DEVELOPMENT OF A ROUGHOMETER FOR UNSEALED ROADS

Authors George Giummarra and Roland Leschinski

ABSTRACT

The ride quality of an unsealed road is a major performance indicator of driver and passenger perception of comfort and safety.

To date the assessment of ride quality on unsealed roads has been largely subjective often causing difficulties in determining which sections of an unsealed road need grading, what grading priority should be allocated and in performance maintenance contracts whether the job has been completed to the required ride quality standards.

In response to this market demand, ARRB Transport Research (ARRB TR) has developed the ‘Roughometer’, an affordable roughness measurement device for unsealed roads. This device will provide practitioners with an objective assessment of ride quality or road roughness calibrated to either NAASRA Roughness Measurement (NRM) or the International Roughness Index (IRI).

The Roughometer removes the guesswork as to which road segments need grading and whether grader operators have met the required ride quality. It should also help resolve the “squeaky wheel” demands. The Roughometer has been developed to be practical, easy to use, robust, low cost, portable and provide reasonable accuracy. It can be readily applied to any sedan, station wagon or four wheel drive vehicle by attaching a device to the rear axle, tapping into the vehicle’s odometer and connecting to a power source (say) the cigarette lighter socket. The information is collected automatically using a small data logger in the vehicle. The logger has a Liquid Crystal Display (LCD) with five push buttons which control all setup and data recording functions.

The purpose of this paper is to describe the research undertaken to define the market demand and user specifications, the technical development process, results of field trials and the appropriateness of the Roughometer to meet user requirements.

INTRODUCTION

Australia has over 500,000 km of unsealed roads which constitute about 70% of the national road network. Most of these roads are in need of improvement and ongoing maintenance. However, due to limited funds, it is essential that practitioners have suitable engineering ‘tools’ to assist them in establishing the most cost effective management procedures for unsealed roads.

Surveys of road practitioners indicated that there is an industry wide need to have a simple, portable, low cost, robust instrument able to provide road roughness information for unsealed roads. This would enable the objective measurement of ride quality on a regular basis and, given the dynamic nature of unsealed road surfaces, would assist in determining network performance, maintenance priorities, intervention levels and auditing maintenance works carried out by a contractor.
MEETING A NEED

The ride quality of an unsealed road is probably the major performance indicator of driver and passenger comfort and safety. It also has a significant impact on the overall vehicle operating cost associated with the road and is a key factor in determining a road agency’s grading programs.

To date the assessment of ride quality on unsealed roads has been largely subjective often causing difficulties in determining which sections of an unsealed road need grading, what grading priority should be allocated and in performance contracts whether the job has been completed to the required ride quality standards.

If a more objective measurement was required, the Council had the choice of a vehicle response type Bump Integrator (NAASRA Tower) or a Laser Profiler. The Bump Integrator has the disadvantage of requiring a dedicated modified vehicle whose responses change over time and is dependent on vehicle speed and load. While the Laser Profiler provides extremely accurate results, it may be difficult to justify the relatively high cost of data collection when the roughness of the unsealed road can change so quickly.

From discussions with numerous practitioners in rural parts of Australia and New Zealand it has been established that a road roughness measurement device for unsealed roads that can provide an objective assessment of ride quality would be welcomed by the road maintenance industry.

Establishing User Needs

In mid 1998, an expression of interest (EOI) for the development of a low cost and easy to use device to measure road roughness for unsealed roads was sought from practitioners. This was via the Local Road Newsletter (ARRB 1998) and a separate EOI form sent out to about 250 selected road agencies responsible for managing significant unsealed road assets.

Expressions of interest were received from 54 road agencies and others, giving a response rate of 22%. While the majority of responses were from Local Government, there were also a number from State Road Authorities, Forestry and overseas agencies.

A further measure of the support for the development of the Roughometer was sponsorship funding of over $20,000. This was provided by various road agencies to assist in the feasibility trials on the basis that if the device proved successful a discount would be provided on the sale price of the device.

From discussions with a number of local road practitioners and this market analysis, it was concluded that there was a strong enough interest in this potential product to justify further consideration.

Concept Design

The concept design for the Roughometer was based on a lightweight and portable device which could be easily attached to any passenger vehicle and was able to be readily transferred from one vehicle to another when required.

The device should operate at close to normal travel speed to enable the collection of roughness data while undertaking other routine inspection duties by field staff. The device differs from Response type instruments (such as the NAASRA Tower) by using a sensor to measure the road profile from the axle movements. The IRI and NAASRA values are then calculated from this profile. The device should require minimal calibration and would not need to be dedicated to a particular vehicle.
Various road practitioners were approached to ascertain their requirements for a roughness measuring device. The following performance criteria were established.

**Robust.** To ensure it can handle a wide range of rough roads and treatment by various field staff.

**Practical.** Able to be used by field staff with minimal training.

**Accuracy.** To be adequate given the variety of road surfaces and regular changes in surface condition. The results to be reported with an uncertainty of better than ±15%.

**Repeatability.** Using a similar vehicle and travel speed, results should be repeatable within the accuracy limits listed above.

**Adaptable.** Easy to mount on a variety of vehicles but mainly 4 WD, sedans and truck utilities.

**Reporting.** Data collected in the field to be electronically transferred into a Personal Computer (PC). Software supplied to provide average roughness results for each nominated road section.

**Low cost.** Device to be affordable to rural road agencies.

**FEASIBILITY STUDY**

Given the key criteria above a feasibility study was undertaken to ensure the desired outcomes could be achieved. This involved an investigation by a consultant of deriving a surface roughness metric from the vertical acceleration - time history of a vehicle wheel travelling on unsealed roads. The study was based on a vehicle dynamics simulation.

The aim of the study was to provide:

- a recommendation of the technical feasibility of the device with an estimated probability of success in the prototype stage.
- the design requirements or technical specification of the component parts of the device, if found to be feasible.
- the method of operation of the device, speed of travel, type of vehicles suitable
- order of accuracy.
- a clear indication of whether the vehicle will have to cruise at an almost constant speed or can vary speed during a run.

Specific criteria were defined as follows:

- able to provide repeatable and accurate results on surfaces with an IRI from 3 to 11 m/km, possibly up to 14 IRI
- machine accuracy within ±10% IRI for 95% of measurements
- operate at varying vehicle speeds over the range of 20 to 80 km/h

The approach adopted for the study (Duell 2002) was to derive a surface profile from the vehicle rear wheel vertical accelerations, and calculate the IRI of the derived profile. Simulations were run to investigate the following variables.

- vehicles types
- variety of profiles
- speeds ranges
**Vehicle dynamics simulation methodology.**

The vehicle dynamics simulation used was a multi degree of freedom lumped mass parameter system of a two-dimensional pitch plane model of the vehicle. A typical two-axle vehicle model is shown schematically in **Figure 1**

The raw profile data used in the study were a combination of synthetic profiles from a Virtual Test Facility data set as well as some measured unsealed road profiles. The synthetic profiles provide a full range of wavelengths with random phasing and are generally free of transient effects. As a result, they were useful for testing the dynamic response of vehicle systems and examining trends in dynamic performance.

Vehicle modeling data from three vehicle types was used:

- Ford Falcon sedan,
- Landrover Defender
- Toyota Landcruiser

**SIMULATION RESULTS**

**Accelerometer Sampling Rate.**

It was calculated that a sample rate of 200mm of vehicle travel would be sufficient and indeed the results showed that there was no discernible improvement in accuracy if the samples are acquired at less than 40mm intervals. This is consistent with the typical sampling rate of the laser profilers as well.

**Accuracy**

The results showed accuracy was achieved for both the synthetic and measured profiles of between 10 and 20%. It was evident that the improved accuracy figures were at a simulated survey speed of around 50 km/hr and below. At 80 km/hr, errors of 20 - 30% were more typical. This was as expected as, at the higher speeds, the wheel and suspension systems would have difficulty following the profile, especially if there were transients. An accurate roughness metric requires that the vehicle wheel closely follows the profile.

This is not regarded as a serious problem as, for the rougher roads, it would be uncomfortable and possibly unsafe to survey at high speeds.

There was also some optimisation possible by adjusting the loads and tyre pressures. Particularly at 50 km/hr, errors between 9% and 16% were calculated.

Speed variations of +/- 10% were judged as being unlikely to have any noticeable effect on the accuracy, although the effect varied slightly from vehicle to vehicle.

**Test Conclusions**

The report concluded that it was technically feasible to build a device to sample rear wheel accelerations, from which a roughness metric could be derived. Better results would be obtained with large 4WD vehicles than a full sized sedan and if speeds were kept to around 50 km/hr and
the road was relatively free of transients, then an error of around 15% could be expected. The accelerometer should be accurate to frequencies of at least 50 Hz and have a range of 12g.

**PROTOTYPE ASSEMBLY AND FIELD TESTING**

As a result of the encouraging results achieved during the feasibility stage a trial system was assembled and some on-road tests performed. The basic system components are shown below in Figure 2.

The test set up was assembled from components used in the well proven ARRB TR portable laser profiler.

- The accelerometer was the same model as that used for the inertial referencing of the laser units. The range was extended as per the theoretical expectations.
- The distance transducer was the standard 2000 pulse per rev. ‘Rotopulser’.
- Signal conditioning, filtering and power supplies were adapted from those used in the portable laser conditioning unit.
- Data acquisition was via the PCMCIA DAQ card in a laptop and using the portable laser acquisition program.
- Data was processed using a modified version of the laser processing software. This program already contains modules for generating profile using a combination of accelerometer data and laser data. It was relatively simple to have the program calculate profile from the accelerometer alone. The standard IRI calculation routine is also included in this program.

Initial tests had the accelerometer mounted on the Distance Measuring Device (DMI) itself. A single channel Laser Profiler was mounted on the vehicle and data collected simultaneously for a number of runs on a variety of roads. IRI collected from the laser/accelerometer sensor was compared against that collected with the accelerometer only. Tests revealed a constant offset and by analysis of the Power Spectral Density (PSD), a peak at 2 metres was identified. It was deduced that this was the same as the circumference of the wheel upon which the DMI was mounted. Unfortunately, this wavelength is well within the pass band for the IRI calculation. Mounting of the DMI would have a significant effect on the power in this spectral peak, i.e., a more off centre mounting would result in greater eccentricity as the DMI spins and consequently a much greater peak at two metres and a higher IRI. The results would be very dependent on the installation.

To remove this variable from the results, subsequent tests had the accelerometer mounted on a simple bracket attached to the vehicle axle with a U-Bolt as close as possible to the hub. This configuration was in fact adopted for the final product.

The first series of tests were conducted with the equipment mounted on a Ford Falcon Station Wagon. A second series was run with the accelerometer mounted on the axle of an older Nissan Patrol 4WD.

The reference IRI values for the unsealed roads were obtained with an ARRB multi-laser profiler (MLP). Previous attempts to measure IRI with a rear mounted portable laser system were unsuccessful due to the effect of dust and mud interfering with the laser signal. The MLP has the lasers mounted in a beam attached to the front of the vehicle and with this configuration, repeatable results were possible on the unsealed road.
The initial tests were run on several unsealed roads with a variety of roughness values including loose gravel and corrugations. They attempted to identify and quantify the instrument’s performance with respect to:

- Different Roughness levels.
- Different Roughness Types (e.g. varying wavelengths)
- Different survey speeds
- Different vehicle types. Dependence on Suspension/Tyre/Vehicle Mass etc.

**Results of Tests**

*Figure 3* show the results of testing on an unsealed road (Rossiter Rd). The accelerometer was mounted on the driver side, rear axle of the Falcon Station Wagon.

Note the consistent results at the higher speeds and the completely unusable results at the lower speed, 20 km/hr. The legend shows the different speeds of approx. 20, 40, and 60 km/hr. To verify the accuracy as well as the repeatability, the same section was surveyed using the MLP. Multiple runs were made at speeds of 20, 40 and 60km/hr. Considering the lack of a defined lane, the MLP results were very consistent and independent of speed variation effects with a typical spread of results less than 1 IRI.

**Comparison of MLP laser measurements and the accelerometer only results.**

After removing the ‘rogue’ 20km/hr results from the accelerometer only data, the four runs were compared with the averaged MLP runs. The results are shown in *Figure 4*. The dotted line shows the Laser ‘reference’ data with the other lines showing a typical spread of results around the reference.

**Mounting the Accelerometer on a different vehicle type**

To investigate the results on a different style of vehicle, the accelerometer was mounted on the axle of the Nissan Patrol 4WD. The 1994 Falcon station wagon’s suspension provided a soft and smooth ride, whereas the 1992 model 4WD had quite a stiff suspension with a considerably heavier body.

12 Runs were made on the same unsealed road (6 north and 6 south) with the accelerometer mounted on the rear axle of the Nissan Patrol. Survey speeds were 20, 30, 40 and 60km/hr. In all cases, the ‘rogue’ results were at the lower speeds, 20 and 30 km/hr. With these omitted and the multiple 40 and 60 km/hr runs averaged, the results were more realistic as shown in *Figure 5*. Note that the 60 km/hr runs measure a lower IRI at the higher levels of roughness. The accuracy of the profile measurement (and hence the IRI result) depends on the wheel faithfully following the road surface. With the stiffer suspension, it appears that at the higher speeds, the wheel tends to skip along the top of the bumps, underestimating the roughness. The graph shows a high degree of correlation between the MLP laser results and the accelerometer at 40 km/hr but considerably less at the higher speed of 60.

To confirm these results on a variety of roads and of varying roughness, the 4WD was run over a number of different unmade roads in the area. The results were consistent in that the optimum survey speed for this vehicle appeared to be around 50 km/hr with lower speeds setting up a resonance in the suspension, producing erroneous higher IRI readings and high speeds producing low results.
Test Conclusions:

- Survey speed was a significant factor on the unmade roads and caused a significant difference in the performance of the Falcon and the Patrol. Low speed surveys in both vehicles produced results which were unusable. Suspension resonances in particular at 20 km/hr resulted in very large IRI figures which bore no relationship to the true IRI. The Falcon results at 40 and 60 km/hr were quite acceptable.

- The Patrol’s IRI performance at 60 km/hr was also significantly worse. In this case, producing a lower IRI compared with the low speeds producing a higher IRI. As predicted by the theoretical study, it would appear that the suspension and vehicle weight characteristics have a significant bearing on the accuracy of the Roughometer.

- The 4WD Nissan Patrol used was a fairly old model with quite stiff suspension characteristics. The ride was noticeably rougher at the lower speeds on the unmade roads. A more modern 4WD with a ‘sedan like’ ride would probably give results closer to the Falcon.

- The Roughometer reports would be more meaningful if they use an arithmetic error band of $\pm 1$ IRI when binning the roughness results.

PRODUCT DEVELOPMENT

Encouraged by the results of the field tests, it was decided to go ahead with the product development based on the low cost accelerometer, a hand held data acquisition and control unit and a PC based data processing and reporting package.

Accurate distance measurement is achieved either with a new ARRB designed DMI which can be easily mounted on the wheel nuts or by utilising the existing distance pulses available from the vehicle’s odometer sensor.

User evaluation

A prototype Roughometer was given to three Councils and a Forestry agency to evaluate whether the device met their specific requirements. The results of the trials and comments received were most favourable, indicating that the initial requirements and design brief had been largely met. A number of suggestions were provided to further improve the operation of the device. The evaluation form completed by the selected agencies and a summary of the responses received is provided in Appendix A.

Comments from the evaluation group included improvements to:

- enable editing of survey information such as Road name, section designator, operator, comments etc.
- label and edit events which had been entered during the survey
- be able to open and edit previously processed surveys
- be able to enter alpha-numeric characters during the survey
- include GPS referencing in the data acquisition and reporting
- increase data transfer speed
- the graphs to include more information, e.g. control points, events, date of survey etc.
While most of the comments and suggestions were able to be implemented in the first production model, some of the features such as GPS referencing and an alphanumeric keypad were beyond the scope of this exercise. They will be considered for the ‘Mk 2’ model.

The user evaluation was a useful exercise for establishing particular user requirements and debugging the system as new users would often find ‘features’ or problems which hadn’t come to light during the initial development testing.

ROUGHOMETER PRODUCT DESCRIPTION

The Roughometer was released in September 2002. It is an affordable roughness measurement device for unsealed roads that can provide an objective assessment of ride quality or road roughness calibrated to NAASRA Roughness Measurement (NRM) or the International Roughness Index (IRI).

The various components provided in the package are shown in Figure 6 and described below in Table 1. The location of the various components in the vehicle is shown in Figure 7.

<table>
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<td><strong>Vehicle Hardware Components</strong></td>
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<td>• Hand held data collection unit, the ‘Roughometer Controller’</td>
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<tr>
<td>• Interface module</td>
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<tr>
<td>• Cable set</td>
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<td>• Roughness sensor and mounting brackets</td>
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<td>• User Manual.</td>
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<tr>
<td><strong>Office Components</strong></td>
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<tr>
<td>• Download (communications) cable</td>
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<tr>
<td>• Plug pack Power Supply</td>
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<tr>
<td>• Roughometer Processing Software CD</td>
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The Controller is used by the surveyor to perform all the set up and survey functions. It provides operator feedback during the survey, accepts Control Point and Event inputs from the operator and acquires Distance, Time and Roughness data. All data are stored in non-volatile internal memory. Information collected in the logger is transferred electronically into a PC back in the office to produce road roughness reports.

The results are available for defined intervals, such as 100 m, or for the road segments between control points. The roughness values can be expressed in NRM and/or IRI values. A graphical output showing how roughness values vary along a route surveyed is available to help determine grading programs. Examples of the two types of reports produced are shown in Figures 8 and 9.

SUMMARY

The Roughometer for unsealed roads has been developed to address road practitioners’ requirements for an objective road condition on the Roughometer are measurement device that is practical, easy to use, robust, low cost, portable and provides reasonable accuracy.

The Roughometer should remove the guesswork when determining which road segments need grading and whether grader operators have met the required ride quality. It should also help resolve the “squeaky wheel” demands. Over time it should prove to be a valuable engineering tool which will assist practitioners better manage their unsealed road assets and achieve greater efficiencies.

It is envisaged that over time this current model will be improved and enhanced to meet additional user needs, such as GPS references and extended reporting options.
REFERENCES


AUTHOR BIOGRAPHIES

George Giummarra graduated as a Fellow from the Royal Melbourne Institute of Technology in 1970 in Civil Engineering and gained a Master of Engineering Science (Transportation) degree from Monash University in 1984. George’s work experience has extended across a wide range of engineering activities including transport planning, road design, construction, research and traffic engineering. Much of George’s work, before beginning at ARRB, was associated with VicRoads and its predecessors, and a secondment to a Local Government planning authority.

At ARRB, George has been responsible for the establishment of research programs and technology transfer activities for Local Government and other agencies associated with local roads across Australia and overseas. George has been successful in providing a number of projects aimed directly at meeting the needs of local roads. This has included the preparation of Manuals relating to Unsealed Roads, Sealed Local Roads and Local Roads Bridge Management.

Roland Leschinski currently holds the position of Chief Engineer in the Equipment Group. He has been with ARRB Transport Research since 1990. During this period he has had engineering involvement with Weigh-in-Motion systems, Vehicle Counting and Classification equipment, Road Profilometry and Road Geometry systems. He has also had an ongoing interest in vehicle detection sensors. His involvement has included electronic design, prototype manufacture, evaluation and systems integration. He has marketed ARRB products and expertise at conferences and exhibitions as well as being engaged in installation and training both locally and overseas.

Roland has also been responsible for a number of research projects with published reports and papers including Inductive Loop Bicycle Detection, and Railway Level Crossing Technologies and Strategies.

The time with ARRB included two years leave to work in the Atmospheric and Space Physics laboratory at Davis station Antarctica. Previous work experience includes 12 years in the Telstra Research Laboratories and three years in electronic R&D with a theatre electronics company.
FIGURES

Figure 1  Two-axle vehicle model with independent suspensions

Figure 2  Prototype Assembly
Figure 3  
Results of Speed Testing on an Unsealed Road

Figure 4  
Results of Accelerometer versus MLP
Figure 5  Accelerometer on a Nissan versus a MLP

Figure 6  Roughometer Package Components
Figure 7  Roughometer cable connection layout

Figure 8  Report showing Roughness profile
### Field Data Sheet

ROAD NAME: CARDINIA RD  
SECTION: FROM: PRINCESS HWY TO: HENRY RD  
TRAVEL DIRECTION: SOUTH  
REFERENCE: RD S01/B  
VEHICLE: FORD STATION WAGON  
OPERATOR: JOHN SMITH  
COMMENTS: ANNUAL ASSESSMENT

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Average Value: X

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Figure 9 Report showing ride quality in various roughnesses bins
Appendix A

ROUGHOMETER FOR UNSEALED ROADS

PROTOTYPE EVALUATION FORM (SUMMARY OF RESPONSES)

The purpose of this form is to provide feedback on the trialing of the Roughometer supplied to your Council /organisation for a limited period. Please provide your honest and frank comments to enable ARRB to obtain valuable feedback as to the use, effectiveness and applicability of the Roughometer to better manage your unsealed roads. Indicate by a cross your assessment for each of the performance criteria listed

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Comments……………………………………………………………………………………………………

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<tbody>
<tr>
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Comments……………………………………………………………………………………………………

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<th>Low cost to ensure that the device is affordable in rural Shires or other local road agencies. Indications are that a sale price will be less than $10,000.</th>
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<tbody>
<tr>
<td>Score</td>
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