Investigation of Factors Affecting Pavement Roughness

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Abstract

Asphalt concrete pavement is the most common type of pavements used in Egypt and around the world. Several factors can affect the pavement performance. A good understanding of these factors would enable pavement specialist to build smooth, cost effective, and long-lasting pavement that requires little maintenance and satisfies user needs. Several methods can be used to evaluate the pavement performance. Among these methods is the pavement roughness. In 1986, the Long-Term Pavement Performance (LTPP) project was established as a part of Strategic Highway Research Program (SHRP) and it was aiming to construct a large scale database to satisfy a wide range of pavement information needs. This project was designed to allow for a comparison of the performance of different pavement sections under various sets of loading and environmental conditions.

The main objective of this research is to evaluate the effect of service life and pavement thickness on the pavement roughness. The data from the LTPP database were used to develop mathematical models correlating the pavement thickness, service life, environmental conditions, traffic levels, and subgrade type to pavement roughness. These models recommended that the effect of increasing the thickness on the expected service life is negligible for the conditions of low traffic, dry environment, and medium temperature. Traffic level does not have a considerable effect on deterioration rates of pavement roughness in case of coarse subgrade and dry environment.

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Key words

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1. Introduction

Asphalt concrete pavement is the most common type of pavements used in Egypt and around the world. The actual pavement service life is usually less than the expected design life. As a result, an extra budget will be spent to bring these pavements back to a satisfactory level of serviceability. A good understanding of the pavement performance, as occurs in the field, and the factors affecting this performance would enable the engineers to build smooth, cost effective, and long-lasting pavement that requires little maintenance and satisfies user needs. Several methods can be used to evaluate the pavement performance. Among these methods is the pavement roughness.

Pavement roughness is one of the most effective parameters that can be used as an indicator of the pavement performance. This parameter can be also used to evaluate the vehicle operating costs and safety with respect to the pavement conditions. The International Roughness Index (IRI) is the most widely used technique for measuring pavement roughness. It is a ratio of a standard vehicle's accumulated suspension motion divided by the distance traveled by the vehicle during the data collection (1). Several factors can affect the pavement roughness. Among these factors are the traffic loading, pavement thickness, subgrade type, and environmental factors.

In 1986, the Long-Term Pavement Performance (LTPP) project was established as a part of Strategic Highway Research Program (SHRP). It is proposed as a wide-range database to assess the long term performance of pavements under various traffic loading conditions, environmental factors and other factors (2). This project was designed to allow for a comparison of the performance of different pavement sections under various sets of loading and environmental conditions. The database of this project can help to a large extent in increasing pavement life through understanding the pavement performance based upon a systematic observation of in-service pavement performance.

The main objective of this study is to investigate the effect of the service life and pavement thickness under different traffic loading, environmental conditions, and subgrade type on the pavement roughness. This study is divided into four main parts; the first part gives a brief description about the LTPP project. The second part presents the technique used to evaluate the pavement performance. The third part describes the data collection and analysis, while the fourth part presents the summary and conclusions.

2. LTPP Project

During the early 1980s, the Transportation Research Board (TRB) of the National Research Council, under the support of the Federal Highway Administration (FHWA) and with the cooperation of the American Association of State Highway and Transportation Officials (AASHTO), undertook a Strategic Transportation Research Study (STRS) for the deterioration of the highway and bridge infrastructure system. The study proposed that a Strategic Highway Research Program (SHRP) be initiated to focus research and development activities on improving highway transportation system. In 1986, the Long-Term Pavement Performance (LTPP) project was established as a part of the study (2).

This study was conducted as a large scale database on pavement characteristics to satisfy all pavement information needs, identifying how pavement performs and to know more about the factors affecting the pavement performance such as traffic, environment, road construction materials, construction quality, and maintenance practices. The test sections of LTPP projects are classified to General Pavement Studies (GPS) or Specific Pavement Studies (SPS). The GPS sections had been constructed before they were selected to be part of the LTPP test sections. On the other hand the SPS test sections were designed, constructed, maintained in a way that allow to study the effect of specific factors on the pavement performance (2).SPS program incorporates nine studies from SPS-1 to SPS-9. The focus in this study will be on the sections of SPS-5 experiment.

3. Pavement evaluation

There are four characteristics of pavement condition that can be used to evaluate the pavement quality (3):

- Pavement roughness (rideability).
- Pavement distress (surface condition).
- Pavement deflection (structural failure).
- Skid resistance (safety).

Pavement roughness refers to irregularities in the pavement surface that affect the smoothness of a ride. The World Bank found road roughness to be a primary factor involving the road quality and user cost (4). Pavement unevenness cause significant road-vehicle dynamic interactions and usually involves the increase of vehicles and road structure damage, as well as decrease of the ride quality (5).Roughness can be measured using several techniques, in this study the focus will be on the IRI method.

IRI was proposed in Brazil by the World Bank as a standard statistic to correlate and calibrate roughness measurements (6). IRI is used to define a characteristic of the longitudinal profile of a traveled wheel track and establish a standardized

roughness measurement. The commonly recommended units for IRI are meters per kilometer (m/km) or millimeters per meter (mm/m). The IRI is determined based on the average rectified slope (ARS), which is a ratio of a standard vehicle's accumulated suspension motion (in mm, m) divided by the distance traveled by the vehicle during the measurement (m, Km). The IRI scale versus the ride quality is shown in Table 1.

Table 1: FHWA pavement roughness versus ride quality

| Condition Term	IRI	Ride Quality
Very Good	< 0.95 m/km	Acceptable 0 – 2.68 m/km
Good	0.95 – 1.49 m/km	
Fair	1.50 – 1.88 m/km	
Poor	1.89 – 2.68 m/km	
Very Poor	> 2.68 m/km	Unacceptable

4. Data collection and analysis

Data collection

As mentioned before, the analysis will be carried out utilizing the data available for SPS-5, which includes 197 test sections from 17 states (15 from USA and 2 from CANADA), as shown in Table 2.The data available cover most of the factors affecting the pavement performance. These factors include the pavement characteristics, traffic levels, subgrade type, and environmental conditions. However, before the data could be analyzed, data collected from these sites and sections had to be checked against irregularities and missing of the data that may have been existed during collection or documentation.

Table 2: Sections under study

State	# of sections	State	# of sections
Alabama	10	Mississippi	10
Arizona	11	Missouri	10
California	22	Montana	10
Colorado	11	New Jersey	11
Florida	14	New Mexico	9
Georgia	15	Oklahoma	10
Maine	10	Alberta	9
Maryland	14	Manitoba	9
Minnesota	12		

To examine the data against possible data irregularities, the trend of IRI versus the factors under study was examined on the available sections. A linear relation between the roughness (IRI) and the time under the study for all sections were established. The aim of this step is to separate the sections that exhibit the trend of decreasing IRI with time due to possible data irregularities. The sections that displayed the negative trend were excluded from this study. Figure 1 shows an example for the negative trend of IRI with service life.
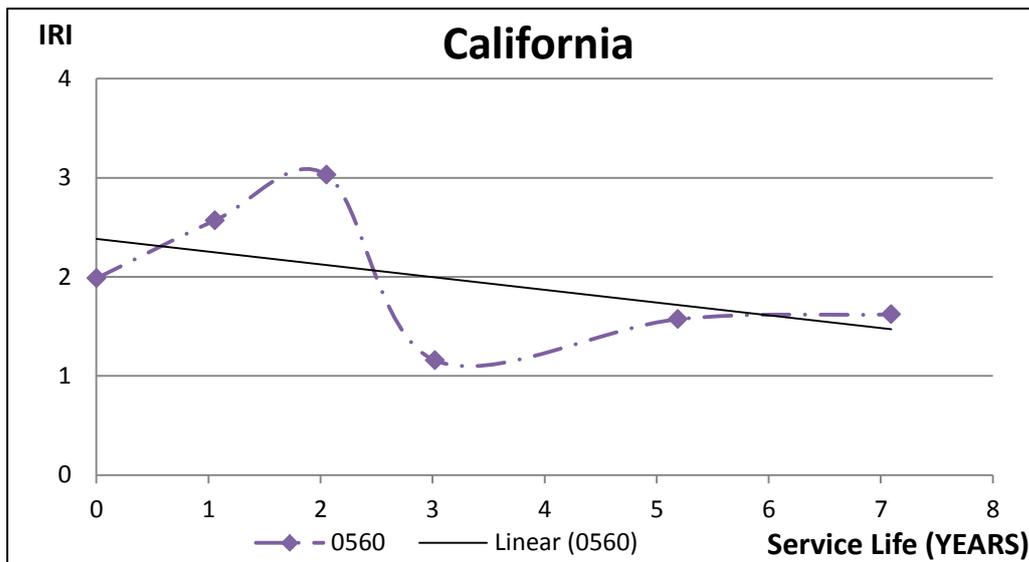
Figure 1: Example of checking the trend of the IRI with the time

Finally, a total number of 89 sections from 9 states were used for the analysis on this study as shown in Table 3.

Table 3: Sections used for analysis

State	# of sections	State	# of sections
California	20	Montana	9
Colorado	8	New Jersey	7
Georgia	8	New Mexico	5
Maryland	11	Oklahoma	10
Minnesota	11		

Factors affecting pavement Roughness

As mentioned before, the factors that will be taken into consideration in this study will include; service life, pavement thickness, traffic levels, subgrade type, and maintenance practices. These factors will be extracted from the LTPP database. A brief description about these factors is given below:

- **Service Life (SL):** LTPP gives a date for every inspection or maintenance time. In this study the service life is a subtraction between the first date the pavement started working and the last date given at the data.
- **Pavement Thickness (TH):** The characteristics and thickness for each pavement layer is given at LTPP database. In this study, the pavement thickness is calculated by using the Asphalt Institute (AI) conversion factors. These factors are used to determine the equivalent asphalt concrete thickness corresponding to each layer at the pavement structure. The summation of these thicknesses can be used as an indication to the strength of the pavement structure. The Asphalt Institute Conversion Factors are shown in Table 4.
- **Subgrade Characteristics (SC):** Several tests are performed on the subgrade and recorded in the LTPP database. In this study the subgrade type is determined according to AASHTO classification system based on the percentage passing sieve number 200 available in LTPP database. The subgrade is classified as a fine subgrade if more than 35% of the samples by weight passes sieve number 200 and takes a code of 0 in the analysis. On the other hand, the subgrade is classified as a coarse subgrade if 35% or less passes sieve no 200 and takes a code of 1.
- **Construction Number (CN):** It is a number that identifies the changes in the pavement structure caused by rehabilitation treatments or application of maintenance treatments. When a section is constructed, it is assigned a CN of 1. CN is incremented by 1 for each maintenance time regardless of its impact on the pavement structure. For example, crack sealing causes a new construction event to be generated, even though it does not cause a significant change in the pavement structure (2).
- **Traffic Level (TL):** The Equivalent Single Axle Load (ESAL) for each state is given in the LTPP database. In this study the traffic level was divided into two main categories. The first one is the low traffic which has less than 1500ESALper lane for a year and takes a code of 0 in the analysis. On the other hand, the second category is the high traffic which has more than 1500 ESAL per lane for a year and takes a code of 1.

Table 4: Asphalt Institute Conversion Factors (7)

Description of Layer Material	Conversion Factor
• Native subgrade.	0.0
• Granular subbase or base - CBR not less than 20. • Cement modified subbases & bases constructed from low Plasticity Index (PI) soils.	0.1 - 0.3
• Cement or lime-fly bases with pattern cracking.	0.3 - 0.5

• Asphalt concrete surface and base that exhibit extensive cracking and serious deformation in the wheel paths.	0.5 - 0.7
• Asphalt concrete surfaces and bases that exhibit some fine cracking and slight deformation in the wheel paths but remain stable.	0.7 - 0.9
• Asphalt concrete, including asphalt concrete base, generally uncracked, and with little deformation in the wheel paths.	0.9 - 1.0

Models definitions

The linear regression analysis technique was used to develop a mathematical model to relate the pavement's IRI to the factors under the study. As a single model that would be applicable to all the sections included in the study could not be developed, the sections were first classified according to perception (dry or wet), temperature (low, medium or high), traffic level (Low or High), and subgrade type (Course or Fine). Then, a unique model was developed for each group, where the dependent variable in each model was the IRI. The independent variables included in the models were the pavement service life, pavement equivalent thickness, subgrade type, construction number, and finally the traffic level.

Models are described in Table 5, which summarizes the constants and the correlation factor (R) for each model. Several trials were carried out to establish the best form for each model as given below:

- Model 1: Dry, Low Temperature, Low traffic, and Fine Subgrade

$$IRI = a + b \times SL + c \times CN + e \times TH$$

- Model 2: Dry, Medium Temperature, Low Traffic, and Fine Subgrade

$$IRI = \exp (a + b \times SL + c \times CN + e \times TH)$$

- Model 3: Dry, Medium Temperature, and Coarse Subgrade

$$IRI = a + b \times SL + c \times CN + d \times TR + e \times TH$$

- Model 4: Wet, Medium Temperature, Low Traffic, and Coarse Subgrade

$$IRI = \exp (a + b \times SL + c \times CN + e \times TH)$$

- Model 5: Wet, Medium Temperature, High Traffic, Coarse Subgrade

$$IRI = a + b \times SL + e / TH + f / TH2$$

Where

SL = Service life (years),

TH = Thickness (in),
TR = Traffic Level,
CN = Construction number, and
a, b, c, d, e = Models Constants.

Table 5: Constants of Developed Models

Model	R	a	b	c	d	e	f
1. Dry, Low temperature, Low traffic, Fine subgrade	0.85	0.514	0.055	0.278	-†	-0.034	-†
2. Dry, Medium Temperature, Low traffic, Fine subgrade	0.89	-0.712	0.045	0.017	-†	-0.010	-†
3. Dry, Medium, Coarse subgrade	0.54	0.840	0.042	0.104	0.271	-0.049	-†
4. Wet, Medium Temperature, Low traffic, Coarse subgrade	0.7	0.353	0.013	0.147	-†	-0.065	-†
5. Wet, Medium Temperature, High traffic, Coarse subgrade	0.85	0.214	0.050	-†	-†	2.734	18.83

†Parameter was excluded from the model as it was statistically insignificant

Analysis

The developed models were used to study the effect of the pavement service life and the pavement thickness, under various conditions, on the pavement roughness. In the previous equations, selected values of independent variables were entered and the equation was solved to determine the IRI. To neutralize the effect of the thickness and the construction number while the effect of the service life is investigated, these two variables were assumed to be constant and their values were set as 12 inch and 2 respectively. Figures 2 to 4 show the effect of the service life on the pavement roughness. On the other hand, to neutralize the effect of the service life and the construction number while the effect of the thickness is investigated, these two variables were assumed to be constant and their values were set as 4 years and 2 respectively. Figures 5 to 7 show the effect of pavement thickness on pavement roughness.

From Figures 2 to 4 the following can be concluded:

• An appreciable rate of deterioration for IRI is obvious for all models.
• Model 3 (dry, medium temperature, coarse subgrade) indicates that the traffic level affects the IRI value but doesn't affect the IRI rate of deterioration for a pavement constructed on a good quality subgrade.

- Comparing the results for Models 1(dry, low temperature, low traffic, fine subgrade) and 2 (dry, medium temperature, low traffic, fine subgrade) show that the IRI deterioration rate under medium temperature condition is lower than that under low temperature condition.
- For Model 4(wet, medium temperature, low traffic, coarse subgrade), increasing the service life had a small effect on the IRI deterioration rate. This may be explained by the small effect the low traffic has on the roughness for a pavement constructed over a good quality subgrade.
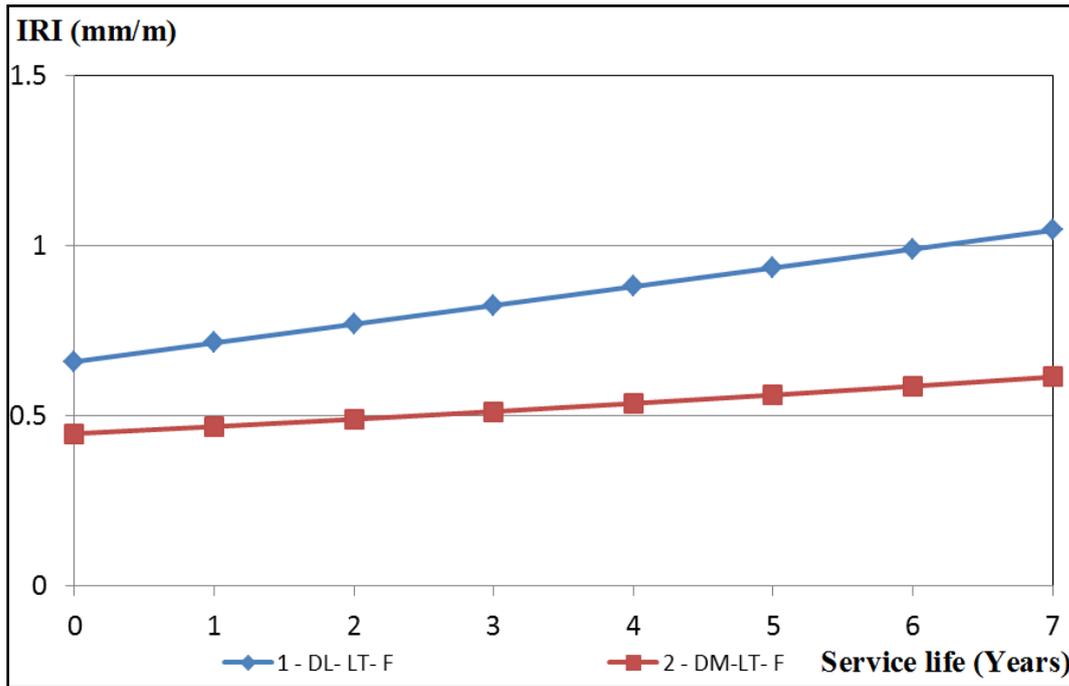
Figure 2: Effect of Pavement Service Life on International Roughness Index for Models 1 and 2
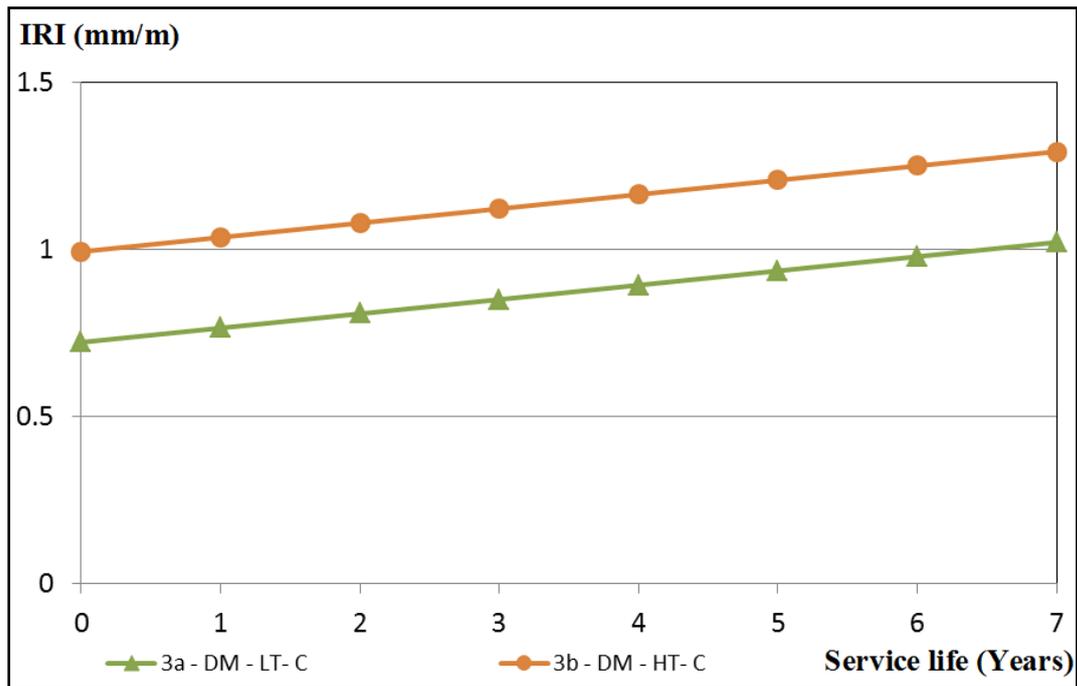
Figure 3: Effect of Pavement Service Life on International Roughness Index for Model 3
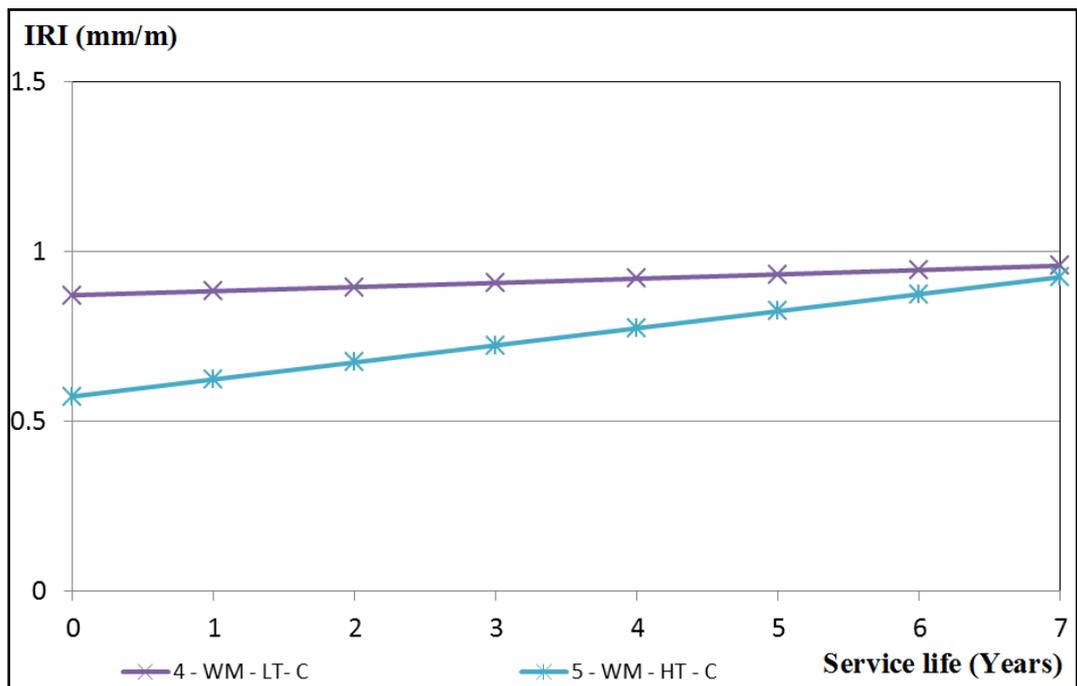

Figure 4: Effect of Pavement Service Life on International Roughness Index for Models 4 and 5

From Figures 5 to 7 the following can be concluded:

- For all models except Model 2 (dry, medium temperature, low traffic, fine subgrade) the effect of increasing the thickness is appreciable on pavement roughness.
- For Model 2 (dry, medium temperature, low traffic, fine subgrade), increasing the pavement thickness had almost no effect on pavement roughness. This finding may be explained by the small effect the thickness has on the roughness for a pavement constructed under the favorable conditions of low traffic level and dry pavements condition.
- Comparing Models 4 (wet, medium temperature, low traffic, coarse subgrade) and 5 (wet, medium temperature, high traffic, coarse subgrade) shows that the traffic level had almost no effect on pavement roughness. This may be explained by the small effect the traffic level has on the pavement roughness constructed over a good quality subgrade.
- On the other hand, for Model 3 (dry, medium temperature, coarse subgrade) the traffic effect on the pavement performance is not significant when comparing the low and high traffic. This again may be explained by the small effect the traffic level has on the pavement roughness constructed over a good quality subgrade.
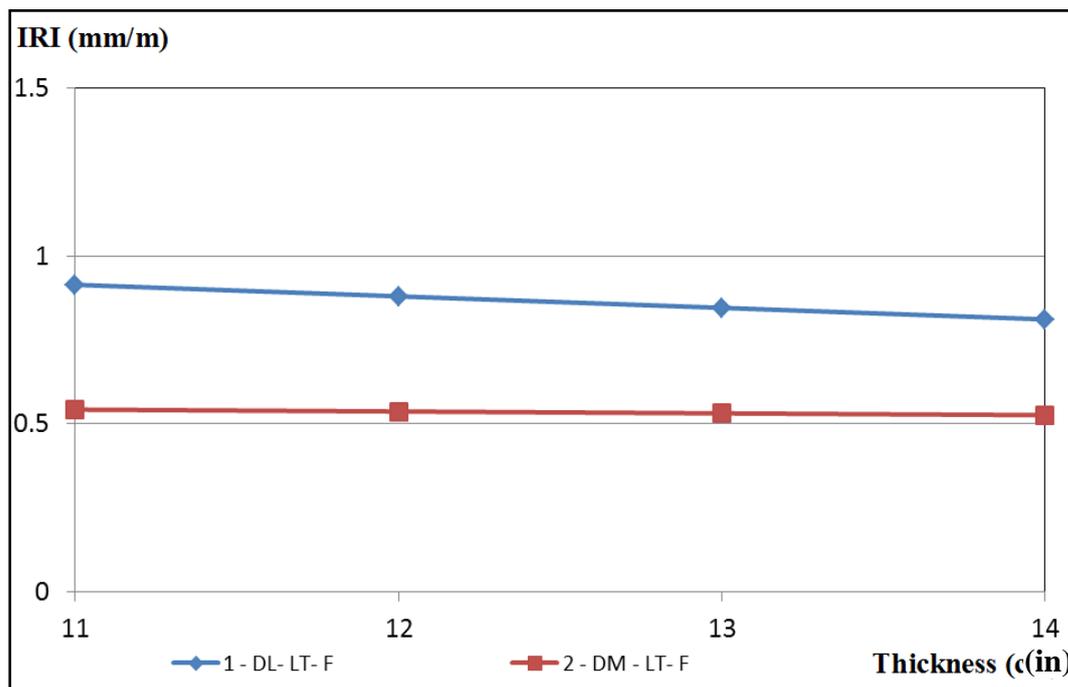
Figure 5: Effect of Pavement Thickness on International Roughness Index for Models 1 and 2
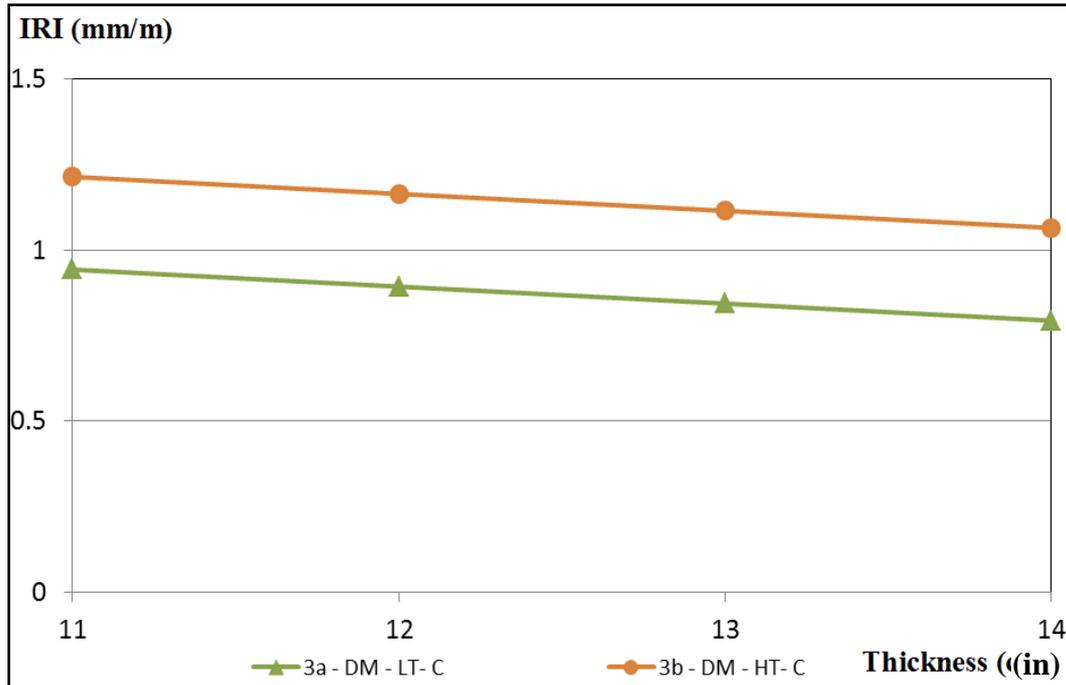
Figure 6: Effect of Pavement Thickness on International Roughness Index for Model 3
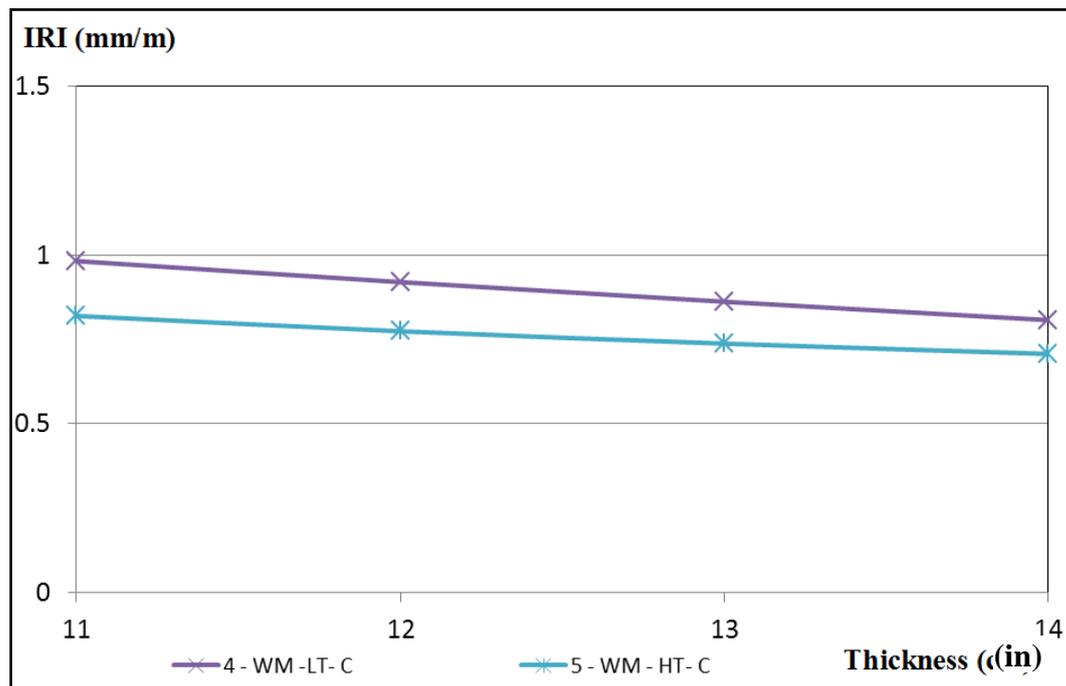

Figure 7: Effect of Pavement Thickness on International Roughness Index for Models 4 and 5

5. Summary and conclusions

The main objective of this study was to investigate the effect of the pavement thickness and service life on the pavement roughness. The data available in the LTPP project, for section SPS-5, were collected and analyzed. Based on these data, mathematical models were developed to predict the IRI as a function of the pavement thickness, traffic level, subgrade type, construction number, and environmental condition. These models were classified according to environmental conditions, traffic level and subgrade type. The developed models were used to study the effect of the pavement thickness and service life on the pavement roughness. Based on the results of the developed models, it was concluded that the effect of increasing the thickness on the pavement roughness is negligible for the conditions of low traffic, dry environment, and medium temperature. In case of a good quality subgrade and dry environment the traffic level has a small effect on the IRI rate of deterioration.

6. References

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