ROUGHNESS EVALUATION OF JORDAN HIGHWAY NETWORK

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ABSTRACT

Road Roughness is defined as an expression of irregularities in the longitudinal profile of pavement surface that adversely affects the ride quality of a vehicle thus causing discomfort to road users. In this research the ARRB Roughometer III was used to measure the roughness of all the primary and secondary highways in the Hashemite Kingdom of Jordan. This is the first time such a study was performed on a national scale. To verify the accuracy of the selected roughometer measuring device, two 500 m sections were surveyed manually using high accuracy level machine and were also surveyed using Roughometer III. Both methods gave very close results for both sections. Coded roughness level maps of the whole road network were generated. A total of 5820 lane km's were surveyed and analysed. After analysing the survey results, it was found that 70% of the surveyed roads were classified as "Excellent" to "Very good", while 20% were classified as "Fair", 8% were in "Poor" condition, and just 2% of the surveyed network was in "Bad" condition. Since about one third of Jordan national highway network is in Fair, Poor and Bad conditions it is recommended that serious actions and maintenance plans should be taken to improve road conditions in Jordan.

INTRODUCTION

Road Roughness is defined as an expression of irregularities in the longitudinal profile of pavement surface that adversely affects the ride quality of a vehicle thus causing discomfort to user. (Sayers, M. and Karamihas, S.,1998). Smoother roads are required because they provide comfort and safety to road users, reduce vehicle operating cost by reducing fuel and oil consumption, tire wear, maintenance cost and vehicle depreciation, and reduce pavement maintenance cost (WSDOT , and Ihs and Magnusson 2000). Roughness is typically quantified using different indices such as Present Serviceability Rating (PSR), Present Serviceability Index (PSI), Ride Number (RN), and International Roughness Index (IRI) (Sayers, M. and Karamihas, S., 1998)

The International Roughness Index (IRI) is a scale for roughness based on the simulated response of a generic motor vehicle to the roughness in a single wheel path of the road surface. IRI true value is determined by obtaining suitably accurate measurement of the profile of the road, processing it through an algorithm that simulates the way a reference vehicle would respond to the roughness inputs, and accumulating the suspension travel. It is normally reported in inches/mile or meters/kilometre (Thomas Gillespie, 1992, and Sayers, M. and Karamihas, S., 1998).

In this research, the ARRB Roughometer III was used to measure roughness of primary and secondary highways in the Hashemite Kingdom of Jordan. This is the first time such a study was performed on a national scale. ARRB Roughometer III is a World Bank Class 3 roughness measurement device. It was selected in this study because of its low cost and it can give a good idea about the whole road network. To verify the accuracy of the selected roughometer measuring device, two 500 m sections were surveyed manually using high accuracy level machine with rod. World-Bank TP-46 and ASTM E-950 specified test procedures were followed in this survey. One of the selected sections was smooth, and the other one was rough. PROVAL software developed by the University of Michigan Transportation Research Institute (UMTRI) was used to calculate the IRI of both sections.

Full roughness evaluation of The Jordan Highway Network of primary and secondary highways was performed in this study. Coded roughness-level maps of the whole road network were generated. Roughness results were used to select the road sections that required further analysis and maintenance.

Objectives

The main objective of this study was to find the International Roughness Index (IRI) of primary and secondary highways across the Hashemite Kingdom of Jordan. The roughness measurements were performed for the extreme right lanes. For the divided dual carriage ways, both directions were surveyed. While for the other roads, the surveys were performed for the main directions

Road Roughness Definition

Everyone who drives or rides in a vehicle over the surface of a highway pavement can subjectively judge the smoothness of the ride. Road smoothness is the opposite of road roughness. The American Society of Testing Materials ASTM-E867 (ASTM, 2005) defines roughness as "*The deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage, for example, longitudinal profile, transverse profile, and cross slope*". Since this study concentrates on the longitudinal profile, therefore, road roughness is defined as an expression of irregularities in the longitudinal profile of pavement surface that adversely affects the riding quality of a vehicle, and thus affects the user. Smoother roads are required because:

- they provide comfort and safety to road users (Figure 1),
- they reduce vehicle operating cost (Figure 2), by reducing fuel and oil consumption, tire wear, and maintenance and depreciation costs and
- they reduce pavement maintenance cost (Figure 3), smooth roads result in less dynamic loading from truck traffic which reduces pavement distresses thus resulting in less maintenance and lower life cycle cost. Therefore it is expected that smoother roads will last longer.

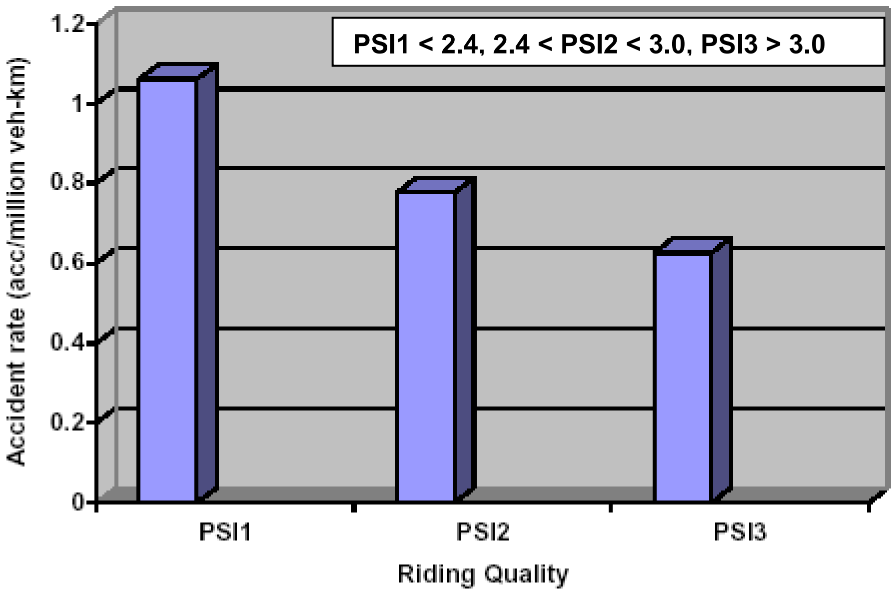

Figure 1: Effect of riding quality on vehicle accident rate (Bester, 2003)

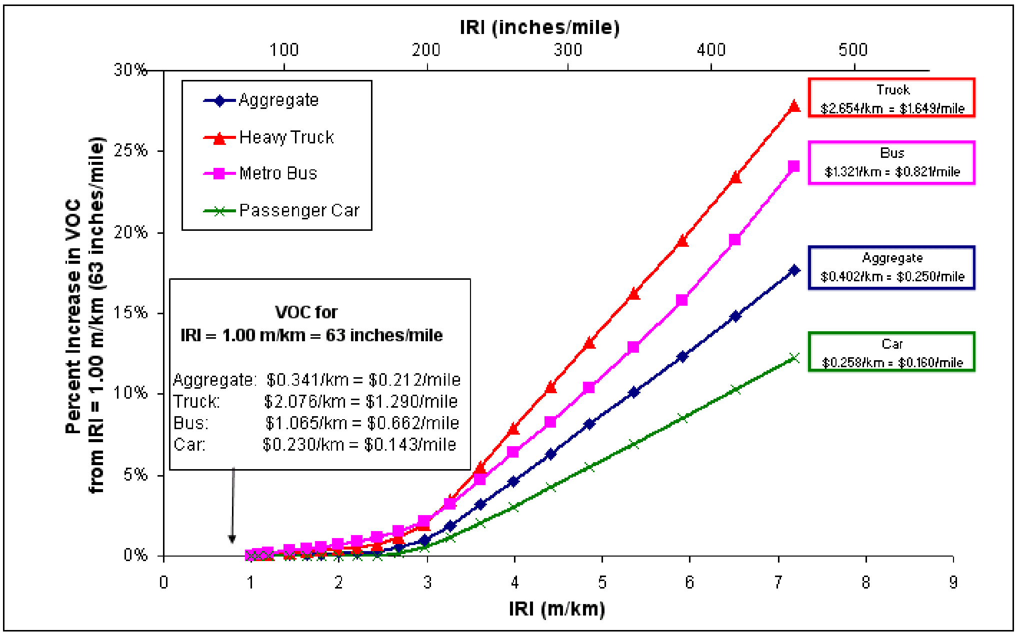

Figure 2: Percent increase in vehicle operating costs (VOC) for various vehicle types as a function of roughness (http://training.ce.washington.edu/WSDOT/Modules/11_pavement_management/11-3_body.htm#alternative_comparison).

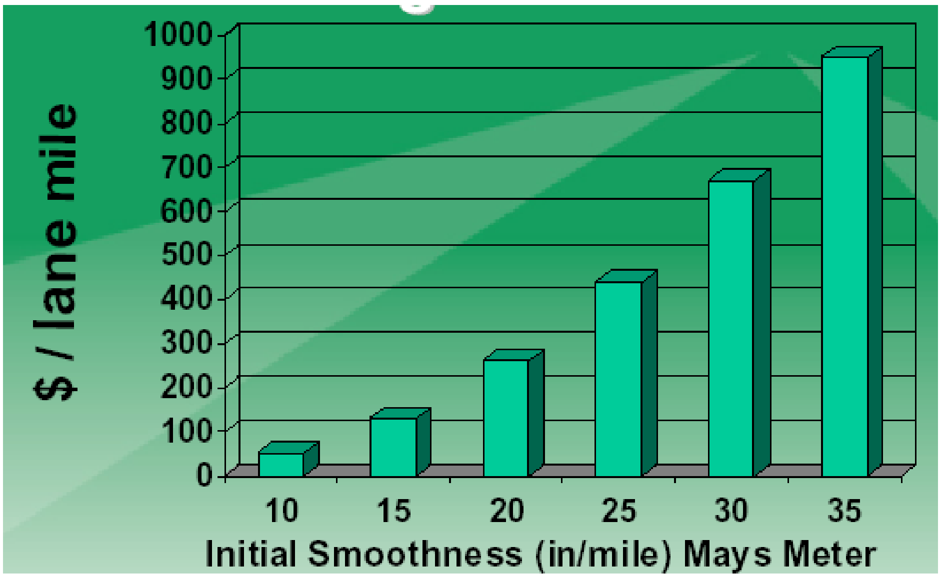

Figure 3: Effect of the initial pavement roughness on average annual maintenance cost (Janoff, 1990)

Roughness Measuring Methods

There are two main methods for measuring road smoothness. They are:

- Subjective ride quality surveys (serviceability surveys)
- Objective roughness surveys.

As stated earlier, Roughness is typically quantified using different indices such as Present Serviceability Rating (PSR) which is based on panel of engineers rating (subjective). Present Serviceability Index (PSI) is a surrogate measure for PSR. PSI is based on physical measurement of pavement roughness using special equipments (objective) (Garber and Hoel, 2003). The PSI is obtained from measurement of roughness and distress (e.g., extent of cracking, patching, and rut depth) but many estimate PSI using a subjective rating as in PSR which is discussed in the next paragraph. Roughness, the absence of smoothness, is the dominant factor in estimating the PSI of a pavement (Flexible Pavements of Ohio, 1988).

The evaluation using PSR is systematic but subjective. The PSR scale ranges from 0 through 5, with 5 representing the highest level of serviceability. New pavements typically have PSI values between 4.0 and 4.5. Pavements typically need resurfacing when the PSR value drops to 2.0 - 2.5. At this level, there is a huge increase in the number of drivers/passengers who rate a road as "unacceptable". This method is considered a simple assessment tool, but the problem is that it is a subjective method and it depends on the evaluators opinions. Figure 4 shows individual present serviceability rating form.

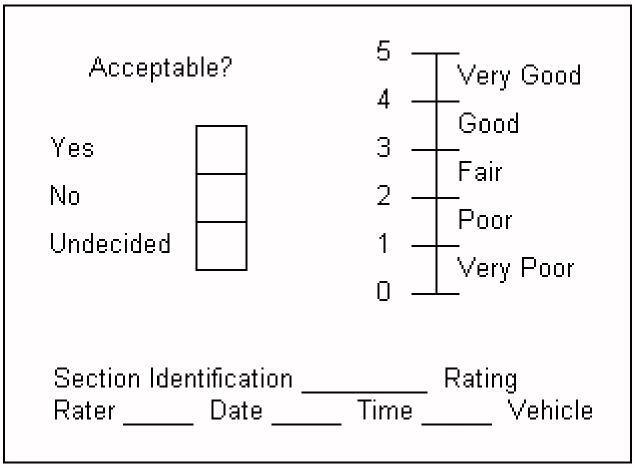

Figure 4: Individual present serviceability rating, form (http://training.ce.washington.edu/wsdot/Modules/09_pavement_evaluation/09-2_body.htm)

The other smoothness measuring method is the measurement of road roughness. One of the earliest methods for measuring road roughness is the deviations on a straight edge, which consisted of laying a straight edge on the pavement and measuring the gaps. Specifications called for a maximum allowable deviation from a straight line, typically 0.02 feet in the 12 foot straight edge (Thomas Gillespie, 1992, and Sayers, M. and Karamihas, S., 1998).

The use of the straight edge led to the development of the rolling straight edge, from which modern profilographs were developed. These devices have wheels at both ends, supporting a frame that acts as a straight edge. A measuring wheel is mounted on the frame. The wheel measures the road's longitudinal profile, i.e., the bumps and dips in the pavement surface. The accumulated total of the measured deviations is expressed in an inches-per-mile rating. A rating of 5 to 7 inches per mile generally means a smooth riding pavement (Flexible Pavements of Ohio, 1998).

Another method of measuring road roughness is by the use of a Response Type Road Roughness Measuring System (RTRRMS). These devices road meters measure the accumulated axle displacement as the vehicle traverse a test section. These devices are installed in vehicle to record accumulated suspension stroke which is then normalised by the distance travelled to produce a roughness statistic. When operated correctly, these devices can accurately obtain continuous measurements of the road profile at highway speeds. Advantages of the RTRRMS are: Low initial and operating costs, ease of operation, and High measuring speeds. While RTRRMS Disadvantages are: Output sensitive to vehicle characteristics, and that they require frequent calibration (Sayers et al., 1986).

International Roughness Index (IRI)

Almost every automated road profiling system includes software to calculate a statistic called the International Roughness Index (IRI). IRI is a scale for roughness based on the simulated response of a generic motor vehicle to the roughness in a single wheel path of the road surface. It is normally reported in meters/kilometre or inches/mile (NCHRP, 1978).

In order to calibrate the response-type systems to give similar IRI values, an ideal system was defined to develop mathematical models of the vehicle and road meter. The system is called a quarter-car (Sayers, M. and Karamihas, S., 1998). It calculates the suspension deflection of a simulated mechanical system with a response similar to a passenger car. The simulated suspension motion is accumulated and divided by the distance travelled to give the IRI. Figure 5 shows the approximate range of IRI roughness on different types of roads (Sayers, M. and Karamihas, S., 1998).

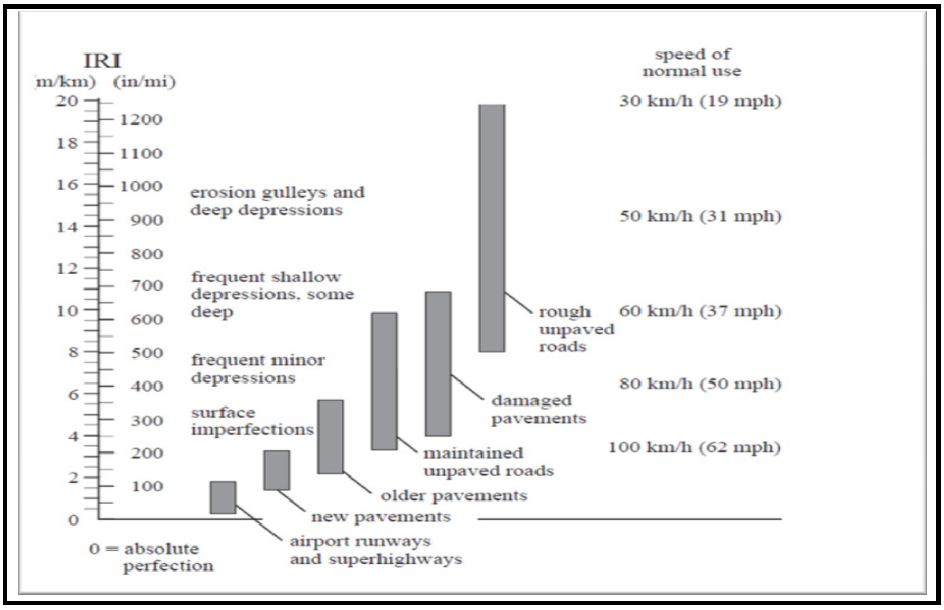

Figure 5: Approximate ranges of IRI roughness on different types of roads (Sayers, M. and Karamihas, S., 1998).

WORK PREPARATION

Selection of Roughness Measuring Device

In this research ARRB Roughometer III was used to measure roughness of both primary and secondary roads. The ARRB Roughometer III is designed to provide roughness data for both sealed and unsealed roads at a project and network level. The Roughometer III can be used to: compare and analyse road roughness across the network and help determine sites requiring remedial repair; and monitor roughness deterioration trends, for example, by reviewing successive survey results spaced over several months. The Roughometer III uses a combination of wheel-mounted motion sensor (accelerometer) and a distance input to measure the response to the longitudinal profile of the road. When the system is driven within the recommended speed range (30 to 60 km/hr), measured roughness is largely independent of vehicle mass and suspension characteristics. The Roughometer III outputs are used to calculate the International Roughness Index (IRI).

Checking Roughometer III Accuracy

To verify the accuracy of the selected roughometer measuring device, Roughometer III, two 500m sections on road number 35 going to Madaba in Jordan, were surveyed manually using high accuracy level machine with rod. World-Bank TP-46 (Sayers et al., 1986), and ASTM E-950 (ASTM, 2005) "*Measuring the Longitudinal Profile of Travelled Surfaces with an Accelerometer Established Inertial Profiling Reference*" specified test procedures were followed in this survey. Section 1 located on Amman-Madaba West Highway which has smooth surface, while Section 2 located on Amman-Madaba East Highway which has some roughness. As an example, Figure 6 shows the general profile of section 1.

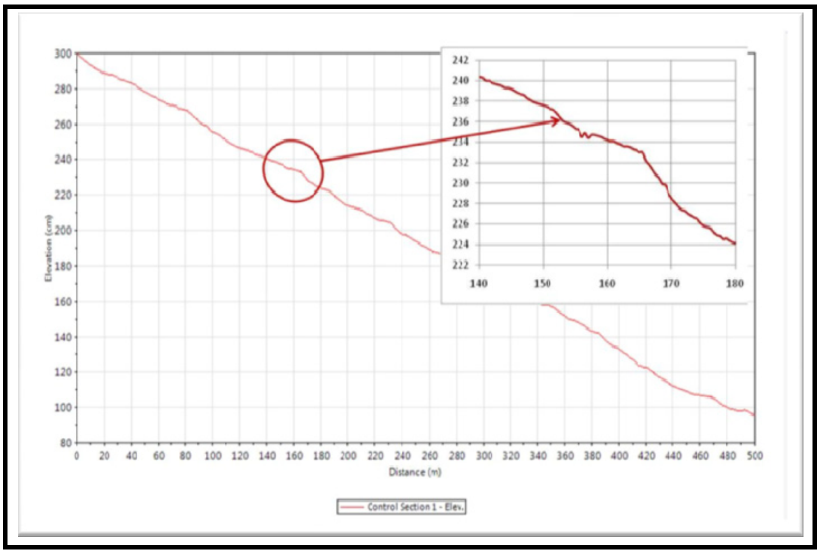

Figure 6: General Profile of Section # 1.

Profile Viewing and Analysis (PROVAL) software, version 3 (Transtec Group, 2010) was used to calculate IRI of both sections. Calculated IRI values of both sections by PROVAL software were 2.42 and 5.28 m/km, respectively. Both sections were also surveyed using Roughometer III. Roughometer III gave 2.59 m/km and 5.09 m/km for both sections, respectively. Results obtained from both methods indicate that the difference between the manual method and Roughometer III survey method is less than 0.19 m/km. This difference is less than the specified limits by the World Bank Class 3 roughness measurement devices. Therefore it was determined that the Roughometer III was an appropriate device to be used for this project.

OBTAINED ROUGHNESS RESULTS

The Roughometer III was used to measure the roughness of Jordan highway network, which consist of 9000 km of which 3500 km primary highways, 2500 km secondary highways. The survey included both primary and secondary highways across the whole Kingdom. For the divided dual carriage ways, roughness survey was performed for both directions, while for the other roads, the roughness survey was just performed for the main direction. In all surveys, the roughness measurements were done for the exterior right lanes. A total of 5820 lane km's were surveyed and analysed.

During the survey, any features of interest along the roué (such as intersection, road works, bridges, etc) are recorded. After the completion of a survey, data was analysed and reported at 100m intervals using the supplied software

Obtained data were grouped in three different worksheets according to road type. One worksheet was generated for the main direction of the primary highways, the second worksheet was for the back direction of the primary highways, and the third worksheet was for the secondary roads. As an example, Table 1 shows one page of the generated table for the main direction of the primary highways worksheet.

Obtained IRI values were further analysed to have a full idea about the condition of the whole Jordan highway network. IRI results were grouped in five roughness level groups according to IRI values. Table 2 shows these groups. It was found that while 77% of the surveyed primary roads are in "Excellent" to "Very good" levels, just 60% of the surveyed secondary roads are in "Excellent" to "Very good" levels. In addition, 17% of the primary highways are in "Fair" condition, while 26% of the secondary highways are in "Fair" condition. In addition, 5% and 1% of the primary highways are in "Poor" and "Bad" condition, respectively, while 11% and 3% of the secondary highways are in "Poor" and "Bad" condition, respectively. Figure 7 shows the percentage of each level for the whole road network. It can be noticed that 70% of the surveyed roads are in "Excellent" to "Very good" conditions, while 20% are in "Fair" condition, 8% are in "Poor" condition, and just 2% are in "Bad" condition.

Table 1: IRI for main direction of Primary Highway # 35 between roads 566 and 624

Road Number	Start Intersection	End Intersection	Distance, km	Cummulative Distance, km	IRI, m/km	Speed, km/hr	Latitude	Longitude	Altitude	Events
35	566	556	0.1	46.5	4.9	54	31.52065	35.785741	709.5	
35	566	556	0.2	46.6	5.3	51	31.51974	35.7857598	709.1	
35	566	556	0.3	46.7	4.3	54	31.51885	35.7858572	706	
35	566	556	0.4	46.8	2.8	39	31.51795	35.7860169	700.9	PM END,PS
35	566	556	0.5	46.9	4.4	44	31.51707	35.7861819	699.4	
35	566	556	0.6	47	4.3	43	31.5162	35.7859542	702.3	
35	566	556	0.7	47.1	3.4	44	31.51538	35.7855009	705.9	
35	566	556	0.8	47.2	3.3	43	31.51457	35.7850337	712.4	
35	566	556	0.9	47.3	4.1	45	31.51376	35.7845793	720.8	PM START
35	566	556	1	47.4	3.4	39	31.51295	35.784166	726.8	
35	566	556	1.1	47.5	5.9	32	31.51207	35.7838055	727.7	PM END,PS ALHASHMYIAH
35	566	556	1.2	47.6	3.6	49	31.51121	35.7835664	724.9	
35	566	556	1.3	47.7	3.9	55	31.51032	35.7834137	720.1	
35	566	556	1.4	47.8	3.8	59	31.50942	35.7833967	713.1	PS
35	566	556	1.472	47.872	3.7	54	31.50864	35.7834123	706.5	
35	556	624	0.1	47.972	3.5	48	31.49842	35.779807	719.2	END PM
35	556	624	0.2	48.072	5.1	45	31.49752	35.7798292	712.5	I, I
35	556	624	0.3	48.172	3.4	49	31.49661	35.7798341	706.8	
35	556	624	0.4	48.272	3.6	49	31.49571	35.7798565	702.2	
35	556	624	0.5	48.372	3.1	47	31.49489	35.7802378	698.9	P.S.

Table 2: Roughness levels for the different IRI ranges

	Roughness Level	**Colour Coding in Generated maps and tables**
Below 2.0	Excellent	Blue
2.0 – 3.99	Good	Green
4.0 – 5.99	Fair	Magenta
6.0 – 10.0	Poor	Red
Above 10.0	Bad	White

Average IRI values for all highway sections were calculated and tables were generated for all road sections. As an example, Table 3 shows part from one of the generated tables. For ease of referencing, colour coded roughness-levels maps showing roughness levels of the whole road network were also generated.

The roughness results for the primary and secondary highways indicate that the primary highways are in better conditions than secondary ones. This can be attributed to the fact that primary highways in Jordan receive more attention in design, construction, and maintenance than other highway categories. In addition, Primary highways are expected to have less distresses, in spite of higher traffic volume they serve, due to higher traffic speeds and the extra attention they receive.

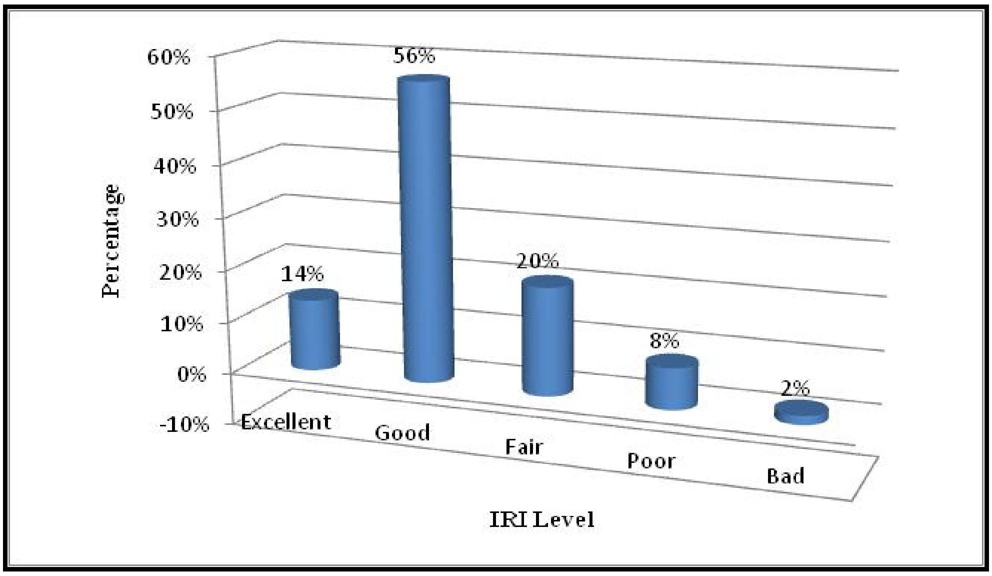

Figure 7: Distribution of IRI roughness levels for the entire Jordan Highway network.

Table 3: Average IRI values for some of Jordan highway sections

NATIONAL ROADS ACCORDING TO THE EXISTING CLASSIFICATION									
ROAD No.	ROAD SECTION		MPWH LENGTH		Number of Lanes	Main Direction		Reverse Direction	
	Start Node #	End Node #	Section	Cumul.		Surveyed Distance	IRI (m/km)	Surveyed Distance	IRI (m/km)
55	10\55	55\142	7.3	7.3	4	5.4	4.2	6.2	4.3
	55\142	55\156	0.5	7.8	4	0.3	2.7	0.3	6.2
	55\156	55\153	6.9	14.7	2	3.0	4.0	6.5	4.1
	55\153	55\172	4.3	19.0	2	2.5	3.8	3.5	3.7
	55\172	55\146	1.4	20.4	2	0.6	3.3	1.3	4.0
	55\146	55\164	1.4	21.9	4	0.4	3.2	1.1	3.7
	55\164	55\166	2.9	24.8	4	1.0	3.6	2.0	3.5
	55\166	55\171	1.4	26.2	4	0.7	4.1	1.2	3.8
	55\171	55\176	4.8	31.0	4	3.8	3.4	3.9	4.2
	55\176	20\55	4.4	35.4	4	3.3	5.2	3.5	5.4
60	15\60	35\60	29.3	29.3	2	29.8	3.2	29.9	3.3
61	15\61	61\90	15.2	15.2	4	14.8	4.3	14.4	3.9
	61\90	61\15	11.7	26.9	4	12.7	5.3	11.8	2.4
62	62\35	62\723				4.0	5.7		
	62\723	62\65	19.5	19.5	2	20.0	3.2		
65	10\65	20W\65	8.6	8.6	2	7.8	4.1		
	20W\65	65\171	2.0	10.6	2	2.0	4.5		
	65\171	65\176	17.3	27.8	2	17.0	3.7		
	65\176	20\65	12.4	40.3	2	12.6	2.7		
	20\65	65\184	6.5	46.7	2	6.6	3.4		
	65\184	30\65	6.2	52.9	2	5.9	3.0		
	30\65	30W\65	5.4	58.3	2	5.3	3.1		
	30W\65	65\437	21.2	79.4	2	20.8	2.5		
	65\437	40W\65	2.9	82.4	2	3.0	3.6		

The roughness results also revealed that about 40% of the secondary highways, which consist one third of the Jordan national highway network, are in fair condition or worse. This implies that secondary roads users in Jordan are at higher risk in regards to road safety due to roughness since higher roughness can reduce safety as presented earlier in Figure 1, and as reported by the Swedish study made by Ihs, velin, and Wicklund (2002) who found increased accident numbers on uneven roads. Furthermore, it is expected that vehicle operating cost will be higher since many previous studies proved that as road roughness increases, vehicle operating cost increases which was presented in Figure 2. The roughness results also convey a clear message to Jordan government and the highway sector that budgeting problems could arise due to the expectation that pavement maintenance cost will go up as road condition get worse (see Figure 3 above) which might reduce the budget share allocated for new necessary projects.

Last but not least, the conditions of the Jordan highway network, which shows that approximately one third of Jordan national highway network are in fair condition or worse, suggest that actions need to be taken to improve road conditions in Jordan. The current conditions, which are expected to decline with time, could have bad impact on Jordan economy and carry future environmental concerns. As indicated earlier, smoother roads will enhance safety, reduce operating cost and pavement maintenance, and sustain healthy environment.

CONCLUSIONS

This investigation was undertaken to find the International Roughness Index (IRI) of both primary and secondary highways across the Hashemite Kingdom of Jordan. Based on the findings of the performed roughness surveys, the following conclusions can be drawn:

1. The roughness measurement comparison study proved that the difference between the results of the precise manual roughness survey method and Roughometer III survey method is less than 0.19 m/km, which is less than the specified limits by the World Bank for Class 3 roughness measurement devices.
2. For Jordan primary roads, 77% of the surveyed roads are in “Excellent” to “Very good” roughness levels, 17% are in “Fair” condition, 5% and 1% are in “Poor” and “Bad” condition, respectively.
3. For Jordan secondary roads, 60% of the surveyed roads are in “Excellent” to “Very good” roughness levels, while 26% are in “Fair” condition, and 11% and 3% are in “Poor” and “Bad” condition, respectively.
4. For all the surveyed roads, 70% are in “Excellent” to “Very good” conditions, while 20% are in “Fair” condition, 8% are in “Poor” condition, and just 2% is in “Bad” condition. In other words, approximately one third of the network is in fair or worse condition.
5. Approximately one third of the Jordan national highway network, are in fair condition or worse which suggest that actions need to be taken to improve road conditions in Jordan. The current conditions of the Jordan highway network, if not improved, could have bad impact on Jordan economy, endanger road safety and have environmental concerns.
6. Secondary highway users in Jordan are at higher risk than primary highway users in regards to road safety due to roughness since higher roughness can reduce safety.
7. It is recommended that more research is needed to be done to evaluate the complete Jordan national highway network and study the impact of road roughness on safety, environment, operating cost, and maintenance cost for Jordan.

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