EVALUATION OF A SMARTPHONE ROUGHNESS METER

M R SCHLOTJES[1], A VISSER[2], and C BENNETT[1]

[1]The World Bank Group, 14 Martin Place, Sydney, 2000, NSW, Australia

Telephone: +61 2 9235 6403; Email: mschlotjes@worldbank.org

[2]Department of Civil Engineering, University of Pretoria, Pretoria, 0002, South Africa

Telephone: +27 82 922 2927; Email: alex.visser@up.ac.za

ABSTRACT

The remoteness of the Pacific Island Countries (PICs), similar to parts of Africa, creates difficulties, both logistically and economically, to undertake detailed in-country investigations on the road networks. Therefore, rapid assessments of the condition of the existing road pavements are required to determine the level of required donor investments to maintain the integrity of the road network. This paper explores the use of *Roadroid,* a simple android application, as a low cost solution to evaluating road roughness in the Pacific region. The case study presented in this paper demonstrates the use of the *Roadroid* application on the road network in Kiribati, one of the smaller and debatably the most remote PIC. The results from the study discuss the performance and practicability of the android application, primarily as an Information Quality Level-3/4 information device, in the Pacific region.

The results from the field surveys supported the delivery of an Information Quality Level-3/4 device. The large variation reported in the surveys between the International Roughness Index collected was attributed to the small sampling intervals embedded in the device. Post-processing of the data, which averaged the unfiltered data across one kilometre sub-sections along the main road in South Tarawa, reduced the variability reported across the road network and provided results consistent with what experienced evaluators expected. Field surveys were conducted with the smartphone device and the data was analysed post survey. However, the statistical reliability of the device was less satisfactory when the roughness measurements were compared across various speeds. However, within the accuracy limits of an Information Quality Level-3/4 device, considered to be ±20 % of the International Roughness Index, the equipment more than satisfied the need.

Roadroid can assist the asset management of road networks by offering a low-cost solution to monitoring and reporting on the roughness condition of pavements in the Pacific region, as well as in other developing regions. Although this paper reports on the performance of the device, further comparison is recommended to confirm the reported International Roughness Index values accurately reflect the condition of the road pavement. To do so, it is recommended to comparatively study the results from the *Roadroid* android application with those from specialized instrumented vehicles, such as a laser profilometer.

1 INTRODUCTION

Pacific Island Countries (PICs) are characterized by small, remotely located communities that are scattered across several islands in the Pacific Ocean. Coupled with small and growing economies, the demand on the existing road networks is cumbersome. With limited capacity of the Governments, road maintenance is often deferred to donor organizations, such as the World Bank Group, to finance.
The size and populations of the remote PICs vary. Tuvalu is one of the smallest Pacific States and accommodates approximately 12,000 residents on 26 km^2 of land area. The sealed road network length in Tuvalu is only 18 km. Kiribati, one of the more remote PICs, is larger with a land area of 811 km^2, population of 100,000+, yet is scattered across 3.5 million km^2 of the Pacific. On South Tarawa, the length of the sealed road network is approximately 36 km (World Bank, 2011a; World Bank, 2011b).

The remoteness of these countries, as is the case in Africa, creates difficulties, both logistically and economically, to undertake detailed in-country investigations on the road networks. Technical assistance and expertise from developed countries provide support to the Governments of PICs that characteristically have limited capacity, both financially and operationally, to sufficiently evaluate network performance. In most cases, larger and more expensive items employed in methods of collecting road condition data are mobilized in-country, increasing the already high costs of road assessments in the Pacific. Mobilization time is greatly dependent on the shipping schedules in the region and, given the remoteness of the islands, is often intermittent with ships only visiting some of the islands every 6 weeks. As a result of the above, delays in road evaluations and increased costs, in comparison to developed countries, are experienced in PICs. Local technical staff are unfortunately not well versed with the sophisticated measures such as the International Roughness Index (IRI). Therefore, rapid assessments of the condition of the existing road pavements are a necessary input to an economic evaluation of investments, and are required to determine the level of required donor investments to maintain the integrity of the road network – an asset to the country.

Roadroid (version 1.2.1) is a simple android application which evaluates the roughness of paved road pavements. Compared to other specialized instrumented vehicles in the market (Harrison and Park, 2008), *Roadroid* is a low cost and easily portable solution that makes use of the built-in triaxial accelerometer. The latest version of *Roadroid* can be installed from http://roadroid.com/app/roadroid.apk.

This paper explores the use of a low cost solution to evaluate road roughness in the Pacific region. The case study presented in this paper demonstrates the use of the *Roadroid* android application on the road network in Kiribati, one of the smaller and debatably the most remote PIC. The results from the study discuss the performance and practicability of the android application, primarily as an Information Quality Level (IQL)-3/4 (Paterson and Scullion, 1990) information device in the Pacific region, with application in Africa. Unlike precise roughness measurement devices, such as laser profilometers, IQL 3/4 devices provide an approximation of the roughness, generally on the order of +/- 20% of the true value. They are used for screening studies, economic analysis, but not detailed design.

2 THEORETICAL FRAMEWORK OF THE STUDY

2.1 Conceptual Design

As discussed above, *Roadroid* is a low cost and highly portable roughness meter (it is a smartphone and holder), which has been developed in Sweden (Roadroid, 2013). The test environments in Europe differ to the implementing environments in the Pacific particularly in respect to the roughness levels, traffic loadings and weathering, pavement types, and fluctuations and variability between the seasons. The success of the *Roadroid* android application on Swedish road networks is noted in (Roadroid, 2013); however, the geographical transferability of the application has yet to be explored. Therefore, the design of this study focuses on implementing a low cost solution and evaluates the transferability of *Roadroid* to developing countries in the Pacific region.

2.2 Objectives of the Study

The objectives of the study were two-fold: (i) to determine the effectiveness and appropriateness of the *Roadroid* android application to the PICs with limited capacity in collating road condition data; and (ii) to evaluate the performance of the *Roadroid* android application, as an IQL-3/4 device, for road pavement types typical of those in the Pacific region. To demonstrate these objectives, this paper considers a case study focused in Kiribati, located in the Pacific region, where the *Roadroid* android application was implemented in-country.

3 ROAD CONDITION REPORTING

Road roughness, measured using the International Roughness Index (IRI) scale, is defined as the response of a standard vehicle to deviate from the longitudinal profiles of the road surface and subsequently affects the riding quality (Sayers et al., 1986). This should not be confused with macro- or micro-texture, which are defined as the undulations resulting from voids between the aggregate chips and cavities on the aggregates, respectively. The latter influence the friction of the road surface and contribute to the traffic noise of the road, yet should not affect the performance of the road in regards to road roughness. Figure 1 presents typical and expected IRI values for a variety of pavement types.

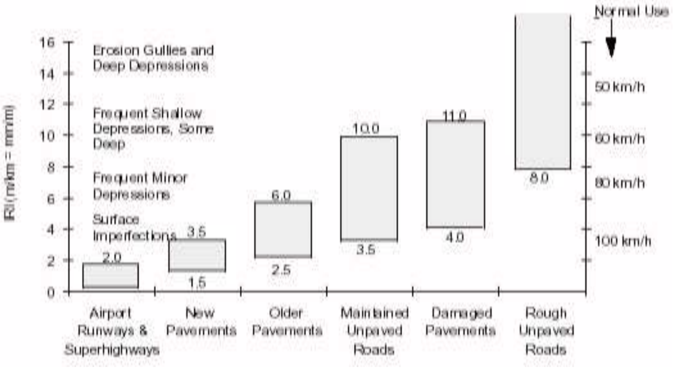

Figure 1: IRI Scale (Sayers et al., 1986)

4 INFORMATION QUALITY LEVEL

Road condition data and the information collected through road inspections can be presented in either simple or detailed terms. The level of information reported in the data collected in the field is dependent on the variety of effort and level of sophistication of the collection and processing methods. The amount of detail presented as information can increase depending on the task and overall situation. For example, at a greater distance, the outline of an object is identifiable but the features and attributes of the object are undetectable. As one moves closer to the object, the amount of detail recognized from above increases so the features of the object become clear.

The idea behind this led to the development of the concept of IQL (Paterson and Scullion, 1990). Figure 2 shows definitions of each IQL. The detailed data at the base of the pyramid can be aggregated into fewer individual data items, collectively, to be considered as higher IQL data. The use of the data determines the IQL of the data collected.

This paper explores the use of the *Roadroid* android application in the collection of road roughness data. It is proposed that the collected data will be used in the decision making process at a network level, opposed to a project level. More specifically, the data will be used in the evaluation of the road roughness condition across the network. Therefore, the performance of the device, as an IQL-3/4 device, was assessed.

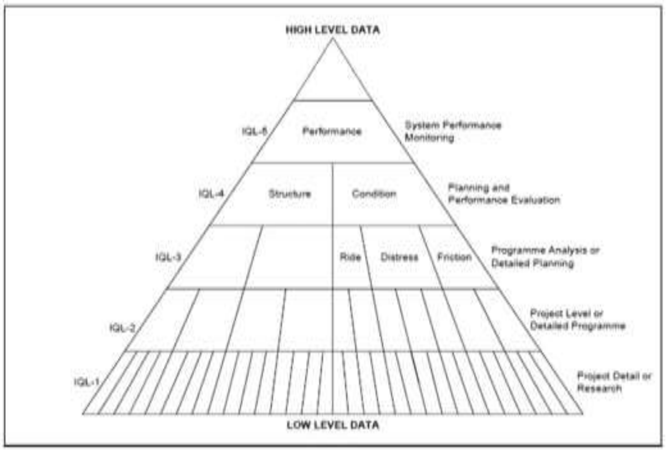

Figure 2: Information Quality Levels (IQL) definitions (Bennett and Paterson, 2000)

5 SMARTPHONE APPLICATIONS

The introduction of smartphones has opened an industry of smartphone applications that are accessed daily, for example public transportation timetables, GPS activities, and weather and news updates. With the availability of wireless internet connections on all smartphones, location tools within the applications are possible. However, as many of the PICs are remote, generally the infrastructure capacity is limited and the availability of wireless internet on the more remote and less developed PICs are not yet available, as the Pacific seldom offers continual access to the internet through 3G or 4G networks to their cellphone users. The developed world is much more advanced than the PICs with: (i) a larger population and usage of smartphones within the countries; (ii) faster and more reliable connectivity, particularly accessibility to the internet, provided by the telecommunication providers; and (iii) the capacity for research and development of smartphone applications. The limited telecommunications capacity faced by PICs restricts the breadth and diversity of the applications available to developing countries. Constructively, the *Roadroid* android application does not rely on continual cellphone connectivity when in use, instead utilizes the GPS functions in-built in the smartphone, and therefore the limited infrastructure capacity in the Pacific is not anticipated to negatively affect the performance of the device.

Using smartphones to report road condition has been a topic of research studies as early as the late 2000s. A number of research studies have explored the use of smartphones in road condition reporting. One study focused on utilizing the accelerometer, microphone and in-built GPS features in smartphones to detect potholes and bumps in the road (Mohan et al., 2008) in developing regions where the urban traffic flow is high. In such cases, traffic flow patterns are more complex than in developed countries due to the varied road conditions resulting from the potholed roads and heterogeneous vehicle composition. Other studies have reported on the success of in-built accelerometers to detect potholes, specifically, to further inform a real-time alert system and enhance the response of the Road Controlling Authority and remedial works (Ghose et al., 2012; Mednis et al., 2011). The in-built GPS functions have also been utilized in reporting on real-time traffic congestion (Ban et al., 2009).

This paper does not intend to provide a comparison of the existing smartphone applications nor review the technology architecture and platforms behind the development of the *Roadroid* android application. Instead, this paper addresses the practicability of the device in low income, remote countries with variable road network conditions. The use of other road roughness applications, android or others, and a comparison of the applications against industry standard practices for IRI data collection will be reported in supplementary case studies.

6 CASE STUDY

6.1 Background

The islands of Kiribati are located in four separate hemispheres, resulting in one of the most geographically dispersed countries in the world. South Tarawa, the south-western island, is a distance of at least 3,300 km from the most north-eastern island, Christmas (Kiritimati) Island. Approximately half of the total country's population resides on South Tarawa. The employment rate in Kiribati is 18 % (World Bank, 2011b).

Unlike other PICs, South Tarawa is a series narrow islands connected by causeways, which encompasses a lagoon. At the widest part, South Tarawa is some 2000 metres wide, but most of the islands are 200 metres wide or less. A single main paved road runs the length of the island, with a local street network in the villages. Most of this road is surfaced with a chipseal, although in some places, typically the urbanized community areas, the main road has been surfaced with a thin AC layer. The Government of Kiribati has limited funds to invest in preserving the integrity of their road network. As a result, the main road is in very poor condition and deteriorating. The road is scattered with unfilled potholes, which not only poses a safety hazard but increases the travel time of the road users and vehicle operating costs. The traffic composition comprises of mainly light vehicles, light heavy commercial vehicles included. The use of heavy commercial vehicles in Kiribati is infrequent as there is no industry requiring such vehicles and machinery. However, as donor involvement is set to increase in the future, infrastructure development of the island will accelerate with many of the proposed projects involving heavy machinery using the network to access the construction sites.

6.2 Study Methodology

Data was collected using the *Roadroid* android application, which was downloaded on a *Samsung Galaxy SII* smartphone as recommended by the developers of the application, in March 2013, and mounted in a medium-sized hatchback vehicle. Accordingly, the vehicle setting selected for the mounted device was a standard / medium sedan vehicle. The smartphone was mounted to the windscreen and calibrated further following the guidelines that accompany the device (Roadroid, 2013).

The aim of the analysis was to:

1. Assess the instrument’s effectiveness for a network roughness survey of the main road on South Tarawa;
2. Test the repeatability and reliability of the device at various speeds, and
3. Evaluate the practicality and applicability of a smartphone application for use in developing countries, such as the PICs.

6.2.1 Network Roughness Data. Using the *Roadroid* android application, roughness data was collected along a 24 km length of the main road on South Tarawa, in both lane directions, from the Betio Causeway toll bridge to Bonriki International Airport. The current condition of the main road inhibited a vehicular speed of greater than 50 km/h, although the speed travelled across the sample length varied due to (i) other vehicular traffic influences, (ii) pedestrian safety, (iii) the number of speed humps on this section of road, and (iv) the condition of the road surface on some road sections being so bad the vehicle could not comfortably travel above 20 km/h. The *Roadroid* android application does not operate under vehicle speeds of less than 20 km/h and therefore IRI data is not collected when the speed it too low (*Roadroid*, 2013). The roughness data was assessed against subjective roughness estimates from two experienced highway engineers. Unfortunately, at the time of surveys, conventional IRI instruments such as laser profilometers were not available in Kiribati for a comparative assessment. This is to be the focus of subsequent case studies. However, given the extensive testing throughout the development of the *Roadroid* android application – albeit on Swedish roads – the roughness values recorded by the device can be assumed dependable for the intended purposes of this case study and implementation of an IQI-3/4 device.

6.2.2 Repeatability and Reliability. A repeatability and reliability exercises were conducted to determine the speed and vehicle dependency of the *Roadroid* android application, if any. To do so, the asphalt airport runway at Bonriki International Airport was repetitively measured at various speeds. The wheelpaths chosen were on either side of the centreline, typical of the position of the gears of an aircraft. Photographs depicting the runway surface are presented in Figure 3.

The exercise recorded roughness measurements for three speeds: 30 km/h, 40 km/h, and 50 km/h. Two runs were completed at 30 km/h and 40 km/h, and three runs at 50 km/h, along the asphalt airport runway at Bonriki International Airport, where one run in this exercise was defined as a single trip in either the Eastbound or Westbound vehicle tracks.

The study extended the investigation of the repeatability performance of the *Roadroid* android application to consider whether different vehicles have any effect on the repeatability of the IRI measurements. The roughness data recorded from the operation of each vehicle was not processed post survey because of a storage bug, which has since been remedied by the developers. Therefore, this paper only reports the interpretations of the authors given their first-hand observations of the readouts. Two vehicles of identical make and model (Suzuki Grand Vitara) were employed in this exercise in Tonga, where the roughness along a very smooth asphalt surfaced road was measured. As with any sample testing, a repeated wheeltrack was established along the road surface to minimize the variation between roughness measurements from vehicular wander and speed variation – something that becomes difficult given the natural variance in human (driver) behaviour.

Figure 3: Surface condition of the Bonriki International Airport runway in South Tarawa. (L) Ponding, as a result of depressions. (R) Severe degradation of the surface, resulting from a basecourse layer failure and patching.

6.2.3 Practicality and Applicability to the PICs. The Roadroid (2013) provided the study with a guide to operating the *Roadroid* android application once installed on the smartphone device. The success of a tool is greatly dependent on the ease of use to the user. The study considered three attributes of the application to appraise the practicality of *Roadroid*, including:

1. User input required while recording IRI measurements while conducting field surveys;
2. Accessibility of post-survey data processing and analysis, and
3. The overall performance of the device in accurately evaluating the roughness of road networks in PICs, given a visual inspection of the road surface.

6.3 Results and Analysis

6.3.1 General Road Network Roughness Surveys. The roughness of the main road connecting Betio Toll Bridge to Bonriki International Airport (Northbound), and return (Southbound), in South Tarawa are presented in Figure 4. The device records an IRI roughness measure at a time interval of one second, as opposed to distance based. The raw (unfiltered) data is presented in Figure 4a, which reports a large variance in IRI along the road length. This detailed low-level data exceeds the detail necessary of IQL-3/4 data, and therefore the raw unfiltered results from each direction were manually averaged over a one kilometre length (refer Figure 4b). The developers are updating the application to include a feature where the user can select their preferred section length for reporting. It can be seen from Figure 4b that the average IRI across the road length is similar between the two lanes (10.3 and 10.8), despite the severe deterioration.

While the road is heavily damaged with numerous potholes along its length, the expected IRI, given the scale presented in Figure 1, was estimated as only up to 12, while *Roadroid* indicated that approximately 20 % of the one kilometre lengths exceeded an IRI of 12 (refer Figure 4b) and individual 1 second readings were about 20 IRI. This, and other testing, suggested that there was an issue with the roughness filters used by *Roadroid* and that this was resulting in short wavelength roughnesses being over-reported. The developers are currently calibrating the system with the results from a laser profilometer on asphalt surfaced pavements.

6.3.2 Speed Dependency. One of the aims of the repeatability and reliability exercise in Kiribati was to determine the speed dependency of the *Roadroid* android application, if any. The accuracy of the reporting of the smartphone application was investigated in other exercises in this case study. Therefore, for this exercise, the focus remained on the statistical difference between several runs on the same wheeltrack, with any outliers removed purposefully, to prevent skewed distributions, and consideration given to the natural wander of human driving behaviour. Bonriki International runway is 2 kilometres long. For consistency across the exercise, a path of 1650 metres was established. To ensure sufficient data was available for the statistical analysis, the IRI data recorded at every one second interval was averaged over 100 metre sub-sections.

Figure 5 depict the correlation between the recorded roughness measurements, averaged over 100 metre sub-sections, given the various vehicular speeds. The data reported larger variation across areas of the pavement where defects were present, such as in Figure 5 (R) where the significant deterioration and patching attempts shown in Figure 3 are located at 900 metres in the Westbound direction.

It was found the *Roadroid* android application exhibited repeatability over the longer sampling sections consistent with IQL-3/4 assessments compared to the data recorded at every one second interval. The analysis of the raw unfiltered data showed a high degree of variation between the recorded measurements, particularly at the higher speeds investigated in the study (50 km/h). This observation, compared with those presented in Figure 5, suggests the use of small sampling intervals is not statistically reliable.

The significance of the differences between the runs at each speed was analysed using paired t-tests. As shown in Table 1, repeatability was observed across 5 of the 6 tests, suggesting that the *Roadroid* android application consistently measures roughness at a given speed. Table 2 presents the results of the paired t-tests when comparing the recorded IRI across various vehicle speeds. The results were less satisfactory and it can be concluded the reliability of the smartphone application is poor between various speeds. However, as IQL-3/4 data is typically used in a network-level capacity for the purpose of informing pavement maintenance works (Bennett and Paterson, 2000), the accuracy of an IQL-3/4 measurement was considered appropriately for the intended purpose of the device to be +/- 20 % IRI, and the smartphone device does reflect this type of repeatability.

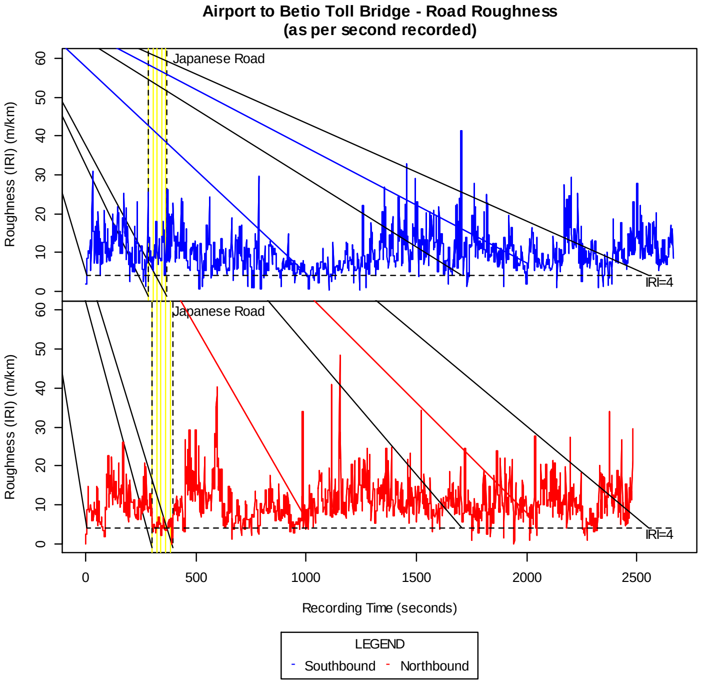

Figure 4a: Raw (unfiltered) data

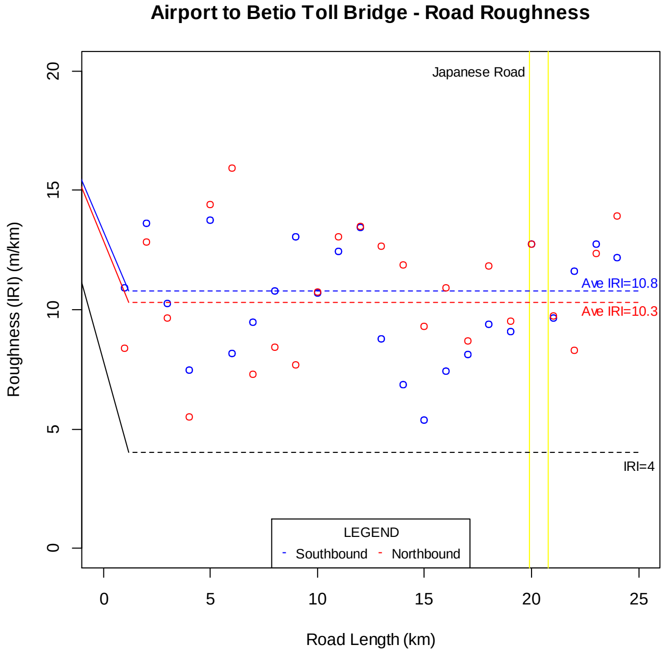

Figure 4b: Averaged data per kilometre

Figure 4: Roughness recordings for the main road in South Tarawa, Kiribati

Table 1: Sample Statistics for the Repeatability Exercise

Speed (km/h)	Direction	Run	Sample Statistics (IRI)		Repeatability[1]
			Average	Standard Deviation	
30	Eastbound	1	3.51	1.63	No
		3	3.09	0.78	
	Westbound	2	3.34	1.16	Yes
		4	3.21	1.39	
40	Eastbound	5	4.27	1.23	Yes
		7	4.36	1.37	
	Westbound	6	4.64	2.11	Yes
		8	4.58	2.24	
50	Eastbound	9	4.04	1.27	Yes
		11	3.97	0.97	
		13	3.89	0.91	
	Westbound	10	4.38	1.62	Yes
		12	4.28	1.43	
		14	4.43	1.85	

[1] Based on the reported p-values.

Table 2: Reliability between Vehicle Speeds

Direction	Speed (km/h) Comparison	P-Values	Reliability
Eastbound	30 – 40	< 0.0005	No
	30 – 50	< 0.04	No
	40 – 50	< 0.04	No
Westbound	30 – 40	< 0.0005	No
	30 – 50	< 0.0006	No
	40 – 50	> 0.05	Yes

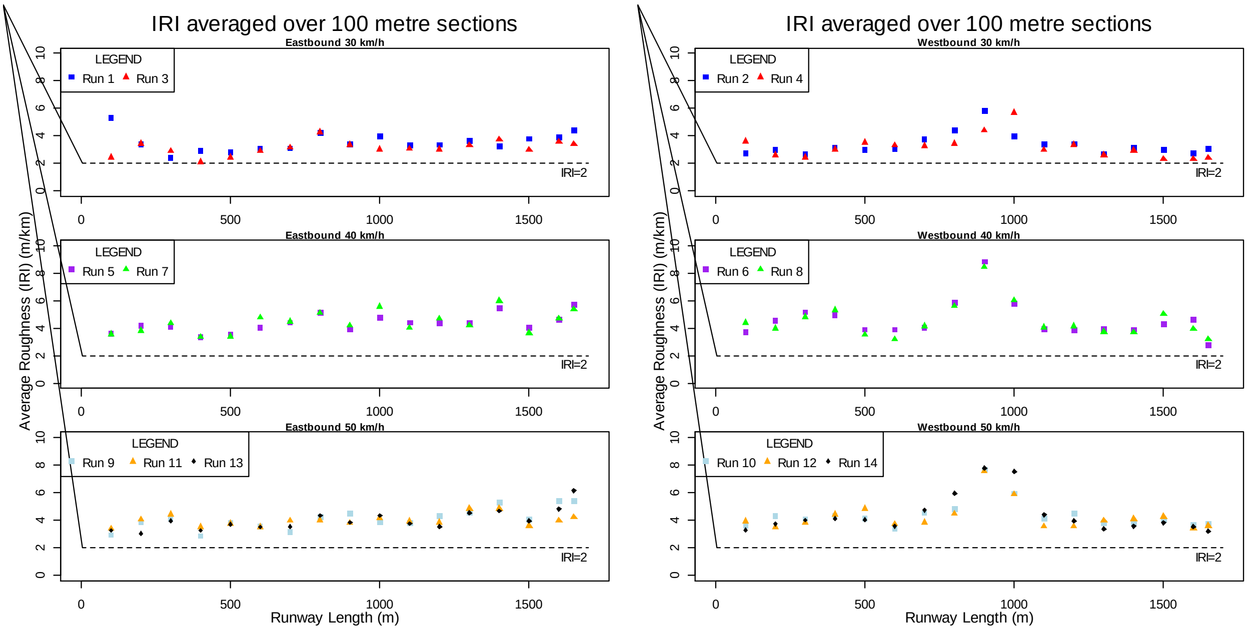

Figure 5: Eastbound (L) and Westbound (R) runs for the repeatability exercise on the Bonriki International Airport runway in South Tarawa, Kiribati

6.3.3 Vehicle Dependency. A second phase to the repeatability and reliability exercise explored the dependency of the *Roadroid* android application on the vehicle used to mount the device. Despite the failure of the instrument to record the data for post-survey analysis, the observations noted during the exercise, which involved two vehicles of identical make and model, were:

1. Poor repeatability with data as a result of small sampling lengths across all speeds;
2. A large amount of variation between the raw (unfiltered) IRI measurements, and

3. Inconsistencies in the recorded IRI values between the two vehicles.

Although some variation was anticipated in this exercise due to the variable nature of human (driver) behaviour, the inconsistencies between the IRI measurements recorded with the device exceeded those that were expected. Although the vehicles were of the same make, the tyre pressures were not measured at the time, and because of the lack of time, the measurements could not be repeated. It was postulated that the higher tyre pressure caused larger variation in IRI and that it was more prone to texture effects than the softer tyre. The reported variation in the IRI values could be attributed to this hypothesis, and will be explored further in succeeding case studies.

6.4 Practicalities

The operation of *Roadroid* is simple and requires little input from the user once the survey commences. Once calibrated, the device easily records the roughness of the road and stores the information within the device. The information can easily be uploaded to the developers' webpage for post-processing, if the user opts for post-processing via the developers; otherwise manual post-processing is possible. The data upload to *Roadroid* server requires a Wi-Fi connection. On upload, raw data is compressed to a zip-file and transferred to the server by File Transfer Protocol (FTP) or Hypertext Transfer Protocol (HTTP). After a successful upload, the compressed files are also stored on the smartphone to prevent accidental loss or deletion of data. These backups can be manually deleted by the user, which is only possible when the device is connected to a computer. Alternative data submission is available via email directly from the smartphone.

A promising feature of the *Roadroid* android application is the ability to capture GPS photographs of the road surface very easily while conducting the survey. Along with the survey data, these photographs are processed post-survey and presented, by location, on a map.

During the operation, it was found that an event marker to designate different road features such as junctions or change of surfacing type would have been useful. The developers have been updating the *Roadroid* software to provide this feature. In addition, on-going development is addressing the concerns expressed in this paper and to provide a more consistent and reliable device.

7 CONCLUSIONS

This paper has presented an analysis of the performance of the *Roadroid* android application as a low-cost solution for road condition surveys. The case study investigated the performance of the *Roadroid* android application in Kiribati, a PIC with limited resources and capacity to conduct in-field road condition assessments. To demonstrate the applicability of the device in the Pacific region, the study determined the effectiveness of the device in the Pacific environment and evaluated the performance of the IQL-3/4 device in Kiribati. Given the low cost of the smartphone device compared to specialized instrumented vehicles in the market, implementing such routine road and pavement condition surveys of road networks in the Pacific region is feasible and affordable for PIC governments. It allows unskilled technical staff to collect data, and provides potential donors / funders with objective measures of the road quality. Such data is a necessary input to an economic evaluation of investments.

The results from the field surveys supported its use as an IQL-3/4 device but suggest that there is a filtering issue resulting in an upwards bias for the roughness measurements. For the network survey, it showed consistent average roughnesses over long sections. Although roughness is reported at one second intervals, the work suggests that it would be more appropriate to report them over longer sampling intervals, such as 100 m.

Repeatability of *Roadroid* was observed where consistency in IRI recordings at the same vehicle speeds was noted. The statistical reliability of the device was less satisfactory when the roughness measurements were compared across various speeds. However, within the accuracy limits of an IQL-3/4 device of +/- 20 % of the IRI, the equipment satisfied the need. It would be prudent for those using *Roadroid* to adopt a constant survey speed as is used with other IQL-3/4 instruments, such as 50 km/h. The study suggested variations between two vehicles used to mount the device and concluded the device is potentially vehicle dependent, but this dependency could be within the limits of an IQL-3/4 device and thus not be a practical issue.

With improvements to the filtering, and the adoption of larger sampling intervals, *Roadroid* has great potential as a low-cost, practical device for measuring road roughness at IQL-3/4 level. This would assist the asset management of road networks in developing countries by offering a low-cost solution to monitoring and reporting on the roughness condition of pavements.

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