

The CSIR's contribution to the development of innovative technologies and solutions for enhanced road system performance

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Abstract

Road infrastructure is a key driver in supporting and stimulating socio-economic development. The South African road network, similar to those of other countries, needs to accommodate a wide spectrum of roads, ranging from light road pavement structures for local access to heavy-duty road pavements for national corridors. However, the scale of the South African economy is such that expensive pavement solutions, such as those used in Europe and North America, are seldom affordable. Hence, uniquely South African solutions had to be developed, calibrated and validated, supporting the optimal and sustainable utilisation of our limited and distinctively different resources. In this paper, the CSIR's contribution to, and impact on, road pavement design, construction and maintenance is presented.

1 Introduction

Since the 1970s, the CSIR has made a major technological and economic impact on the design, construction and maintenance of South African roads. It has had an impact, for instance, on the development of national and regional pavement design standards and guidelines, the development of material specifications and guidelines, the development of human resources, capacity building in the road construction industry, the development of innovative products and designs, and the provision of cost-effective infrastructure engineering solutions.

Key to the above is the Heavy Vehicle Simulator (HVS) Associated Technology Development Programme (hereafter referred to as the HVS Programme), which has been both a driving and a uniting force in national road research over the years. This said, the CSIR has also been involved in other, non-HVS-related research and development activities in road engineering which have contributed equally to the current state of knowledge and expertise in the sector. These include, for instance, R&D work conducted on low-volume roads and more specifically on the maintenance and upgrading of gravel roads; the development of a software support platform for project-level pavement design; and the development of laboratory and field testing methods and equipment.

Although it is still too early to assess its impact, the CSIR is also assisting the road construction industry to position itself for the future. In fact, most of the projects in which the CSIR is currently involved are geared towards achieving this. Examples of these projects include: (a) the development of a new South African pavement design method for the South African National Roads Agency (SANRAL); (b) research into new materials to prolong the structural design life of flexible pavements (e.g. High-Modulus Asphalt for the Southern African Bitumen Association); and (c) the CSIR's investment in the *i-Roads* programme ("Innovative technologies and solutions for enhanced road system performance") which focuses on the development of:

- an advanced road pavement materials design and evaluation platform
- innovative new materials for use in roads, such as nanophosphor, vegetable-based binders and photocatalytic pavement surfaces
- GIS-based information for practitioners on karst aquifer groundwater hazards, high-risk areas for potential landslides and areas with potentially expansive clays
- advanced road pavement design methods, such as finite-element modelling
- enhancing the understanding of tyre contact stresses to encompass full vehicle-pavement interaction
- infrastructure-environment interaction, and the impacts thereof on material selection and design, as well as structural design
- environmentally friendly pavement solutions.

2 Impact of the HVS-Associated Technology Development Programme

2.1 Background

The Heavy Vehicle Simulator (HVS) is a mobile machine developed by the CSIR in the early 1970s, which subjects road and airfield pavements to accelerated trafficking. In essence, it is a mobile laboratory taken to the road to evaluate the structural behaviour and capacity of the road under full-scale conditions. It is able to simulate the equivalent of 20 years of traffic in as little as three to six months, thus assisting engineers to understand the mechanisms of traffic-associated road failures. The HVS thus makes it possible to obtain quick results related to the damage caused by traffic, the mechanisms of failure and the influence of various controlled environmental factors on the behaviour and performance of pavements.

For nearly 40 years, the HVS has had a dominant influence on the development of South African pavement engineering capabilities. The extent of this influence has been well documented through contributions to various international conferences, on both direct HVS applications and the associated development of rational analysis/design methods and their practical implementation (Freeme et al., 1982; Horak et al., 1992; Rust et al., 1997; Kekwick et al., 1999; Verhaeghe et al., 2006; Du Plessis et al., 2008).

HVS testing allows the prediction of the performance of new road materials and structural designs, as well as the optimisation of road designs through the testing of full-scale trial sections well ahead of their implementation in practice, thus effecting cost savings and avoiding expensive failures. In addition, the technology has been used on in-service roads to determine their expected remaining life, as well as to determine optimum rehabilitation and maintenance procedures to prolong their life. The above are generally short-term objectives which are often well defined and aimed at solving specific problems over a relatively limited time period.

In contrast, long-term objectives of the HVS programme are geared towards the broader goal of providing more cost-effective, environmentally friendly pavement construction and rehabilitation techniques. In addition to this, pavement construction methods using high labour inputs form a part of the concentrated effort to address the pressing issue of sustainable job creation.

HVS testing adds to the development of the skills and understanding of the behaviour of pavements directly involved in the testing process. The knowledge gained must also be transferred to other practitioners, and in South Africa this has been successful through a variety of mechanisms, including courses, workshops and seminars, apart from direct input into documentation and guidelines.

Although the analysis and interpretation of data from specific HVS tests are usually focused on addressing short-term objectives, each test contributes directly to a data/knowledge base that becomes a platform from which structural design models for pavements can be developed. In this way every HVS test contributes towards the longer-term objectives of the Programme.

Embarking on an HVS programme with the sole intention of addressing the pressing problems that require immediate solutions may be reason enough to justify such a programme, but realising the long-term objective of HVS testing will maximise the return on investment. Consequently, it is viewed as essential that a successful HVS programme should have longer-term objectives outlined from the beginning. This,

then, provides focus for the programme, enables both researchers and funders to share a common vision and forms the basis of the particular research and implementation strategy.

Whereas HVS testing is often conducted on purposely designed trial sections, most of the advances in road engineering in South Africa have come from HVS testing on actual roads. The advantage of this type of road evaluation stems from the greatly reduced time needed to obtain meaningful indications of long-term (real-life) performance, which allows the earliest possible appraisal of novel materials and techniques in seeking optimal, cost-effective pavement materials and designs.

2.2 Strategic objectives

The HVS Programme is designed to be supportive of relevant key strategic areas of the overall transport goals on national and provincial levels. Figure 1 shows how the HVS Programme contributes to these strategic areas (GPDRT, 2010).

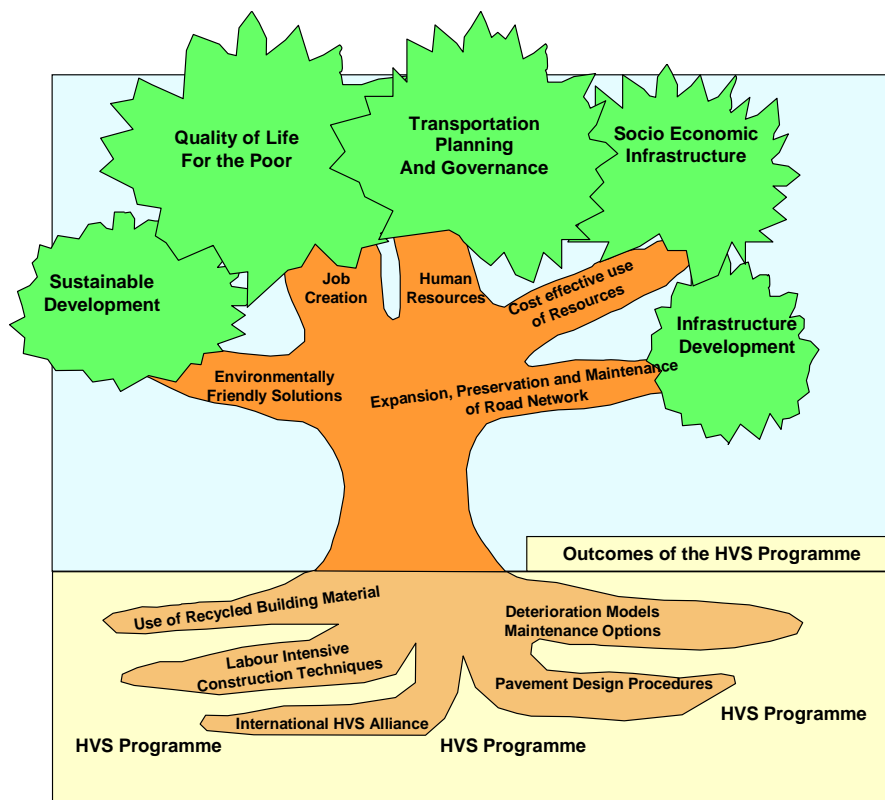


Figure 1: Relevance of the HVS Programme to the Agenda for Transport

In 1995, the six strategic objectives for the HVS Programme were to develop, improve understanding of, verify or evaluate:

1. the design and performance of pavement structures suitable for basic access roads and collectors for rural road networks;
2. labour-intensive construction (LIC), friendly pavement compositions and LIC techniques;
3. techniques for upgrading existing gravel (and other) low-volume pavement structures;
4. the use of innovative, cost-effective materials and methods, optimising the use of in situ materials (treated and untreated);
5. technologies for the preservation of the existing road network in order to extend its service life, and
6. technologies for optimising the use of scarce construction materials.

The above strategic objectives were aimed at supporting the broader national and provincial goals that were set to address the South African challenges for transport provision and socio-economic infrastructure developments.

The period from 2000 to 2003 saw a shift in the strategic focus of the HVS Programme. The shift in focus was driven by the increase in traffic volumes on the more heavily trafficked public transport routes and freight corridors, and by the need to maintain and rehabilitate these roads more quickly to reduce traffic delays. This was also compounded by stricter environmental legislation and the decline in availability of non-renewable aggregate sources. Hence there was a move towards the investigation and adoption of more sustainable and environmentally friendly technologies that consume less energy, enable greater use of waste or by-products in road construction and promote the reuse of existing road construction materials. An example of the latter is *cold in-place recycling* of the existing base and wearing course material, with stabilisation of the recycled material generally being carried out using foamed bitumen or bitumen emulsion, both with or without cement. A series of HVS tests, coupled with an elaborate laboratory test programme, were conducted on cold in-place recycled mixes, which culminated in the development of guidelines for the appropriate design and use of cold in-place recycling with bitumen emulsion and foamed bitumen (Asphalt Academy, 2009). These guidelines have since been validated and further refined following the completion of Long-Term Pavement Performance (LTPP) studies.

The other major shift in the prevailing strategy occurred during the period 2004 to 2009 when the need was identified to investigate concrete and composite pavements for use on both high- and low-trafficked roads. The HVS was used to test heavy-duty pavements in a jointly sponsored programme with the South African National Roads Agency Ltd (SANRAL) and the Cement and Concrete Institute (C&CI). HVS studies have also been undertaken to assess the performance of *ultra-thin, continuously-reinforced concrete pavement overlays* (UTCRCPC; concrete thickness of 30–50 mm) and investigate whether this innovative concept can be used as a cost-effective rehabilitation alternative for heavily trafficked roads (Kannemeyer et al., 2008). The successful completion of the latter has led to its application on the Gauteng Freeway Improvement Project (GFIP), as well as on National Route 1 in the Western Cape. At the other end of the scale, studies have also been conducted on labour-intensively constructed *ultra-thin reinforced concrete pavements* (UTCRCPC) for the upgrading of unpaved township roads as part of the Gauteng Expanded Public Works Programme. Based on the results obtained from extensive HVS testing, guidelines have been drafted to ensure the successful application of this technology on low-volume township roads (Du Plessis et al., 2009).

Concurrently, the need was identified for improved (innovative) designs and materials for *hot-mix asphalt*, again targeted at optimising rehabilitation and improvement options for the major public transport routes and freight corridors of Gauteng. The main objective is the provision of more durable, longer-lasting materials requiring less frequent maintenance interventions, which will reduce delays and traffic disruptions. These designs have been subjected to HVS trafficking, tested in the laboratory and integrated into LTPP studies with the ultimate aim of reviewing and revising the current design guidelines for hot-mix asphalt.

2.3 Quantification of benefits

In the face of increasing pressure on the roads budget, it became essential to proactively define and quantify the benefits arising from the HVS Programme. To this end, an independent, peer-reviewed assessment (termed the “HVS Benefit Study”) was performed to identify and quantify the benefits stemming from the HVS Programme (Jooste & Sampson, 2005, 2008). The study focused specifically on those benefits that are relevant to the stakeholders and which are congruent with the South African National Research and Development strategy.

The study grouped the benefits of the HVS Programme into two categories:

- *Direct benefits* – benefits that rely primarily on quantifiable project outcomes. In the context of road technology development projects, these benefits arise because of improved technologies that lead to more effective design and construction processes, which in turn reduce agency and road user costs. These benefits can, to some extent, be quantified in economic terms by means of indicators such as the benefit-cost ratio.

- *Indirect benefits* – benefits that arise because of the development process. These benefits largely concern human resource development and the development of a better understanding of material and pavement performance. These benefits are not readily quantified in economic terms and are best monitored and evaluated through indicators and trend analyses. Apart from local indirect benefits, the HVS Programme has enabled South Africa to be seen internationally as a world leader in the field of pavement design.

Direct economic benefits of the HVS Programme

The HVS Benefit Study has shown that the technical impact of HVS development work can be generalised into the following three categories: (i) optimised materials and pavement design, which lead to reduced construction costs; (ii) more reliable design and maintenance practices, which reduce the likelihood of costly early failures, and (iii) more cost-effective materials and pavement design, which optimise the time between maintenance interventions and reduce pavement life-cycle costs. Examples of HVS findings that have influenced national practice include:

- The dramatic effect of water, which influences designs and maintenance procedures
- Underestimation of the bearing capacity of light pavement structures, which led to the alteration of the catalogue of designs
- Deformed pavements have not necessarily failed structurally (traffic moulding)
- The concept of deep versus shallow pavement composition being accepted and applied
- Pavement designs must strive for strength-balance
- Cemented-base-only pavements used only for very light traffic by road authorities
- The development of a high-quality crushed stone base (G1) material which proved to be the top performer in the national specification document
- Inverted pavement design philosophy proven to be sound and used by all road authorities
- The influence of a sound aggregate skeleton in hot-mix asphalt in combating rutting (surface deformation)
- The impact of thicker hot-mix asphalt overlays on improved constructability and performance
- HVS findings incorporated into the South African Mechanistic Design Method.

The benefits that stem from specific HVS projects were quantified in relation to the costs of the projects. Figure 2 shows an estimated benefit-cost ratio for different discount rates. The range is based on economic calculations compiled with feedback received from road agency personnel and practitioners during formal, documented interviews.

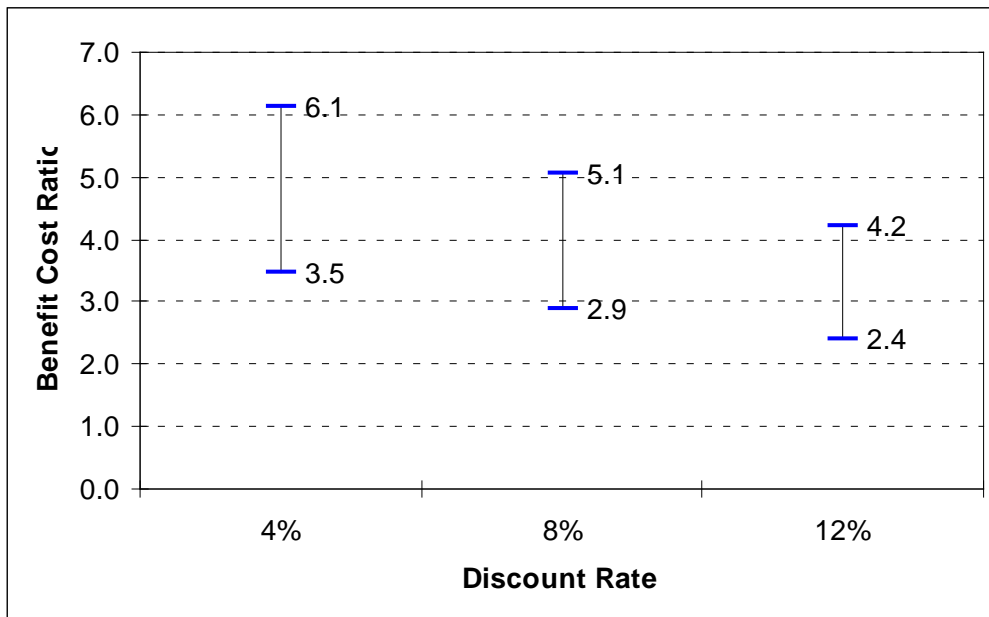


Figure 2: Estimated benefit-cost ratios for specific HVS projects

The quantifiable benefits of the HVS Programme were found to be significant: for a discount rate of 8%, between R3 and R5 is returned for every R1 invested in the HVS Programme.

Another direct benefit of the HVS Programme is the international transfer of HVS-associated technologies either through collaborative research programmes, such as the Californian Accelerated Pavement Testing Programme, or through direct sales of Heavy Vehicle Simulators and surveillance equipment. There are currently eight HVS facilities forming part of research programmes in the USA, Europe, China and India, which have cumulatively generated approximately R200 million of income for South Africa over the last 18 years.

Indirect benefits of the HVS Programme

Three main benefit streams identified by the South African National R&D strategy objectives are: (i) contribution to better business performance (including performance of public service departments); (ii) contribution to technical progress; and (iii) contribution to the development of Science, Engineering and Technology (SET) human capital.

The benefits arising from better business performance are generally those that are directly quantifiable in economic terms, while the other two main benefit streams result in benefits that are more intangible and indirect in nature (i.e. the so-called 'Indirect benefits').

Over many years, HVS investigations and their associated development of human resources, new technologies and international alliances have impacted significantly on the people of South Africa. For instance, the HVS Programme provides a stable training ground for individuals wishing to specialise in technologies related to road design, construction, maintenance and rehabilitation. Over the past 40 years, 24 Master's and 18 Doctoral degrees have been completed by staff directly involved with HVS research.

Although difficult to quantify in economic terms, there is little doubt that the contribution of the HVS Programme to technical progress and human capital development will have huge economic benefits over the long term. The simple linear benefit assessment process followed in the study failed to take into account the further downstream benefits and the impacts of these benefits on the population at large.

Examples of these impacts include road user cost savings (due to fewer road closures and rehabilitation interventions) and technology transfer to local and international practitioners, which has raised the technical competence of local pavement engineers. Aspects such as environmental and sustainability benefits have also not been quantified.

3 Unsealed road design maintenance and upgrading programme

3.1 Background

More than 75% of the proclaimed South African road network consists of earth or gravel roads, collectively defined as 'unsealed roads'. The annual cost of maintaining these is extremely high and the natural loss of material from these roads renders them unsustainable in the long term. Many of the best-performing materials have been depleted and many of the skills required for cost-effective material location, construction and maintenance of gravel roads have been lost.

A large project carried out in the mid-1980s involved the monitoring of 110 sections of gravel road (following a full factorial experiment) in the provinces of Gauteng, Mpumalanga, Limpopo and the North-West, as well as in Namibia). This allowed optimum specifications for the selection of gravel wearing course materials to be developed. In addition, deterioration models for the prediction of annual gravel loss, rate of increase in road roughness and expected roughness after grader blading were developed.

This work resulted in the production of a design, construction and maintenance manual for gravel roads, which was published by the Committee of State Road Authorities (CSRA, 1990). Although the research carried out and the manual were widely disseminated, implementation was slow and piecemeal. The prediction models were successfully incorporated into most of the Gravel Road Management Systems (GRMS) implemented in southern Africa. These systems were used to predict the maintenance requirements, frequencies, budgets, etc. for road authorities. However, full implementation of the recommended specifications and construction techniques only started after about 10 years. The Western Cape Provincial Administration employed the specifications and recommendations on all new work and significant improvements in the performance of roads were immediately recorded. The improvements were such that the prediction models (based on roads constructed to the previous specifications and methods) were found to overpredict the rates of deterioration significantly. Subsequent investigations (Van Zyl et al., 2003) have shown that the entire maintenance process can be revised (with significant cost savings) if the roads are properly constructed in the first place.

3.2 Improvement and upgrading

It was noted that although unsealed roads may be constructed to the necessary standards, they are still unsealed roads and thus influenced by traffic and the environment to a considerably greater extent than sealed/paved roads. Work was therefore commenced on investigating various proprietary materials marketed locally for the palliation of dust and improvement of material properties. This work is still ongoing, with experiments being done in various provinces and national parks. The investigations have shown that certain materials can be cost-effectively utilised, but their performance is directly related to the construction materials being used, the standard of construction and the traffic and environmental conditions.

In order to assist road authorities with the decision as to whether the use of these products is cost-effective, a suite of tests was developed and this now forms the basis of an Agrément Certification Programme for these non-traditional soil stabilisers and surface treatments.

An intensive investigation into the structure and performance of nearly 60 roads constructed using marginal quality materials and/or thin pavement structures throughout South Africa was carried out in the early 1990s. This indicated that for roads carrying light traffic (between 50 and about 400 vehicles per day), it can usually be cost-effective to surface the road with an appropriate bituminous surfacing using materials that would normally be considered unsuitable or inferior for the underlying support layers. This immediately allowed the construction of sealed roads at significantly lower costs. In addition, the use of simpler, more easily constructed and cheaper bituminous surfacings was also investigated and guidelines produced.

3.3 Impact

The impact of the work on unsealed roads is only now being felt. Although the cost of construction using the new specifications is slightly higher than previously, the savings in maintenance and gravel loss easily outweigh this cost. This becomes even more significant when a monetary (or environmental or sustainability) value is applied to the materials being utilised, which would normally be totally lost through erosion and wear within seven years of application. With the new 'aggregate tax' currently being implemented by the government, the cost of gravel is likely to increase significantly and any reduction in gravel loss will have a significant economic impact.

The improved riding quality resulting from better material selection also has a major effect on road user costs. These costs exceed the construction and maintenance costs of unsealed roads by orders of magnitude and reductions in the user costs have a significant impact on the overall economy of the country.

Software to quantify and compare the economics of unsealed and low-volume sealed roads was developed, originally in the 1990s and updated in 2005, to include more recent research, as well as the ability to account for environmental and social benefits (Sabita, 2005).

An example of the implementation of the upgrading developments occurred in the Gundo Lashu project in Limpopo province. The original objective of this project was to develop local skills for the construction of unsealed roads. After an investigation into the local construction materials and conditions by the CSIR, it was proved that the construction of sealed roads using the same construction teams would be more cost-effective. As a result of this, over 1 000 km of sealed roads have been constructed instead of the original gravel roads.

As a result of the research into unsealed and low-volume sealed roads, the CSIR has gained the reputation of being a world leader in this field. Two Doctoral degrees have been earned in this area and the CSIR specialists are regularly invited as keynote or invited speakers at conferences in the United States, the Middle East, Australasia and South America.

4 Software support platform: Pavement analysis and design software

Part of the mandate of the CSIR is to develop technology that will assist in service delivery and support the economy of the country directly and indirectly. Over the years and in support of the road pavement industry, the CSIR has developed Windows-based software packages known as the Pavement Analysis and Design Software (PADS) series, consisting of a number of components used for new and rehabilitation pavement design. User input is provided through intuitive graphical user interfaces (GUIs). The series currently consists of five packages for mechanistic-empirical pavement design (Me-PADS[®]), design traffic estimation (Traf-PADS[®]), deflection analysis (Back-PADS[®]), rehabilitation design (Pro-PADS[®]), and pavement temperature prediction (Thermal-PADS[®]).

4.1 Me-PADS[®]

The Me-PADS[®] module is a mechanistic-empirical design package based on the South African Mechanistic-empirical Design Method (SAMDM) with a Multi-Layer, Linear-Elastic (MLLE) analysis engine. User input consists of defining the pavement geometry, material resilience and strength properties, and loading conditions. Results visualisation consists of profile and contour plots, as well as a summary of the structural capacity results.

4.2 Traf-PADS[®]

The Traf-PADS[®] module is a design traffic estimation package based on the Technical Recommendations for Highway (TRH16) procedure. The two main components of the package are a component to calibrate the load sensitivity of the pavement and a component to process the traffic sample. The load sensitivity is calibrated using either the American Association of Highway and Transportation Officials (AASHTO) damage law or a mechanistic-empirical calculation routine. The load sensitivity of the pavement is calibrated for a range of loads from very low values to values exceeding the legal axle load limit. A number of options are available to define the traffic sample from which axle load histograms are

developed for the traffic analysis. Weigh-in-motion (WIM) data can be imported into the software directly from the South African (RSA) standard for WIM output files, and multiple vehicle classification options may be selected, ranging from a total vehicle count to a classified vehicle count.

4.3 Back-PADS®

The Back-PADS® module is a deflection analysis package that calculates deflection bowl parameters and layer resilient modulus values from Falling Weight Deflectometer (FWD) data. The package allows the analysis of a single deflection bowl specified by the user or multiple deflection bowls from FWD output files, and provides for up to nine deflection sensors. The software is compatible with FWD output file formats. The back-calculation is done for up to eight pavement layers using a linear-elastic, multi-layer engine and steepest decent search algorithm, with the option to fix or limit layer modulus values. Summary plots are provided in the software and the data are presented in a spreadsheet format compatible with Microsoft Excel.

4.4 Pro-PADS®

The Pro-PADS® module is a package for rehabilitation design aimed at project-level integration of all the design analyses, including visual assessment, materials data, traffic analysis and pavement analysis and design. This package allows the consolidation, processing and analysis of all the information collected during a rehabilitation project. All the information entered into the software is linked to the location where it was collected with an indexing system based on the chainage, lane and wheel-path where the data were collected. Data are represented by an icon on a strip-map of the project.

4.5 Thermal-PADS®

The Thermal-PADS® module is a package for pavement temperature prediction for use in performance grade (PG) binder selection. Currently, Thermal-PADS® contains weather data from 65 stations, while air temperature data are available at the Weather Service for over 400 South African weather stations. Bitumen in South Africa is classified by penetration index. Penetration values determined at 25°C provide limited information about the performance of the binder at elevated or low temperatures. The same holds true for other parameters determined at standard temperatures. The extreme temperatures at which the requirements are passed by a bitumen determines the PG for that bitumen. The PG temperatures refer to the seven-day maximum average temperature at a depth of 20 mm in the asphalt layer and the minimum surface temperature at a site. Thermal-PADS® can be used to determine these design temperatures. Furthermore, the Thermal-PADS® module provides the mean value, the standard deviation and the 98th percentile value for the design temperatures. Clients should specify the required reliability based on the importance of the road.

5 Test methods and equipment

Over and above the HVS and its associated instrumentation, a range of test methods and associated equipment for the road construction industry have been developed and implemented. These include:

- Stress-In-Motion (SIM) technology
- Dynamic Cone Penetrometer (DCP)
- Laboratory Mixer for foam-stabilised road materials, including recycling
- Erosion Test Device for stabilised road layers in wet conditions
- Rapid Compaction Control Device (RCCD)
- HVS pavement performance monitoring instrumentation
- Gravel roads test kit.

5.1 Stress-In-Motion (SIM) technology

The Stress-In-Motion (SIM) technology originated from the HVS test programme, and is specifically designed to quantify the rather complex tyre-road interaction mechanisms associated with a rolling tyre on the surface of the road (Maina & De Beer, 2005). It is focused on the three-dimensional stress field at the rubber-road contact interface to inform on appropriate tyre loading as input for the mechanistic road design methodology mentioned earlier. An impressive list of external clients has made use of the CSIR's SIM technology, including the Technical University of Delft (TuDelft) in the Netherlands, the University of California at Berkeley and the California Department of Transportation, the Texas Department of

Transportation, and recently the Florida Department of Transportation (USA). Locally, an important demonstration project has been completed for SANRAL, and a user-friendly data base exists to provide road designers with tyre data for road design (and tyre design) purposes. Over the years, more than 20 different pneumatic truck tyres have been tested with the HVS and various SIM systems, and the data are currently available in a dedicated tyre database from the CSIR. In conjunction with the data, the CSIR developed the TyreStress software technology package, a stand-alone user-friendly software package.

A design data pack of the SIM technology for SIM Mark V is available at the CSIR and SIM Mark VI is almost ready for field acceptance testing using the HVS; it includes a three-dimensional Weigh-In-Motion (WIM) capability. This development is another world first and, if it proves to be durable, could be transferred to industry for production and use in both the roads and the truck tyre design and evaluation domain.

5.2 Dynamic Cone Penetrometer (DCP)

The Dynamic Cone Penetrometer (DCP) is an ideal tool for the evaluation of gravel roads, lightly trafficked surfaced road structures and subsurface investigations for major types of road structure. Value addition was done on the DCP post-data analysis process in the currently available Windows-based DCP software. With this technology, in association with the HVS test programmes, a road structure classification system was developed for the classification of light surfaced road structures, where a road structure is classified as either 'deep', 'shallow' or 'inverted'. By knowing this, a better definition of the road structure allows for optimum initial design, maintenance and also rehabilitation design of such structures. The DCP is very sensitive to in situ moisture content and is ideal in this respect, quantifying the effect of improper drainage and associated seasonal variations in road structures. The former is critical for road designers, road technicians and road owners for sustainable light road structures in a network.

Empirical functions were developed with HVS technology by which the structural capacity of the above road pavement types can be estimated with a fair degree of accuracy; this is an indispensable tool for road technicians and road designers. Currently, there are more than 100 users of the CSIR DCP software. The CSIR also manufactures the DCP and its components for industry. The DCP is now an ASTM standard in the USA, and is a locally defined technology for use in the current guidelines for the design, maintenance and upgrading of appropriate roads and associated standards in southern Africa, as well as on major road rehabilitation projects. Regular courses on the use and interpretation of the DCP are held at the CSIR.

5.3 Laboratory mixer for foam stabilised road materials, including recycling

During early 2002, a need was identified for a unique mixer for foamed bitumen treated recycled road materials in the laboratory. The development of the mixer was done in association with a producer of road recycling equipment in Germany. The result of this development is a robust, easy-to-use, twin-shaft pug-mill mixer with variable speed and direction, capable of mixing 25–30 kg of material (previously only 2 to 3 kg of material could be mixed) ranging from clays to gravel with a maximum aggregate size of 19.5 mm. The mixer was developed to work together with an existing foamed bitumen production plant for laboratory mix design of these recycled materials. After mixing, the device is rotated and the sample discharged into the cover for easy handling. Extensive testing confirmed that the bitumen is distributed evenly throughout the mix, closely simulating field conditions.

The mixer has a potential application that is wider than the initial application with bitumen foam recycling, and this potential can still be exploited. Mixing of any road material for the purpose of stabilisation or modification can be done in most soil laboratories.

Since 2002 approximately 50 of these mixers have been successfully produced and are currently active in the field of foam-based recycled pavement technology around the world. A few units have also been sold to local and overseas universities for purposes of research on recycled materials.

5.4 Erosion Test Device for stabilised road layers in wet conditions

Extensive HVS testing on main road structures, especially near the coast in KwaZulu-Natal during the 1980s, identified a rather unique type of wet failure of these road structures, resulting from the combined

effect of repetitive tyre loading and wet conditions. The failure mechanism identified was an erosion type of failure, where subsurface soil from the upper and, to a lesser extent, the lower stabilised sub-base was displaced underneath the road surfacing layers, causing a type of permanent deformation pattern on the surface of the road. Closer investigation identified the problem, and a laboratory wheel-track device, referred to as the Erosion Test Device, was designed and manufactured for use in the laboratory to evaluate stabilised road materials for erodibility under the actions of wet trafficked conditions. A test protocol was developed and forms part of some design protocols currently available in southern Africa. Applying this test protocol and its associated failure criteria to candidate stabilised road materials serves to limit the use of substandard materials and hence reduce the risk of premature road failure in wet conditions, in general. Several Erosion Test Devices have been manufactured and also sold to private practice. One was sold to the University of Texas at Austin, USA.

5.5 Rapid Compaction Control Device (RCCD)

An increased need for, and therefore spending on, trench reinstatements (service utility trenches) in the urban environment resulted in a need for increased quality control of the degree of compaction achieved with the reinstatement of road layers in these trenches. The need was for a quick and relatively easy way to evaluate layerworks during back-filling operations. The Rapid Compaction Control Device (RCCD) was developed and implemented in industry. The RCCD is a unique impulse road layer penetrometer, based on a spring-loaded hammer and mechanical trigger mechanism which is operated by a single semi-skilled operator. Correlations were also developed during a laboratory study between the RCCD, DCP and the California Bearing Ratio (CBR). The RCCD was successfully developed and today over 250 units have been manufactured and sold by the CSIR. The device is now being actively used in road and trench layerworks in many urban and rural environment contracts, as well as in quality control of unsealed roads as discussed in Section 5.7.

5.6 HVS-associated instrumentation

In conjunction with the HVS, numerous unique pavement sensors and instrumentation techniques have been developed to measure various engineering parameters, such as stresses and strains at various depths, permanent layer deformation and elastic movements. One of the successes is the Multi-Depth Deflectometer (MDD). This CSIR-patented product is used to measure in-depth pavement layer behaviour in terms of elastic and plastic movements (Basson et al., 1983). Other associated instrumentation includes a wireless Profilometer (for the measurement of surface deformation or ruts), a wireless Road Surface Deflectometer (for the measurement of surface deflections), a Crack Activity Meter (measuring two-dimensional crack movements on bridge decks and concrete joints) and an automated data acquisition system (for automatic data capturing of all associated instrumentation).

5.7 Gravel roads test kit

As a result of a project for the International Labour Organization (ILO) in Kenya, a quality control system specifically for unsealed roads constructed using labour-based methods was developed (ILO/ASIST, 1998). This was followed by a request to develop a 'kit' that would include all of the equipment necessary to carry out the recommended testing. This was done and the kit is supplied in metal trunks containing various combinations of simple and robust test equipment. More than 100 kits have been sold, mostly to overseas institutions (e.g. United Nations Office for Project Services – UNOPS).

6 Concluding remarks

In this paper an attempt has been made to summarise some of the contributions made by the CSIR to the advancement of knowledge on the design, construction, maintenance and rehabilitation of road pavements. Over the past 40 years, the HVS and associated laboratory studies have proved invaluable in the development of cost-effective pavement design solutions, some of which are unique to South Africa, and in the generation of new knowledge on the behaviour and performance of road materials and pavement systems. These and other studies, such as those conducted on low-volume and unsealed roads, have led to the development of not only user guidelines and specifications, but also hard and soft products, such as laboratory or field test equipment or methods, and the PADS series of software products. These outcomes have been taken up by road authorities and practitioners both locally and internationally, and are being used by them on a routine basis.

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Note

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