# 3D TECHNOLOGY FOR MANAGING PAVEMENTS

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## Abstract

Advances in instrumentation have led to the development of new technologies that provide a number of options for collecting pavement condition data. Manual methods have been successfully replicated, automated and then further improved. For instance, 3D laser sensors were first introduced as a means of measuring the transverse profile of the pavement in much greater detail than a straight edge or even a multi-point laser profiler. However, with further advancements this technology is now being used to identify cracks and other defects in the pavement surface. This paper looks at how 3D technology can be used to measure pavement cracking as well as other pavement condition parameters that are of interest to state and local government agencies.

**Key Words: 3D, analysis, automated, cracking, data collection, maintenance, pavement condition**

## Introduction

In this era of reduced funding and competing priorities, how can road agencies best maintain the condition of their most valuable asset, the road network? One way is by implementing a pavement management system to help them make the most of their roads budget. This is something which became popular in Australia in the 1980s when agencies started to develop an interest in the strategic management of the road network (Sheldon 2004). However, for a pavement management system to be of value, it must be populated with fit-for-purpose data which accurately represents the pavement condition.

There are a variety of pavement management systems employed by local government agencies in Australia such as SMEC, RAMM, dTIMS etc. Whilst a large range of data items can be saved within the databases of the various systems, their respective modelling tools may use all or some of the items for their decision making and reporting.

Out of all the pavement condition parameters measured, surface distress is often the primary parameter upon which decisions are made. Surface distress usually comprises a number of individual defects such as delamination, potholes, ravelling, patching etc. One of the most important is cracking. A cracked surface allows the ingress of water into the sub-layers which can lead to the rapid deterioration of the pavement, especially if the pavement is subject to high traffic flows or heavy loading.

Cracking is also one of the hardest distresses to identify, particularly using automated or semi-automated methods. Road agencies have been keenly awaiting an accurate, repeatable and economically viable means of automatic crack detection, particularly fine cracking, as the earlier it is identified, the quicker the cracks can be sealed and the damage to the pavement minimised.

The recent development of 3D crack measurement systems has gone a long way to fulfilling this need.

## From manual to automated

Twenty to twenty-five years ago, before the advent of mobile crack detection systems, cracking was assessed on foot. For example, in its foreword, the Austroads guide to visual assessment states, ‘the guide is intended for use by a pedestrian observer’ (Austroads 1987).

Manual data collection is slow, expensive and relatively unsafe as the rating team is exposed to the prevailing traffic conditions. It also limits the length of the road network upon which decisions are based. For example, ROCOND90 is a popular methodology for manual pavement condition monitoring. Its recommendation for crack measurement requires only a 50 m sub-section of the carriageway to be rated, even though the length of the section may be several kilometres long (Foley 1999). This results in only a very small portion of the actual pavement surface being assessed.

The development of video-based survey vehicles such as the Automated Road Evaluation Vehicle (AREV) in the late 1980s (Yeaman 1991) improved the efficiency and safety of the data collection. In the late 1990s ARRB expanded its data collection capability by integrating a digital imaging system with a dedicated pavement camera into its pavement data collection platform (Wix 2012). However, these systems were only semi-automated as the images were still required to be rated manually, a subjective process that does not always lead to accurate and/or repeatable results. However, it did allow for 100% coverage of the road network and the requirements of the visual rating systems could be applied to the pavement images collected by the digital imaging systems.

In time, the introduction of external lighting and the improved performance of the pavement cameras resulted in higher resolution images and the ability to see finer cracks. ARRB as well as other equipment manufacturers tried to take advantage of the improved image quality by developing software to automatically identify the cracks. However, these efforts met with only limited success and in most instances the results had to be manually audited.

One exception is the RoadCrack system developed by the then Roads and Traffic Authority of New South Wales in conjunction with the CSIRO in the mid-1990s. This system is capable of automatically identifying and classifying cracks down to a 1 mm width without human intervention. The system utilises a bank of four adjacent modules that are aligned across the pavement, each fitted with a high resolution line scan camera and its own lighting system that generates an image every 500 mm. The measurement area is limited to the width of the vehicle platform which is nominally 2.2 m which means the size of the image recorded by each module is approximately 500 x 550 mm.

The RoadCrack system was initially mounted on a truck and was much larger than most common survey vehicles but in 2011 the system was modified and upgraded by ARRB so that it could be installed on a much smaller 5th wheel trailer platform which is shown in Figure 1.

Figure 1: RoadCrack system – new trailer version

One of the main benefits of the RoadCrack system is that it can generate cracking outputs in real time whilst travelling at highway speed. This alleviates the need to store large volumes of imaging data for post-processing and it also means that the cracking results are immediately available at the end of each survey run. To achieve this outcome, the system relies upon a powerful lighting system and specifically developed crack identification algorithms.

Whilst being suitable for rural road networks and major arterial roads, the size of the RoadCrack vehicle is still significantly larger than a typical survey vehicle and does not lend itself to local road surveys especially in urban environments. This is an area where 3D systems have a significant advantage.

### Development of 3D systems

The development of the 3D system has been an interesting journey, a journey that began with a desire to improve transverse profile measurement.

Traditionally, rut depth has been measured with a straight edge and wedge and this is what the developers of automated data collection systems have attempted to emulate. The first automated systems capable of measuring rut depth only had 3 sensors, either laser-based or ultrasonic, with which they could measure rutting. This was partly due to the cost of the sensors and also the limitations of the data logging systems. Two sensors were situated in the wheel paths and one along the centre line of the survey vehicle. Rather than measuring the actual rut, the system measured the heave in the pavement and was sometimes called a rut index.

In time, developers built systems with multiple sensors, covering 3 m or more, which provided a more accurate representation of the transverse profile. Of course the number of sensors that can be mounted on the front of a vehicle is limited by space and cost. Consequently, developers began to look at other technologies such as spread laser systems. These systems which project a laser line on the pavement surface are capable of measuring thousands of points which give a very accurate representation of the transverse profile of the pavement. Due to the high data rates, these systems were originally limited to taking measurements every metre at highway speeds. However, the speed of the sensors has improved and it is now possible to measure the high resolution transverse profile every 5 mm or less. A 3D image of the pavement surface is created by combining the contiguous transverse profiles.

## Automatic Crack Detection (ACD) system

The ARRB Automatic Crack Detection (ACD) system is based on the Laser Crack Measurement System (LCMS) developed by INO and marketed by Pavemetrics, a Canadian company. The system has been fully integrated into the ARRB Hawkeye survey platform and operates in tandem with Hawkeye’s other data collection modules.

The ACD comprises two high-performance 3D laser units that are fitted to the rear of the survey vehicle, 2.2 m above the pavement as shown in Figure 2. Each unit consists of two main components: a high-power spread line laser and a high-speed 3D camera mounted off-axis to the laser light source. When combined, the two 3D laser units project a 4 m wide laser line consisting of over 4,000 measurement points onto the pavement. Half of the image is captured by each camera which interprets the distortions to the straight laser line as variations in the vertical surface profile. Because of the high pixel resolution, measurement accuracies of 0.5 mm are claimed.

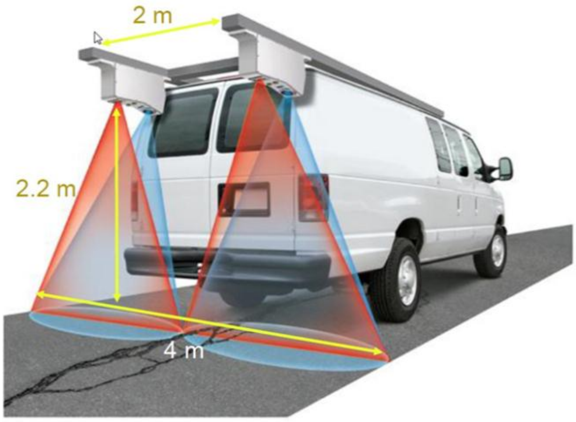


Figure 2: Configuration and measurement range of ACD (picture courtesy of Pavemetrics)

A picture of the road surface can be built up by combining sequential transverse profiles which, at 90 km/h, are only 5 mm apart (less at lower speeds). The LCMS sensors produce both range and intensity profiles which are merged to produce a 3D image. The information contained in this image allows the ACD system to automatically identify cracks and a variety of defects.

## Outputs

The data processing software divides the road surface into small sections 5 m long by 4 m wide which are automatically checked for cracks and other surface defects. The results of the analysis are written to an XML file which contains the location of any cracks, as well as their widths, along with other relevant information about the survey including other pavement condition parameters. The user can then generate a 3D image of the pavement with (or without) the crack map overlaid on the image as shown in Figure 3.

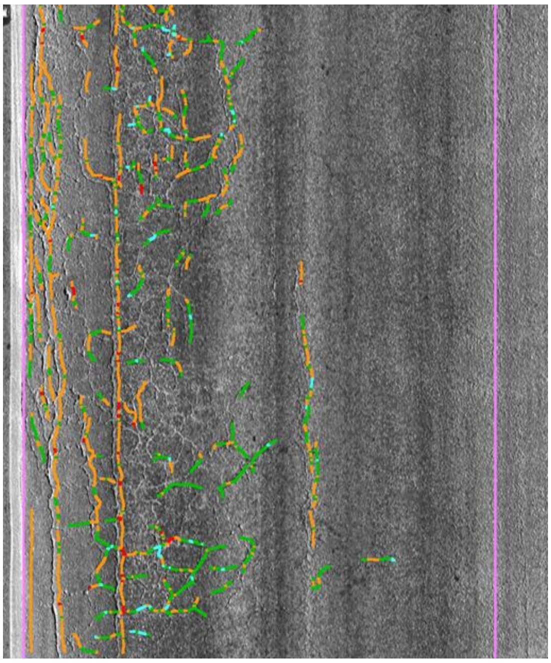

Figure 3: Example of crack map overlaid on 3D image

The variation in the colour gives an indication of the average width of each crack. In Figure 3, the largest cracks are shown in red, the smallest in light blue. The pink lines indicate the area in which the cracking is analysed and are automatically determined based on the presence of the more reflective line markings.

As shown in Figure 3, the 3D system is capable of producing a high-resolution picture of the road surface in which cracks and other defects are readily identifiable. However, like most automated systems, the LCMS isn't perfect and some of the fine cracks can be missed especially if 'pumping of fines' is evident. This can be improved by modifying the analysis algorithms.

## ACD and historical data sets

For historical continuity it is important that any new technology can produce outputs that are compatible with those that have been collected previously. If not, the agency must decide whether to discard its old data and start afresh. A good example of the successful implementation of a new technology is the laser profiler which was used to replace the NAASRA roughness meter, a response type road roughness meter system which measures axle- body separation. While the laser profiler reports International Roughness Index (IRI) in units of m/km and the NAASRA meter reports roughness counts per kilometre, the measurements from both systems can be linearly correlated. This enables NAASRA roughness to be reported from IRI measurements and vice versa (Prem 1989). Thus a newer more efficient and accurate system could be used to measure road roughness and still report NAASRA counts, allowing agencies to continue to utilise their historical data sets for modelling etc.

Similarly, for road agencies it is important that the 3D system produces results that are compatible with the crack reporting requirements of their pavement management system (PMS) or road management system. In most cases this means being able to replicate visual crack measurements that have been made either on foot or through the window of a slow moving van. Consequently, the 3D images must be capable of determining some or all of the following:

- type of cracking (crocodile, transverse, longitudinal, block etc.)
- extent of cracking (percentage of pavement affected)
- severity (average crack width).

As shown in Figure 4, the resolution of the images is sufficient to identify the crack type and, because the image is calibrated, the extent of cracking can be accurately measured in both the longitudinal and transverse directions. 3D systems can also measure crack width which allows the severity of the cracking to be determined.

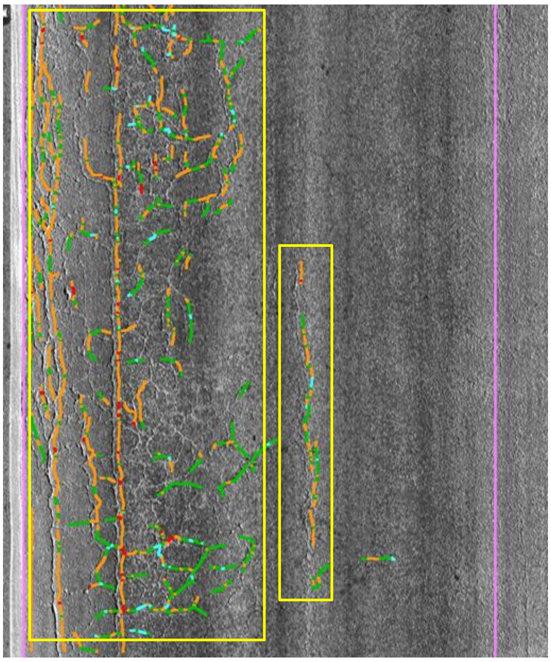

Figure 4: Example of crack type identification

Whilst the crack map and crack widths are determined automatically by the analysis software, the type and extent of measurements must be made manually. Alternatively, integrators may develop their own software to automatically classify and determine the extent of the cracking. This is the preferred methodology as it eliminates the need for human input and produces an objective, repeatable measurement.

There is a possibility that the use of this new technology will result in a greater number of cracks and other defects being identified than had been previously. Consequently, agencies with a PMS may have to reassess their intervention levels for triggering maintenance activities and take this into account when developing their works programs.

It is recommended that a 3D system is only used on sealed surfaces as the presence of dust will negatively affect its performance.

## Testing

The ACD has been extensively trialled by ARRB. Its repeatability and reproducibility was tested over numerous test sites with asphalt, concrete and spray seal surfaces. An example of the level of internal repeatability that can be achieved with the ACD is shown in Figure 5.

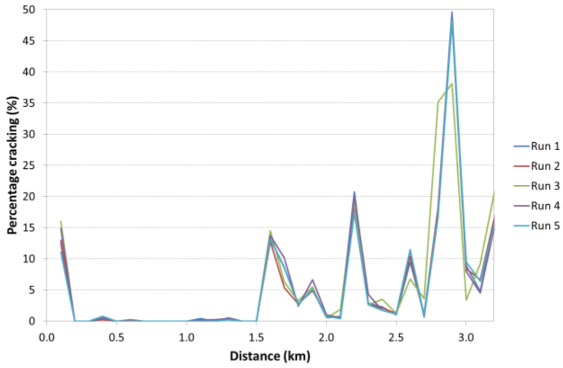


Figure 5: ACD repeatability on dense graded asphalt

The system was also compared against the aforementioned RoadCrack system.

Comparing the two systems presented a challenge as the width of the pavement measured by RoadCrack is nominally only 2.2 m compared to 4.0 m for the ACD. However, a method was developed that divided the ACD image into blocks, limited the width of measurement and thereby mimicked the RoadCrack output. The final result is reported as the number of cracked blocks per 100 m.

The ACD outputs were then compared against the results recorded by the RoadCrack vehicle over several test sites. As shown in Figure 6, the two systems were found to have a high correlation.

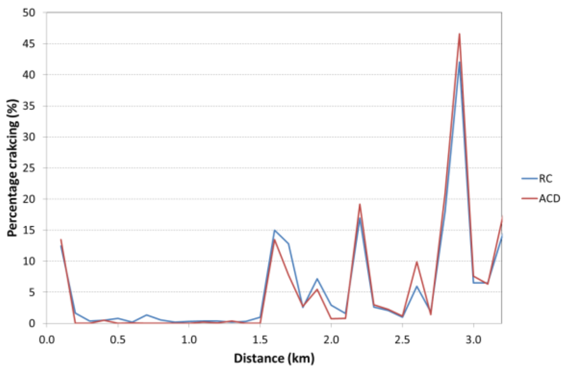


Figure 6: Comparison of ACD and RoadCrack outputs on dense graded asphalt

However, it should be noted that some differences between the two systems did occur, particularly on sprayed seal surfaces.

ARRB also undertook separate trials for two state roads agencies, VicRoads and the Department of Planning, Transport and Infrastructure (DPTI) in South Australia. The successful outcomes of the trials led to the ACD being used for their annual pavement condition surveys albeit on a trial basis. At the time of writing, the VicRoads survey had been processed and delivered and the data collection phase for the DPTI survey had just been completed.

The two road agencies required quite different cracking analysis. The VicRoads methodology was the more basic of the two, simply requiring each image to be divided into two 2.5 x 4 m frames. Each frame was then assessed as being 'cracked' (containing one or more cracks) or 'not cracked'. The number of cracked frames was reported as a percentage of the total frames per 100 m across the road network. In doing this, the software was imitating the manual methodology which had been employed previously.

To assess the accuracy of the results, each image was also visually checked by a rater and any discrepancies were noted. This cross-checking highlighted several instances where the ACD was reporting false positives, i.e. a crack was being reported when there was none. For example, Figure 7 shows an example where the join between the pavement surface and the kerb was being incorrectly reported as a crack.

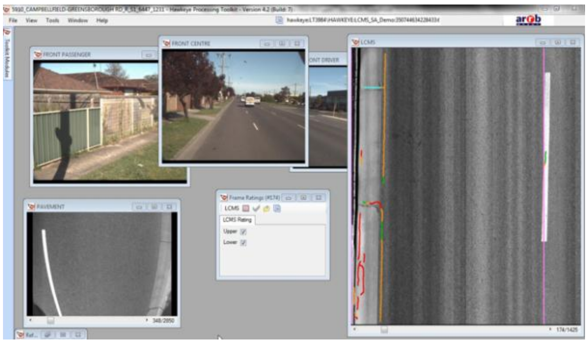

Figure 7: Example of a false positive (joint between kerb and pavement in far right image)

This information has been fed back to the manufacturer and was used to modify the crack reporting algorithms. As the ACD continues to be used and further feedback is received, it is expected that the number of false positives will be reduced to an acceptable level.

DPTI has requested a more extensive analysis using a 3 by 5 m grid, centred on the middle of the image and reporting crack type, extent and severity for each frame of the grid. Previously, DPTI had used RoadCrack for its crack measurements but has chosen to trial the ACD due to its ability to produce a result that is more in line with requirements and also produce results that are similar to the historical RoadCrack data.

### Advantages of 3D measurements over 2D technologies

One of the major advantages of 3D imaging over conventional area or line scan cameras is that it does not require additional lighting to overcome the effect of shadows. This significantly reduces power consumption. 3D systems can even operate at night without compromising the quality of the images.

A comparison of the images recorded by the ACD and a standard digital imaging system using natural lighting in shadowy conditions is shown in Figure 8.

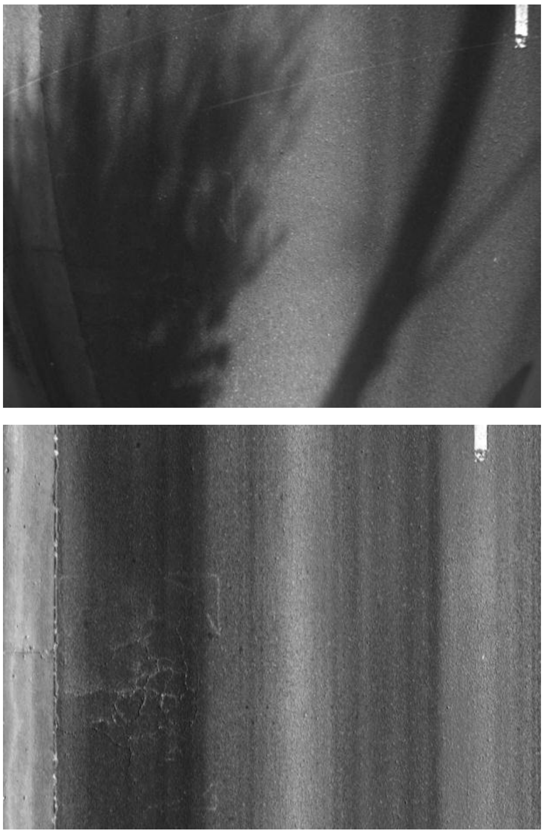

Figure 8: Comparison of outputs in shadow (2D camera above, 3D camera below)

As shown in Figure 8, the 3D images are also unaffected by lens distortion but more importantly 3D systems measure an extra dimension – depth – which can be used to identify various pavement surface condition parameters in addition to cracks. These include the following:

- Rutting – rutting is determined from the transverse profile which comprises more than 2,000 measurement points in each 2 m wheel path. This equates to a 1 mm transverse resolution which is significantly greater than the current point laser systems which typically have up to 15 lasers. The rut depths are recorded every metre and averaged to give a single value for either a specified interval or for a complete road section. The software can also limit the analysis to the trafficable width of the pavement as the 3D systems have the ability to identify line marking and edge drop off.

- Potholes and delamination – a 3D system can locate potholes and delamination and by measuring their depth and diameter calculate their area and volume. This enables the accurate calculation of fill material required for pavement rehabilitation. Figure 9 shows an example of a pothole identified by the ACD.

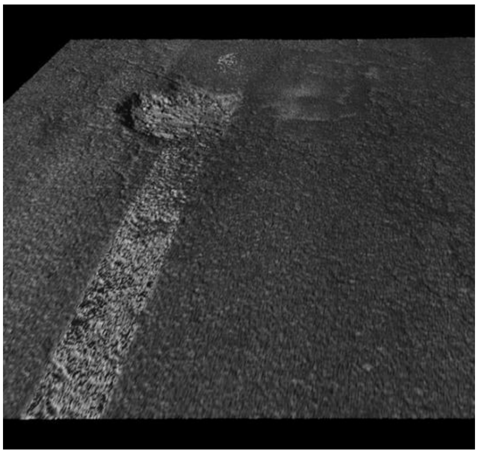

Figure 9: 3D image of a pothole (picture courtesy of Pavemetrics)

- Ravelling – this is defined as the 'progressive disintegration of the pavement surface by loss of both binder and aggregates' (Austroads 1987). The ACD identifies ravelled surfaces by calculating the volume of aggregate loss over the area. The 3D picture shown in Figure 10 shows an example of ravelling identified by the ACD.

Figure 10: 3D image of ravelling produced by ACD (picture courtesy of Pavemetrics)

- Surface texture – a laser profiler usually measures macrotexture longitudinally over the pavement. However, there is no reason why macrotexture cannot be measured in the transverse direction also using a 3D system. The ACD meets the sampling requirements specified in the relevant Austroads guide for measuring pavement texture (Austroads 2011). The texture outputs of the ACD have also been compared against other texture measuring devices with good results. An example of the correlation between the ACD and a reference device is shown in Figure 11.

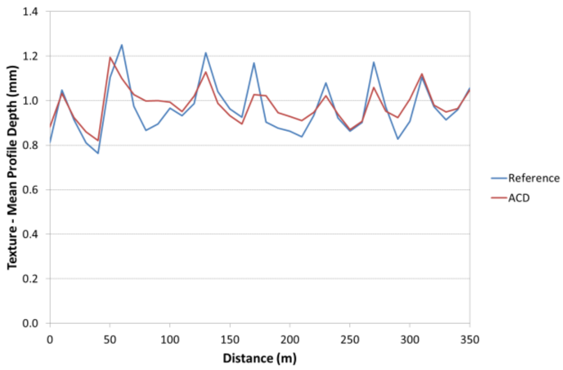


Figure 11: Texture comparison between ACD and reference device

Another feature of the 3D system is its ability to measure the reflectivity of the pavement surface. This enables the automatic detection, classification and assessment of lane markings, directional markings etc.

At present, the developers are also investigating how transverse profiles from the ACD can be linked together to create longitudinal profiles from which the International Roughness Index (IRI) can be calculated.

## Conclusions

Whilst there is currently no single data collection system that can measure every pavement surface parameter of interest to local road agencies, 3D systems are capable of accurately measuring a number of parameters which are critical to most pavement management systems. These include rutting, texture, cracking, delamination, potholes and ravelling. As the technology and analysis software continues to improve, it is more than likely 3D systems will measure an even wider range of pavement elements. The small size and low power requirements of modern 3D systems means that they can be integrated into a standard data collection vehicle, making this technology ideal for local road networks in both urban and rural environments.

One of the most important features of a 3D system is its ability to produce high-resolution pavement images, independent of and unaffected by ambient lighting conditions. These images can be processed by powerful software to automatically detect cracking and provide an assessment of crack type, extent and width. This data can then be collated and formatted, emulating the visual crack assessment, to produce results that are compatible with the information contained in a road agency's PMS or historical database.

The superior images from a 3D system can also be analysed manually to assess features and parameters for which there may currently be no automatic processing. For instance edge-break, the quality and continuity of line markings, presence of reflective markers, surface type, etc.

As with any automated system, 3D systems will not always be 100% correct but they do produce an objective and very repeatable result over 100% of any road network in a safe and economical manner.

Visual assessment of the pavement surface has come a long way from the days of walking the pavement or viewing it through the window of a slow-moving van. Australian state road agencies have already begun trialling 3D technology thus showing their willingness to adopt new technologies for managing road pavements (Sheldon 2004). The results show that 3D technology has the potential to improve on the accuracy and extent of pavement condition data currently collected by state and local government agencies.

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## Author biography

Richard joined ARRB Group in 1990 and has over 20 years of experience in pavement condition data collection for state and local government agencies. He presently holds the position of Principal Consultant in the Systems Group where, as a member of the Technical Advisory Group, he focuses on the improvement of ARRB's data collection technologies and systems. Richard's activities with ARRB Group have included the management of large scale network level pavement condition surveys, both locally and internationally, and the development and verification of ARRB's data collection equipment. He has also contributed to the development of the Austroads test methods for pavement data collection and is a member of ASTM committee E17 on Vehicle Pavement Systems, as well as a steering committee member of the US-based Road Profile Users' Group. Richard specialises in road roughness measurement and has authored several papers.

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