INTEGRATION OF EXISTING AND EMERGING DATA COLLECTION TECHNOLOGIES IN AUSTRALIA

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ABSTRACT

The road network is a valuable and high-cost asset and maintaining it in the most economical and efficient manner requires regular monitoring of its condition. Therefore, most road agencies engage in, or commission a program of regular automated pavement data collection using a vehicular platform.

Technological advancements, some originally developed for non-road applications, have made it possible to collect additional data which can help a road agency to better manage its road network as well as the assets and infrastructure that are adjacent to it. Integrating these new technologies presents a challenge to developers of data collection equipment who are keen to take advantage of the latest developments while maintaining the equipment's useability, data integrity and affordability.

This paper provides a brief history of the development of automated pavement condition equipment by ARRB Group culminating in the ARRB Hawkeye system which was designed to allow the integration of both existing and emerging technologies into its data collection and processing platforms. In particular, it looks at the integration of several systems obtained from third party developers, and describes the various processes that were involved.

1 INTRODUCTION

Vehicle mounted pavement condition monitoring systems have been successfully employed by road agencies throughout the world to help assess and monitor the condition of their road networks.

Over time numerous advancements in automated pavement data collection technology have been made and the number of pavement condition parameters that can be monitored automatically has steadily increased. This has presented a challenge to equipment developers as they strive to integrate these and existing technologies into their data collection platforms whilst ensuring that the data collected is accurate, objective and repeatable.

Each Australian State Road Authority (SRA) is well aware of the benefits of collecting pavement condition data across their road networks and they all use automated data collection systems for this purpose. As all but one state relies on third party service providers to collect all or the majority of this data, there is a heavy reliance on service providers to be innovative and to incorporate new technologies into their data collection platforms. There are significant economic benefits for the road authorities if a number of technologies can be combined so that only one survey is required rather than two or more.

With the above in mind, a key design criterion for ARRB's Hawkeye platform was the ability to fully integrate current technologies along with new and innovative developments. This capability, although desired, had not been achieved by ARRB in its earlier developments.

2 THE ARRB PROFILOMETER

ARRB's initial foray into automated pavement condition data collection goes back to July 1985 with the commencement of project P435, 'Development of a High Speed Profilometer'. The project was supported by the SRAs who had identified, amongst other things, a need for the development of a practical tool for the calibration of the National Association of Australian State Road Authorities (NAASRA) road roughness meter, which at the time was the standard device for measuring road roughness in Australia and New Zealand.

The NAASRA meter is classified as a response-type road roughness system (RTRRMS), which measures the axle-body separation of the host vehicle to which it is mounted and reports this as NAASRA roughness counts. Being an RTRRMS, the suspension components of the host vehicle, along with tyre pressure and operating speed, all affect the roughness measurement. Therefore, the system requires frequent calibration against a stable reference otherwise it is impossible to determine whether an observed change in roughness is due to a change in the longitudinal profile of the pavement or a change in the vehicle characteristics (Prem 1989).

Historically, this was done by correlating the results from a vehicle mounted NAASRA meter against a standard roughness measuring vehicle maintained by ARRB which was also fitted with a NAASRA meter. According to the NAASRA meter's standard operating instructions, each system should be calibrated biennially and a routine check performed every 3,000 kilometres of travel (NAASRA 1981).

Replacing the standard vehicle with an inertial laser profilometer, whose measurements are unaffected by the dynamic performance of the host vehicle, was seen as major benefit as there would no longer be the need to maintain a standard reference vehicle. This is explained in more detail in the 1989 report by Prem.

Interestingly, prior to the commencement of the project, an attempt was made to purchase a profilometer from an overseas manufacturer. However, due to the high purchase cost, the SRAs decided to support the development of a local system by ARRB.

Figure 1: Original ARRB profilometer with its developer Dr. Hans Prem in August 1986

By August 1986 the new profilometer was operational and had been fitted to ARRB's standard roughness vehicle as shown in Figure 1. It consisted of 3 laser opticators, two of which were situated in the host vehicle's wheel paths. Each of these was paired with its own accelerometer to measure the longitudinal profile of the road from which the International Roughness Index (IRI) was determined. A third laser was situated in the centre of the vehicle, which was used along with the other two lasers to provide an estimate of the rutting in the pavement.

Apart from an upgrade to the data logging system, the profilometer platform remained the same until 1992 when ARRB produced a 5 laser profilometer, capable of providing an improved measure of rutting in the passenger wheel path for the New South Wales road authority. However, this system used the same componentry and software as the original 3 laser profilometer and it was not until 1993 when a change to a new platform was made.

3 THE NEED FOR NETWORK-LEVEL DATA

Around the same time that ARRB commenced the development of its first inertial profilometer, several of the Australian SRAs had begun to either implement or investigate using pavement management systems (PMS) to better manage their road networks. However, most of the pavement condition data needed to populate the PMS was being collected manually, with the exception of roughness, making it impractical to collect pavement condition data across entire road networks which were often tens of thousands of kilometres in length (Jameson et al. 1988).

The desire to collect pavement condition data across 100% of their road networks resulted in the SRAs from three states, New South Wales, Queensland and Victoria, commissioning a trial of a vehicle mounted automated data collection system which was capable of collecting multiple pavement condition parameters. The objective of the trial was to assess the system's suitability in meeting their PMS requirements. As no system existed in Australia, apart from the ARRB profilometer which essentially only measured road roughness, they selected the Laser Road Surface Tester (RST), an automated pavement data collection system developed by the Swedish Road and Traffic Institute (VTI) (Jameson et al. 1988). The SRAs had been made aware of this system through presentations made by Dr P Arnberg of VTI in Melbourne and Sydney in 1986.

The testing was undertaken in 1987 using the system shown in Figure 2. It was fitted with 11 lasers and was capable of measuring a 3.2 metre wide transverse profile. The system could also measure roughness (inertially), rutting and macrotexture as well as providing an indication of cracking.

Figure 2: Swedish Laser Road Surface Tester in Australia in 1987

The results of the study, which also included over 12,000 kilometres of data collection in three states, were presented in the report from Jameson et al. While some modifications to the equipment were recommended, the trial demonstrated that the system could provide an accurate and objective measurement of roughness, rutting and texture across 100% of a large-scale network. In the ensuing years, the RST was used by at least two SRAs to undertake numerous large-scale network-level surveys.

4 ARRB'S NEXT GENERATION PROFILER

With the success of the RST trial and the SRAs' need for objective and repeatable pavement condition data (demonstrated by the increased use of the ARRB profilometer to collect roughness data), it was proposed that ARRB commence the development of a prototype multi-laser profilometer (MLP) with the ability to integrate existing data collection technologies (Clerk et al. 1994). The express aim of the project was to develop an integrated road monitoring vehicle. The project commenced in July 1993 and the first MLP was commissioned in 1994.

Further drivers for the project came from two separate sources. Firstly, road condition measurement technology had been identified as a national research priority. The development of the MLP was to be undertaken as part of the National Strategic Research Program which was endorsed by ARRB's Research Advisory Committee and its member authorities (Clerk et al. 1994). Secondly, ARRB, along with a local New Zealand partner, Beca Carter Hollings and Ferner Ltd., was successful in winning a Transit New Zealand (TNZ) contract to trial the collection of high quality road condition data using an MLP across almost 21,000 kilometres of the New Zealand state highway network annually between 1994 and 1996.

The MLP, which is shown in Figure 3, was a significant step forward. In addition to measuring roughness it was also capable of measuring rutting and texture at highway speeds. The system consisted of 13 lasers, enabling it to measure a 3 metre wide transverse profile and produce accurate rut measurements (especially when compared with a 3 laser profiler). Two of the lasers could also measure macrotexture and their outputs were found to have a high correlation with manual texture measurements (Hallett and Wix 1996).

Figure 3: MLP with development team in February 1994

A GPS receiver and logger to help produce large-scale ‘distress’ maps and a voice activated pavement distress recording system called VODEL used to log the location of pavement shoving as identified by either the MLP driver or operator, were also integrated into the system (Clerk et al. 1994). However, their use was discontinued after the first annual TNZ survey due to excessive GPS drop-outs and a severe underestimation of the shoving present on the network (Hallett and Wix 1996). At this time, work had also commenced on developing a videotape based multi-camera imaging system for pavement condition assessment and roadside asset location which was integrated into a later version of the road monitoring vehicle.

5 FURTHER DEVELOPMENTS

The MLP proved to be a robust platform with ARRB’s last system being decommissioned in 2011. It was estimated that the MLP platform had surveyed approximately one million lane kilometres of pavement in Australia and New Zealand since 1994. This figure would be substantially higher if the survey kilometres from MLPs used in other countries were included.

Whilst the MLP was a significant improvement on the original 3 laser profilometer, the goal of developing a fully integrated road monitoring vehicle or platform was never fully realised. During the course of its life the MLP was refined. For instance, the number of cables was reduced, new and more accurate lasers were introduced and the size of the signal conditioning rack was made smaller etc. but the system itself essentially remained the same. However, in the late 1990s an important development took place. Several stand-alone but complementary pavement data collection systems were installed onto a single host vehicle to produce ARRB’s first network survey vehicle (NSV). This vehicle consisted of an MLP, an imaging system (initially videotape based before being upgraded to a digital system) as well as ARRB’s inertial road geometry measurement unit known as Gipsitrac. Gipsitrac was developed in 1990 and has the ability to measure road geometry and generate centre-line maps of a road network with or without the assistance of GPS. This NSV could measure multiple pavement condition parameters in a single pass and since its development, was used extensively to collect data for each of the SRAs. An example of an early NSV is shown in Figure 4.

However, operating all three systems concurrently required the use of a programmable keypad with limited functionality. For example, the operator could start and end acquisition on all the individual systems simultaneously and even enter control or reference points but not comments. Each system still required its own individual computer and there was no common operating system. When preparing to collect data, each system had to be set up individually and the operator would need to switch between viewing screens during data collection. Further to this, each system had its own data processing software. As such, the NSV could not be classified as a 'truly' integrated road survey platform.

Figure 4: ARRB NSV

6 THE BIRTH OF THE HAWKEYE PLATFORM

Although the pre-Hawkeye NSV proved to be very successful, its shortcomings were generally acknowledged and in 2002 development of a totally new road survey platform was initiated with the goal of making it *'the world's best road survey platform'* (ARRB 2003). The Australian government also assisted with an AusIndustry grant to help fund the development.

The development team spent much time researching and discussing the requirements of the new platform. This included in-depth interviews with members of ARRB's own data collection team, which by that time had had more than 10 years of experience using the existing NSV as well as a variety of other survey equipment. They also evaluated other pavement data collection systems that were available at the time.

The new road survey platform, was designed with an architecture which would enable it to meet several key requirements, for example the platform had to be:

- modular – to allow new and existing technologies to be integrated into the platform
- scaleable – making the system easily upgradeable through the addition of extra transducers such as cameras and lasers.

This required the development of both new hardware and software. The acquisition software had to be capable of collecting and storing data from each of the modules and the processing software needed to report and review the data from every module. The software would be Windows based as this was the most commonly used operating system at the time.

Another marked difference was how the pavement condition parameters measured by each module would be aligned. The original NSV used distance, measured via a common distance measurement transducer mounted on a wheel of the host vehicle to align the outputs of the different systems. The new system would use a time based key, generated by a central hardware module called the Heartbeat. This 'Primary Key' which would be assigned to all of the data points collected by each of the modules to enable the processing software to identify their relative position.

The first prototype NSV built on the new platform was commissioned in 2005 and consisted of the following four modules:

- digital laser profiler (DLP) with 13 lasers capable of measuring roughness, rutting and texture
- digital imaging system (DIS) with 4 roof mounted asset cameras and a pavement camera situated behind the vehicle
- GPS (or DGPS)
- distance measurement.

As with the development of any new platform there were teething problems, yet the new system was successfully employed to undertake a 32,000 kilometre survey of the Western Australian road network. Much useful feedback was received from the survey crew and suggested improvements were incorporated into the platform.

Whilst keeping several of the features of the previous profiling and imaging systems, the new platform provided many additional ones and a much greater functionality including real-time feedback (visual and voice) through its Windows-based data acquisition system called Onlooker.

On the data processing side, the Processing Toolkit is a single Windows-based program capable of reviewing, rating and processing each of the data streams into custom reports and spatial data sets for presentation in graphical information systems. In practice, this was a vast improvement on the previous system with its individual processing programs.

7 INTEGRATION OF EXISTING TECHNOLOGIES

Over time, new acquisition and processing modules were integrated into the platform. These were capable of collecting additional pavement condition data and other complementary data sets, such as information on roadside assets. This was often an involved process requiring the development team to familiarise themselves with the new equipment and its capabilities. Some of the issues considered include:

- the format of the output data
- data access e.g. serial port, Ethernet, Firewire, Cameralink, Wifi
- amount of data produced
- data transfer and processing rates
- is real-time processing required for feedback to the operator or is the data simply written to disk?
- whether the data acquisition is time or distance based
- requirements of users
- report formats
- data interrogation etc.

Whilst much effort can be involved in the integration, once completed, each new module is essentially ‘plug and play’.

The following is a brief description of some of the additional modules that have been integrated into the Hawkeye platform:

7.1 Road Geometry and Mapping

One of the first modules to be integrated was the ARRB Gipsitrac unit. As mentioned previously, Gipsitrac is an inertial measurement unit with GPS capable of measuring road geometry (crossfall, grade, horizontal and vertical curvature) as well as centre-line mapping, even in the absence of GPS. The development team were well acquainted with its operation and consequently the hardware was easily integrated into the Hawkeye platform. In this instance, the biggest challenge proved to be integrating the full functionality of Gipsitrac’s standalone processing software into the Processing Toolkit. An iterative approach was chosen, whereby additional features were incorporated into the Toolkit with subsequent software releases.

7.2 Spread Laser Transverse Profiler Measurement

Spread laser technology offers an alternative to point laser systems that may use from 5 to 20 or more point lasers to measure the transverse profile of the pavement. In 2010 the Laser Rut Measurement System (LRMS), manufactured by INO in Canada, was successfully integrated into the Hawkeye platform. The system uses two 3D laser sensors mounted on the rear of the host vehicle to digitise adjacent transverse sections of the pavement. Each sensor captures a 2 metre wide transverse profile with up to 640 measurement points which allows the system to measure a lane width of up to 4 metres wide at normal traffic speeds. To help integrate the LRMS, INO provided a series of data software libraries (DLL) to assist the developers. The system is capable of providing a more detailed picture of the transverse shape of the pavement than a point laser system.

7.3 LiDAR

LiDAR is an acronym for light distance and ranging and has been used in geographical surveying for many years. LiDAR systems can either be used statically or on a mobile survey platform such as an NSV. The system uses a rotating laser that records distance from the unit to the surrounding objects and thereby builds a three-dimensional picture of its location known as a point cloud.

Whilst high resolution LiDAR systems exist, they are generally expensive, require large amounts of data storage and significant processing time. As such, ARRB chose to integrate a relatively low-end unit, manufactured by SICK, but which had standard outputs, was easy to install on the host vehicle and was not data intensive.

The resultant point clouds can be used to provide accurate measurements of bridge heights, road widths, vegetation envelopes etc. The system has been used for numerous road safety projects where the distance to roadside hazards has been important. An example of a point cloud is shown in Figure 5.

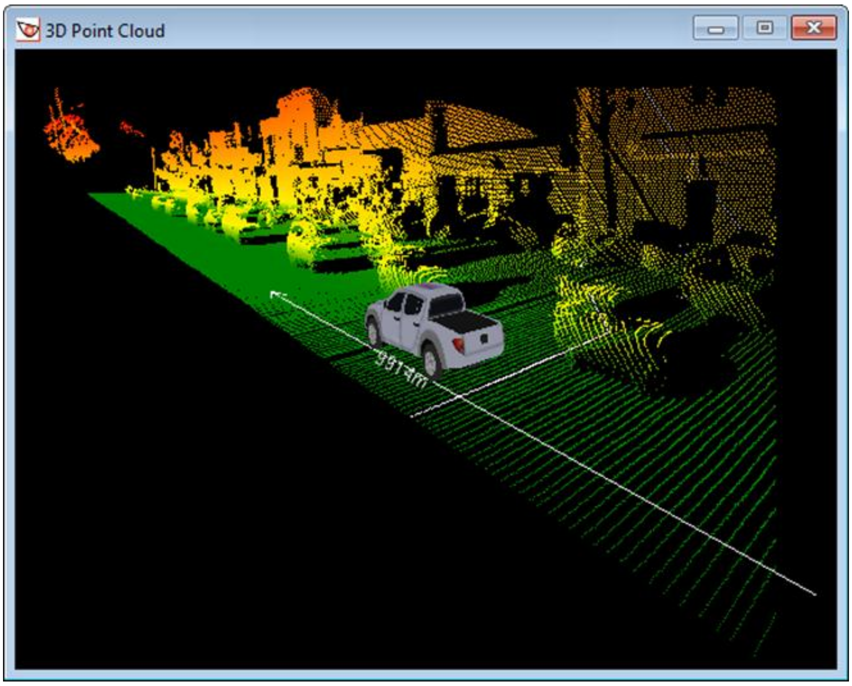

Figure 5: Example of 3-D point cloud in an urban environment

7.4 Line-scan Pavement Cameras

The original pavement camera used was a high-resolution area-scan camera. Whilst adequate for identifying most pavement defects, it fell short when used to identify cracking, particularly fine cracks on sprayed seal pavements. To improve crack identification, the area-scan camera was replaced with twin line-scan cameras capable of sampling every one millimetre of the pavement. This resulted in higher resolution images with less distortion which significantly improved crack identification. Camera changes have not been limited to pavement cameras as several upgrades have also been made to the asset cameras to take advantage of new models as they become available. The system architecture allowed their ready integration into the Hawkeye platform.

7.5 RoadCrack – an Example of Co-creation

In 2010, ARRB was asked by the Roads and Traffic Authority of New South Wales (RTA NSW) to submit a proposal to re-develop its automated crack detection system called RoadCrack. (RTA NSW has since changed its name to Roads and Maritime Services New South Wales (RMS NSW)). The system shown in Figure 6 is mounted on a truck and was originally developed in the mid-1990s by the RTA NSW in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Today it is still the only system capable of repeatably measuring cracks down to 1 millimetre on sprayed seals in real time at highway speeds.

This re-development involved the replacement of several key hardware components which had been superseded and/or were no longer available. The operating and processing software was also migrated from a 13 computer UNIX-based environment to a single Windows-based industrial PC. New Hawkeye compatible componentry was developed and integrated into the acquisition system of the Hawkeye platform. The project was a great example of co-creation between a road agency and an equipment developer and required dialogue with members of the original development team and a significant review of the existing system documentation.

After testing, the RoadCrack system, now operating on the Hawkeye acquisition platform, was used to survey several thousand kilometres of the Tasmanian road network without any major issues. The success of the re-development led to a contract variation to build a smaller, trailer mounted RoadCrack system with resulting improvements to manoeuvrability, operator comfort, operating speed and fuel efficiency.

Whilst the reduction in the size of the RoadCrack system was seen as important, a more significant benefit was that the trailer had been designed to also carry a 13 laser DLP. This allows the simultaneous collection of pavement condition and cracking data and provides a significant economic benefit to RTA NSW by reducing the number of surveys from two to one. The trailer mounted system is also shown in Figure 6.

Figure 6: RoadCrack (left) and RoadCrack trailer with DLP beam in 2011

In May 2012 a validation exercise was undertaken which proved that the results from RoadCrack trailer with integrated DLP were the same as those collected by the individual systems mounted on separate survey vehicles.

With RoadCrack now integrated into the platform, any of the aforementioned modules can be mounted to the truck or trailer and ‘plugged in’ to the acquisition system allowing multiple data sets to be collected at the same time.

8 INTEGRATION OF EMERGING TECHNOLOGIES

Equipment developers are continually looking for compatible or complementary technologies to integrate into their survey platforms. By attending relevant conferences, participating in working groups, conducting literature reviews, through social media and the internet and developing collaborative working relationships with equipment manufacturers, developers endeavour to keep abreast of new and emerging technologies.

For example, ARRB actively engages the Australian SRAs through round-table discussions and regular communications to assess their needs in terms of pavement data collection and to inform them of any emerging technologies that they may not be aware of.

At present, ARRB is working to integrate the following technologies into the Hawkeye platform:

8.1 Laser Crack Measurement System

The Laser Crack Measurement System (LCMS) manufactured by INO, is an emerging technology that is being readily embraced by service providers and equipment developers. It comprises two high-performance 3D laser units that are fitted at the rear of the survey vehicle, vertically above the pavement. Each unit consists of two main components; a high-power spread-line laser and a camera. The 2 metre wide laser line is projected on to the pavement and the image is captured by the camera which allows it to measure the transverse profile of the pavement to a 0.5 mm height resolution and 1 mm transverse resolution. A picture of the road surface can then be built up by combining sequential 4 m wide transverse profiles which, at 100 km/h, are only 5 mm apart (less at lower speeds). The images are also unaffected by shadows.

A local trial of a LCMS unit was undertaken in January 2012 which included a comparison with the aforementioned RoadCrack system. Pavemetrics Systems, the company which has the licence for the LCMS and LRMS, also provided a technical expert to assist in the testing and to get a better understanding of Australian requirements.

The LCMS comes with its own image processing libraries containing algorithms to extract crack data including crack type (transverse, longitudinal or crocodile) and severity. These libraries can also be used to identify other pavement distresses and will be utilised by the development team when integrating the LCMS into the Hawkeye platform.

8.2 Mobile Retro-reflectivity Measurement

Road markings and raised pavement markers (cats eyes) are important features of a road network as they provide the needed delineation to allow road users to safely navigate and drive the road network. As such, ensuring that these markings are visible is critical, especially at night-time. An assessment of their condition can be made by measuring their retro-reflective properties. This is typically done by using a hand-held instrument. However, as levels of traffic flow increase this has become more dangerous, to both the user and the drivers on the road. As such, there has been a growing demand for mobile retro-reflectivity units in Europe (Lundkvist 2010) and elsewhere including Australia where mobile reflectivity services are undertaken by one road agency and are also available through at least one service provider.

In 2011 a LTL-M mobile retro-reflectivity unit was obtained from Delta, a Danish company. Integration of the system into the Hawkeye platform was commenced shortly after. The system operates at normal traffic speeds and appears to be an efficient means of covering 100% of a road network. Apart from retro-reflectivity measurements it also measures daylight contrast, an assessment of the visibility of the line marking in daylight, and can identify both single and double lines and distinguish whether they are solid or broken as well as locate raised pavement markers.

In late 2011 the system was successfully used to undertake a 2,000 kilometre trial for VicRoads, Victoria's state road authority.

8.3 Friction Testing

Skid resistance is a measure of the friction between the contact area of a tyre and the pavement and is an important pavement condition parameter in terms of road and airline safety. Friction has been shown to be dependent on both the micro and macrotexture of the pavement. Therefore, knowing the macrotexture of the pavement can be advantageous (Oliver and Halligan 2006) and often complements the skid resistance measurements made by friction testers.

In 2011, ARRB collaborated with Airport Surface Friction Tester (ASFT) in Europe to integrate a Hawkeye macrotexture measurement system into an ASFT airport friction tester and is presently working on the integration of an ASFT trailer unit into the Hawkeye platform for project level and airport use.

9 THE CURRENT STATE OF PLAY IN AUSTRALIA

From 1986 to the mid-1990s ARRB was the only manufacturer and supplier of automated pavement data collection equipment in Australia. However, since then the increasing need and demand for pavement condition data has seen a small number of other Australian based companies and service providers begin manufacturing their own pavement data collection systems. Some have chosen to design their own sensors and acquisition hardware whilst others have integrated 'off-the-shelf' technologies into their data collection platform. However, the Australian market still remains small compared to that of North America and Europe.

Over time the price for data collection services has also reduced significantly. In 1989 the quoted price for collecting automated roughness, rutting and texture on a rural network was in the vicinity of AUD $30 per lane kilometre which is the equivalent of $55 in today's currency. However, in 2012 most road agencies are paying less than $20 per lane-kilometre for the same information and in some instances additional data such as imaging, road geometry, GPS etc.

This reduction in costs can be attributed to a number of factors such as:

- cheaper and more readily available sensors such as lasers, inertial sensors, cameras, GPS receivers etc.
- an enormous increase in computing power and performance at a vastly reduced cost
- the development of highly integrated data collection systems allowing multiple data sets to be acquired simultaneously in a single pass, thus reducing the high cost of manpower and the need for multiple vehicle platforms
- integrated and flexible data analysis programs which promote efficiencies through automated data quality checking, batch processing, visualisation of results and automatic exports to presentation programs such as spread sheets, and GIS packages.

A prime example of the value of integrating more than one system into a single platform is the integration of pavement roughness, rutting and texture measurement into RoadCrack. It is estimated that this will result in a minimum 25% cost saving for RMS NSW.

The proliferation of equipment now available in Australia to collect pavement condition and asset management data for road agencies has also led Austroads, the association of Australian and New Zealand road transport and traffic authorities, to develop standards and test methods that are aimed at harmonising data collection methods and achieving consistent and transportable results.

10 SUMMARY

When ARRB built its first profilometer platform, the main focus was on collecting road roughness data. However, an opportunity to develop a new data collection platform arose when the SRAs expressed the need for additional pavement condition data to better manage their road networks.

Whilst ARRB's first effort to develop a multi-function road survey vehicle met with considerable success, it failed to produce a truly integrated system. However, this shortcoming was addressed in a new acquisition platform which was specifically designed to allow the integration of new and existing technologies. This required careful planning and in some instances, the need to adopt a collaborative approach with the technology supplier.

Since its commissioning, numerous technologies have been successfully integrated into the Hawkeye platform with good results. Some of these technologies are able to measure pavement condition parameters such as roughness, rutting, texture, cracking as well as road geometry. Others provide information on the roadside assets and the area surrounding the pavement.

One major benefit of the platform comes from being able to run multiple modules on the same host vehicle. This can lead to efficiency gains and a reduction in survey costs, particularly if only one survey is required rather than two or more. A good example of this is the RoadCrack trailer which has been designed to carry a DLP beam thus removing the need for two separate surveys.

ARRB continues to look for and evaluate new technologies that meet the needs of the SRAs and other users. The efficiency gains realised with a fully integrated and flexible acquisition platform have been proved over many years and a commitment to long term development will ensure its value into the future.

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