Performance Prediction Models for Flexible Pavements in Sri Lanka

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ABSTRACT

The pavement prediction model forecasts the future PCI ratings based on pavement category, thickness, traffic, pavement life period and existing PCI rating. Nevertheless, with time and inclusion of newer pavement types, there was a need to adjust the prevailing pavement performance models. In addition to, pavements management systems need to develop new models for newer pavement types as well. Some developed pavement performance models in the earlier for the Road Development Authority (RDA) Sri Lanka is used by the roadway segments to predict the future condition and rehabilitations of its network. The available data collections in the roadway agencies in Sri Lanka was used for the research study and the methodology and the analysis section depended on that data collection. Probably we were given the IRI data collections which were done in southern expressway section in Sri Lanka. Based on that data, the analysis part was done for determine the pavement roughness deterioration curves. With a comparison of the developed models, the most suitable model was taken at 95% confidence level with 0.8009 R^2 value. This study displays outcomes about of standardizing the present performance models, and creating unused models for the different asphalt forms within the roadway network in Sri Lanka. A comparison of IRI progression with pavement age and traffic volume is also conducted to see if there are major differences between such models developed in other countries. The anticipated expectations condition of the asphalts is utilized in assessing its outstanding benefit life to disappointment, which is of prompt utilize in prescribing future upkeep and recovery necessities for the arrange.

KEYWORDS: *International Roughness Index, performance model, flexible pavement, rehabilitation*

1 INTRODUCTION

During the studies of the pavement life under given structure there are some main goals can be determined in the pavement design and analysis, such as environmental, traffic conditions. Exact asphalt execution forecast speaks to a vital part in ordering upcoming support and recovery requirements, and anticipating upcoming asphalt condition in a pavement management framework. Roadway transportation area contribute a major character in accessing the development of any region or the country. Sri Lanka has very good road connectivity with approximately 13,000 km span of roadways (RDA, 2021). The pavement maintenance and rehabilitation side, there are two types of pavement failure methods identified. Such as structural failures and functional failures. The functional failure of flexible pavements and serviceability of the pavement accounts with the physical pavement characteristics; i.e., roughness, cracks, potholes etc. In past, there were many methods used for the evolution of the flexible pavement conditions, either visual inspections or very expensive equipment operated by well-trained engineers using various techniques. But that methods had some errors during the estimation of the roadway conditions, especially in visual inspection method (Kim, 2006).

Also, other methods were not effective in economically. Because of that, engineers found some alternative methods for evaluating the flexible pavements conditions in more effective way. The functional conditions become as a most effective method for evaluating the flexible pavements conditions and several predictions models based on functional factors of flexible pavements were defined from many researchers. At the same time, 'performance models' were made a fundamental background in any pavement management system used by roadway authorities (Sandamal & Pasindu, 2020). The pavement performance model is a basic role of the pavement management system (PMS). Generally, this models are developed to understand the advancement of cracking, roughness, and potholes in flexible pavements. The objective of this research is to develop a pavement performance model to evaluate the variation of roughness for the relevant contributing factors such as traffic volume, pavement age and initial construction quality. It is important to decision making in the PMS during the rehabilitations and services in flexible pavement roads. Models involve the complex interaction between vehicles, environment, structures, maintenance, and construction as well (Chen et al, 2020).

2 LITERATURE REVIEW

2.1 Background

The pavement performance model is a basic part of the pavement management system (PMS). Normally, a strategic and data driven system is used by the pavement management system to optimize the budget provision to different type of maintenance and rehabilitations of the road pavement projects (Kargah-Ostadi, 2019). The main purpose of using the pavement performance model is to assesse the pavement rehabilitation and maintenance cost. Because it is not feasible to maintain and rehabilitation the pavement structures in same way under the financial situation of the roadway agencies and local government. If there are reliable pavement performance prediction model, it may be easy to enhance the rehabilitation and maintenance plan of the whole roadway network under the existing fund. Likewise, the pavement prediction models can be used correspondingly with other statistics, such as pavement rehabilitation budget model to govern the funding level required for the entire roadway system to attain at a predetermined stage of performance (Kim, 2006).

2.2 Roughness Evaluation

In the 1970s, the World Bank supported various enormous field experiments and research works, which were looked for more convenience maintenance substitute for roadway pavements. As a result, pavement roughness was defined as a most suitable primary indicator of the user cost related with flexible pavement conditions. In 1982, the World Bank suggested the IRI value as an ordinary static to calibrate the roughness measurements in road pavements (Sayers et al, 1986). There was a past study, which was conducted by Chandra et al. to evaluate the relationships between the pavement roughness and distress parameters like potholes, revealing, cracks and patches in India, demonstrates a nonlinear model with better R^2 value. In this study, researchers used an advance technology of Artificial Neural Network (ANN) for analyze the data which were obtained by surveying of four national expressways in India (Chandra, 2013). Elghriany et al. found, there is a significant effect from pavement roughness to the traffic safety of the road. That evaluation was done by a study of the different road surface conditions (change of IRI value) and accident rates of relevant road segment. Then it defined the significant relationship between the IRI value and crash rates. In this study, varies models were examined and finally quadric model formula was obtained as a most possible one. The final results of this study were more useful for the road agencies to improve the transportation system and decision making in road maintenance and rehabilitation stages (Elghriany et al, 2016).

Albuquerque and Núñez identified the roughness as a better predictor for assess the pavement condition. Therefore, their study based on the IRI and those models were developed for the asphalt pavement LVR network in northeast of Brazil. In this case, IRI was consider as the dependent variable and weather, structural number, EASL and AADT were takes as the independent variables. In this study, researchers collected data in Ceará State in northeast Brazil using a local virtual reality network. Age data, rainfall data, elevation data, temperature data, traffic data, layer material, and roughness data were comprised in the data base. Four models were established for the collected data, and the validity of each model was then analyzed. A scatter plot was utilized to compare the observed data was checked against values predicted by the model. Throughout that four type of models, HMA model demonstrated 0.87 values as the R^2 value and other models showed 0.15 and 0.09 R^2 respectively. However, HDM 4 model despite the highest R^2 values. The results of this analysis revealed that the model proposed in this study predicted roughness values in HMA pavements better than models proposed by Queiroz, Paterson, and the HDM-4 system due to regional variances (Albuquerque & Núñez, 2011).

3 METHODOLOGY

3.1 Study Methodology

In this study, it mainly focused to IRI data other relevant parameter's data which were mentioned in the introduction section. Usually, that data are obtained from the flexible pavement sections stored in an existing road management data base system. The proposed procedure was made a possible pavement performance model based on the availability data. Modeling performance prediction is greatly aided by collecting data. In the absence of any measured data from the site area, no calibration data were available for the model. Because of that, a critical road segment should be determined based on the review of available data. Data collection was supposed to be one of the most challenging tasks in this study, study required the continues and different kind of dependent and independent variable data. It is more convenience to select road segment, which roughness conditions and other relative parameters range varies with worst condition to best condition. That was better to analysis works as well. Furthermore, road segment is to be as straight segment as much as possible.

3.2 Data Collection and Process

The data required for creating pavement execution models incorporates execution estimations and variables influencing asphalt performance. These data comprise inalienable issues that got to be tended to utilizing preprocessing methods. For developing a model to predict IRI, the pavement distresses parameters and IRI data have been used for modeling and its validation. There was a huge challenge during the data collection stage in this study, because, currently Road Development Authority has proper data collection system regarding to the pavement distress data, like cracks potholes etc. but there some issues raised when borrowing that data, because some data can be only reviewed by the official computer system. But yearly IRI data collection was conducted by the RDA for both A, B class roads and the expressway. Because of that, southern expressway section (E01) data were taken for the analysis work in this study. Mainly, IRI, AADT and age data were collected based on section wise of the southern expressway. Table 1 shows that section names, relevant length and the lanes of each and every section of the study section.

Table 1. The road sections of southern expressway, Sri Lanka

Road Section	Length (Km)	Lanes
Kottawa – Kahathuduwa	6	4
Kahathuduwa – Geanigama	7	4
Gelanigama – Dodangoda	21	4
Dodangoda – Welipenna	11	4
Welipenna – Kurudugahahethekma	21	4
Kurudugahahethekma – Baddegama	12	4

Variable data like AADT, age, IRI and the weather data the IRI prediction models were obtained depending on the earlier mentioned independent variable data by using the SPSS software or appropriate software. That apparatus would be useful for the accurate scientific models in every data analysis work. But for the simplicity, excel software was used for the analysis. In this study an analysis of simple linier regression and multiple linear regression were conducted to do compute the correlation factor and correlation hypothesis, and to determine whether there is a statistically significant relationship between IRI and the other independent parameters. In order to that, statistical hypothesis tests display a p-value to determine whether distresses affect IRI values significantly or not. Also, fitted regression model was judged to be adequate when the coefficient of multiple determinations (R^2) was calculated. According to the R^2 statistic, the regression model makes up a significant portion of the variance of the response variable. General Regression equations take the form described in Equation 1 and 2 (Chandra, 2013).

- Simple linier regression model.

$$Y = ß_0 + ß_1X + Ɛ \quad (1)$$

- Multiple linier regression model.

$$Y = ß_0 + ß_1X_1 + \ldots\ldots + ß_nX_n + Ɛ \quad (2)$$

In this case, Y is taken as the dependent parameter (response), X is taken as the independent parameter, and $ß_0$ and $ß_1$, $ß_n$ are the intercept and the regression coefficients in order. For this data analysis a excel worksheet program was used. The data was examined and tabulated and graphs were drawn to describe the data collection trend, build models, and record correlations and relationships between pavement roughness (IRI) and types of distress and other parameters. A regression model linking IRI and distress values was constructed through the use of regression techniques. Based on the results of the statistical tests, a suitable model was then chosen. Several types of regression functions were used in constructing the regression model: linear, quadratic, and logarithmic nonlinear. But, as mentioned in earlier, the models were taken from the linier type.

4 DATA ANALYSIS AND RESULTS

4.1 Pavement age vs. IRI

In the initial stage IRI and the pavement age data were analyzed. Considering the data variation between the IRI and age of the pavement it seems that IRI value increasing with the pavement age. Considering that relationship, simple linier regression analysis method was chosen for develop the models between the IRI and the pavement age. Basically the IRI distribution variation with the age depends on the relevant pavement segments. Generally, most of the road segments demonstrates their IRI value gradually increases with the age and sometimes there may be little fluctuations. The overall data in the database was sorted at randomly and divided into several sets to eliminate any possible bias, referred to as every road segment between two interchanges data. All data groups composed most of the data, at around higher percentage, which was utilized to develop the simple linier regression models. The developed models would represent all sections' mean behavior in a particular pavement family.

Table 2. Output summary of IRI vs. age analysis in different segment of Southern Expressway, Sri Lanka

Road Segment		**Static values**				**Models**
	R^2	p value		t static value		
		Intercept	Age	Intercept	Age	
Kottawa - Kahathuduwa	0.2964	0.000	0.0043	73.74	3.18	1.551 + 0.014 Age
Kahathuduwa-Gelanigama	0.6541	0.000	0.000	158.60	6.745	1.484 + 0.013 Age
Gelanigama – Dodangoda	0.6404	0.000	0.000	70.51	6.54	1.208 + 0.024 Age
Dodangoda – Welipenna	0.3491	0.000	0.001	99.13	3.58	1.058 + 0.008 Age
Welipenna – Kurudugaha	0.8000	0.000	0.000	163.21	9.824	1.163 + 0.015 Age
Kurudugaha – Baddegama	0.0401	0.000	0.367	233.72	-0.918	1.152 - 0.009 Age

The correlation coefficient of IRI and age is lies in better range and the p-value is equal to within 0 – 0.008 range. As mentioned in Table 2, few section's data variations were out of the significant level and most of the results were in the significant level. An age-IRI relationship indicated by the positive sign of the correlation coefficient. In terms of the correlation factor, it was estimated about that the half of the IRI and age observations were distinguishable by a linear association. The best representation for the age data of all road segments was given by the formulas. According to Table 2 most suitable model was determined which indicated that the relationship between IRI and age was statistically significant at 5% significance level. Along that criterion, Welipenna – Kurudugahethekma road section was taken as the most critical model, which indicated the most critical static values as shown in Equation 3.

$$IRI = 1.1626 + 0.015\ AGE \quad (3)$$

4.2 Annual Average Daily Traffic (AADT) vs. IRI

IRI and the AADT data were analyzed through the simple linier regression analysis process. The variation of the AADT and the IRI values can be identified similar as the previous one. That clearly identify if the AADT values increase the IRI values also increase. Because, usually the AADT value is increasing with time. When considering the AADT values of each section there were two different values in both sides, then sum of that two values was used for he analysis, unless it will be complicated. The variation of both parameters indicates a positive relationship between the AADT and IRI values. The output results of the simple linear regression analysis between the IRI and AADT are presented in Table 3.

Table 3. Summary of IRI vs. AADT analysis in different segment of Southern Expressway, Sri Lanka

Road Segment		**Static values**				**Models**
	R^2	p value		t static value		
		Intercept	AADT	Intercept	AADT	
Kottawa - Kahathuduwa	0.362	0.000	0.004	73.74	3.18	1.545 + 0.000715 AADT
Kahathuduwa-Gelanigama	0.569	0.000	0.000	110.97	5.63	1.470 + 0.0000754 AADT
Gelanigama – Dodangoda	0.578	0.000	0.000	39.97	4.63	1.177 + 0.000178 AADT
Dodangoda – Welipenna	0.453	0.000	0.008	64.23	2.84	1.048 + 0.0000686 AADT
Welipenna – Kurudugaha	0.737	0.000	0.000	92.98	8.21	1.130 + 0.000134 AADT
Kurudugaha – Baddegama	0.047	0.000	0.279	199.22	-1.09	1.155 + 0.0000068 AADT

Based on the results, it can be concluded that there is a positive relationship between both parameters. It is evident, there is a trend in the linearity of the relation. Almost all cases shows the critical R^2 values which lie above the 0.5. Also the p-values indicate that almost all cases have the better significant relationships. Further it indicates that the relationship between the IRI and AADT is statically significant at 5% significance level. The best representation for the AADT data was given by simple linier regression formula which was obtained for the Welipenna – Kurudughahethekpma section which is shown on Equation 4:

$$IRI = 1.130 + 0.000134\ AADT \quad (4)$$

4.3 Weather versus IRI

The table 4 shows the one of the road segment's (Welipenna – Kurudugaha) main output of the simple linier regression analysis between the weather and the IRI progression. Actually, that values indicates a negative relationship between the precipitation, temperature and the IRI value. Also, there is no definite trend in the linearity of the relationship. The intercept coefficient of this relationships varies between 1.2-1.6 ranges. In other hand, considering the coefficient of the independent variable of the precipitation, that analysis shows it lies in negative range. That is why it mentioned in earlier this was a negative relationship.

Table 4. Weather data analysis output in analysis in different segment of Southern Expressway, Sri Lanka

Statics	Temperature	Precipitation
R^2 Value	0.05	0.004
p value	0.26167	0.7644
t value	-1.1495	-0.3037
Coefficient	-0.0135	-0.00001658

Further this output values shows that the p-values also in the out of the range. Generally p-value should be lower than the 0.05, it means the 95% significant level. In this case, p-values indicate that the models were not in the significant interval. Because of that, relationship between the precipitation and the IRI cannot be expressed as the linier one. In such a case, R^2 values are also in very lower range. Based on that reason, a non-linier relationship might be developed for it.

4.4 Residual Variations

The difference between the predicted and observed IRI values (residuals) are plotted against the predicted IRI values in Figures 1 and 2. The residuals vary mainly between −0.03 and 0.03 m/km and expand in a horizontal band around the zero line. No specific pattern is observed in the residuals' distribution, indicating a good fit for a linear model. Figures 1 & 2 indicate the residual variation of the IRI vs age and IRI vs AADT respectively of section Welipenna – Kurudugahaethekpma. Because, that section indicated the most significant model prediction section.

Figure 1. Residual variation in IRI vs. Age at Welipenna – Kurudugahahethekpma section

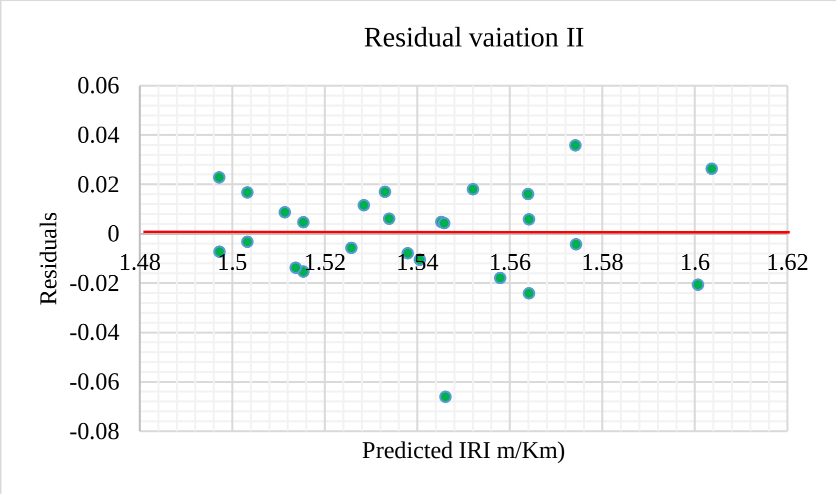

Figure 2. Residual variation in IRI vs. AADT at Welipenna – Kurudugahahethekpma section

4.5 Final models and Validation Process

Table 5 shows significant correlation between both independent variables (AADT & age) and IRI values. In ANOVA-test, the p-values are zero, indicating that the regression models show significant variation in the IRI response variables. The relationship between IRI and independent parameter's values is sufficiently supported by the data. It is clear, that the segment of Welipenna – Kurudugahahethekpma demonstrates most significant static values throughout the all other modeling static values, like p-values, test static value, stranded error. As well as, the coefficient of multiple determinations (R^2) is equal to 80.1%, which means that 80.1 percent of the IRI values are represented and explained by the regression model. Because of that, the model which was obtained for the Welipenna – Kurudugahahethekpma road section is taken as the most significant model throughout this final multiple linier regression analysis.

Table 5. Final linier regression models

Road Segment	**Static values**							**Final Models**
	R^2	p value			t static value			
		Intercept	AADT	Age	Intercept	AADT	Age	
Kottawa - Kahathuduwa	0.319	0.000	0.3820	0.14	49.87	-0.899	1.5277	1.574 + 0.33 Age + 0.0000105 AADT
Kahathuduwa-Gelanigama	0.677	0.000	0.0211	0.0106	93.82	1.285	2.77	1.5 + 0.0243 Age + 0.000068 AADT
Gelanigama – Dodangoda	0.459	0.000	0.0021	0.000	40.74	-3.37	5.18	1.305 + 0.064 Age - 0.000036 AADT
Dodangoda – Welipenna	0.419	0.000	0.0172	0.017	49.23	-1.66	2.57	1.09 + 0.0216 Age - 0.000014 AADT
Welipenna – Kurudugaha	0.8009	0.000	0.0012	0.001	73.5	0.35	2.35	1.16 + 0.014 Age + 0.00005 AADT
Kurudugaha – Baddegama	0.0590	0.000	0.0256	0.0256	35.6	0.45	2.54	1.159 - 0.00002 Age + 0.0021 AADT

However, the all relationships are much strong enough for distress types to be used to predict pavement roughness condition and final linier regression model shown in Equation 5; which is based on Welipenna – Kurudugaha.

IRI = 1.16 + 0.014 Age + 0.00005 AADT (5)

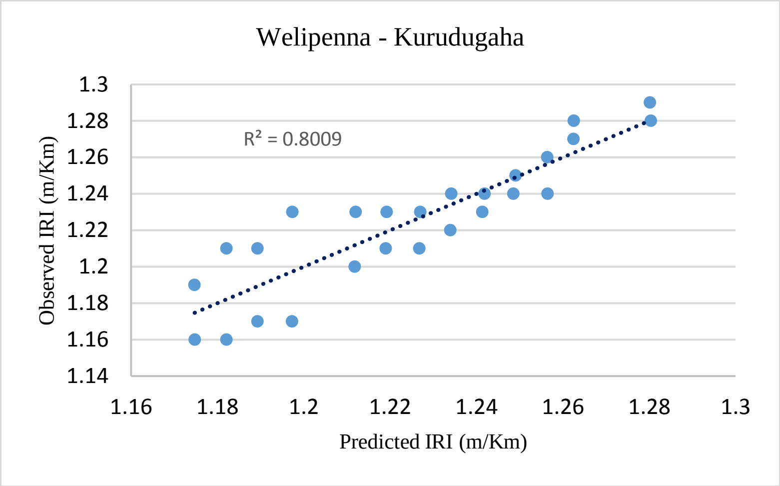

Figure 3. Relationship between observed and predicted IRI basedon proposed model

4.6 Comprehensive overview of developed models

A comprehensive overview was conducted between the model which evaluated in this study and the several other performance models evaluated by some different studies in different countries. Both of the proposed model and other existing roughness deterioration models in other countries are shown in the Table 6.

Table 6. Predicted models present study and past studies

Other Models		Predicted model in this study
Japan	IRI = 1.182 + 0.203 age + 0.123 YESAL	IRI = 1.16 + 0.014 Age + 0.00005 AADT
Sri Lanka (National Roads)	IRI = 6.86 – 4.66exp ^ (-0.0006Age^3.46) IRI = 2.15+ 0.0003Age^1.7343(1 + ADT^0.5075)	
France	IRI = 5.09 - 2.5*IRI + 1.7*Depth - 1.74*Duration + 0.706ESAL*Duration	
UK	Ln (ΔIRI +1) = Age(4.5FI +1.78CI +1.09FTC + 2.4PRECIP + 5.39log(ESAL)/ SN	

As shown in Table 6, some significant similarity and relative variations can be determined from both models. In this study intercept value is taken as 1.16. That is some average value of the IRI progression of the expressway in the initial stage. Considering that, relatively same intercept values can be observed from the other studies models. When looking the independent variables, several foreign performance models like in Japan, UK, took the ESAL parameter instead of AADT which was utilized in present study. But similar sense is made by both parameters to the performance model. All most all of prediction models which were developed in foreign countries, adopted the weather factors. Because, that type countries have most significant weather patterns (e.g.: summer, winter) and the most of pavement deteriorates under those scenarios. But, In Sri Lankan context that type of huge weather variation are not happened. Because of that, weather parameter is not really sensitive for the country context.

5 DISCUSSION

In this study, the effects of the flexible pavement deterioration parameters like IRI, pavement age, Annual average daily traffic (AADT) and the weather, which contributed in the selected expressway road segments was investigated. The results of the current study represented that the ride quality and the general parameters which could affected he flexible pavement. This research was carried out using flexible pavement sections located in the southern expressway section (E-001), with considering the pavement serviceability index (PSI) which better demonstrates the pavement deterioration progression based on the overall pavement deterioration parameters. Therefore, it was possible to determine hoe pavement structure, traffic, age and weather condition are involved on the selected flexible pavement segment's deterioration process throughout this study.

It was also found that as traffic demand, in this case AADT data was considered, increased pavement condition deteriorated and precipitation and temperature was analyzed as the most influence factors. Also, the pavement age value increased along that, pavement condition also deteriorate. But, in his study precipitation and temperature conditions data were analyzed based on segment wise. However, that data was not indicated the exact point condition, also indicates the overall area's condition. In terms of temperature, the annual average temperature and, the annual average temperature were little bit critical to influence the pavement deterioration especially in IRI progression in Sri Lanka country context. Also, considering the precipitation, the road section was divided in to two sections and that data were analyzed separately. That analysis output results showed that the road sections in the high precipitation zones experienced a faster deterioration process that on other area's sections. However, the final models did not indicate the higher significant static values from both precipitation and weather factors. Because, in Sri Lanka haven't the significant season cycles, like summer, winter. Because of that, annual data experienced very low variation.

In this study, mainly focused the simple and multiple linier regression model prediction process and it shows reasonable fitting for the gathered data samples. The computed p values for each and every road segment are below the 0.05 value and most of the intercepts are equal to zero and independent variable parameters are nearly equal to the zero. Throughout the final result, considering the static values Welipenna – Kurudugahahethakpma road segment's model was taken as the most significant model, which shows the most reasonable and significant static values. This indicates a significant multiple linier relationship between IRI and the independent parameters of AADT and age. The results of both simple linier and multiple regression coefficients illustrated 95% confidence that AADT and age are the most significant pavement deterioration parameters. However, it is realistic to conclude that IRI may completely reflect pavement deterioration conditions.

6 CONCLUSIONS

This study was carried out to obtain the most precise flexible pavement deterioration model using the existing data base. Six different pavement sections from southern expressway in Sri Lanka connecting Kottawa to Baddegama interchanges was selected in this study to evaluate the relationships of three types of pavement deterioration parameters of AADT, age and weather with the IRI values. The analysis was carried out to check the relationship between the above mentioned dependent and independent parameters. Based on the results, the final regression model was taken from the Welipenna – Kurudugahahethekpme section throughout all other predicted statistical models that relate IRI values to the independent parameter density values were established. The final model indicted the R^2 value of 0.8009 which was the highest value compared to others. The results indicate that while 95% statistically confidence level relationship exist between IRI and the deterioration parameters under the study. These relationships are normally strong enough for IRI to be used as a surrogate measure for pavement condition. It can be concluded that, it is possible this study will stimulate new modeling efforts in flexible pavement maintenance sector. Also provides valuable assistance in figuring out when to implement maintenance programs by defining a time frame for it and providing support to the authorities for setting-up the budget priority index and designing strategies for effective maintenance programs.

The future studies needs to be conduct to the wider range of the pavement distresses, like cracks, potholes, revels and the roughness. Especially, the additional predictor variables should be focused that impact on the pavement condition on the PSI. Other than that, it will be possible to do a data survey for the above mentioned distresses in local condition. For the future researchers, it is better to collect the relevant data, and based on that data prediction can be done, because the existing data is not easily accessible. The public accessible data bases are already available in other countries, like USA, Australia. But in Sri Lanka, those road data are not accessible. It is much needed to make a critical data base which can be accessible to the public. Otherwise before researchers will develop the models, they need to start to data collection several years before the model development.

7 ACKNOLEDGEMENT

A special thanks goes out to expressway management division in Road Development Authority for providing the information and the data as requested.

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