Analysis of Rutting and Roughness Distresses in PCC Pavements Overlaid with Asphalt Concrete

Kavussi, A.
Associate Professor, Tarbiat Modares University, Tehran, Iran

SYNOPSIS

Concrete slab pavements overlaid with bituminous mixes are common pavement types in many countries. In City of Winnipeg in the province of Manitoba (Canada), most of the pavements are of concrete slabs overlaid with a dense graded bituminous mix. Cracking on the slab pavements and rutting on bituminous mixes are the visible distresses. These are mainly attributed to the harsh climatic conditions that dominate the region.

A manual pavement condition survey was performed and it was observed that the street pavements exhibited several distress types. However, the distresses that negatively affect road users are mainly limited to roughness and rutting. These are actually the two distress types that could not properly be evaluated in the manual survey. Roughness would best be determined at traffic running speeds and rutting in composite pavements is sometimes mixed up with localized deformation or shoving distresses.

In order to determine the above two distress types, a profiling survey was carried out using an automated road surface profiler (ARSP). Rutting and International Roughness Index (IRI) parameters were determined on 108 lane kilometers of the city streets. A correlation analysis was then performed on the achieved data.

No strong correlation was found between the various surface distress types that were detected in the manual mode and the rutting and IRI roughness data that were collected using ARSP. In addition, general statistical analysis of the data indicated that the distribution of rutting can best be expressed in a log-normal distribution.

Analysis of Rutting and Roughness Distresses in PCC Pavements Overlaid with Asphalt Concrete

Kavussi, A.
Associate Professor, Tarbiat Modares University, Tehran, Iran

INTRODUCTION

Road roughness and rut measurements help in pavement management systems to set maintenance priorities and prepare programs for road repair operations. Surface roughness can be derived from “elevation”, “slope” or “acceleration” profiles. In the manual system, this is performed by measuring elevation differences along the longitudinal profile, while rutting is measured as the elevation difference at different cross sections.

In City of Winnipeg in Manitoba, where most of the street pavements are of concrete slabs overlaid with a bituminous layer, the city authorities have established a manual pavement condition survey program to measure the distresses. However, this method of surveying is time consuming and it is difficult to perform safely on highly trafficked arterial streets.

In addition, with the manual survey, some distress modes are overlooked and some others are under looked. In fact, road roughness levels, measured manually at stationary conditions, cannot properly reflect the actual pavement surface roughness at normal or high traffic speeds. These are better evaluated if automated systems are used.

In this work an automatic road surface profiler (ARSP) was used to measure roughness and rutting distresses on randomly selected arterial streets. The aim was to investigate the eventual correlation between surface distresses that are measured manually with rutting and roughness data that are collected using ARSP.

BACKGROUND

Pavement surface roughness is a major factor that affects vehicle operating costs and road safety. Dewan and Smith (2002), working on vehicle operating costs (as affected by road roughness), established correlations between pavement roughness and the various pavement distresses.

The roughness profile, distinguished from the elevation profile, was defined by Sayers (1990). A roughness profile consists of a continuous line plot representing a series of roughness index values such as International Roughness Index (IRI).

IRI that has first been developed under the sponsorship of the World Bank (Sayers et al, 1986) is now the standard scale on which road roughness information is reported in many countries (ASTM E-1926, 1998, Gillespie, 1992 and Sayers, 1995).

Road profile measurement, using automated systems, is a promising technique that began in 1960’s when Spangler and Kelly (1966) developed the inertial profiler at the General Motors Research Laboratory. As profiling capability became the rule for many highway agencies, IRI became the most widely used summary index for road roughness measurements (Sayers and Karamihas, 1996). IRI that is measured in mm/m or m/km is reported to be: a) relevant as indicator of pavement serviceability, b) independent of the particular equipment used to measure it, c) internationally and geographically transferable, and d) time stable (Hajek, et al, 1998).

In a quarter car model, for example, this is defined as the accumulated suspension motion divided by the distance traveled. In the automated high speed systems, IRI is calculated with an algorithm that moves the model at 80 Km/h over the measured pavement profile. It is important to note that while the pavement profile can be measured at any speed, the simulation is always run at 80 Km/h.

Although IRI can be determined using simple methods such as rod and level, the automated surveying, performed using vehicles that travel at normal traffic speeds, has promising potential to provide the needed information in a productive and cost effective manner (Sayers et al, 1986).

Lin et al (2003) indicated that IRI can be used either to evaluate the quality of pavement projects or to fully respond to the characteristics of the pavement deterioration process. These latters showed that among several common distress modes in asphalt pavements, severe potholes, patching and rutting have the highest correlation with IRI; and cracking and bleeding have the least correlation.

Dalimier and Torrent (2001) determined IRI values on some concrete pavements in Argentina and showed that the newly constructed concrete pavements had IRI values ranging from 2 to 4 m/Km that are quite good values compared with some high quality asphalt roads. However, little data has been collected from concrete pavements overlaid with asphalt mixes.

URBAN CONSIDERATIONS

IRI measurement is commonly performed to evaluate rural road networks and because of certain limitations some researchers believe that the IRI index is not suitable for urban areas (La Torre et al, 2002). The major limitations are as it follows:

- IRI parameter was originally developed and calibrated for vehicles traveling at 80 Km/h. Many urban sections operate at considerably lower speeds and the actual user perception of road roughness at the operating speed may be different than the conditions at 80 Km/h.
- Urban road networks are often shorter and less consistent than rural roads. The surface conditions and pavement structure can change significantly and frequently within short distances.
- Urban streets often interface with drainage and utility networks including the presence of utility manholes and gutters on pavement surfaces. These objects may act to distort the automated survey results.
- Pavement surface conditions deteriorate significantly at intersections due to the presence of cross rutting in the intersection and shoving on the approaches.
- Inertial based laser profilers require that the data are collected using vehicles that travel at a consistent speed, which may be difficult to achieve in an urban environment.
- There is a certain amount of built-in roughness caused by reversing longitudinal grades, especially on curbed sections. This roughness is a function of the spacing of drainage high and low points and can be as high as 0.5 mm/m.
- Bridge decks and rail crossings can distort the data and there should be a procedure to account for their interference.

EXPERIMENTAL WORK

Manual Distress Survey

Distress surveying was performed manually on randomly selected concrete pavements overlaid with a bituminous layer. The distresses were detected and measured at three different severity levels; namely, low, medium and high severities. The average summary of the prevalence of the various distresses is reported in Table 1. As it can be noticed from this table, with the manual survey, certain distresses were detected more often than certain others. And some distresses, such as rutting and roughness, have not been detected at all.

Automated Survey

In addition to the conventional distress survey, 108 lane kilometers of the arterial and collector streets in Winnipeg were surveyed under a pilot testing program. This was performed using the ARSP shown in Photograph 1. Although several data can be obtained using this system, only rutting and roughness distresses were measured in this work.

After performing a filtering operation on the collected data, the mean rut and IRI values were reported for each street portion in a uniform condition. The average rutting and IRI values in three major streets of the city, for example, are reported in Tables 2 to 4 while the full data is reported elsewhere (EBA, 2001).

Table 2 reports the average rut depth values in the three streets using a dipstick manual device and the ARSP automated machine. The dipstick, shown in Photograph 2, measures the difference in elevation between the two sides of its base plate. To obtain a profile using this method, the differences in elevation between these two points are accumulated as the dipstick is “walked” along the desired path.

The data in Table 2 are from the right wheel paths in the three streets. It can be seen that the difference between rutting values that were detected in the two systems (i.e ARSP and dipstick) varies from 1 to 3 mm only.

Table 1- Prevalence of surface distresses in street networks in Winnipeg

Surface distress	Percentage of occurrence
Raveling (LRav, m^2)	87.15
Transverse cracking (LTCr, m)	14.61
Longitudinal cracking (LLCr, m)	13.36
Joint damage (LJt, m)	12.46
Joint damage (MJt, m)	6.33
Alligator cracking (LACr, m^2)	5.54
Patching damage (LPat, m^2)	4.94
Raveling (MRav, m^2)	2.68
Block cracking (LBCr, m^2)	2.33
Transverse cracking (MTCr, m^2)	1.69
Longitudinal cracking (MLCr, m)	1.05
Joint damage (HJt, m)	0.33
Alligator cracking (MACr, m^2)	0.22
Block cracking (MBCr, m^2)	0.18
Patching damage (MPat, m^2)	0.15
Alligator cracking (HACr, m^2)	0.02
Raveling (HRav, m^2)	0.00
Transverse cracking (HTCr, m)	0.00

Note: *L, M and H = low, medium and high severities*

In Table 3, rutting values from the manual system is reported for both right and left wheel paths in the above streets. It can be seen that the differences between these two are quite high in some streets and rather low in some others. The streets that were subjected to excessive deformation showed greater differences in rut values in the wheel paths.

Table 4 reports the average IRI data for the above streets using again both the manual and the automated systems. Comparing the values for the two systems, it can be noticed that the differences are quite high. Repeating the test in one road section several times, it was concluded that the ARSP system provides more reliable results. This confirms the standard procedures of the determination of IRI that recommend using high speed vehicles to collect IRI data.

Photograph 1- The automated road surface profiler (ARSP)

Photograph 2- The Dipstick used for manual profile measurement

Table 2- Average rutting data obtained with the manual and automated methods

Street Name	Segment Length (m)	Average Rut Depth (mm), using dipstick	Average Rut Depth (mm), using ARSP	Difference (mm)
Fermor	270	13	10	- 3
Grant	500	5	4	- 1
St. Mary's	345	1	2	+ 1

Table 3- Average rutting and IRI data measured using a dipstick

Street Name	Segment Length (m)	Dipstick IRI (m/km)	Average Rut Depth LWP (mm)	Average Rut Depth RWP (mm)

Fermor	270	2.97	14	11
Logan	455	5.15	5	17
Grant	500	4.02	5	4
St. Mary's	345	4.08	1	1

Note: *LWP= left wheel path; RWP= right wheel path*

Table 4- IRI as measured with the manual and automated systems

Segment	Segment Length (m)	Manual IRI (m/km)	Automated IRI (m/km)	Difference (%)
Fermor	270	2.97	2.90	- 2%
Grant	500	4.02	4.49	+ 12%
St. Mary's	345	4.08	3.37	- 17%

Correlating the various distresses with IRI and rut depth values in a street, a matrix of coefficient of determination (r^2) between IRI, rut depth and the most occurred distresses can be obtained. Table 5 reports a typical example of these matrixes on a major street in Winnipeg. A value of one indicates a perfect correlation and a value of zero indicates no correlation. In this table the distresses are converted into percentages so that these are not affected by the street segment lengths.

Comparing the correlation values in Table 5, it can be seen that there is little relationship between any of the variables. Thus, based on the data from this study, it can be resulted that correlations cannot be used to reduce the amount of the data that is needed to be collected. This is the reason why from the 108 lane-kilometre streets surveyed in this research only rut depths and IRI values are reported from the automated system.

Table 5- Coefficients of determination (r^2) between various distresses

Distresses	Average		Percent							
	IRI (mm/m)	Rutting (mm)	LRav	LTCr	LLCr	LJt	MJt	LPat	LBCr	LACr
Average IRI (mm/m)	1									
Average RUT (mm)	0.09	1								
LRav (%)	0.27	0.40	1							
LTCr (%)	0.01	0.19	0.01	1						
LLCr (%)	0.00	0.35	0.12	0.27	1					
LJt (%)	0.41	0.04	0.07	0.07	0.04	1				
MJt (%)	0.27	0.01	0.03	0.04	0.03	0.57	1			
LPat (%)	0.13	0.31	0.23	0.21	0.05	0.01	0.00	1		
LBCr (%)	0.10	0.33	0.16	0.04	0.03	0.01	0.00	0.42	1	
LACr (%)	0.00	0.13	0.00	0.03	0.03	0.04	0.02	0.01	0.12	1

ANALYSIS OF WAVELENGTH CONTENTS

Analysis of the wavelength contents from the longitudinal profiles will help to identify the causes of roughness distress. Doré et. al. (2002) found that determining the portion of IRI that is attributable to different wavelengths is effective in diagnosing the specific problems at C-LTPP test sections. These researchers also found that there were significant differences in profiles from the different segments when examining the cumulative distribution.

For the purpose of analyzing the wavelength contents in this research, the roughness values of the raw profiles were reduced by applying “moving average filters” of lengths: 0.9, 1.8, 2.7, 3.6, 5.4, 7.2, 9.0, 12, 15, and 21 m. Performing this operation, it was considered appropriate to remove wavelengths shorter than the filter lengths of 20 m. The IRI values were then calculated from the filtered profiles. Wavelength content is expressed as the percentage of IRI attributable to waves of a certain length range. A reporting interval of 20 m was also considered to be suitable for rut depth measurements. Larger intervals tended to filter out extreme high and low values and obscure useful results.

The cumulative effect of the various wavelengths was analyzed on the above mentioned streets and the results are reported in Figure 1. It can be seen that the effect of the wavelengths were quite pronounced while there are little differences between the results from the different streets.

Given that there is little variation between the various segments in the wavelength contents of IRI data, it can be concluded that this analysis cannot be used to determine the type and extent of the distresses. Information on wavelength content may be useful for answering questions about the benefits of the various maintenance or rehabilitation alternatives. For example: if wavelength values less than 4 m could be removed, what would be the improvement in IRI values?

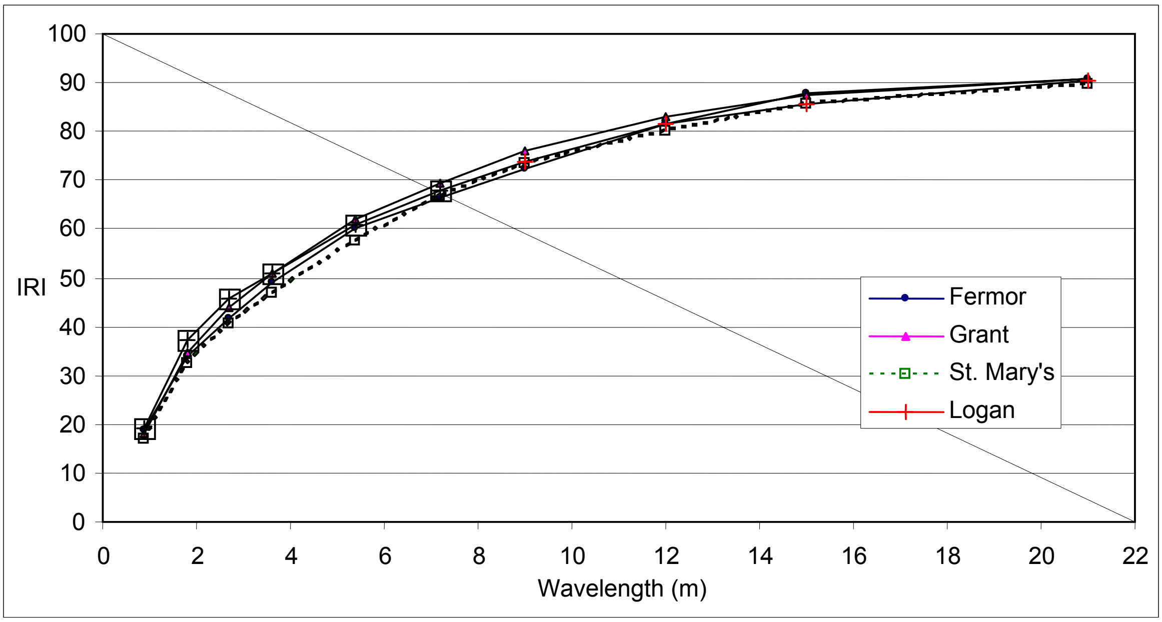

Figure 1- Cumulative effect of wavelength content on IRI

STATISTICAL DISTRIBUTION OF IRI AND RUT DEPTH VALUES

The distribution of IRI and rut depth values, based on current conditions of the streets and road surfaces, can be useful for forecasting future network conditions and for using IRI and rut depth values to predict the extent of the various surface distresses. The data that is normally distributed will be a straight line on a normal quantile plot. Drawing the normal quantile plots of IRI and rut depth values that were obtained from each street would help to determine the above subject.

Figure 2 shows the normal quantile plot of IRI data for one street. It can be seen that the IRI data are clearly not normally distributed. This is evident from the distances between the points of the normal quantile plot from the normality line.

Plotting the same data on a log normal distribution of IRI values, a better correlation could be obtained, as it can be seen from Figure 3. In fact, the scattered data in this figure are quite close to the normality line.

The same phenomenon was through for rutting distress. In fact, with reference to Figures 4 and 5, it can be seen that similar results occurred for the rutting data, although the normal quantile plot of rut values contained more scattered data than the case of IRI values.

Comparing “normal” and “log normal distribution” curves of IRI and rut depth values, Figures 6 and 7 could be plotted. With reference to these figures, it can be seen that the “log normal” distribution of IRI and rutting values have a lower bound of zero with a population mean relatively close to zero while the “normal” distribution plots seem not to be suitable for both IRI and rutting parameters. This is because in the case of normal distribution plots, the distribution curves continue to IRI and rutting values less than zero. Hence, it can be concluded that for both IRI and rutting data the natural log of data from a log-normal distribution can better simulate the data on a normal quantile plot.

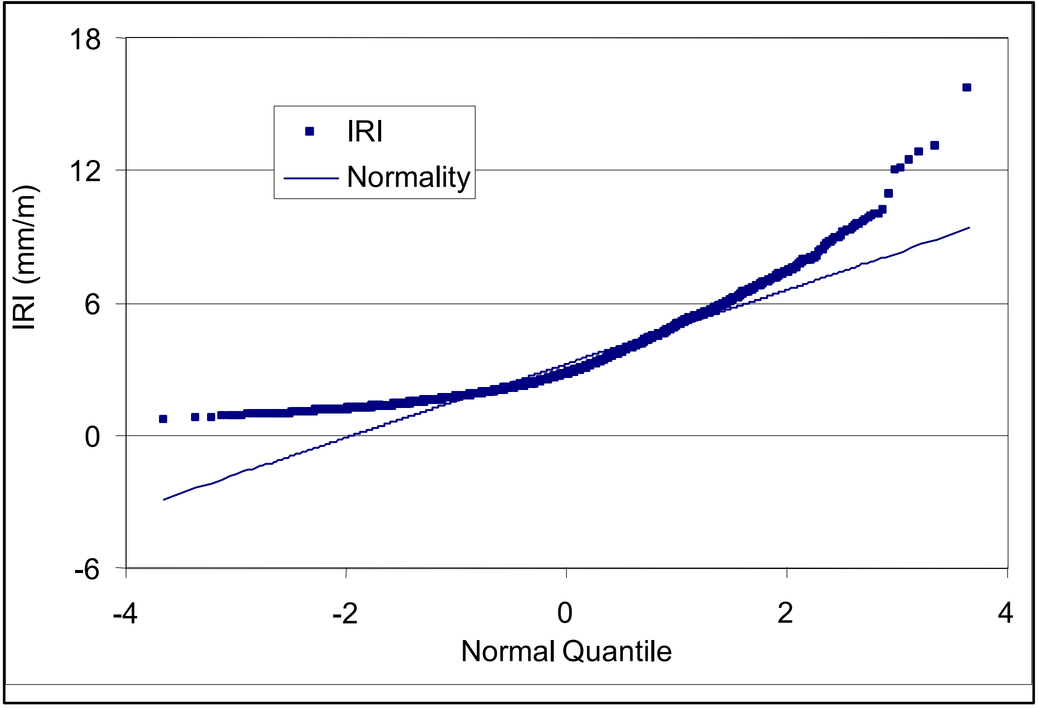

Figure 2- Normal quantile plot of IRI data

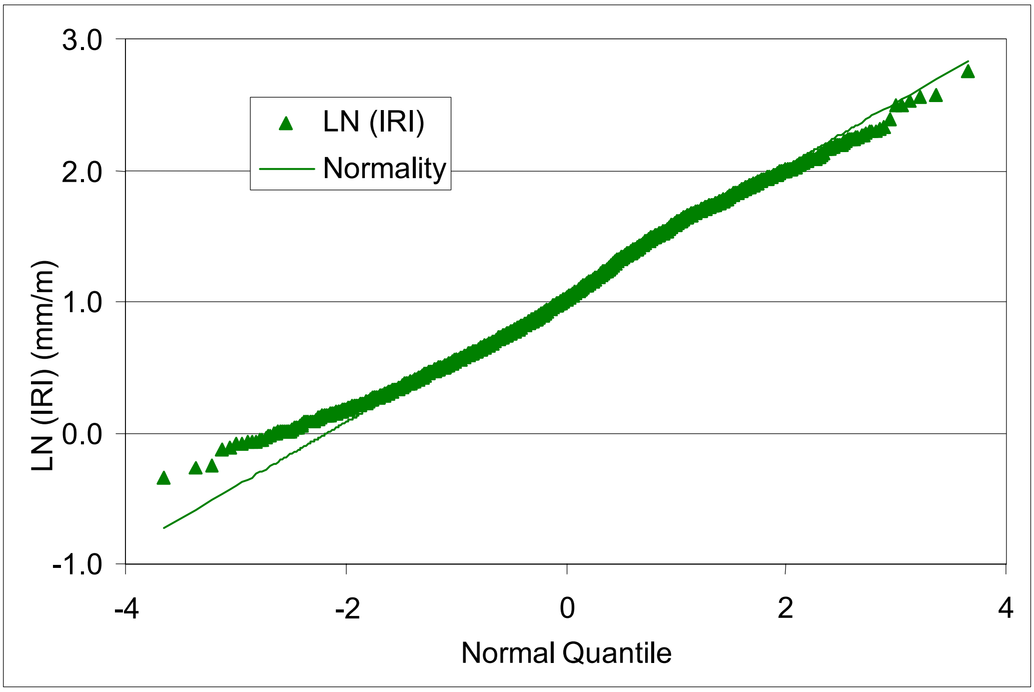

Figure 3- Normal quantile plot of the natural log of IRI data

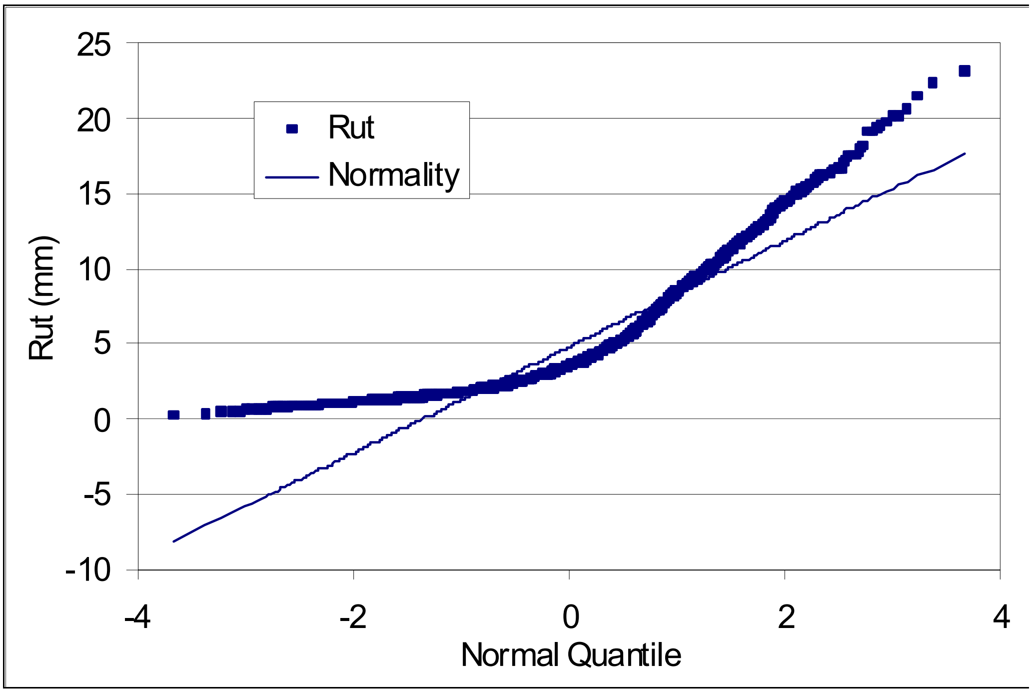

Figure 4- Normal quantile plot of rut data

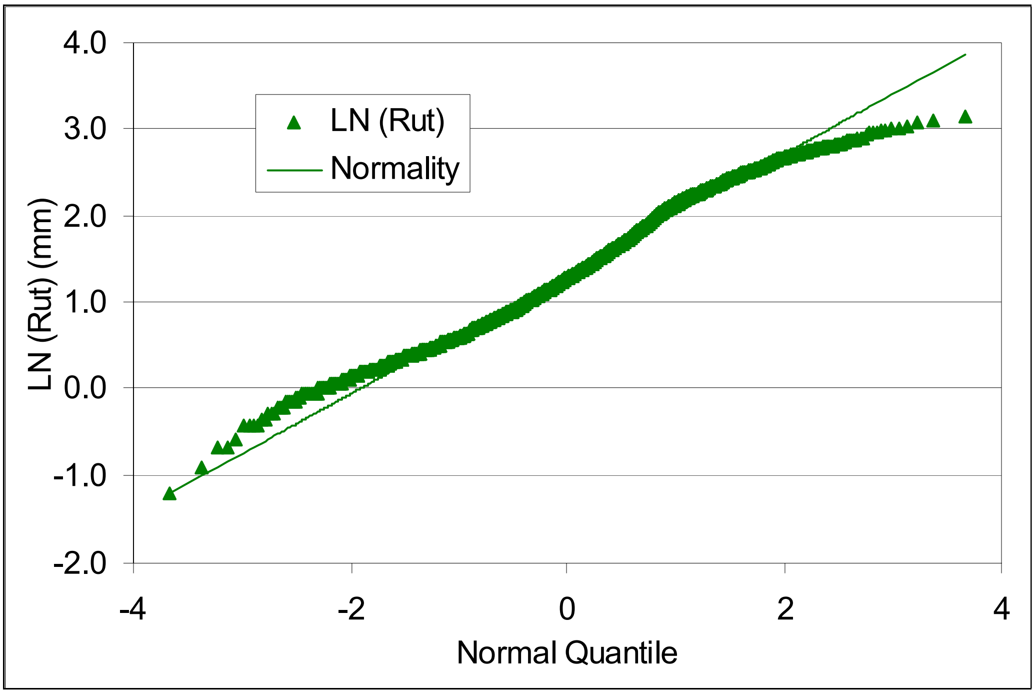

Figure 5- Normal quantile plot of the natural log of rutting data

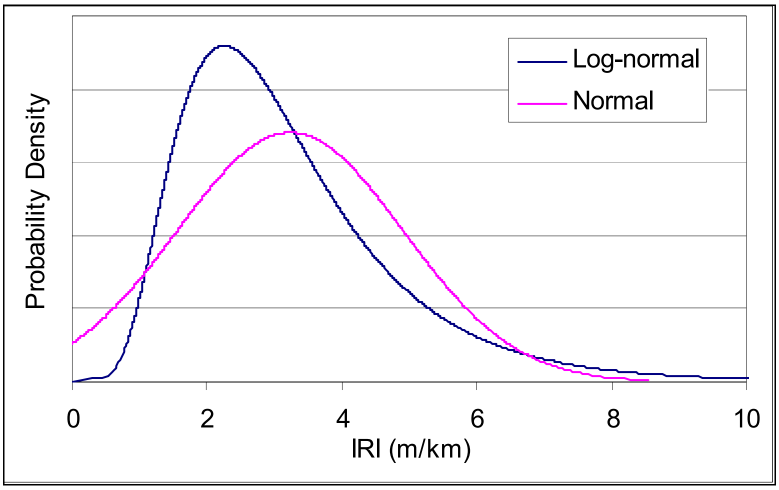

Figure 6- Log-normal and normal distributions of IRI data

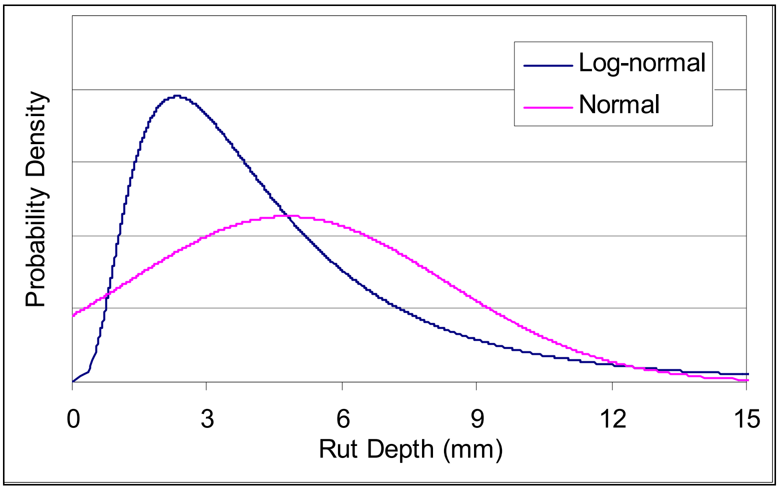

Figure 7- Log-normal and normal distributions of rut depth values

CONCLUSIONS

Based on the manual distress survey and the IRI and rutting data that were collected in city streets in Winnipeg, the following conclusions could be drawn:

1. The distress data that were collected using the automated profiler (ARSP) does not agree with the distresses that were detected manually. The correlations between IRI and rutting data, determined using ARSP, and the other manually detected distresses were rather poor.
2. The above poor correlations mean that the correlations cannot be used to reduce the amount of data collected to evaluate the street surface conditions under study in this work.
3. A reporting interval of 20 m is recommended for rut depth measurements. Larger intervals tend to filter out extreme high and low values and obscure useful results.
4. Investigating the distribution of IRI data and rut depth values through normal quantile plots, it resulted that these cannot properly fit in a simple normal distribution. The log normal distribution showed quite better representation.

ACKNOLEDGEMENT

The author thanks Dr. A. Shalaby and Mr. A. Reggin for providing the necessary data and for their assistance during the author’s sabbatical leave period in the University of Manitoba in Canada

REFERENCES

ASTM E1926 (1998), Standard practice for computing International Roughness Index of roads for longitudinal profile measurements, American Society for Testing and Materials, USA.

Doré, G., Flamand, M., Pascale, P. (2002), Analysis of the wavelength content of the longitudinal profiles for C-LTPP test sections, Canadian Journal of Civil Engineering, Vol. 29:1, February, pp. 50-57.

Dalimier M. and Torrent R. (2001), Improvement in IRI values of concrete pavements constructed in Argentina with slip form pavers, 7th International Conference on Concrete Pavements, 9-13 September, Orlando, Florida, USA.

Dewan, S.A. and Smith R.E., Estimating IRI from pavement distresses to calculate vehicle operating costs for the cities and counties of San Francisco Bay Area, Paper No. 02-2734, Transportation Research Board Annual Meeting, Washington DC, 2002

EBA Engineering Consultants Ltd. (2001), Road profile survey of collector and arterial roadways in Winnipeg, Manitoba, EBA Engineering Consultants Ltd., Edmonton, Alberta, Canada.

Gillespie, T.D. (1992), Everything you always wanted to know about the IRI, but were afraid to ask, Meeting of the Road Profile Users Group, Lincoln, Nebraska, September 22-24, p 13.

Hajek, J., Kazmierowski, T.J., Musgrove, G. (1998), A switch to the International Roughness Index, Presented at the 77th Annual Meeting of the Transportation Research Board, Washington, D.C., USA.

La Torre, F. Ballerini L. And Di Volo N., Correlation between longitudinal roughness and user perception in urban areas, Transportation Research Record No. 1806, Transportation Research Board, 2002, pp 131-139

Lin, J.D., Yau, J.T. and Hsiao, L.H. (2003), Correlation analysis between International Roughness Index and pavement distress by neural network, Presented at the 82nd Annual Meeting of Transportation Research Board, Washington D.C., USA.

Sayers, M.W., et al (1986), Guidelines for conducting and calibrating road roughness measurements, World Bank Technical Paper Number 46, p 87.

Sayers, M.W., Gillespie, T.D. and Queiroz, C. (1986), International experiment to establish correlations and standard calibration methods for road roughness measurements, World Bank Technical Paper 45, Washington D.C., USA.

Sayers, M.W., Profiles of roughness, Transportation Research Record No. 1260, Transportation Research Board, National Research Council, 1990, pp 106-111

Sayers, M.W. (1995), On the calculation of International Roughness Index from longitudinal road profile, Transportation Research Record 1501, Transportation Research Board, pp. 1-12.

Sayers, M.W. and Karamihas, S.M. (1996), Interpretation of road roughness profile data, Contract DTFH 61-92-C00143, Final Report, Federal Highway Administration, USA.

Spangler, E.B. and Kelly, W.J. (1966), GMR Road profilometer - A method for measuring road profile, Highway Research Record 121, Transportation Research Board, pp 27-54.