway section by creating buffer of appropriate radius not exceeding 10 km using Geographical Information System GIS ArcMap. The number of days in a year having average temperature less than 25°C is termed as low temperature days and those with average temperature greater than 25°C is termed as high temperature days. Therefore, the accumulated low and high temperature days for the model input in °C days were obtained by multiplying number of days with lower and higher temperature by the corresponding average temperatures for the year.

4. Results and Discussion

Prior to the model development, relation between individual independent variables was checked by developing correlation coefficient matrix. Table 1 shows the correlation between the five independent variables considered in the study. As the table 1 shows the correlation coefficients for the variables are between 0.01 to 0.63. Therefore, the variables are found to be weakly and, in some cases, moderately correlated indicating absence of strong multicollinearity between the independent variables. Therefore, all five independent variables are considered for the development of the regression model.

Table 1: Pearson correlation coefficient matrixes

Variables	IRI_0	CV	RF	TD_l	TD_h
IRI_0	1	-0.2	0.03	-0.02	0.01
CV	-0.2	1	0.31	0.38	0.43
RF	0.03	0.31	1	0.6	0.63
TD_l	-0.02	0.38	0.6	1	0.58
TD_h	0.01	0.43	0.63	0.58	1

For the development of the IRI prediction model, the dataset was randomly sorted and split into two sets, referred to as the "in-sample" and "out-of-sample" data. The in-sample group composed of 85% of the dataset and was utilized to develop the regression model. The remaining 15% the dataset, referred to as the "out-of-sample" or "testing data" was utilized to assess the regression model's prediction efficiency.

Multiple linear regression over the in-sample data was carried out using Microsoft Excel to find the relationship between the IRI and the defined five independent variables. Statistical tests were carried out at the level of significance of 5%. The regression findings were subjected to an Analysis of Variance (ANOVA) to determine the model's suitability. The null hypothesis was that the IRI has no relationship with IRI_0, CV, RF, TD_l, and TD_h, while the alternate hypothesis was that the IRI does. In addition, another hypothesis test was used to determine the regression coefficient of each of the independent variables, with the null hypothesis being that the coefficient equals zero and the alternate hypothesis being that it does not equal zero. Tables 2 and 3 summarize the results of the ANOVA test and hypothesis test on the regression coefficients, respectively.

Table 2: ANOVA results.

	df	SS	MS	F	p-value
Regression	5	23718.09	4743.61	1942.07	0
Residual	3044	7435.13	2.44		
Total	3049	31153.22			

Table 3 shows p-values for the test statistics of all the five independent variables are less than 0.05 indicating that all the five variables considered in the study have statistically significant relationship with the IRI value. The intercept and partial regression coefficients for each parameter are given in the table 3. The total standard deviation of the model is 1.563 and the adjusted R square value is 0.761 which implies that about 76% of variation in IRI can be explained by the initial IRI, traffic and the climatic factors.

Table 3: Test statistics and regression coefficients

	Coefficients	Standard Error	t Statistics	p- value
Intercept	-1.556	0.116	-13.41	6.98E-40
IRI_0	1.302	0.014	91.51	0
CV	0.000174	2.78E-05	6.26	4.29E-10
RF	0.000153	2.87E-05	5.34	1.01E-07
TD_l	0.000169	1.66E-05	10.20	4.72E-24
TD_h	0.0000794	9.69E-06	8.20	3.52E-16

Based on the test results of the multiple linear regression analysis, the IRI prediction model for pavements of national highways in Nepal can be expressed as given in equation (2). Partial regression coefficients for all five independent variables are positive. Therefore, the the pavement roughness or the IRI value increases with increase in the initial roughness or IRI, commercial vehicle traffic, rainfall, and accumulated low and high temperature days.

$$IRI= -1.556+1.302\ IRI_0+0.000174\ CV + 0.000153RF + 0.000169\ TD_l + 0.0000794\ TD_h \quad (2)$$

In order to explain the robustness of the model, the IRI prediction in model was tested on the out of sample dataset. Figure 1 is a plot of observed roughness versus predicted roughness for the dataset. The expected IRI values are synchronous with the observed IRI values.

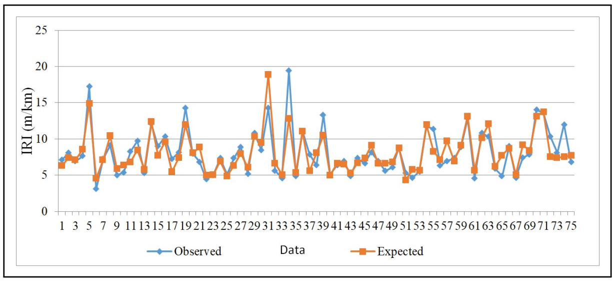

Figure 1: Comparision between observed and predicted data for IRI.

Similarly, figure 2 provides a graphical presentation of the observed versus predicted IRI with respect to the line of equality. The R square value for the testing data was obtained to be 0.794 slightly higher than the R square value of the model itself. Therefore, overall, the model shows acceptable statistics and is able to reasonably predict IRI for the pavement sections in Nepal.

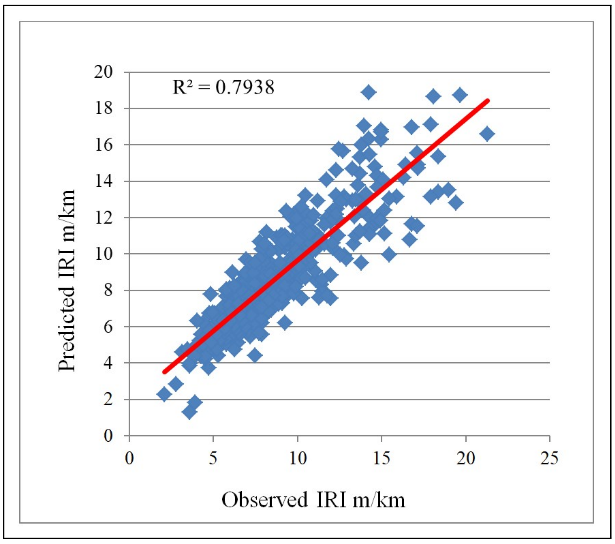

Figure 2: Observed IRI versus predicted IRI

5. Conclusion and Recommendations

With an aim to support the pavement maintenance and planning of national highways in Nepal, an IRI prediction model was developed based on multiple linear regression. Five independent variables: the initial roughness (IRI_0), commercial vehicles (CV), rainfall (RF), and accumulated low and high temperature days (TD_l,TD_h) are considered in this study. Traffic, climatic and pavement roughness data from DoR Nepal, DHM Nepal and RBN were utilized for the development of the model. Test results show that:

- Multicollinearity between the five independent variables is weak to moderate with the correlation coefficients varying from 0.01 to 0.63.
- Regression analysis and the validation tests reveals that IRI can be predicted to reasonable accuracy as a linear function of initial IRI, commercial vehicle traffic, rainfall, and the accumulated low and high temperature days with R square value of 0.761.
- Test statistics shows all the five independent variables are statistically significant with p-values in all cases much less than 0.05.

The developed models help to reliable prediction of the IRI pavlue of pavement section that may occur in future. Which in turn will improve the evaluation and prediction of Nepalese National Highways pavement condition, thus assisting in making consistent and

cost-effective maintenance strategy.
Structural conditions of pavement which can be another important parameter to affect IRI could not be considered in this study due to unavailability of structural data and material properties data which is one of the major limitations of the study and can be considered in further studies. Further, adopting advance modeling technique, such as machine learning, to model complex relationships between the dependent and independent variables and enhance the model predicting capability is another potential area of future research.

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