

SOUTH AFRICAN PAVEMENT ENGINEERING MANUAL

Chapter 14 Post-Construction



**AN INITIATIVE OF THE SOUTH
AFRICAN NATIONAL ROADS AGENCY SOC LTD**

Date of Issue: October 2014

Second Edition

South African Pavement Engineering Manual
Chapter 14: Post-Construction

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Chapter 14

Post-Construction



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BACKGROUND

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You are
here



SCOPE

The South African Pavement Engineering Manual (SAPEM) is a reference manual for all aspects of pavement engineering. SAPEM is a best practice guide. There are many relevant manuals and guidelines available for pavement engineering, which SAPEM does not replace. Rather, SAPEM provides details on these references, and where necessary, provides guidelines on their appropriate use. Where a topic is adequately covered in another guideline, the reference is provided. SAPEM strives to provide explanations of the basic concepts and terminology used in pavement engineering, and provides background information to the concepts and theories commonly used. SAPEM is appropriate for use at National, Provincial and Municipal level, as well as in the Metros. SAPEM is a valuable education and training tool, and is recommended reading for all entry level engineers, technologists and technicians involved in the pavement engineering industry. SAPEM is also useful for practising engineers who would like to access the latest appropriate reference guideline.

SAPEM consists of 14 chapters covering all aspects of pavement engineering. A brief description of each chapter is given below to provide the context for this chapter, Chapter 14.

Chapter 1: Introduction discusses the application of this SAPEM manual, and the institutional responsibilities, statutory requirements, basic principles of roads, the road design life cycle, and planning and time scheduling for pavement engineering projects. A glossary of terms and abbreviations used in all the SAPEM chapters is included in Appendix A. A list of the major references and guidelines for pavement engineering is given in Appendix B.

Chapter 2: Pavement Composition and Behaviour includes typical pavement structures, material characteristics and pavement types, including both flexible and rigid pavements, and surfacings. Typical materials and pavement behaviour are explained. The development of pavement distress, and the functional performance of pavements are discussed. As an introduction, and background for reference with other chapters, the basic principles of mechanics of materials and material science are outlined.

Chapter 3: Materials Testing presents the tests used for all material types used in pavement structures. The tests are briefly described, and reference is made to the test number and where to obtain the full test method. Where possible and applicable, interesting observations or experiences with the tests are mentioned. Chapters 3 and 4 are complementary.

Chapter 4: Standards follows the same format as Chapter 3, but discusses the standards used for the various tests. This includes applicable limits (minimum and maximum values) for test results. Material classification systems are given, as are guidelines on mix and materials composition.

Chapter 5: Laboratory Management covers laboratory quality management, testing personnel, test methods, and the testing environment and equipment. Quality assurance issues, and health, safety and the environment are also discussed.

Chapter 6: Road Prism and Pavement Investigation discusses all aspects of the road prism and pavement investigations, including legal and environmental requirements, materials testing, and reporting on the investigations. The road pavement investigations include discussions on the investigation stages, and field testing and sampling (both intrusively and non-intrusively), and the interpretation of the pavement investigations. Chapters 6 and 7 are complementary.

Chapter 7: Geotechnical Investigations and Design Considerations covers the investigations into fills, cuts, structures and tunnels, and includes discussion on geophysical methods, drilling and probing, and stability assessments. Guidelines for the reporting of the investigations are provided.

Chapter 8: Material Sources provides information for sourcing materials from project quarries and borrow pits, commercial materials sources and alternative sources. The legal and environmental requirements for sourcing materials are given. Alternative sources of potential pavement materials are discussed, including recycled pavement materials, construction and demolition waste, slag, fly ash and mine waste.

Chapter 9: Materials Utilisation and Design discusses materials in the roadbed, earthworks (including cuts and fills) and all the pavement layers, including soils and gravels, crushed stones, cementitious materials, primes, stone precoat fluids and tack coats, bituminous binders, bitumen stabilized materials, asphalt, spray seals and micro surfacings, concrete, proprietary and certified products and block paving. The mix designs of all materials are discussed.

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Chapter 10: Pavement Design presents the philosophy of pavement design, methods of estimating design traffic and the pavement design process. Methods of structural capacity estimation for flexible, rigid and concrete block pavements are discussed.

Chapter 11: Documentation and Tendering covers the different forms of contracts typical for road pavement projects; the design, contract and tender documentation; the tender process; and the contract documentation from the tender award to the close-out of the Works.

Chapter 12: Construction Equipment and Method Guidelines presents the nature and requirements of construction equipment and different methods of construction. The construction of trial sections is also discussed. Chapters 12 and 13 are complementary, with Chapter 12 covering the proactive components of road construction, i.e., the method of construction. Chapter 13 covers the reactive components, i.e., checking the construction is done correctly.

Chapter 13: Quality Management includes acceptance control processes, and quality plans. All the pavement layers and the road prism are discussed. The documentation involved in quality management is also discussed, and where applicable, provided.

Chapter 14: Post-Construction incorporates the monitoring of pavements during the service life, including traffic monitoring, the environment, and pavement condition monitoring. The development, and causes and mechanisms of distress are illustrated and explained. A description of pavement management systems is provided. Routine and preventative maintenance are discussed, as are rehabilitation and reconstruction.

FEEDBACK

SAPEM is a “living document”. The first edition was made available in electronic format in January 2013, and a second edition in October 2014. Feedback from all interested parties in industry is appreciated, as this will keep SAPEM relevant.

To provide feedback on SAPEM, please email sapem@nra.co.za.

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1. INTRODUCTION

When construction has been completed the pavement enters various operational stages, including:

- Initial bedding in and **defects liability period**, occurring soon after construction.
- **Design life** and normal operations with **routine maintenance**.
- Distress occurrence and **preventative maintenance**, to guard against moisture ingress and moisture accelerated distress.
- **Terminal condition** and rehabilitation.

These stages need to be carefully managed by the road authority to maximise the pavement life and its related performance. For example, it is well known that timeous maintenance significantly extends the pavement life of a well designed and constructed pavement, depending on the traffic loads, subgrade conditions and environment. Therefore, preventative maintenance is essential for all Southern African roads, and forms an important element of most Pavement Management Systems (PMS).

Monitoring the performance of pavements and related PMSs, as well as project level rehabilitation assessments, provides valuable information that must be fed back into the entire pavement engineering system, particularly into amendments to design standards and specifications.

This chapter describes the activities and actions that need to be taken by the parties involved in managing the pavement, to ensure its longevity and achievement of the expected performance, or better. Feedback and communication actions that help to improve the entire Pavement Engineering System are also discussed. The elements involved are illustrated in Figure 1.



Defects Liability Period

The defects liability period is normally 12 months. During this period, the Contractor is liable for any defects that are not part of normal "wear and tear".

Upon expiry of the defects liability period, the contractor is paid any outstanding retention monies, and the works are taken over by the road authority.

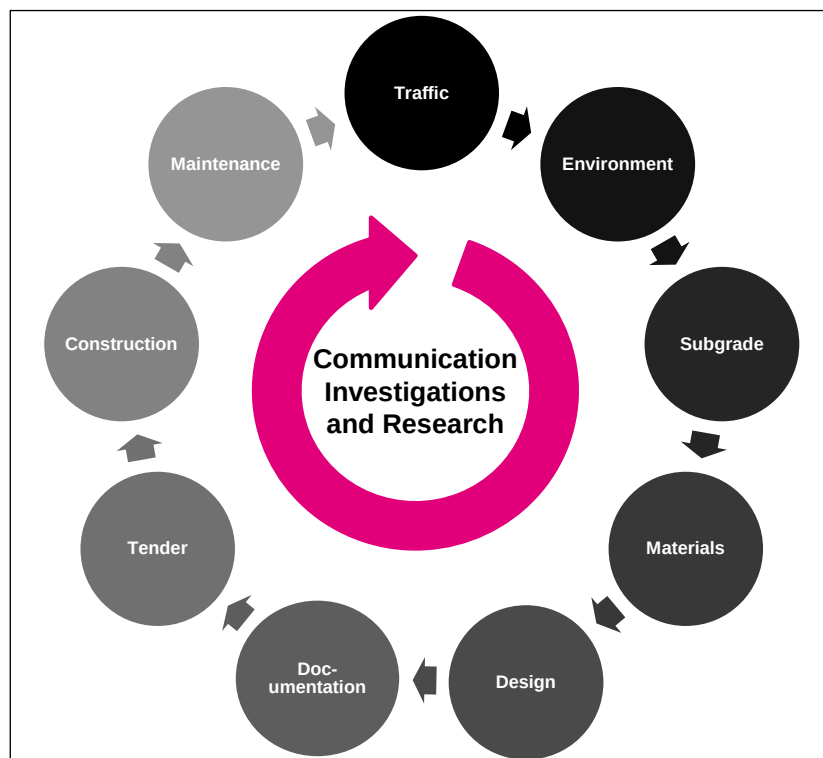


Figure 1. Pavement Engineering System

Each element in the system has an influence on the ultimate performance and life of the pavement. The system objectives generally include achieving the design life of the pavement without resorting to excessive maintenance expenditure. This requires constant monitoring of each element, and providing feedback to industry on aspects that do not achieve the expected results.

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Most of the elements of the system are discussed in detail in previous chapters of this manual, for which specific references are given in Table 1. However, all previous chapters are aimed at providing information that is relevant to pavement design. This chapter is aimed at introducing the systems and procedures used to monitor and manage the pavement system, to ensure that pavements achieve their design lives or better, and to provide for continuous improvement in performance and cost-effectiveness.

Table 1. Chapter References for Elements in Pavement Engineering System

System Element	Chapter	Section in Chapter
Traffic	Chapter 6: Road Prism and Pavement Investigation	4. Accommodation for Traffic Investigations
	Chapter 10: Pavement Design	4. Design Traffic Estimation
Environment	Chapter 6: Road Prism and Pavement Investigation	3: Legal and Environmental Requirements
	Chapter 10: Pavement Design	3.7. Environmental Considerations
Subgrade	Chapter 3: Materials Testing	2. Tests on Soils and Gravels
	Chapter 4: Standards	2. Standards for Soils and Gravels
	Chapter 6: Road Prism and Pavement Investigation	5. Road Prism Investigation
	Chapter 7: Geotechnical Investigations and Design Considerations	3. Geotechnical Investigations 4. Fills 5. Cuts
	Chapter 9: Materials Utilisation and Design	2. Roadbed 3. Earthworks
	Chapter 10: Pavement Design	5: Pavement Investigation and Design Process 7, 8, 9: Structural Capacity Estimation
Materials	Chapter 3: Materials Testing	All sections
	Chapter 4: Standards	All sections
	Chapter 5: Laboratory Management	All sections
	Chapter 6: Road Prism and Pavement Investigation	8. Materials Testing for Investigation
	Chapter 7: Geotechnical Investigations and Design Considerations	4. Fills
	Chapter 8: Material Sources	All sections
	Chapter 9: Materials Utilisation and Design	All sections
Design	Chapter 6: Road Prism and Pavement Investigation	5. Road Prism Investigations 6. Potential Problem Areas in the Roadbed 7. Road Pavement Investigation
	Chapter 7: Geotechnical Investigations and Design Considerations	4. Fills 5. Cuts
	Chapter 9: Materials Utilisation and Design	All sections
	Chapter 10: Pavement Design	All sections
Documentation	Chapter 6: Road Prism and Pavement Investigation	9. Composition of Test Data and Reporting
	Chapter 7: Geotechnical Investigations and Design Considerations	9. Composition of Test Data and Reporting
	Chapter 11: Documentation and Tendering	3. Design Documentation 4. Contract Documentation Preparation 7. Contract Documentation
Tender	Chapter 11: Documentation and Tendering	5. Tender Documentation 6. Tender Process
	Chapter 12: Construction Equipment and Method Guidelines	All sections
	Chapter 13: Quality Management	All sections
Maintenance	Not discussed in detail in this manual, refer to Concrete Road Construction Manual (C&CI, 2008), and Routine Road Maintenance Manual (SANRAL, 2009)	

2. ROAD ASSET MANAGEMENT

The pavement and its formation and surfacing are components of the road asset, which are managed as part of road asset management systems (RAMS). The concepts of road asset management are described in detail in the TRH22 Pavement Management Systems Manual, which is currently being updated. This manual expands on all the concepts of road asset management as part of the broader topic of asset management contained in the ISO 55000 series.

The Pavement Engineer needs to recognize the need for ongoing management of the pavement to ensure that it reaches or exceeds its expected useful life. It also needs to be understood that asset management is an ongoing process that is set up to ensure continual improvement of the system and its ability to manage these assets, as illustrated in Figure 2.

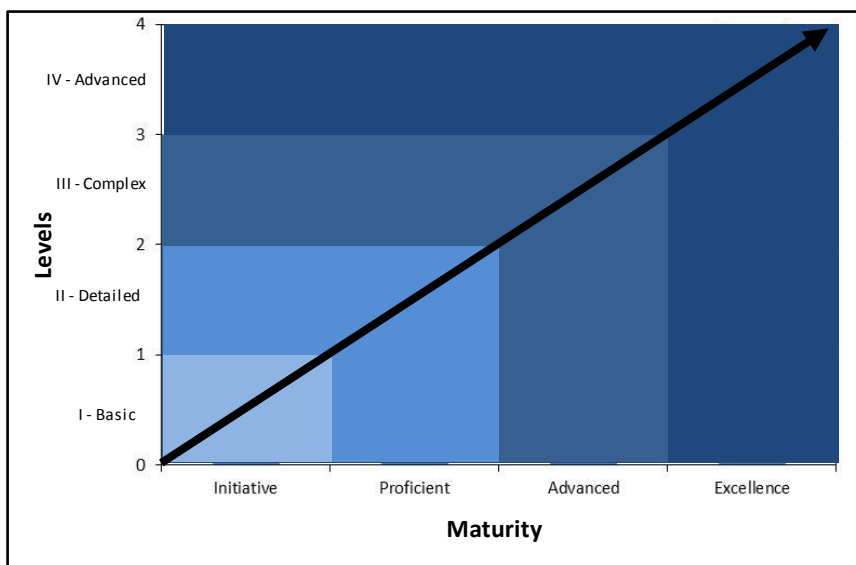


Figure 2. Road Asset Management Systems (RAMS): Stages of Development

The following seven concepts are outlined in the ISO 55001 standard with a view to improving asset management in general, for the benefit of stakeholders:

- The Organization
- Leadership
- Planning
- Support
- Operation
- Performance Evaluation
- Improvement

The TRH 22 manual takes this further with respect to road asset management. Its ten parts include:

- Part A: General and Organisation
- Part B: Inventory Data
- Part C: Asset Valuation
- Part D: Usage and Condition Data
- Part E: Indices
- Part F: Situational Analysis
- Part G: Needs Determination
- Part H: Asset Management Plans
- Part I: Feedback Loop

The following sections focus specifically on pavement management and related activities.

2.1 Sustainability

In addition to a broad understanding of asset management, the pavement engineer also has to have a broad understanding of sustainability. Sustainability is often described as making up three pillars: economic growth, ecological balance and social progress, as represented in Figure 3 (Drexhage and Murphy, 2010; Heemskerk, et al).

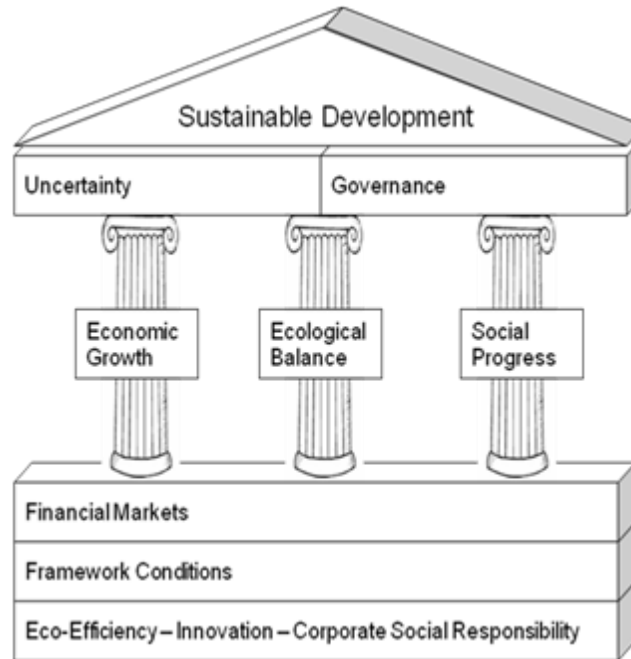


Figure 3. Three Pillars of Sustainability

In the context of pavement engineering, the pillars have the following focus:

(i) Economic Growth

This means ensuring that the pavement design makes optimal use of local materials and resources and maximizes the benefit/cost ratio of pavement projects. Maintenance and rehabilitation, and their affordability, also need careful consideration. Overall, the road and its pavement should provide a smooth comfortable and safe surface for the movement of goods and people to contribute to the economic growth of the country.

(ii) Ecological Balance

This involves trying to ensure that the pavement materials do not deplete natural resources, and do not cause harm to the natural environment through the use of pollutants. At best, the pavement should only consume minor amounts of new materials and assist to dispose of waste, for example, the use of ground rubber in bitumen-rubber asphalt.

(iii) Social Progress

This pillar involves trying to ensure that designs and works are aimed at furthering social equity. The involvement of communities in the construction and the maintenance of infrastructure is a key aspect of this. In addition, the designs need to ensure that the road facilitates access to markets and opportunities for all people.

These pillars in turn support sustainable development, which reflect all of the activities undertaken as part of road asset management and are aimed at deriving maximum value from the assets over their lifetimes.

3. PAVEMENT MONITORING

Various elements of the pavement engineering system are monitored over time. These are discussed briefly in the following sections.

3.1 Traffic

In addition to determining the axle loads used for the pavement design, traffic also needs to be monitored, regulated and enforced to ensure that overloading does not occur. Axle loads measurements have shown that up to 25%, and more, of truck axles can be overloaded when axle load enforcement is lax. However, this can be reduced to less than 5% with good enforcement. Sophisticated axle load measurement and enforcement weighbridges have been installed along several national and provincial roads, to facilitate axle load monitoring and enforcement. An example of such a weigh station is the Heidelberg Traffic Control Centre on the N3, shown in Figure 4.



Overloaded Vehicles

Axle loads measurements have shown that up to 25%, and more, of truck axles can be overloaded when axle load enforcement is lax. However, this can be reduced to less than 5% with good enforcement.

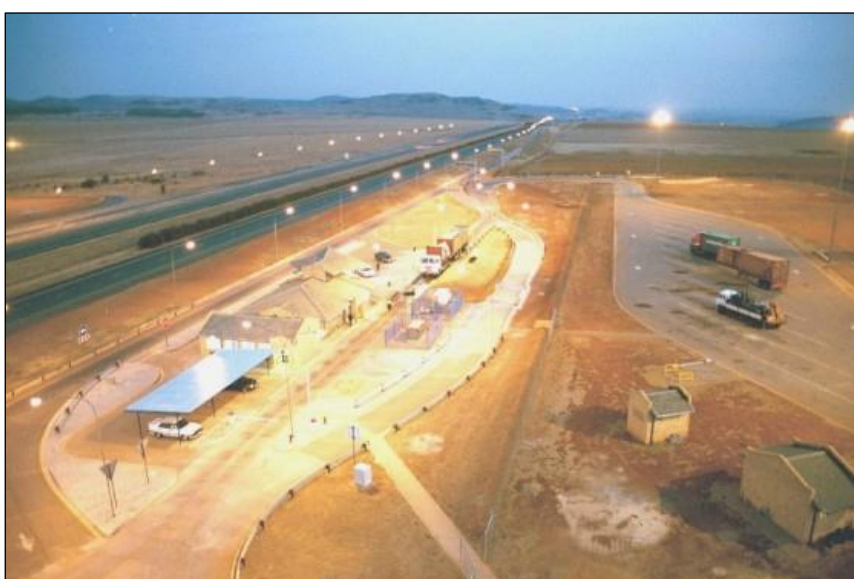


Figure 4. Heidelberg Traffic Control Centre on the N3

Methods of collecting axle load data are set out in TMH3 and TMH8, while recommendations for traffic loads to be used in pavement design are contained in TRH16. Chapter 10: 4 also discusses many aspects of traffic measurement and inputs for design.

Findings on actual loads measured, as well as tyre pressures and axle configurations, are an essential part of the pavement design system and need to be fed back to industry on a regular basis. This allows design procedures and systems to be adjusted to suite the prevailing conditions.

3.2 Environment

The environment influences pavement performance in two ways:

- **Moisture** from the surface or subsurface enters and weakens the pavement layers, or causes moisture related shrinkage and swelling of clay subgrades.
- **Sunlight** heats and softens thick asphalt layers, while ultra-violet radiation hardens bituminous binders, making them more brittle and prone to cracking and shrinking.
- **Freezing and thawing** of moisture in the pavement and roadbed can cause instability and a loss of support for the pavement layers. Freeze/thaw is not a major issue in South Africa, because of the temperate climate.



Moisture in Pavements

Water getting into a pavement, especially a granular base pavement, significantly weakens the material, and can cause premature failure.

On the most important principles of pavement design is to keep water out the pavement.

The concept of moisture entering pavement layers is shown in Figure 5. To prevent moisture ingress, the pavement is provided with a waterproof surfacing, as well as longitudinal and subsoil drainage, as shown in Figure 6.

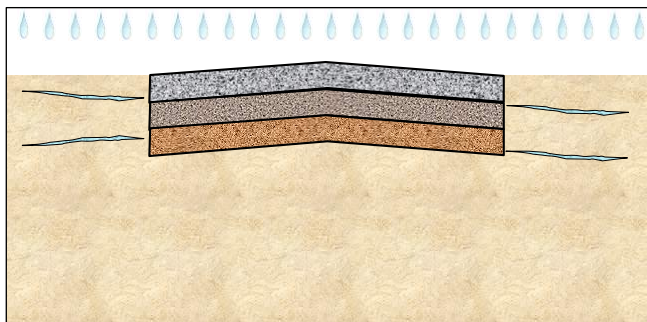


Figure 5. Moisture Entering Pavement Layers

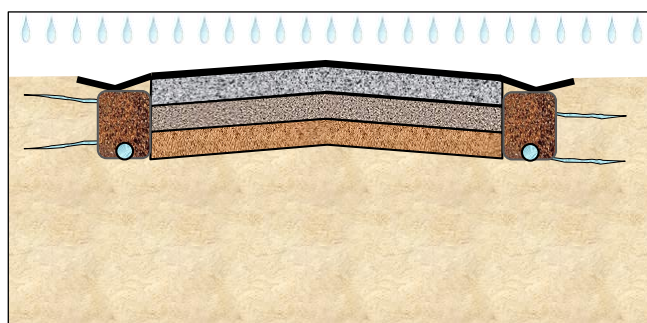


Figure 6. Waterproof Surfacing on Pavement

The waterproofness of the surfacing and effectiveness of the drainage system are very important factors contributing to good performance in pavements. Therefore, these elements are inspected separately during visual inspections to record any problems.

The design of surface and subsurface drainage systems is described in detail in the SANRAL Drainage Manual 5th edition (2006), available for download or hard copy purchase on www.nra.co.za.

When moisture has entered the pavement and weakened the pavement layer, traffic loads can cause deformation that inevitably results in decompaction and further weakening of the pavement. An example of moisture accelerated distress is shown in Figure 7. Once this has occurred, resealing of this portion of the pavement is no longer a viable option.



Waterproofing

The waterproofness of the surfacing and effectiveness of the drainage system are very important factors contributing to good performance in pavements.



Figure 7. Moisture Accelerated Distress

3.3 Condition Monitoring and Visual Assessment

The condition of the pavement and its surfacing and drainage systems should be monitored regularly to identify and repair defects, as well as any changes in the rate of deterioration. The manifestations of distress are discussed in more detail in Section 4.

Visual assessments are used to observe and record distress that is visually apparent in an objective way as possible. To do this, relatively rigid guidelines have been established for assessors to ensure reproducibility and repeatability. Over the years, various guidelines have been available. However, a revised TMH9 will be available in 2014, which will supersede the older manuals, such as TRH6, TRH19, TMH12 and M3-1. The revised TMH9, "Standard Visual Assessment Manual" includes sections for surfaced roads, block pavements, concrete pavements and gravel roads. It describes how to rate distress in terms of degree (severity) and extent (prevalence) of the type of distress.

Monitoring the ability of the surfacings in South Africa to retain their ability to prevent moisture ingress is very important, as most pavements have water-susceptible bases. It is important to realise that it is sometimes very difficult to locate and identify cracking in thin surfacings. Automated systems to detect cracks used in many parts of the world are typically only suitable for detecting wide cracks in pavements with thick asphalt surfacings, and are, therefore, not generally suitable for use in South Africa.



Crack Monitoring

Monitoring the ability of the surfacings in South Africa to retain their ability to prevent moisture ingress is very important, as most pavements have water-susceptible bases. It is important to realise that it is sometimes very difficult to locate and identify cracking in thin surfacings. Automated systems to detect cracks used in many parts of the world are typically only suitable for detecting wide cracks in pavements with thick asphalt surfacings, and are, therefore, not generally suitable for use in South Africa.

3.4 Surveillance Measurements

In addition to the visual observation and evaluation of distress, several mechanical and electronic devices are used to detect problems in a more objective manner. These devices, and their application, are shown in Table 2. Surveys that utilise these devices are often done on a network level on a regular basis. SANRAL for example, surveys their network every two years. Some of the toll concessions survey their network annually. A network survey generally collects less data at wider intervals than a project level survey.

Table 2. Surveillance Devices

Laser Profilometer	Falling Weight Deflectometer (FWD)
This equipment has a beam mounted with several lasers to measure the transverse profile and ruts, and an inertial profilometer to measure the longitudinal profile of each wheel path. Vehicles also typically include a laser with a larger beam to measure the mean profile depth at regular intervals. The vehicle typically operates at highway speeds, and collects extensive data quickly and efficiently. 	The falling weight deflectometer operates by dropping a weight onto the road via a thick rubber pad. The transient pressure pulse caused as the weight strikes the road simulates a tyre passing over the road at highway speeds. The resulting deflection bowl is measured using accelerometers that are mounted on a beam and spaced around 300 mm apart. The accelerations produced are integrated twice electronically to output the deflection at each accelerometer. See Chapter 6: 7.3.4 and Chapter 10: 3.5.1 and 7.6. 
Brake Force Trailer (Griptester)	La Croix Deflectograph
The brake force trailer measures the force required to tow the trailer when the third wheel is braked. The instrument includes an ABS system to prevent sliding. 	The La Croix deflectograph is an automated Benkelman beam mounted on a slow moving truck. As the truck moves forward, the beam is moved forward on a sliding arm and lowered to the surface of the road. The moving wheels of the truck then move towards the end of the deflection beam and the deflection is measured as the difference between its original position when placed on the road and its final position between the rear wheels. 

On behalf of COTO, guidelines have been developed for network level surveillance, and include:

- Guidelines for Network Level Measurement of **Road Roughness** (2007)
- Guidelines for Network Level Measurement of **Skid Resistance and Texture** (2008)
- Guidelines for Network Level Measurement of **Pavement Deflection** (2009)
- Guidelines for Network Level Measurement of **Rutting** (2010a)
- Guidelines for Network Level **Imaging and GPS Technologies** (2010b)

These guidelines provide valuable information on the use of the devices, calibration, planning surveys and how to interpret the data. These guidelines will be published as TMH13. Chapter 6: 7.3 also discusses the use of these devices for pavement investigations.

4. DISTRESS

As the pavement carries traffic during service conditions, several types of defects cause distress to occur with time. Although most distress represents symptoms of underlying problems and is only visible on the surface of the pavement, the location, form and nature of the distress relates to its underlying cause and possible defects. The distress is categorised depending on the part of the pavement to which it relates.

4.1 Distress in Flexible Pavements

The various manifestations of distress in flexible pavements are grouped depending on their origin, location and consequences, such as:

- **Surfacing distress:** Distress of the surfacing that could result in loss of integrity and water ingress into the base.
- **Pavement structural distress:** Distress of the pavement structure itself, caused by either:
 - Traffic loads overstressing the pavement layers, or
 - Environmental, subgrade and construction stresses causing cracking of the layers.
- **Drainage distress:** Areas where drainage is not effective, causing moisture ingress.
- **Functional distress:** Areas where the distress results in functional deterioration of the pavement and causes road user discomfort or reduced safety.

4.1.1 Surfacing Distress

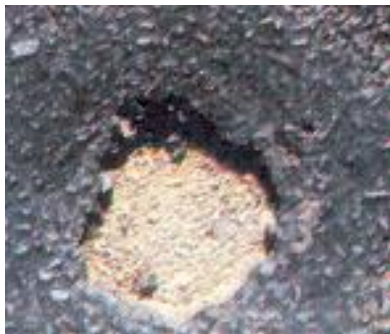
Surfacing distress is distress of the road surfacing and is relatively obvious to observe and rate. The types of surfacing distress for flexible pavements are shown in Table 3.



Block Pavements

Block pavements are not discussed in this chapter, as they are not in widespread use in South Africa, and are not used on national or provincial roads.

Table 3. Surfacing Distress in Flexible Pavements

Surface Cracking Surface cracking generally occurs throughout the pavement and not just in the wheel paths. It is normally caused by shrinkage of the binder due to ageing, and loss of its less durable components. 	Surface Texture Surface texture is an important issue for safety. Smooth pavements have low skid resistance. 
Binder Condition Aged binders become brittle and result in surface cracking and aggregate loss. 	Permeability Permeability is an issue as when water can enter the pavement the base is compromised. 
Aggregate Loss/Ravelling Aggregates become loose in the mix and detach under the action of traffic. 	Surface Failure Surface failures involve loosening of the surfacing and detachment from the underlying base. 
Bleeding (Asphalt Surfacing) Bleeding is caused by the binder migrating to the surface of the pavement, and typically occurs when a mix has a high binder content, known as a "rich" or "fatty" mix. 	Bleeding (Seals) Bleeding seal caused in this case by a binder rising up through a porous seal in a situation with a high temperature. Seals also bleed for other reasons (TRH3). 

Note the following regarding detecting and rating of some surfacing distresses:

- **Binder condition** is difficult to rate as it involves picking out some of the binder with a screwdriver and is dependent on the temperature at which the rating is made. Normally the binder can be rolled into a ball between the fingers to bring it to around 25 °C. The fresher and more lively the binder, the more it colours and sticks to the hands. Dry old binder will not stick and results in very little discolouration. When the binder gets very old and brittle, aggregate loss occurs, which is easy to rate and depends on the amount of visible aggregate loss.
- **Bleeding** is easy to detect and rate.
- **Permeability** is difficult to rate during routine inspections as it is only really visible after a rainstorm. Darker wet areas take some time to dry out due to the quantity of water absorbed by the surfacing. Obviously drier areas adjacent to fine cracks where water has entered the underlying pavement, are also normally clearly visible. TMH9, therefore, does not include a rating for permeability, only for voids that are apparent within the surfacing itself during routine inspections.



Rating Permeability

Permeability is difficult to rate during routine inspections as it is only really visible after a rainstorm.

In addition to the above surfacing distress, some visual assessments also include observations of the surface texture and its variability across the width of the road. This has relevance for skid resistance, as well as the type of treatment to be applied.

4.1.2 Pavement Structural Defects

Pavement structural defects related to deeper problems within the pavement must be recognised. These defects are divided into those that are caused by traffic and are normally confined to the wheel paths, and, those caused by other stresses in the pavement such as drying shrinkage, thermal stresses and deep-seated underlying movements. These defects are either traffic associated or environmentally induced. Traffic associated distresses in flexible pavements are shown in Table 4 and environmentally induced distresses in Table 5.

4.1.3 Drainage Distress

In addition to these manifestations of weaknesses or problems, the drainage condition and related defects are relatively easy to rate in wet weather due to standing water on the road, which leads to pavement distress and is also hazardous for traffic. In dry conditions, it takes some experience to rate the drainage conditions. Indicators such as rutting, vegetation and gravel that trap water on the road, or luxuriant growth of plants alongside the road are normally indicative of poor surface and subsurface drainage, respectively. These are illustrated in Table 6.

4.1.4 Functional Distress

Functional distresses affect the ability of the pavement to carry traffic comfortably and safely. Functional problems occur as a secondary manifestation of the drainage problems. For example, a pothole that causes tyres to burst, and standing water that causes vehicles to run off the road. In these situations, the pavement becomes less fit for its intended purpose of carrying traffic comfortably and safely. In addition to the above direct functional consequences of pavement distress, there are other manifestations that also cause functional problems, as shown in Table 7.

Table 4. Traffic Associated Distress in Flexible Pavements

Crocodile Cracking Crocodile cracking is the typical cracking that occurs in the wheel path when axle loads cause excessive flexure and cracking of the surfacing. They are normally barely visible to the naked eye and then, as water ingresses through the cracks and softens the base, the sizes of the cracks increase and become easily visible. At this stage they are normally associated with deformation. 	Rutting Rutting typically occurs over long sections where the axle loads cause consolidation or shear failure of one or more of the pavement layers. The narrower the rutting, the higher in the pavement the deformation has normally occurred. 
Deformation Deformation is normally confined to short sections with poor drainage where moisture has weakened the pavement and caused local deformation. It quickly becomes associated with crocodile cracking and further accelerated distress. 	Pumping Pumping occurs when fine material from the underlying layer is pumped through surface cracks by traffic loads. It is often the first indicator of pavement failure. It is detectable by fines, looking like white powder, lying at the edges of the crack. 
Potholes Potholes occur when the cracked area of surface lifts off the base and the traffic causes the base to erode. 	Patching Patching is the end result of one of the above forms of distress when maintenance is performed. Care should be taken to distinguish between surface patching where surface failures are patched and structural patching, which is not confined to the surfacing. Good quality patching that addresses the cause of distress may result in a long term repair of the defect. However, poor quality patching is normally of a very temporary nature, and generally rapidly deteriorates to form potholes again. 

Table 5. Environmentally Induced Distress in Flexible Pavements

Block Cracking	Longitudinal Cracking
Block cracking occurs when stabilized layers shrink and crack. In most cases this is due to a stabilized base, but in some cases block cracking from a stabilized subbase reflect through the surfacing. 	Longitudinal cracking is normally due to deep-seated movement under the pavement such as slip failure or shrinkage of clayey subgrades. 
Transverse Cracking	Undulations
Transverse cracking is normally caused by rapid cooling and thermal shrinkage of an asphalt layer. This does not occur often in South Africa and when transverse cracking occurs it is normally the early manifestation of block cracking. 	Undulations occur due to moisture related shrinkage and swelling of an underlying clayey subgrade. This is normally caused by seasonal moisture changes or uneven drying due to trees and bushes extracting moisture from the subgrade. 

Table 6. Drainage Distress

Ponding	Vegetation
Surface drainage defects occur wherever water can pond on the surface of the pavement and cause spray, aquaplaning and moisture ingress. 	Luxuriant vegetation alongside the road is normally indicative of standing water alongside the road that can ingress into the pavement layers. 
Edge Build Up	Side Slope
Vegetation along the edge of the road often results in sand build up and entrapment of water on the road. 	Where a gravel shoulder is not maintained for extensive periods, it may end up sloping toward the pavement causing moisture ingress. 
Rutting	
When a pavement has rutted excessively, water is trapped in the wheel path and can cause aquaplaning. 	

Table 7. Functional Distress in Flexible Pavements

Riding Quality Loss of riding quality causes a rough and unpleasant ride, and loss of safe travelling speed. 	Edge Drop Excessive edge drop can be very dangerous if a vehicle runs off the road. 
Edge Break Edge breaks can encroach into the wheel path causing vehicles to have to swerve dangerously. 	Reserve Encroachment When traders encroach into the road reserve, unsafe situations related to pedestrians and stopping vehicles can easily occur. 
Skid Resistance Loss of skid resistance can be particularly dangerous in wet weather. 	Dangerous Potholes Potholes can either cause blowouts, with catastrophic results, or dangerous swerving. 
Bush Encroachment Bush encroachment results in loss of sight distance, or extremely dangerous situations when veld fires occur. 	

4.2 Distress in Rigid Pavements

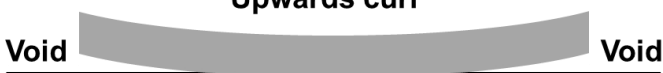
Distress in rigid pavements manifests as:

- **Construction** related distress
- **Structural** failure
- **Functional** distress

4.2.1 Construction Related Distress

Construction related distress occurs from poor construction practices. These are described in Table 8. For more information on construction and quality control of concrete pavements, see Chapter 12: 3.12 and Chapter 13: 8.

Table 8. Construction Related Distress in Rigid Pavements

Curling
Curling results from more shrinkage at the top of the slab compared to the bottom. This generally results from a high water content in the concrete, or from poor curing. Upwards curl Void 
Surface Shrinkage Cracking
Surface shrinkage cracks are due to a high water content and poor curing. This results in prominent secondary transverse or longitudinal cracking as a result of the high stress state. The high stress state can be due to loading, curling or temperature. 
Late Sawing or Misalignment of Dowels
Late sawing or misalignment of dowels during construction results in cracking close to a joint. Shrinkage surface cracking adds to the development of distress in the form of spalling in the crack. 

4.2.2 Surfacing Distress

Surfacing distress related to rigid pavements primarily relates to the competency of the concrete's surface, and is very rare in well-constructed pavements.

4.2.3 Structural Failure

Structural distress in rigid pavements is almost always due to a combination of traffic and environmental stresses. It depends on the type of concrete pavement and includes:

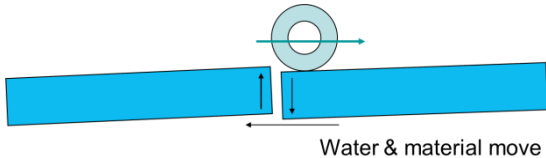
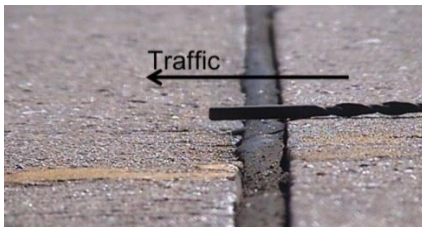
- **Spalling** of the edges of joints
- Corner breaks, D cracking, or transverse and longitudinal **cracking** across a slab
- **Faulting** across joints or cracks in the slabs
- **Punch-outs** in continuously reinforced concrete paving
- Defects in **joint sealants** resulting in moisture ingress and, possibly, pumping

These defects are illustrated, and briefly explained in Table 9.

4.2.4 Functional Distress

Functional distress in rigid pavements is a loss in riding quality due to faulting in jointed pavements, or, shattered slabs of all other types of rigid pavements.

Table 9. Structural Failure in Rigid Pavements

Corner Cracking Corner cracking occurs from curling of the slab and loading under traffic. 	Cracking Close to a Joint Cracking close to a transverse joint as a result of a void between the slab and subbase. 
Lack of Load Transfer A lack of load transfer at transverse joints or cracks leads to relative vertical movements at cracks and joints, pumping of the subbase material, and the development of voids and faulting. 	Faulting 
Closely Spaced Cracks Closely spaced cracks lead to a loss of stiffness of the concrete slab, movement at the cracks under loading, spalling of the cracks and, eventually, to punch-outs and shattered slabs. 	Punch-outs Punch-outs occur from closely spaced cracks. 
Shattered Slabs Shattered slabs as a result of cracking of all forms. 	

4.3 Distress Development

Distress manifests in the pavement at various stages during its operational life, as illustrated in Figure 8. The occurrence of distress prior to the expiry of the design life of the road is indicative of a failure in the pavement engineering system. This is representative of system reliability, and should be investigated in detail to determine the causes and mechanisms of distress. If the causes and mechanisms of distress are not catered for in the conventional pavement engineering systems, these details should be fed back into the system to ensure continuous improvement.

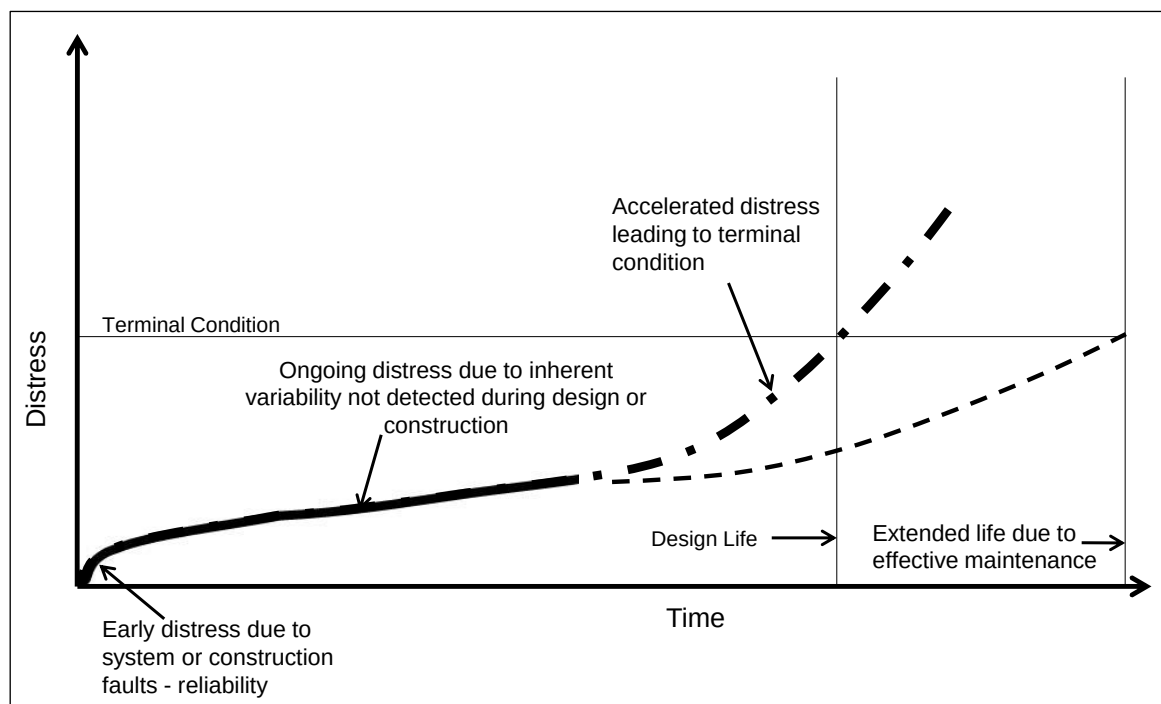


Figure 8. Pavement Distress Development

If the defects occur during the defects liability period and are due to construction defects (patent defects) that were not detected by the QA processes, but are now readily apparent, it must be repaired by the Contractor. One of the major problems is deciding whether the obvious patent defects are the only construction defects that exist, or whether other defects are present but have not yet manifest (latent defects).

Other defects that occur in the early stages of the design life are normally representative of variability that was not detected through the pavement engineering system. It is generally not cost-effective to cater for all possible variability in the design and construction processes, as the investigative costs and related quality assurance processes would be prohibitively expensive. Nevertheless, efforts should be made to limit this to below 0.5% of the length of a wheel path. In other words, while every effort is made to identify and accommodate all potential problems during the course of design and construction, isolated distress may occur early in the life of the pavement due to causes that are not identified and remedied in the normal course of design and construction. These defects should be repaired by addressing the underlying causes. From that point onwards, no further pavement distress should occur until the pavement starts to approach the end of its design life.

When the pavement life approaches its design life, the development of distress accelerates, normally due to traffic loads and moisture ingress. Preventative maintenance should be applied to limit such moisture ingress and extend the life of the pavement for as long as possible.

When the pavement distress starts to approach between 5% and 10% of the length of the wheel path, as defined in TRH4, it is approaching a terminal condition, depending on the functional class of the road, and will require rehabilitation.



Patent and Latent Defects

Patent defects are defects that are patently obvious and require immediate repair.

Latent defects are defects that are not immediately apparent, but will probably result in the pavement not achieving its design life.

4.4 Causes and Mechanisms of Distress

It is important for the pavement engineer to recognize the various forms of distress, and to identify their causes and mechanisms with confidence. There are many techniques that can be applied to do this, the most important of which is to carry out careful observations and apply common sense. In the context of typical South African pavements, which benefit greatly from being kept dry, the following topics provide some basic concepts to determine the causes and mechanisms of distress.

4.4.1 Water Ingress

The first basic step is to determine whether the distress development is accelerated due to water ingress. While it is a given that water ingress accelerates almost all forms of distress, it is important to assess whether the distress has progressed to the point where it is no longer worth spending money on trying to prevent further water ingress. This is normally a function of the degree of deformation that has occurred. Such a situation may occur because:

- **Weakening of a layer** has already occurred to the degree that rapid deformation will continue, or, that it cannot provide adequate support to the layer above or to the traffic loading.
- **Crack movements** that cannot be accommodated, even with a bitumen-rubber seal.

If water is a contributing factor, and its influence can be arrested, it needs to be recognised and considered in all further evaluation. The SANRAL Draining Manual is a good reference for all drainage issues.



Drainage

Drainage is an extremely important consideration for pavements! Water is the primary cause of premature failure, accelerated distress and reduced structural capacity.

All aspects of drainage are comprehensively covered in SANRAL's Drainage Manual and not repeated in SAPEM. Download the Drainage Manual from www.nra.co.za.

4.4.2 Uniform Sections

Distress seldom occurs uniformly over the entire pavement area. Areas of some uniformity need to be identified to group the causes and mechanisms of distress. Once a uniform section is allocated, treatments are kept the same for the section. Determining uniform sections is an important component of rehabilitation analyses, and is discussed in Chapter 10: 5 and in TRH12.

4.4.3 Appearance of Deformation

The appearance of deformation is indicative of how deep-seated the cause is. For example, wide ruts are indicative of deep weakness. This may also be indicative of rutting due to compaction and related settlement, rather than shear failure. It is important to try to identify these differences, as rutting due to compaction results in strengthening of the layers while shear failure weakens the layers. This can be tested using a DCP or deflections, for example.

Deformation that is isolated or variable is inevitably caused by subgrade variation or drainage problems. In particular, deformation in cut and not in fill shows underlying weaknesses or water ingress in the cut relative to the fill. This sometimes occurs at the transition from cut to fill, due to weaker materials in these areas, rather than deeper into the cut where the materials may be less weathered and harder.

Chapter 10: 5.3.2 discusses types of distress and appropriate rehabilitation options for flexible and rigid pavements.

4.4.4 Past Performance

If historic measurements are available, it is useful to try and assess whether the distress has accelerated. Rapid acceleration may be due to moisture ingress, or severe weakening of pavement layers due to fatigue.

4.4.5 Structural Capacity

It is important to assess the structural capacity of the pavement in broad terms, relative to the traffic it has carried. This provides an indication of whether the pavement is approaching the end of its design life, or if it still has significant capacity.

If the pavement has carried little traffic relative to its designed structural capacity, and distress is relatively general, then the cause of the reduced life must be sought. If the distress is only isolated, then this could primarily be due to defects in these isolated places.

Alternatively, if it is fairly old and has carried significant traffic loads without undue deformation, or serious structural distress, then it may continue to carry similar loads for some time in the future, provided it is kept dry and circumstances do not change. If the pavement includes substantial bound layers subject to fatigue-based deterioration, then the present status of such fatigue damage, and some estimate of remaining fatigue life, should be made.

Methods for determining the structural capacity and remaining life are detailed in Chapter 10: 7, 8 and 9.

4.4.6 Construction Defects

Early or isolated distress is often due to construction defects that need to be identified through test pits or other investigations, as described in Chapter 6: Section 5 and 7. It is important for a pavement engineer to be present at every test pit that is dug in the pavement to carefully evaluate every layer and discontinuity, and to try to identify any strengths and weaknesses. Thin biscuit layers, or the presence of water, need to be carefully assessed. Test pits in existing pavement layers are expensive, and their number should be limited. At the same time, the value obtained from each individual test pit should be maximised through careful inspection and evaluation. Test pits should be dug in both good and poorly performing areas to try to identify the differences and possible causes of distress in the poor areas.

4.4.7 Testing

Testing needs to be carefully directed to increase the degree of confidence associated with the investigation results, to arrive at final conclusions, as directed in guidelines, such as TRH12.

Finally, when all the investigations are complete and the results set out in a comprehensive format (See Chapter 10: 5 and TRH12), the causes and mechanisms of distress need to be identified with confidence to ensure that pavement maintenance, repairs or rehabilitation are directed at the causes, and not only the symptoms of distress.



Trial Pits

Test pits in existing pavement layers are expensive and their number should be limited. At the same time, the value obtained from each individual test pit should be maximised through careful inspection and evaluation. Test pits should be dug in both good and poorly performing areas to try to identify the differences and possible causes of distress in the poor areas.

5. PAVEMENT MANAGEMENT SYSTEMS

Pavement Management Systems (PMS) are used to manage the storage and use of current and historic pavement data and network level condition assessments, to programme and prioritise preventative maintenance and rehabilitation. These systems involve regular monitoring of distress, as well as surveillance measurements, and are described in some detail in:

- **TRH22:** Road Asset Management System
- **TMH9:** Standard Visual Assessment Manual

Pavement management systems represent a range of technical tools that are used to meet the strategic, tactical and maintenance scheduling needs of the road authority. They form an important element of the greater asset management framework shown in Figure 9.



Figure 9. Asset Management Framework

Figure 9 shows how the technical tools form one of four major overlapping elements, with issues from each element influencing the other. For example:

- **Administrative arrangements** influence the degree to which the Road Authority's PMS contains extensive details of the road network, or whether detailed pavement maintenance and rehabilitation decisions are outsourced.
- **Owner and customer needs** influence the trigger conditions used for various classes of roads, to initiate improvements.
- **Business arrangements** with consulting engineers include coming up with recommendations on whether to reseal or rehabilitate the road on a project level. The decisions may require detailed condition data. Alternatively, if the PMS has adequate data to make the decision on whether to reseal or rehabilitate, then this information need not be collected again at a project level. Only the information required to quantify the work may be required at a project level.

Pavement management systems take on a variety of forms, with varying complexity. An essential element of a modern PMS is a well-integrated database that forms part of a larger Road Asset Management System (RAMS) and stores the road definitions and related data. The road definition dataset sets out how the road network is structured, and normally consists of road numbers, road types, and start and end kilometres of the road sections and links. It forms the basis for storing all other data normally collected by kilometre distance along the road section. A typical integrated road management data system includes the elements shown in Figure 10. An example of an integrated PMS system where all available data can be viewed graphically, analysed in a spreadsheet, and analysed statistically is shown in Figure 11 and Figure 12.

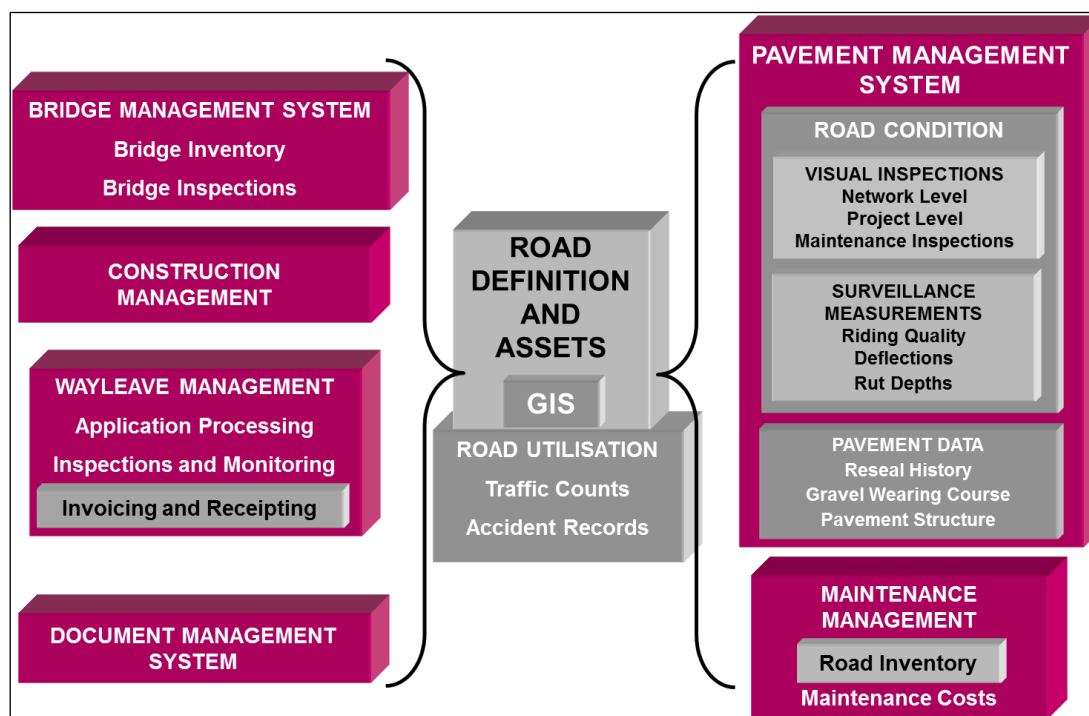


Figure 10. Typical Road Management System Data Layout

An element of PMS systems involves optimisation of preventative maintenance and rehabilitation options to minimise costs, while maximising an objective function such as pavement condition, riding quality, user benefits or some combination thereof.

The PMS systems provide valuable information at a network level, which is used to feed back into the pavement engineering system to improve overall system cost-effectiveness and efficiency.

South African Pavement Engineering Manual

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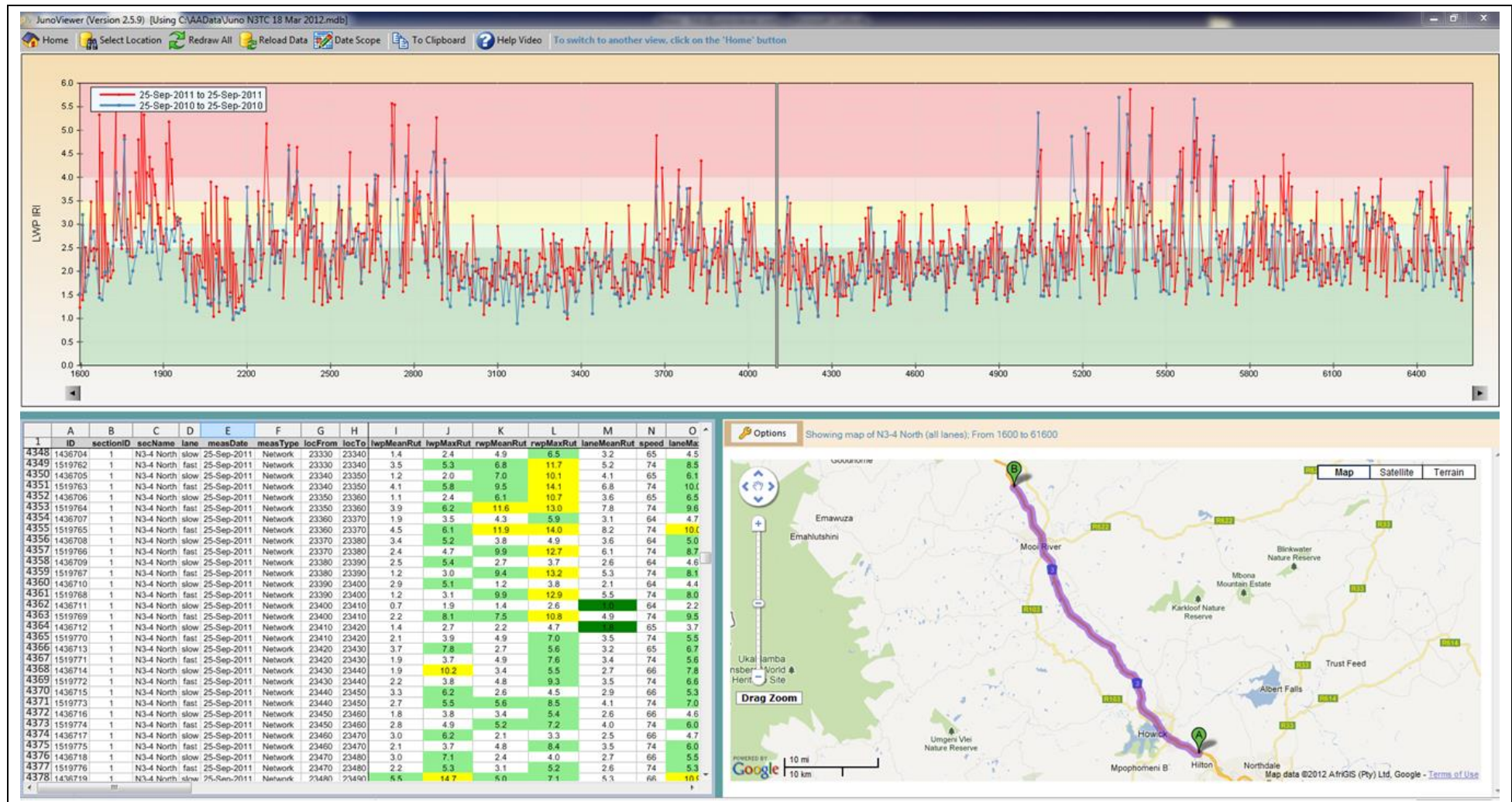


Figure 11. Example of Integrated PMS showing Map and Individual Data

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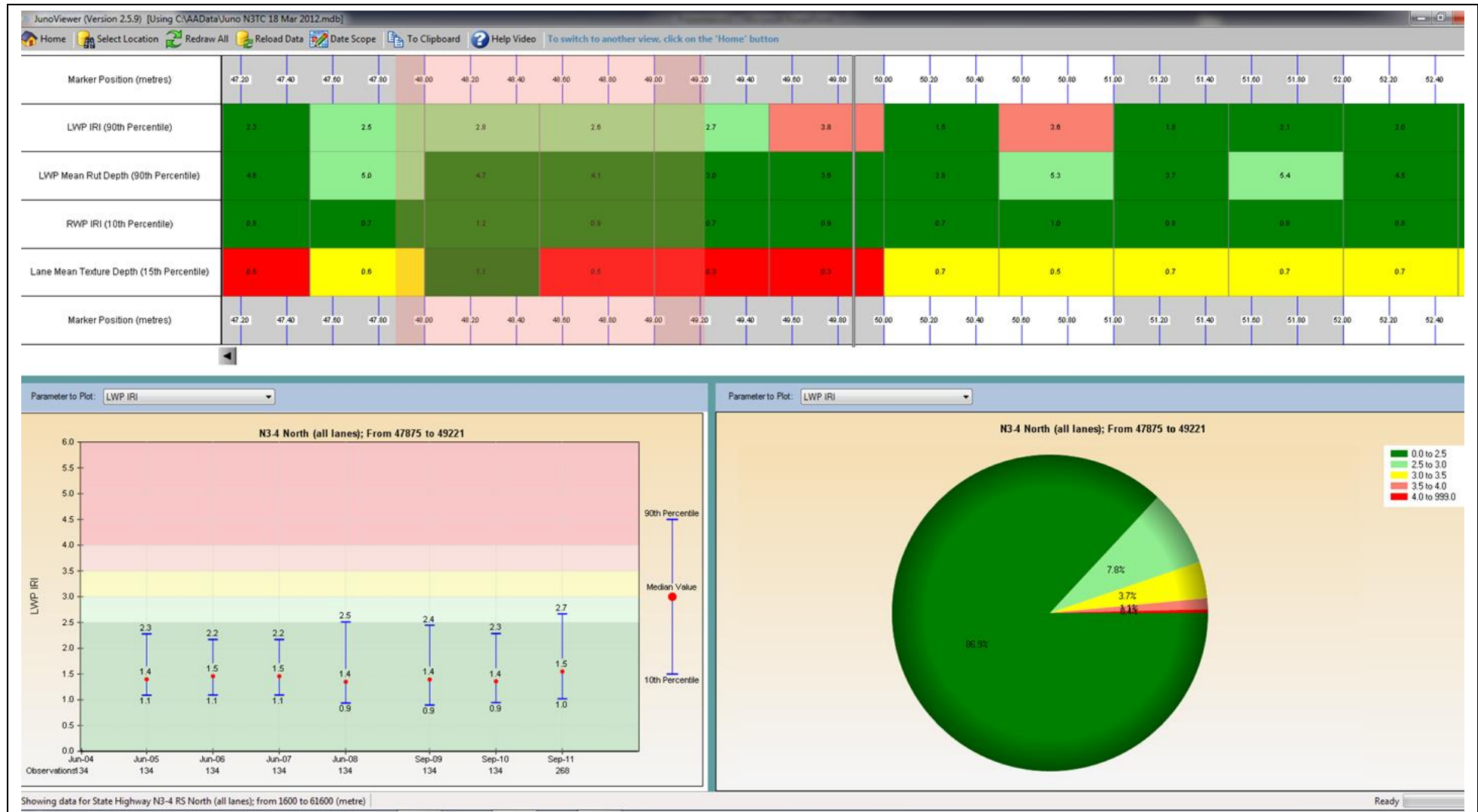


Figure 12. Example of Integrated PMS showing Statistics and Trends

6. MAINTENANCE

6.1 Maintenance Needs

Road managers need to understand their maintenance needs in order to budget and allocate funds to the various maintenance activities. These needs encompass a wide variety of activities and are listed in Table 10, extracted from TMH22.

Table 10. Maintenance Activities

Need Category	Description
Routine Maintenance: Cyclical (3 months to 3 years)	All routine cyclical activities that are carried out on a daily basis, including: • Blading of unpaved roads and shoulders • Drainage maintenance including bridge drainage • Road reserve and vegetation maintenance • Maintenance of ancillary components • Line-marking maintenance
Routine Maintenance: Condition	All condition or event driven repair activities that are carried out at short notice, including: • Drainage repair and reinstatement • Waterway repair and reinstatement • Repair of ancillary components • Crack sealing and patching • Repair of cut and fill slopes • Reinstatement of line-marking • Minor repair of structures • Spot regravelling • Reshaping of unpaved roads
Periodic Maintenance (5-7 years)	Longer term cyclical activities, such as: • Surfacing rejuvenation and thin slurries • Replacement of road sign faces
Resurfacing	Includes the following activities, initiated by condition: • Regravelling • Resealing of the pavement surface using a chip and spray or thin overlay
Special Maintenance	• Resurfacing preceded by extensive patching and repair • Bridge joints and bearing replacement • Major repair of damage to roads, ancillary assets and structures
Rehabilitation	Repairs to the pavement to restore condition and functionality, including: • Light rehabilitation (overlays and/or reworking of base layer) • Heavy rehabilitation (reworking of deeper layers or the addition of new base layer)
Reconstruction	Reconstruction/replacement of the assets
Betterment	This involves upgrades to certain elements of the asset, such as: • Specific alignment and drainage improvements • Intersection improvements • Accident black spot eliminations • Bridge strengthening
Expansion	Expansion of the road in terms of the number of lanes (including structures)
Upgrading	Upgrading of a road from one type to another
New Roads	Construction of entirely new greenfields roads
Ancillary Assets	The construction of facilities, such as weighbridges that are used to prevent damage to the road, or any other major ancillary asset or component.

In the following sections, some of these activities related to pavements are expanded upon.

6.2 Routine Maintenance

Routine maintenance allows any defects that could severely affect pavement performance to be detected at an early stage, through regular maintenance inspections. Typical repairs undertaken as part of routine maintenance, as described in the SANRAL Routine Road Maintenance Manual (RRM), include:

- Patching
- Crack sealing
- Edge repairs

These maintenance activities should preferably be carried out before the distress has extended to the stage that it requires major patching or rehabilitation. These are generally condition-based activities. This means that the condition of pavements needs to be inspected regularly to identify the need for this maintenance. Because PMS network level inspection activities are only carried out on an annual basis at most, custodians of roads must inspect the pavements on a daily, weekly and monthly basis, depending on the level of traffic and importance of the road, to identify any defects and initiate repairs.

6.3 Preventative Maintenance

Preventative maintenance is aimed at arresting the rate of distress development, and reducing the requirements for more substantial maintenance. It typically involves repair of the pavement structure where required. For flexible pavements, resealing to prevent further moisture ingress in accordance with TRH3: Design and Construction of Surfacing Seals is typically done. Such resealing may involve relatively low cost crack or joint sealing, or the application of diluted emulsions, through to more expensive bitumen-rubber chip seals. On concrete pavements, the replacement of individual concrete slabs is also required.

Preventative maintenance may also involve some drainage improvements, to prevent water from accumulating on the pavement surface or in side drains, or reducing the subgrade moisture by means of subsoil drains. The SANRAL Drainage Manual is a good reference for drainage improvements.

All well-managed pavement systems involve a substantial amount of preventative maintenance, applied routinely to retard distress development. These activities are normally initiated through RAMS systems on the basis of the age and brittleness of its surfacing.



Potholes

Potholes are an extreme case of flexible pavement distress. Routine preventative maintenance such as the periodic application of fog sprays, timeous resealing and the sealing of cracks should prevent the occurrence of potholes.

The CSIR has a guideline for potholes repairs: **"POTHoles: Technical Guide to Their Causes, Identification and Repair"**, 2010. Available for download on www.csir.co.za/pothole_guides.



References for Seals

- TRH3: **Design and Construction of Surfacing Seals**. 2007. Available for download on www.nra.co.za.
- For seals using modified binders: TG1: **The Use of Modified Bituminous Binders in Road Construction**. Second edition. 2007. Published by the Asphalt Academy. Available for download on www.asphaltacademy.co.za.
- Further **useful information** is available on the Australian website: www.arrb.org.au/sealing/index. This site was established to assist in the dissemination of good, as well as innovative, international practice in the field of spray seals.
- For slurry seals, SABITA Manual 28: **A Guide on the Design and Use of Slurry Surfacing** (2011). Available for download at www.sabita.co.za.

7. REHABILITATION AND RECONSTRUCTION

7.1 Rehabilitation

When the pavement has deformed to the point where maintenance or the application of a seal can no longer improve the pavement performance, or where its riding quality is unacceptable, then more substantial rehabilitation is required. The rehabilitation design process is set out in detail in TRH12: Flexible Pavement Rehabilitation Investigation and Design and Chapter 7: Section 5 and Chapter 10: 5 of this guideline. Although TRH12 is aimed at flexible pavements, the principles also apply to rigid pavements.

In the case of concrete pavements, rehabilitation may involve substantial slab replacement, joint resealing, crack sealing and overlaying. Various other specialist treatments are also applied, depending on the circumstances.

7.2 Reconstruction

When a pavement has reached the end of its design life and is no longer suitable for the traffic being carried, reconstruction is required. Such a pavement will have several factors that indicate it has reached a terminal condition, such as excessive maintenance requirements, poor riding quality and high accident rates. This reconstruction is often accompanied by widening and other geometric improvements.

8. COMMUNICATION, INVESTIGATIONS AND RESEARCH

The road authority in charge of the pavement is the primary conduit for investigating and researching problems, and communicating results and details of good and poor pavement performance back to industry. Some examples of past successes in this regard are:

- The investigations and development of the **Dynamic Cone Penetrometer** (DCP) pavement investigation and design method (De Beer et al, 1988; Kleyn et al, 1989; De Beer 1991).
- The development and operation of the **Heavy Vehicle Simulators** (HVS) and resulting pavement design methods for, particularly, G1 crushed stone base pavements (Jooste et al, 2005 and 2008)

The communication of problems and results of investigations and research involves informal communication to industry, as well as formal communication through conferences, seminars and industry groups, such as the Road Pavements Forum.

Well designed and well-constructed pavements provide good performance and value for money. However, pavement engineering is not complete when the road is built, and continues to form part of a larger pavement engineering system geared to ensure optimal cost effectiveness and good service to road users and the country's economy.

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TRH Revisions

Many of the TRH guideline documents are in the process of being updated. See the SANRAL website, www.nra.co.za for the latest versions.