

TECHNICAL RECOMMENDATIONS
FOR HIGHWAYS

DRAFT TRH 22

**PAVEMENT MANAGEMENT
SYSTEMS**

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PREFACE

The Technical Recommendations for Highways (TRH) series has been written for the practising engineer, technologist and technician. It describes current, recommended practice in selected aspects of highway engineering. The series is based on South African experience and research results and has the full support of and is issued under the auspices of the Committee of State Road Authorities (CSRA).

This document has been compiled for CSRA by a subcommittee of the Highway Materials Committee of the CSRA. In order to confirm its validity in practice it will be circulated in draft form for a trial period before being finalised and submitted to CSRA for approval. This document, Draft TRH 22, will therefore be in use for a limited period during which you are welcome to send suggestions for improvement to -

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ACKNOWLEDGEMENT

The information and guidance provided by the members of the subcommittee and other persons is appreciated and gratefully acknowledged.

SYNOPSIS

This document provides guidelines to assist road authorities with the implementation and operation of a pavement management system in an endeavour to promote the compatibility of systems.

The guidelines are presented in the following four divisions:

- a) Organisational and implementation matters.
- b) Facets of a basic pavement management system, and the related outputs.
- c) Network level enhancement of the basic system and interpretation of the outputs.
- d) Updating of data and upgrading of the system.

The TMH 9 manual on the visual assessment of flexible paved roads is a companion document to TRH 22.

SINOPSISIS

Hierdie dokument voorsien riglyne om padowerhede te help met die implementering en bedryf van 'n plaveiselbestuurstelsel in 'n poging om die versoenbaarheid van die stelsel te bevorder.

Die riglyne word in die volgende vier afdelings aangebied:

- a) Organisatoriese en implementeringsaspekte.
- b) Aspekte van 'n basiese plaveiselbestuurstelsel, en verwante uitsette.
- c) Netwerkvlak verbetering van die basiese stelsel en interpretasie van uitsette.
- d) Opdatering van data en opgradering van die stelsel.

Die TMH 9 handleiding oor visuele evaluering van geplaveide paaie is 'n bybehorende dokument tot TRH 22.

KEYWORDS

Pavement Management System

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1. INTRODUCTION

1.1 SCOPE OF THIS DOCUMENT

These technical recommendations were developed to provide guidance for implementing and operating a pavement management system (PMS). They are aimed primarily at the system manager, but can also be used by upper management to obtain an overview of the PMS concepts. This document not only covers current practice (the objective of TRH documents), but also proposes techniques which, if implemented, would lead to the availability of more compatible PMS information at national level. Although this document provides guidance and recommendations, the system manager will in many cases have to use engineering judgement in selecting the appropriate methods and defining the system details.

Various aspects of pavement management are at present still under development in South Africa, and current recommended practice does not exist in all facets of PMS (e.g., network optimisation). Many proposed techniques and procedures are currently being evaluated, however. An addendum (yellow pages) incorporating some of these proposals has been added to the TRH 22 to facilitate the evaluation process and encourage comments on these proposals before a decision is made on the possible incorporation thereof into the final document. Care should therefore be exercised when the techniques are used since they have not been accepted as current practice.

There are five major sections in the TRH 22 as shown in Table 1.1. Figure 1.1 shows the master flow diagram for the document and depicts the chapters within the major sections. The first two chapters provide an introduction to PMS. The remaining chapters have been structured to address the various components of a PMS.

TABLE 1.1: MAJOR SECTIONS OF THE TRH 22

CHAPTERS	SUMMARY OF CONTENTS
1 - 2	Introduction and organisational matters
3 - 8	The basic system and basic outputs
9 - 10	Network level enhancement and interpretation of PMS outputs
11	Data updating and system upgrading
Addendum	Techniques and procedures under review at present

A companion document, the TMH 9 (Standard Visual Assessment Manual for Flexible Pavements), provides guidelines for the visual assessment of the condition of flexible paved roads at network level for use in a PMS. The specific information will not be repeated, but reference will be made to it where relevant.

This document has been compiled for use by the road authorities under the Committee of State Road Authorities (CSRA). Although many examples and some techniques apply specifically to flexible paved roads, most of the general concepts and procedures can also be applied to non-flexible paved roads and to urban road networks.

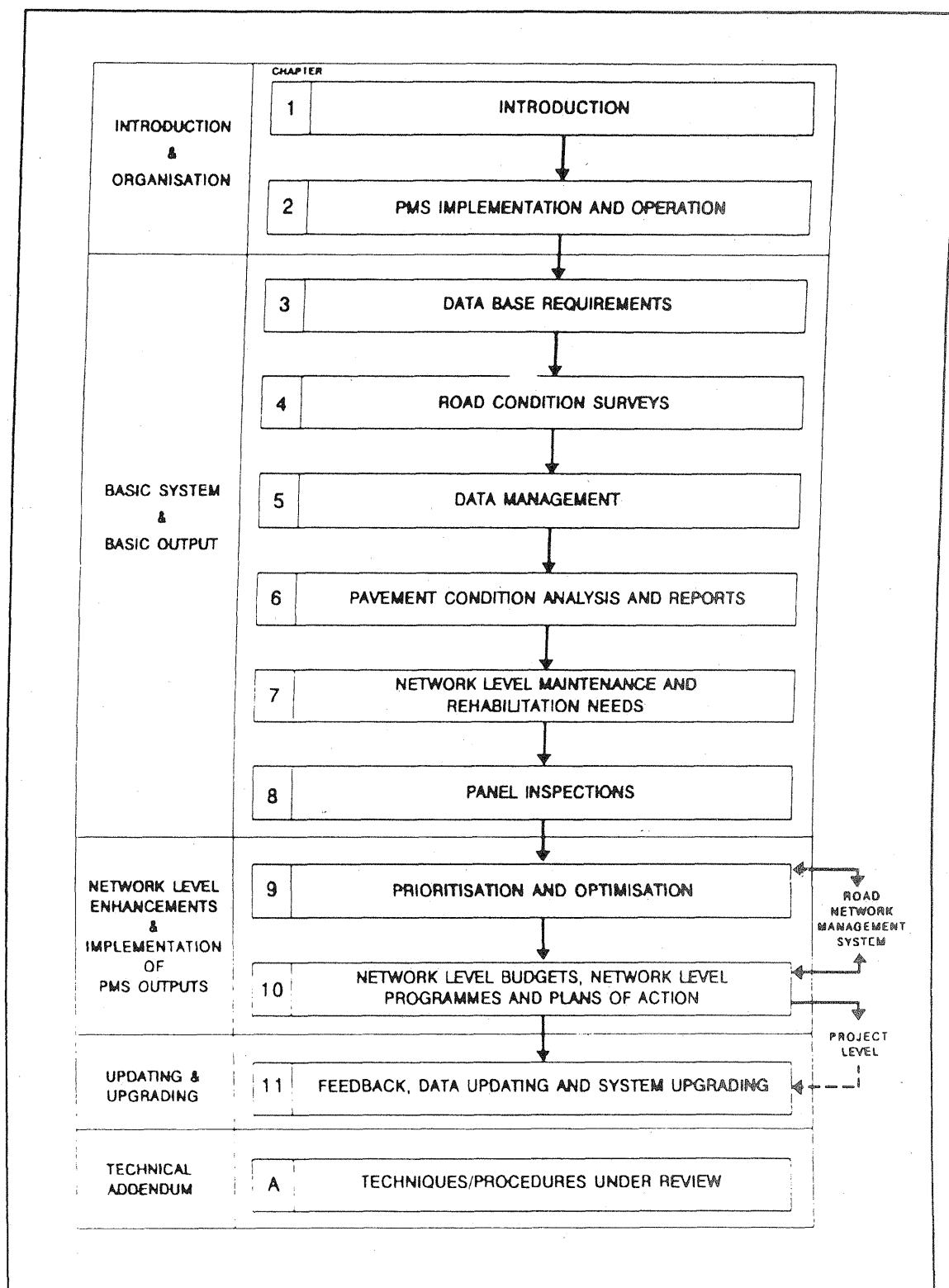


Figure 1.1: TRH 22 master flow diagram

1.2. DEFINITIONS

1.2.1 Pavement management system (AASHTO, 1985)

A pavement management system (PMS) is an established, documented procedure for the execution of the pavement management activities listed below in a systematic and co-ordinated manner. It can also be described as well-developed, documented methods to determine cost-effective what, where, when and who answers for the management of pavements (Carmichael, 1990).

A PMS should provide consistent, objective, and defensible procedures that effectively address the need for road maintenance. A PMS consists of a number of essential elements structured to serve decision-making responsibilities at various management levels and includes the following:

- Pavement surveys related to condition and serviceability (monitoring).
- A data base containing all pavement related information required for decision making.
- Decision criteria based on acceptable standards.
- Analysis scheme (including impact analysis).
- Selection.
- Implementation procedures.

The purpose of a PMS is to improve the efficiency of the decision-making process, expand its scope, provide feedback regarding the consequences of decisions and the results of activities, and ensure the consistency of decisions made at different levels within the same organisation (Hudson, Haas and Pedigo, 1979). The three decision levels in pavement management are depicted in Table 1.2.

TABLE 1.2: THREE PAVEMENT MANAGEMENT DECISION LEVELS

LEVEL	DECISION LEVEL	FUNCTION
1	Policy / Executive level	- Goals - Funding - Authority - Policy - Standards - Aspects of accountability
2	Planning level Project selection <i>(Where to spend money.)</i> Programming <i>(How to spend it.)</i> Budgeting <i>(How much to spend.)</i>	- Targets to serve policy - Total system trade-offs - Levelling of resources - Multi-year scheduling of projects - Cash flow - Prioritisation - Optimisation
3	Execution level <i>(Project construction and maintenance activities)</i>	- Construction - Field costs - Appropriate techniques - Quality control

1.2.2 Pavement management as part of a road management system

A road management system (RMS) is a set of procedures aimed at maximising the utility of a road network. These procedures are used by the managers of the road network, with the aid of computerised facilities, to produce information and evaluate alternative strategies in a specific analysis period and to incorporate feedback mechanisms regarding the various attributes, criteria and constraints involved in optimising the following:

- Maintenance of existing facilities
- Improving facilities to required standards (according to changing circumstances and demands)
- Establishing new facilities when needed.

The management functions or levels for carrying out these tasks are similar to those summarised in Table 1.2.

The planning function of management is addressed by the Road Management System, which comprises the following main subsystems (Report 589/1, 1989):

- Pavement management system
- Geometric management system
- Gravel road management system
- Maintenance management system
- Bridge management system
- Traffic counting procedures and systems
- Accident reporting procedures and systems
- New-road management system (i.e. system of planned new roads with priorities)

These subsystems should be managed in a co-ordinated fashion so that the overall utility of the road network may be maximised. Figure 1.2 shows how the different systems within a total road management system are combined for overall priority determination.

1.2.3 Network level versus project level

1.2.3.1 Network level

Pavement management at network level deals with summary information related to the entire or a large portion of the network. As such, it involves policy and programming decisions frequently made by upper and middle management. Examples of network-level pavement management is the use of PMS information to -

- identify and prioritise candidate projects;
- establish rehabilitation programmes;
- estimate overall short- and long-term needs;
- justify budget requests;
- answer "what if" questions.

This PMS network-level information may include (AASHTO, 1985) the following:

- The current condition of the road network.
- The performance trend of the network, with past history.
- A projection of future needs.
- The estimated impacts of alternative funding plans on future pavement condition.

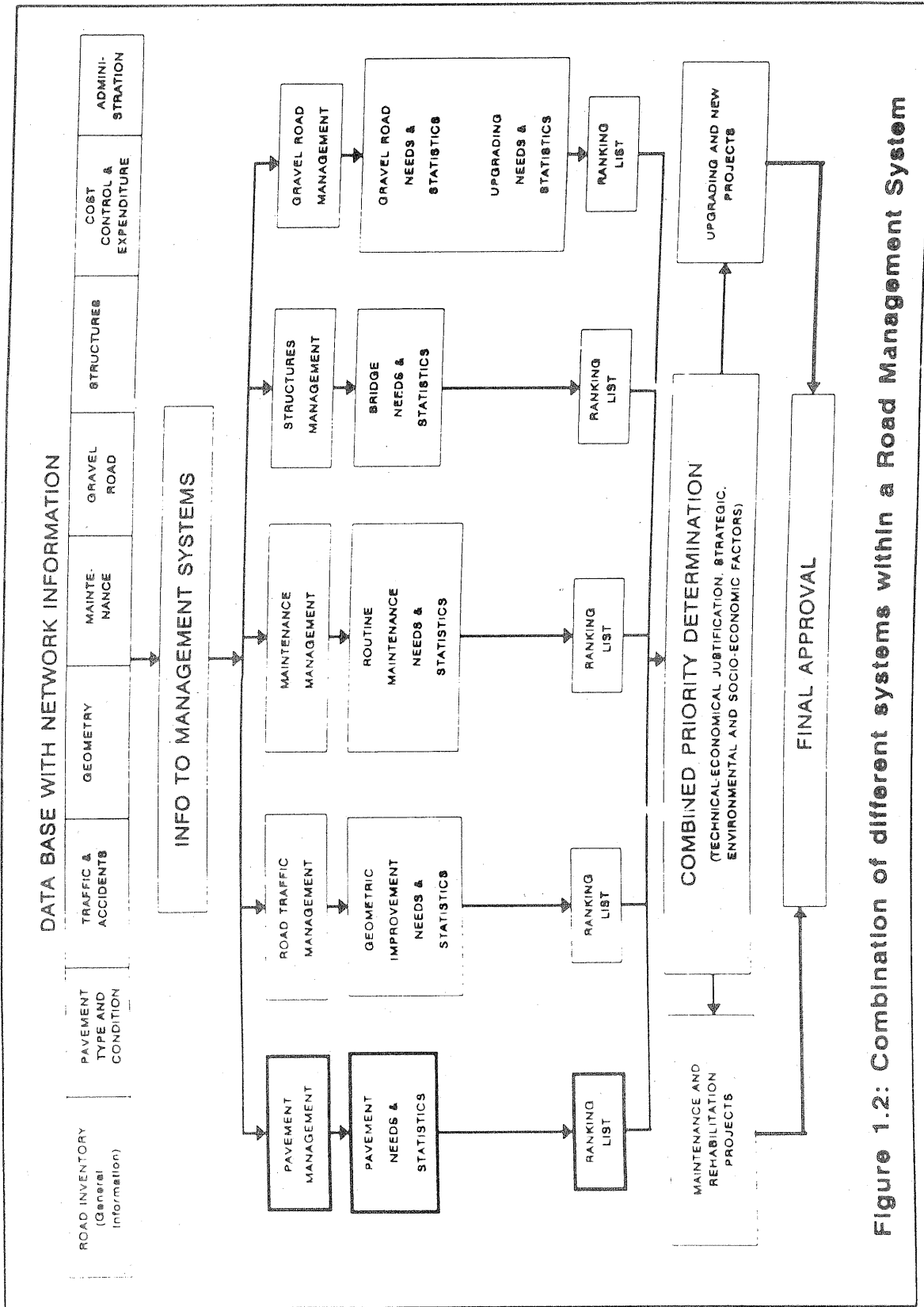


Figure 1.2: Combination of different systems within a Road Management System

1.2.3.2 Project Level (AASHTO, 1985, and Johnson, 1983)

Pavement management at project level deals with detailed and technical information related to a specific pavement section. Consequently, it involves more specific technical management decisions made by middle or lower management. Examples of project level pavement management as it relates to specific pavement sections include the following:

- Details of pavement structures and history of pavement maintenance
- Diagnosis of the problems with each pavement section
- Analysis of life-cycle costs of the alternative strategies being considered for the pavement
- Estimation of costs of various methods or materials that can be used
- Feedback of pavement surfacing and structural performance to provide input into pavement design, construction and maintenance activities
- Details of historical traffic loading.

1.2.4 Other definitions

Definitions such as those for maintenance categories, data-base items and others will be given in the appropriate sections of TRH 22.

1.3 BENEFITS THAT MAY BE GAINED FROM PMS

A well developed and implemented system can provide the following assistance to decision-makers and agencies, as documented in various publications (Al-Salloum, 1987):

a) Data collection, storage and retrieval

Data collection and computerised storage systems can ensure availability of accurate data and potential personnel cost savings. Computerisation permits easy retrieval of historic data and thus evaluation of pavement performance over time.

Most of the subjectivity can be removed from pavement rating through PMS guidelines or manuals, for example the Standard PMS Visual Assessment Manual (TMH 9, 1992) issued by the Department of Transport.

b) Information and communication

The PMS provides reliable and useful information on various facets, such as complete inventory data and pavement condition data. The PMS can inform management, politicians and the public of the present condition and change (improvement or deterioration) in condition over time.

Pavement management can help improve communication within a road authority. This includes communication between divisions and/or districts, using a common reference system with consistent information.

c) Project selection and prioritisation

PMS procedures can lead to consistent project selection and rational prioritisation, providing a sound basis for programming decisions.

d) **Costs and resources**

The PMS procedures lead to improved cost estimates for maintenance and rehabilitation activities. The procedures also improve long-term planning of capital resources with the aim of minimising costs while maintaining the road network at an acceptable level of performance.

e) **Funds**

If there are budget constraints, a measure of the resulting condition of the road network associated with a specific funding level can be obtained. This information may be used to motivate changes in the budget by illustrating the effects of proposed funding levels.

Compatible PMS data will aid national allocation of pavement-related funds to the various regions.

f) **Engineering criteria and policies**

PMS information can help to develop engineering criteria which will improve procedures for the design and construction of pavements.

PMS procedures provide a basis for consistent decision-making in accordance with established policies. It also helps decision-makers to define clearly and to review the explicit basis for their decisions. It is possible to conduct investigations on these data and to change policies based on such analyses.

1.4 POSSIBLE PITFALLS

The introduction of pavement management systems is not always without problems. Some pitfalls to be aware of are described below. (UTG6, 1989, and Smith, 1992)

a) **Inadequate preparation**

The development of a PMS is a major task which must not be undertaken lightly. It is advisable to assess carefully what manpower and funds are required to develop and operate a system and to be prepared to commit these resources for several years.

b) **Lack of staff involvement**

Problems which have arisen in the implementation of pavement management systems have often been the result of employee resistance. The support and involvement of top management are essential in the preparation of a successful management system. Problems may also arise when standards and procedures are set without lower and middle management participation. For a system to be successful it is necessary that it be developed with the participation of staff at all levels and that it be thoroughly understood by them.

c) **Over-refinement of the system**

It is important to get a PMS in operation as soon as possible. An unduly long development period may dampen the enthusiasm of the staff involved and place the credibility of the entire system at risk. The need to adjust and refine the system will become evident when the system is put to use.

d) Complexity of the system

The PMS decision support software may be so complex or poorly documented that the user may not understand the concepts used in the system and may not be able to explain them to others.

e) Wrong organisational level

Since a PMS provides new information affecting many major operating units within the organisation new communication channels, both formal and informal, should be established. When the PMS operating unit is buried deep within the organisational structure, it is difficult for the PMS engineer to communicate with and have access to all of those affected by the implementation of the system.

f) Protection of positions by staff

When a PMS is implemented in a unit of the organisation, or in a newly formed unit, the remaining units within the organisation often feel threatened by the new power of the PMS operating unit. They may resist implementation of a PMS to prevent a perceived loss of power. It is important that staff realise that the system will not present a threat to them but will actually assist them in their work.

g) Needs not matched

Problems may arise where the needs of an organisation have not been addressed or the generated recommendations do not match the available processes. This could happen if the system is developed based only on available data and not on actual needs.

h) Lack of continuity

Often only one person in an organisation is trained in the PMS procedures. When this person is transferred or leaves the whole PMS process may stop indefinitely.

2. PMS IMPLEMENTATION AND OPERATION

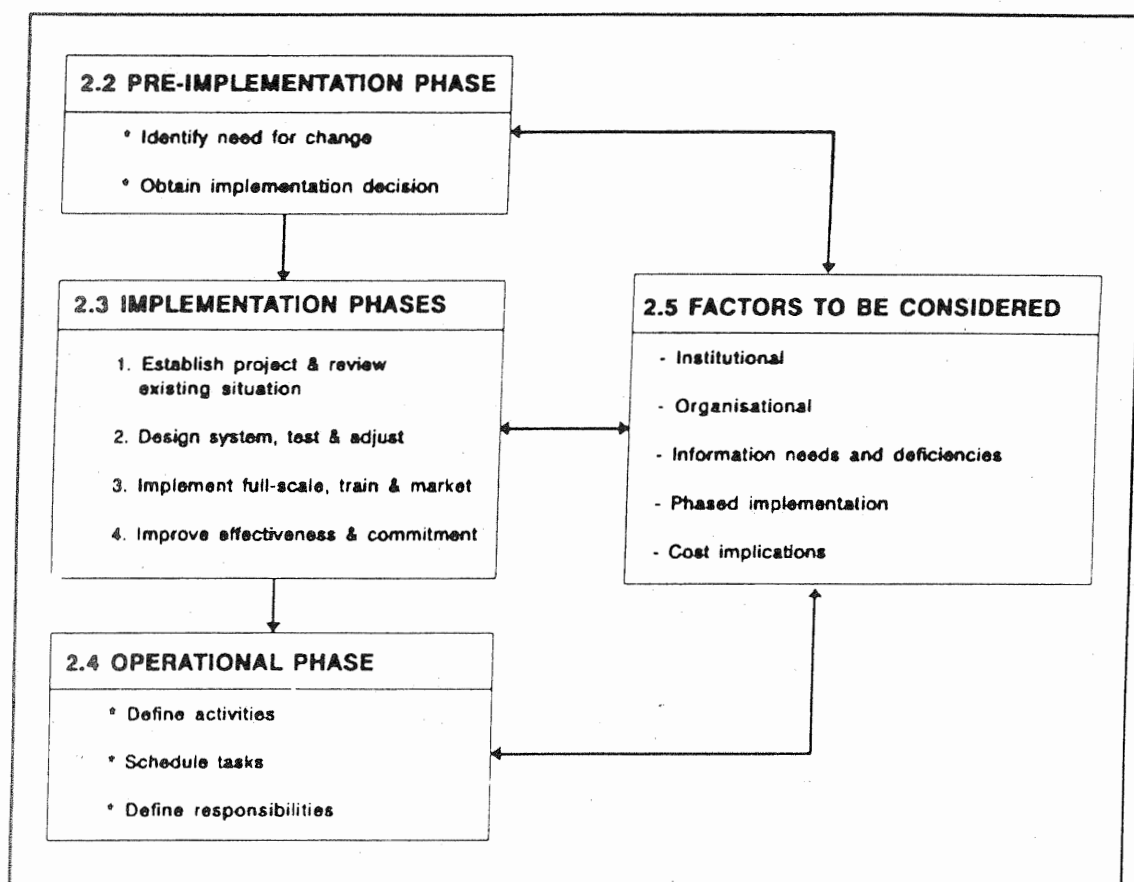


Figure 2.1: Flow diagram of Chapter 2

2.1 INTRODUCTION

To ensure successful implementation and operation of a pavement management system in any organisation, it is important that institutional and organisational factors be considered in detail along with the technical components of the system. As these factors determine the success of a system within an organisation, they must be understood and addressed by the authority prior to the implementation of the system - even before some of the technical issues are addressed.

The purpose of this chapter is to present the PMS implementation phases and the issues outside the technical field which are most important to the success of a pavement management system. Figure 2.1 presents a flow diagram of the subjects addressed in this chapter.

The environment within which the PMS operates is dynamic. Therefore the implementation of a PMS should be a dynamic and interactive process that will address these facets methodically to ensure adaption to the changing needs of the authority.

2.2 PRE-IMPLEMENTATION PHASE

The implementation of a PMS is preceded by the recognition in the road authority that there is a need to change the whole or parts of the pavement management process. This need could exist in activities such as pavement design, construction, maintenance and rehabilitation planning and programming.

The improvement in the pavement management process may be achieved by -

- improving the pavement management procedures;
- better defining standards and strategies; or
- providing better information for decision-making, including the improvement of procedures and standards.

It is therefore important to determine deficiencies in the present procedures and standards, as well as the decision needs and hence the PMS information needs. If there is no apparent need for change in the organisation, change should not be forced. For example, the road network may be small and no formal system may be required, or the existing PMS may meet all present needs.

The pre-implementation phase starts with the identification of the need for change in the pavement management process and ends with the corporate decision to implement a system. The steps associated with this phase are presented in Table 2.1 (Smith, 1992). Successful implementation requires that at least one PMS champion (person who drives the implementation) should be present. Such a person could be appointed by a road authority, or could be the senior officer charged with pavement related activities.

TABLE 2.1: SUMMARY OF PRE-IMPLEMENTATION STEPS

STEP	ACTIVITY
1	Identify need for change.
2	Obtain understanding of system.
3	Identify benefits and costs of system for organisation.
4	Place PMS on decision agenda.
5	Form corporate attitude (e.g., demonstration of an operating PMS, documented information on benefits and costs).
6	Obtain corporate decision for implementation and funding. (Normally for trial implementation. Final implementation decision later.)

2.3 IMPLEMENTATION PHASES

2.3.1 Introduction

The successful implementation of a PMS hinges on the management's total commitment to implementation at all levels. Consequently -

- all levels of staff that will be end-users should be involved in the development of the system from an early stage; and
- the system should comply with the needs of the end-users to promote the usage of the system.

The implementation action may occur in four major phases (Smith, 1992) as shown in Figure 2.1. These phases can also be applied to the upgrading of an existing PMS.

2.3.2 Phase 1: Establish project and review existing situation

Phase 1 normally includes the project specifications and the definition of existing procedures and needs. A summary of phase 1 is presented in Table 2.2.

TABLE 2.2: IMPLEMENTATION : SUMMARY OF PHASE 1

STEP	ACTIVITIES
1. Establish project	Form steering committee. Include members from all affected departments. Objective : Provide support to facilitate changes, prepare goals and monitor progress and expenditure. Form working group. (Could be one person.) Objective : To convert goals into working plan and be responsible for day-to-day implementation efforts. Define project scope and prepare working programme with cost estimate. Finalise corporate approval.
2. Review existing situation	Review existing practices, communication, flow, organisation and decision types (and location). Identify possible deficiencies in existing situation in terms of general structure and particular procedures. Determine needs and make recommendations.

2.3.3 Phase 2: Design or select PMS and test system

Phase 2 includes the designing of the system, or the selection of an existing system based on the identified needs and recommendations proposed in phase 1. This is often followed by the testing of the procedures in the system through a small-scale pilot project, as shown in Table 2.3.

TABLE 2.3: IMPLEMENTATION : SUMMARY OF PHASE 2

STEP	ACTIVITIES
1. Design / select PMS	Do conceptual design of procedures, data elements, data base, data processing, etc. Programme and cost detailed work. Detailed design of PMS and development (modification) of software, etc.
2. Pilot project	Test pavement management process, software, etc., on a small portion of the network through all management steps. Evaluate results and make modifications to suit needs. Document costs and results, and report.

2.3.4 Phase 3: Full implementation

After the pilot implementation, the PMS must be revised where required and implemented at full-scale for the remainder of the network. Table 2.4 presents a summary of these steps.

TABLE 2.4: IMPLEMENTATION : SUMMARY OF PHASE 3

STEP	ACTIVITY
1.	Installation of software and provision of documentation.
2.	Training of staff.
3.	Implementation of procedures. Data collection.
4.	Establishing a user committee with effective decision-making authority and ensuring regular meetings, since this is an ongoing process.
5.	Marketing of system internally and externally.

2.3.5 Phase 4: Improving effectiveness of pavement management

Many consider the system to be implemented once the data has been collected for the entire network and the first set of reports completed. However, a commitment to repeat the PMS activities on a regular basis in the future is required. If the pavement management is to be effective, it must become part of the routine management process and affect the decisions being made. Table 2.5 summarises some of the steps required to ensure effective pavement management operations.

TABLE 2.5: IMPLEMENTATION : SUMMARY OF PHASE 4

STEP	ACTIVITY
1.	Adjust PMS outputs to suit management needs as requested over time.
2.	Ensure commitment to continuing training and execution of PMS activities on a regular basis.
3.	Improve and adjust PMS to keep up with changing needs of authority and capabilities of new technology.

2.4 OPERATIONAL PHASE

2.4.1 General

For a PMS to operate efficiently, its activities must be planned and executed through a system of formal procedures. In planning these procedures, the following should be taken into account:

- What tasks need to be performed
- Who will perform these tasks
- When must they be performed.

The answers to the above questions must be set out in formal procedures to address the operational requirements of the PMS. The three facets of these procedures are presented in sections 2.4.2 to 2.4.4.

2.4.2 Definition of PMS activities

The answer to what tasks need to be performed is provided by the definition of PMS activities. The definition should consist of the following two formats:

- Flow diagrams

The flow diagrams show the activities to be performed and the sequence in which they are to be performed. An overall flow diagram showing only the major tasks, together with more detailed flow diagrams for each major task showing individual activities, must be prepared. An example of a typical overall flow diagram is shown in Figure 2.2.

- Description of PMS activities

A detailed description of each activity must be provided together with reference to specific manuals or guidelines to be used. These manuals may be project specific or standard documents such as the TMH 9.

2.4.3 Schedule of task responsibilities and time

The schedule of task responsibilities indicates who will perform the tasks and/or who will be accountable for the results of the tasks. A time schedule should be added to indicate when the activities are to be performed. Figure 2.3 shows a typical example of a time schedule.

2.4.4 Documentation

Good documentation is essential for the effective and efficient operation of a PMS and will reduce running costs. Documentation that should form part of the PMS includes (FHWA, 1991):

- Executive summary

An executive summary is used as a tool to inform upper management of the capabilities of the system.

- PMS operation procedure manual

This manual contains the full description of the system, including the flow diagrams, description of activities, schedule of task responsibilities, time schedule of tasks, etc. Reference should also be made to applicable standard manuals and guidelines (e.g., TMH 9 and TRH 22).

- Standard manuals and guidelines

Standard manuals and guidelines for use at network level (e.g., TMH 9) and project level (e.g., TRH 12) must be incorporated as part of the system.

- Software documentation

Software documentation should include the following:

- User's Manual : Provides a complete set of instructions for the user to operate the various programs. It should also include a glossary of terms.
- Technical Manual : Provides the theoretical background behind the programs.
- Data Processing Systems Manual : Details the data processing side of the application programs and provides information that an application programmer would require to make modifications to the code.
- Data Dictionary: Provides a detailed definition of each data element.

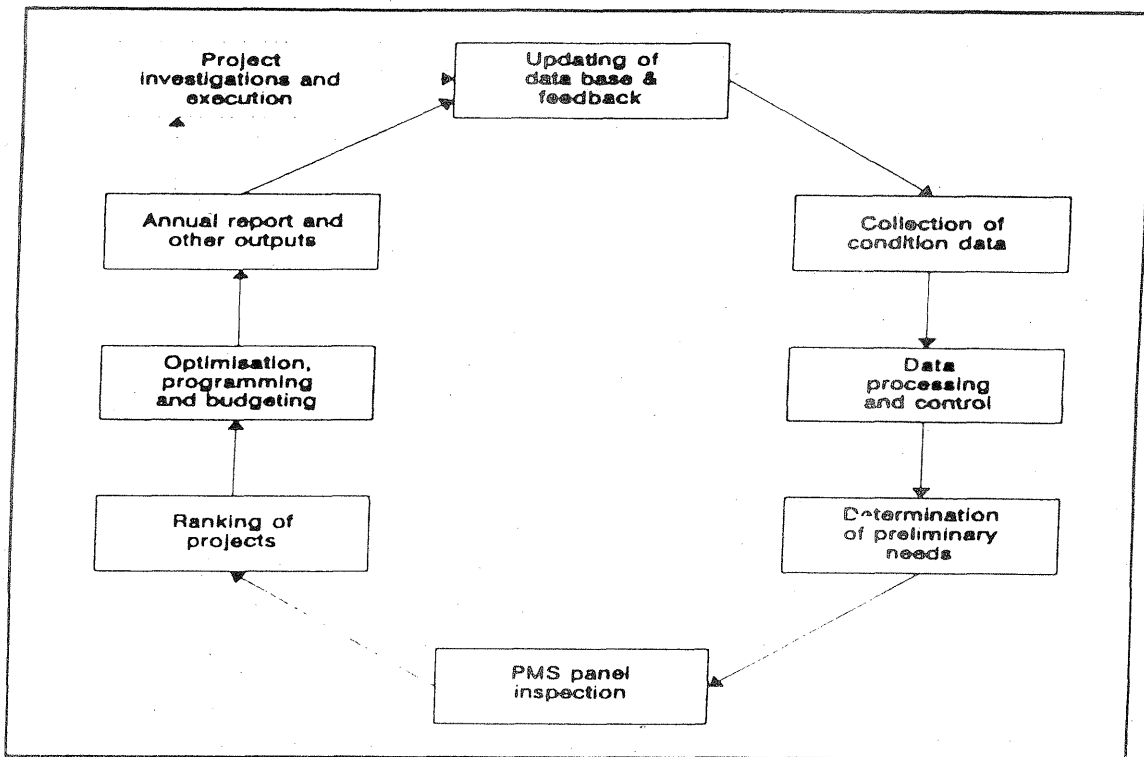


Figure 2.2: Example of typical flow diagram of major annual PMS tasks

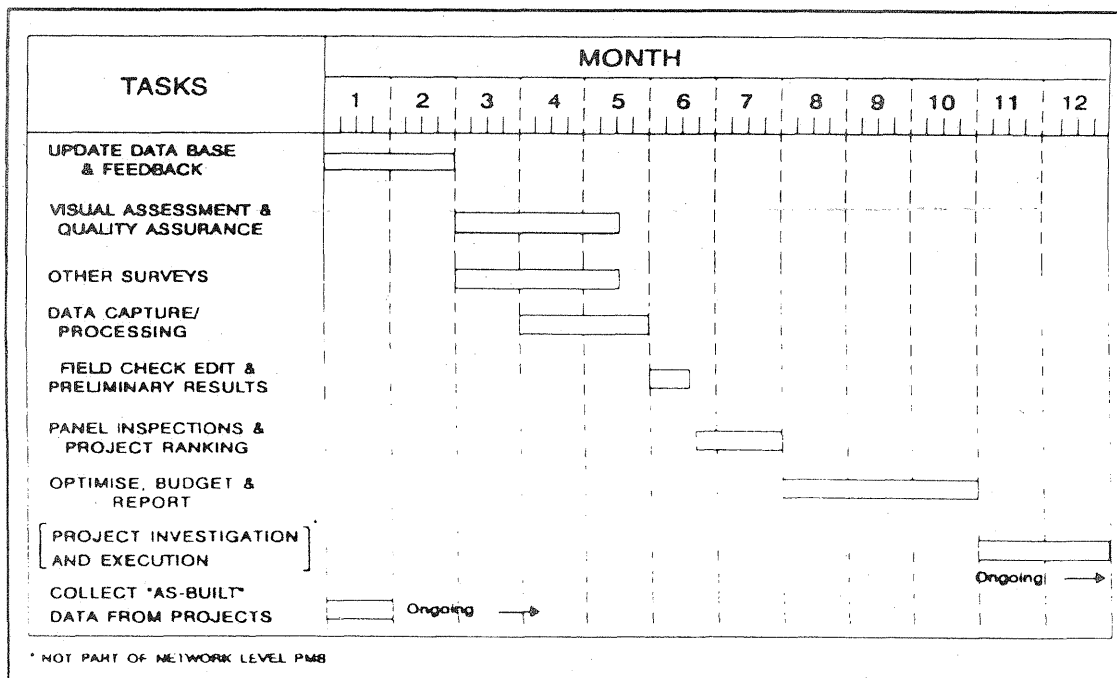


Figure 2.3: Example of typical time schedule of major PMS tasks

2.5 FACTORS TO BE CONSIDERED

2.5.1 Institutional factors

Institutional factors refer to issues that affect or are affected by the environment in which the road authority operates. These include: Sources of funding, compatibility with other systems and communication procedures.

- **Sources of road maintenance funding**

The requirements laid down by the source(s) of road maintenance and rehabilitation funding should be taken into account in the structuring of the data base, outputs and operations. The PMS should be able to provide information required by external funding agencies. Data should be available in time for the preparation of budget schedules.

- **Compatibility of pavement management systems**

It may be a requirement of a controlling agency that information provided by the various authorities under its control should be compatible or even uniform. Uniform data collection and data processing procedures should then be used by these authorities.

- **Communication**

Unless the results obtained from a PMS are effectively communicated to all levels within and outside the roads authority, the full potential of the system may never be realised. Limited maintenance funds may be diverted to projects with higher public visibility. Support for maintenance programmes can be enhanced by using effective communication channels to provide reliable and understandable information to decision-makers. The type and level of information required by management and decision-makers must be investigated in order to report and communicate purposefully.

2.5.2 Organisational factors

Organisational factors refer to PMS issues and interactions within the road authority. The whole organisation and all levels of management in a road authority are affected by the implementation of a comprehensive PMS. It is essential that all levels of management should be fully informed of the details of the PMS and of the benefits and limitations of the system. This will minimise resistance to the successful implementation of the system.

Table 2.6 summarises some organisational factors influencing PMS interactions within a roads authority.

To operate effectively, the position and function of the PMS section must be properly defined within the organisational structure. As stated in Table 2.6, the head of the PMS section (or RMS section) should have adequate authority within the organisation, close to the decision-makers. This will facilitate communication with those affected by the system, including both top and lower management.

TABLE 2.6: ORGANISATIONAL FACTORS

FACTOR	DESCRIPTION
Decision support process	A PMS should be thought of as a tool to assist and improve the existing decision-making process.
Pavement management process	Implementation of a PMS should fit in with the structure of the organisation otherwise it may be ignored. A pavement management process which matches the methods and procedures used by the authority can be integrated into the organisation with relative ease. If changes to the organisational structure and lines of communication are required, these should be well planned and developed.
Organisational level	The head of a PMS section should have adequate authority within the organisation in order to have useful reciprocal communication with all those affected by the system. The authority level also depends on whether there is an RMS manager.
Centralisation of responsibility	A separate section dedicated to PMS functions is desirable so that there can be accountability for the collection and processing of data and the distribution of information.
Resources and authority	The PMS manager should be given sufficient resources and authority to enable him to act decisively in PMS related activities.
Computer department	The role of a computer department in the PMS implementation and operation must be advisory and supportive, but not controlling.
Independence	The PMS section should remain independent of the other related departments (e.g., computer department), but strong reciprocal information links should be established.

PMS may be regarded as a 'line' function or a 'support' function. Unclear definition of this function will inevitably lead to conflict within the organisation. The PMS section collects, processes and stores data, and provides information for decision-making in the pavement management process. The section should therefore act in a support capacity responsible to upper management with sufficient authority to enable decisive action to be taken in PMS related activities. The best results will probably be achieved if the PMS section has a dual role:

- A support function in terms of information for the whole organisation and initial proposals on maintenance and rehabilitation.
- A line function in terms of final programs, budget allocations and action plans in cases where no RMS exists, otherwise in a support function to the RMS manager.

2.5.3 Identification of PMS needs

It is essential that the pavement management needs of an organisation be defined during the implementation phase. Once these needs have been defined, the deficiencies in the current system can be identified and addressed in the design of the new or upgraded system. The following method can be used to identify and classify the pavement management needs of an organisation:

- All levels of management should define the pavement management activities within their scope of work.
- For each activity the management decisions, procedures and standards should be defined. From this, the information needs and deficiencies in current procedures and standards must be identified.
- Once the needs and deficiencies have been identified, they must be classified into long- or short-term needs by rating them in order of importance. This is important as most PMSs are implemented in stages.

The process of identification and classification could be performed through a series of questionnaires and workshop sessions.

2.5.3.1 Short-term needs

The short-term needs are mostly focused on the present condition of the network and the current maintenance and rehabilitation needs at a network level. Short-term needs are listed in Table 2.7.

TABLE 2.7: SHORT-TERM PMS NEEDS

DESCRIPTION
Inventory data.
Present pavement condition (total network and individual roads).
Unconstrained maintenance and rehabilitation needs.
Prioritised schedule of potential projects requiring maintenance and rehabilitation.
Current budget needs.
Definition of PMS procedures and standards.

2.5.3.2 Long-term needs

In addition to the short-term needs, a PMS should provide information for future planning. Consequently, the PMS should have the ability to predict future pavement performance and should therefore include life-cycle costing and optimisation procedures. The information needs listed in Table 2.8 are normally addressed on the long-term.

TABLE 2.8: LONG-TERM PMS NEEDS

DESCRIPTION
Historical pavement conditions and traffic loading.
Forecast future condition and level of service under different budget scenarios.
Selection of best preventive maintenance and rehabilitation alternatives under different budget constraints.
Forecast budget requirements under different levels of service.
Cost-effectiveness of preventive maintenance and rehabilitation strategies over time.
Identification and scheduling of future potential preventive maintenance and rehabilitation projects.
Improvement of PMS procedures and standards.

2.5.4 Phased implementation

Implementation may be conducted in a step-by-step process, whereby short- and long-term needs are addressed in a planned manner as part of an overall programme framework. The steps in a phased implementation depend on the decision needs and resources of the road authority. An example of phased implementation is as follows:

- STEP 1: Establish the data base (refer to Chapter 3).
- STEP 2: Develop a system that collects data on pavement condition and retrieves historical data on maintenance and rehabilitation activities. Develop a rational algorithm to determine the level of service of the road network based on distress measurements and/or condition assessments.
- STEP 3: Incorporate maintenance and rehabilitation decision trees to determine essential activities based on the required level of service and distress levels assessed for each section of road without any budget constraints. Apply a prioritisation routine to candidate projects based on a constrained budget.
- STEP 4: Develop pavement performance prediction equations based on historical data and include an optimisation routine.
- STEP 5: Incorporate a geographic information system (GIS) to facilitate access to information and develop interfacing with other components of the Road Management System.

2.5.5 Cost implications

Funds will be required to implement and operate a PMS. It is therefore important to define the factors that will have significant cost implications so that they may be controlled to ensure compliance with the budget. The addition in value of the PMS over time against the potential cost of each step of a phased implementation should be considered when planning the implementation of the steps.

The decision needs of the agency governs the information requirements and therefore also the cost of a PMS. The discussion of these and other factors is divided into implementation costs and running costs.

2.5.5.1 Factors affecting the cost of implementation

The factors affecting the cost of implementation relate mostly to the method of implementation, the specification of the system and its compatibility with the existing situation. A brief description of these factors is presented below.

(a) Method of implementation

• *Implementation process*

The application of all phases described in section 2.3 will require substantial funding. The omission of some of the steps should however be weighed against the possibility of implementing procedures that may later require changes or replacement at great cost.

• *Phased implementation*

Phased implementation (section 2.5.4) can spread the implementation costs over a number of financial years and provide better control over expenditure. It allows time for staged evaluation of each new process. Problems could be identified and adaptations made to following phases before implementation, limiting expensive changes after implementation.

• *Selection or development of PMS software*

Costs may be saved by selecting and adapting existing software rather than developing these from scratch.

• *In-house/external development team*

The cost of development will be influenced by the composition of the development team. Depending on the available in-house knowledge and resources, the team could include experienced and knowledgeable PMS consultants to assist or manage the implementation process.

(b) Specification of the system

• *Type of PMS*

The level of sophistication of the system (comprehensive versus simple) has a significant influence on implementation. The range of application of the system (project and/or network level) will also influence implementation costs.

• *Amount of information*

The amount of data items collected, the size of the network and the frequency of updating will affect the computer hardware requirements and sophistication of the software. The first two items will also influence the initial inventory data collection costs. The cost effectiveness of the PMS will decrease with decreasing size of the network.

• *Reporting requirements*

Relatively inexpensive paper prints are sufficient if the only requirements are annual reports on funding and levels of service of the road network. Requirements for access on a daily basis may require a link to the GIS. The level of sophistication and the frequency of access to the PMS data will impact directly on computer hardware and software requirements and costs.

(c) Compatibility with existing situation

• *Pavement management process*

The pavement management process which matches the methods and procedures currently used will result in fewer changes and thus lower implementation costs than one which requires major changes in the organisation.

• *Availability of data*

The availability and reliability of the data required for the new system will also influence implementation costs. The provision of an accurate road network map, if not available, may be expensive.

2.5.5.2 Factors affecting running costs

The factors affecting the running costs relate mostly to data requirements, PMS procedures and human resources. A brief description of these factors is presented below.

(a) Data requirements

- *Level of detail of data*

Requirements for high levels of detail will result in high collection and storage costs. Therefore, an appropriate level of detail should be specified for network level condition data to ensure that the maximum coverage of the road network can be achieved on a periodic basis. A high level of detail is required for work at project level, but this will be for only a very limited portion of the work.

- *Frequency of update*

The frequency of collection and the measurement of condition data has a major effect on running costs. There will therefore be a trade-off between running costs and currentness of the data.

- *Accuracy of data collected*

Elaborate procedures to ensure an unnecessarily high degree of accuracy of network level data can result in high costs. However, some form of quality assurance procedure must be implemented, such as training, field checking, etc.

- *Method of data collection*

Automated methods of data collection may have higher implementation costs, but should reduce subjectivity as well as running costs.

(b) PMS Procedures

- *Simplicity of procedures*

PMS procedures should be simple and easy to understand. This will reduce execution time and potential for errors, which will affect running costs.

- *Definition of procedures*

Well-defined and well-documented procedures will result in reduced running costs through reduced execution time, easier transfer of knowledge and lower potential for errors. Good documentation will increase the initial costs somewhat, but will significantly reduce the running costs of the system.

* *Changes*

Allowance should be made in running costs for changes to procedures where needed owing to errors, changing needs or technological advances. It has been estimated that more than 75% of the total cost (including development) of an information system goes towards maintaining that system (i.e., making changes and enhancements).

(c) Human resources

* *In-house or external resources*

Running costs will be affected by the mode of operation. External operators may be used for various PMS activities ranging from periodic short-term activities (e.g., visual assessments, software modifications, etc.) to major activities (e.g., management of information system, including data collection, processing and reporting). A decision to use external operators will depend on factors such as size of authority, size of road network, available technical expertise, staff turnover, etc.

* *Training*

Training of PMS personnel is an essential element of the implementation and operation of the system. Training must continue on a repeating cycle and will therefore influence running costs. Allowance should also be made for the training of managers outside the PMS (users) and even the public on pavement management concepts.

3. DATA BASE REQUIREMENTS

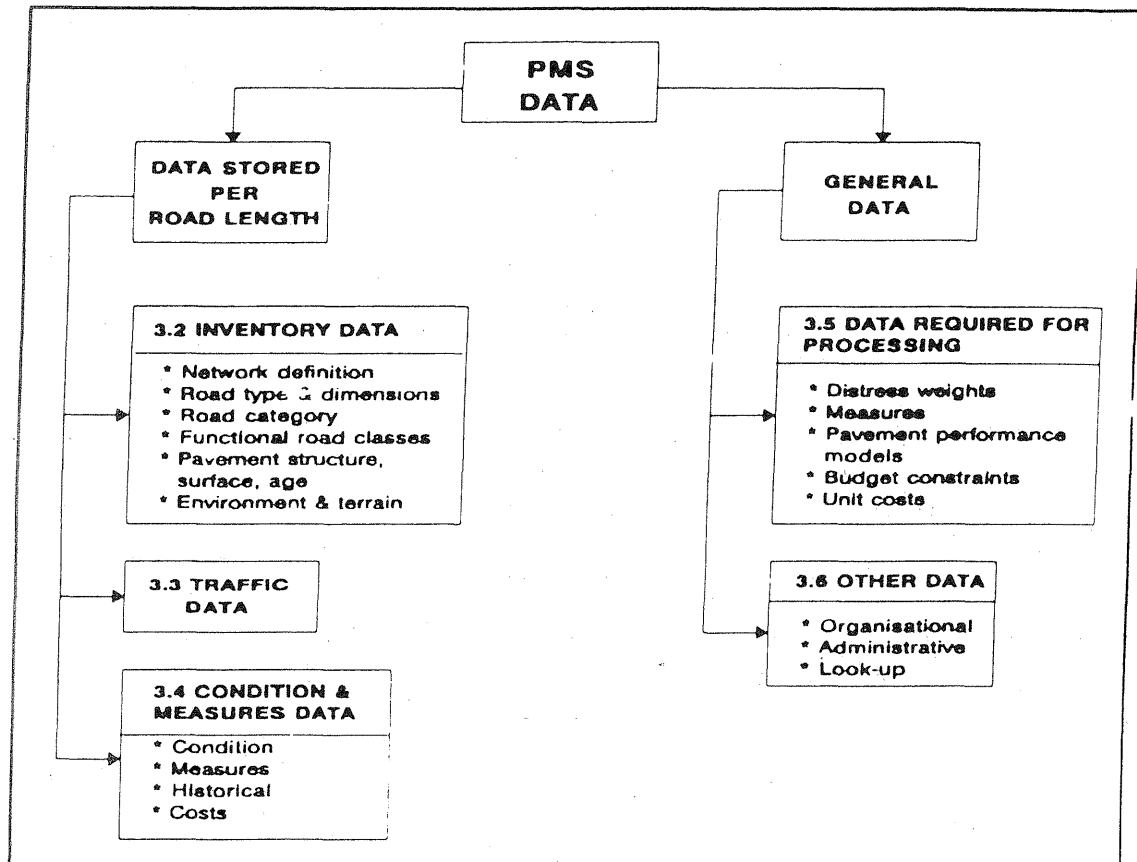


Figure 3.1: Flow diagram of Chapter 3

3.1 GENERAL

A comprehensive data base is the first building block and heart of a PMS. In order to determine the data elements required in a PMS data base, the first step is to determine the decision needs of the authority and hence the type of outputs required by the decision-makers (refer to section 2.5.3). A constraint on the volume and detail of data collected is the cost associated with data collection and processing. To contain costs, only data required for decision-making should be collected.

To allow for the systematic management and access of data, all data should be classified into predefined logical groups. These groups will generally be stored in separate files in the data base. The groups proposed in this chapter are shown in the flow diagram in Figure 3.1.

In addition to the specification of data elements in this chapter, certain data categories (e.g., age classification, Table 3.7) are also defined. Data fields need not always be created in the data base for these data categories, since the data category can mostly be determined from existing data elements. For example, if the year of construction is stored the age classification (Table 3.7) can be determined.

3.2 INVENTORY DATA

The pavement management process requires an inventory of existing facilities. The inventory generally refers to the permanent features of the road network. Most of this data should be stored in the RMS inventory data base (Refer to Figure 1.2). Such data should preferably not be duplicated in the PMS data base.

3.2.1 Network definition

The road network should be divided into road segments based on the rules and procedures encompassed in a PMS network definition procedure. Network definition involves defining three road network attributes, namely the global division, the location referencing and the segment definition. These are discussed briefly below.

Global divisions are used to facilitate the PMS analysis and data management by dividing the road network into manageable units. Examples are shown in Table 3.1.

The **location reference system** is a set of procedures to identify the geographic location of a road and its position relative to other roads in the road network. A common reference system should be used by all systems within a road management system. Standard types of data elements collected in the network definition process are listed in Table 3.1. Three basic methods of referencing pavement segments are as follows (Haas, 1994):

- **Route km-post method:** This is widely used by provincial road authorities. Each route is given a unique number and the starting point is defined. Km-posts are sequentially numbered along the route.
- **Node-link method:** Key points (intersections) are defined as nodes and sections in between defined as links. This is widely used by urban road authorities.
- **Geographic information systems (GIS):** A co-ordinate system is used to define the location of each feature of the network. Connecting relationships between feature co-ordinates define the roads.

TABLE 3.1: NETWORK DEFINITION DATA

NETWORK ATTRIBUTES	DATA ELEMENTS
Global division	Road name/number Route name/number Province name District name Subnetwork/Region name Maintenance unit Ward (political district) Road funding category Road segment code
Location reference	Start description/distance End description/distance Intersection data XY-co-ordinates Direction of carriageway

To facilitate the capture and analysis of visual distress data, roads are divided into segments. Segmentation of roads into practical lengths is necessary for the cost-effective handling of visual assessment data. Instrument survey data are normally stored per test point or predefined length (refer to section 4.5).

The following two segmentation methods are possible:

- **Fixed segmentation:** This method is based on segments being defined at a given point during the development of the PMS. Once defined segments seldom change. TMH 9 (1992) gives standard segment lengths for visual surveys for freeways and rural roads. The advantage of this method is the simplicity of the data structure and ease of locating segments in the field. The disadvantage is that the pavement structure characteristics can change within the length of the segment (Haas, 1994).
- **Dynamic segmentation (FHWA, 1991):** In this method the segment limits change in accordance with changes observed or imposed on the road, such as -
 - traffic;
 - pavement structure;
 - pavement conditions;
 - preventive maintenance; and
 - rehabilitation activities.

This method is not recommended unless a sophisticated referencing system is used to ensure data integrity. Under this system it may also be difficult to obtain historical performance curves. The advantage of this method is the ease of analysis of data which is homogeneous within the segment. Minimum and maximum lengths should be specified.

Road segments are identified by assigning unique codes to each segment. Generally, codes comprise a combination of the global division and location referencing definitions. The global division code used may consist of a geographic reference (e.g., province, region, district, etc.) or else a route or road number (e.g., R28).

3.2.2 Road type, dimensions and PMS attributes

Road type data are required for determining maintenance and rehabilitation needs and standard costing. Current practice for describing road type is shown in Table 3.2.

TABLE 3.2: PARAMETERS FOR DESCRIPTION OF ROAD TYPE

PARAMETER	OPTIONS (CODES)
Carriageway category	Divided (D), undivided (N), single (S)
Number of lanes per carriageway	1, 2, 3, 4, etc.
Shoulder type	Paved (P), unpaved (U)

Standard road dimension data elements are shown in Table 3.3.

TABLE 3.3: ROAD DIMENSION DATA

DATA ELEMENTS	UNIT
Segment length	km
Road width	m
Lane widths	m
Shoulder width	m

PMS attribute data are used to ensure consistency in data-collection procedures.

TABLE 3.4: PMS ATTRIBUTE DATA

ATTRIBUTE	OPTIONS
Survey direction	+ or -
Standard segment length	2 or 5 km

3.2.3 Road category

The road category should be defined according to a combination of parameters, such as importance, service level, traffic and design confidence level (TRH 4, 1993). The road category information is used in data processing, for example in the selection of the rehabilitation measure. Four road categories are described in Table 3.5. Refer to the TRH 4 (1993) document for detailed descriptions of the parameters used in the definitions and the use of the road category in the design of the rehabilitation measure.

TABLE 3.5: DEFINITION OF ROAD CATEGORIES

ROAD CATEGORY	DESCRIPTION FOR INTERURBAN AND RURAL ROADS (TRH 4: 1993)
A	Interurban freeways, major interurban roads.
B	Interurban collectors, major rural roads, major industrial roads.
C	Lightly trafficked rural roads, strategic roads.
D	Special pavements, access roads.

3.2.4 Functional road classification

Roads can be classified into groups depending on their function and importance. A summary of the road classification system developed by the CSRA Subcommittee on Road Classification (1992) and expanded by the Road Classification Consortium (1992) is given in Table 3.6. This information may be used for the presentation of PMS results (further subdivisions are possible).

TABLE 3.6: DEFINITION OF FUNCTIONAL ROAD CLASSES

FUNCTIONAL ROAD CLASSES	DESCRIPTION
Level 1 (Primary)	Roads which provide mobility in the national context. Normal features - - long-distance traffic; - high-speed design standards; and - minimum interference of through traffic.
Level 2 (Secondary)	Roads which provide mobility in the regional context. Normal features - - moderate-distance traffic; - slightly lower design standards than level 1; and - link between towns not situated on level 1 road network.
Level 3 (Tertiary)	Roads which provide mobility in the context of a magisterial district. Normal features - - short trips between district centres and between higher level roads.
Level 4 (Tertiary)	All local access roads providing only local access to the rest of the road network. The main function is to serve land users next to the road network.

3.2.5 Road structure, surface type and age

Information on the history of construction, rehabilitation and maintenance of the pavement is essential. The pavement layers and surface type should be described in accordance with Table 14, in TRH 4 (1993). The accuracy of the information should be indicated, because the reliability of the information sources varies. Common data elements to be included for each pavement layer (including surfacing) are shown in Table 3.7.

TABLE 3.7: ROAD STRUCTURE AND SURFACE TYPE DATA

DATA ELEMENT	DESCRIPTION
Pavement design class	E0, E1, E2, E3, E4 or E5.
Layer description	e.g. surfacing, basecourse, etc.
Material quality	According to TRH 14, e.g. G1, C3, etc.
Stabilising agent	Indicate when applicable, e.g. cement, lime, etc.
Layer thickness	e.g. 150 mm
Year of construction	e.g. 1990
Accuracy indicator	Indicates accuracy of data, e.g. accurate (A), uncertain (U), default (D).

It is preferable to store only the latest structural layer information. Information on previous structures (e.g. before reconstruction) could be stored separately.

The pavement age and surfacing age are classified in Table 3.8. The actual year of construction should be recorded in the data base. For concrete roads only structural ages should be stored, unless overlays, which could be classified as surfacings, have been added.

TABLE 3.8: PAVEMENT AGE CLASSIFICATION (Not stored)

AGE CATEGORY	CATEGORY LIMITS FOR	
	STRUCTURAL AGE (YEARS)	SURFACING AGE (YEARS)
New	Age ≤ 5	Age ≤ 5
Intermediate	5 < Age ≤ 15	5 < Age ≤ 10
Old	15 < Age ≤ 25	10 < Age ≤ 15
Very Old	25 < Age	15 < Age

It is necessary to segment pavements into structure categories, in order to predict pavement performance and determine cost-effective maintenance and rehabilitation strategies. Information should preferably be stored in such a way that dynamic segmentation according to uniform base and/or subbase types is possible. This ensures uniform stiffness profiles, which govern the structural behaviour of the pavements. The categories described next to Base Type in Table 3.9 are recommended for pavement performance structure categories.

TABLE 3.9: PAVEMENT STRUCTURE CATEGORIES (Not stored)

LAYER	CATEGORIES
Base type	Concrete, asphalt, cemented or granular
Subbase type	Cemented or granular

3.2.6 Environmental and terrain data

The climatic region data may be used in determining maintenance and rehabilitation needs, pavement performance models and standard costing. Climatic regions are given in Table 3.10. The first three climatic categories correspond to those in TRH 4 (1993), based on the Weinert N values. "Very wet" regions that have very high moisture conditions, are normally localised. Where localised adjustments are required, the Thornwaite Index (Schulze, 1958) may also be used.

TABLE 3.10: CODES FOR CLIMATIC REGIONS

CODE	DESCRIPTION
D	Dry
M	Moderate
W	Wet
V	Very wet

Terrain type data are used for the calculation of excess user costs, and one of the types must be selected from Table 3.11. The terrain type is defined by gradient and/or curvature, always selecting the worst case. These are very broad guidelines only. Refer to the CB-Roads Program (1994) for more detailed definitions.

TABLE 3.11: DESCRIPTION FOR TERRAIN TYPES

TOPOGRAPHY TYPE	GRADIENT	CURVATURE
Flat	Gradient mostly flat (< 3%).	Curvature has no effect on vehicle running costs.
Rolling	Generally medium gradient (~ 4%) with many sags and crests.	Significant curves for at least 30% of the length.
Mountainous	Generally steep gradient (~ 7%) with many sags and crests.	Very sharp curves for at least 30% of length.

3.3 TRAFFIC DATA

Traffic data are used in pavement performance prediction, in determining feasible maintenance and rehabilitation strategies and in determining excess user costs. Traffic data elements required by the PMS are listed in Table 3.12. Traffic data would normally be stored in the Traffic Counting Management System.

TABLE 3.12: TRAFFIC DATA ELEMENTS FOR PMS

DATA ELEMENT	COMMENT	ACCURACY
Annual average daily traffic (AADT)	Total annual two-way traffic divided by 365 days.	Actual/ Estimated
Percentage heavy (% H)	Percentage of AADT $\geq$ Code 4 (FHWA Scheme F).	Actual/ Estimated
E80/heavy	Number of equivalent E80 axle loading per heavy vehicle	Actual/ Estimated
AADT growth (%)	Current and predicted growth rates.	Actual/ Estimated
E80 growth (%)	Current and predicted growth rates.	Actual/ Estimated

Where the directional split is not even, it may be desirable to provide separate AADT's, E80's and growth rates for each direction.

A classification of AADT values as shown in Table 3.13 is recommended for use in the reporting of PMS information, the selection of repair measures, the prioritisation of projects and in performance prediction models. The five traffic classes are approximately equivalent to the E80 classes defined in the TRH 4 (1993) over a period of 15 years at a 4% growth in E80s and with 10% heavy vehicles.

TABLE 3.13: RECOMMENDED TRAFFIC CLASSES (Not stored)

TRAFFIC CLASS	TRAFFIC CLASS LIMITS		
T0		AADT	≤ 500
T1	500	< AADT	≤ 1 500
T2	1 500	< AADT	≤ 4 500
T3	4 500	< AADT	≤ 13 500
T4	13 500	< AADT	≤ 40 000
T5	40 000	< AADT	

3.4 CONDITION AND REMEDIAL MEASURES DATA

3.4.1 Condition data

Condition data are used to determine the condition of the road network, and cost-effective maintenance and rehabilitation measures. The condition data are stored per road segment in raw and in processed form. Common types of condition data collected for PMS are shown in Table 3.14.

TABLE 3.14: CONDITION DATA ELEMENTS

DATA CATEGORIES	DATA ELEMENTS	
Surface condition: (Visual)	Texture Voids Surfacing failure Surfacing cracks	Aggregate loss Binder condition Bleeding/Flushing
Structural assessment: (Visual)	Block cracks Crocodile cracks Longitudinal cracks Transverse cracks Pumping	Rutting Undulation/Settlement Patching Failures/Potholing
Structural survey: (Instrument)	Deflection DCP Other (e.g. laboratory tests)	
Functional assessment: (Visual or instrument)	Rut depth Riding quality Skid resistance Surface drainage	Side drainage Shoulder condition Edge breaking
Indices: (Visual or instrument)	Visual condition index Priority indices Instrument skid index Structural stiffness index Weighted overall index	

3.4.2 Remedial measures data

In a pavement management system the maintenance and rehabilitation measures data may be split into two levels of detail.

3.4.2.1 Maintenance and Rehabilitation (M&R) categories

The initial classification of the pavement need normally falls under one of the M&R categories. Table 3.15 presents this first level of detail. Such classifications are often used for initial determination of measures and costs. At this stage the type of reseal, for example, is not specified. The table indicates the M&R categories as used by the state road authorities for the allocation of road funds.

TABLE 3.15: MAINTENANCE AND REHABILITATION (M&R) CATEGORIES

M&R CATEGORY	DESCRIPTION
Routine maintenance: (To keep roads in usable condition)	Paved areas - - crack sealing - patching (isolated) - edge repairs Non-paved areas - - Shoulder repairs (patch, regravell) - Shoulder blading
Periodic maintenance: (To keep road in usable condition)	Diluted emulsion spray. Reseal - minor preparatory patching and crack sealing, texture pretreatment FOLLOWED BY resurfacing e.g., single/double seal, slurry or thin asphalt overlay with normal or modified binders.
Special maintenance: (To restore road to acceptable level of service)	Structural reinstatement through extensive patching, crack sealing, edge repairs, rut filling and/or levelling asphalt, AND/OR limited reworking of one in situ layer and one imported layer, FOLLOWED BY a reseal or thin asphalt overlay ($\leq 50\text{mm}$) (drainage reinstatements where required)
Rehabilitation: (To restore road to acceptable structural capacity and level of service)	Extensive reconstruction of existing layerworks, AND/OR the construction of additional layers, which may include the laying of a thick asphalt overlay ($d > 50\text{mm}$). Limited geometric improvements of the existing road could form part of the project. Drainage reinstatements where required.

3.4.2.2 Maintenance and rehabilitation (M&R) measures

The definition of the measures are more detailed than the categories. They can be determined either from more detailed analysis of the pavement condition data and other factors, as mentioned above, or from detailed panel inspections. Table 3.16 depicts some of these measures.

TABLE 3.16: DEPICTION OF M&R MEASURES

M&R CATEGORY (FIRST ORDER LEVEL)	M&R MEASURES (SECOND ORDER LEVEL)
Routine maintenance	Crack sealing Extent: - Localised - Medium - Extensive Patching (Deep or Surface) Extent: - Localised - Medium - Extensive
Periodic maintenance	Extent: Diluted emulsion Reseals - specify seal in terms of type of seal, type of binder and aggregate size, e.g. 13,2 mm bitumen rubber single seal.
Special maintenance	More detailed specification of measure, e.g. - - extensive patching, plus type of reseal or thin asphalt overlay; - limited reworking of one layer, plus type of reseal or thin asphalt overlay.
Rehabilitation	More detailed specification of measures, e.g.: - Extent of reworked layers plus type of surfacing - Thick asphalt or concrete overlay (thickness specified)

3.4.3 Historical data

Current and historical condition data are stored for condition trend and statistical analysis. Historical condition data may be used to develop and update pavement performance prediction models. Normally historical data (e.g. ratings as collected according to TMH 9) are stored separately for possible later use (e.g. when new calculations need to be done on historical data).

The historical condition data are required for the following PMS activities:

- Pavement performance prediction;
- maintenance and rehabilitation performance prediction;
- evaluation of the effectiveness of maintenance and rehabilitation activities; and
- projection of annual maintenance and rehabilitation budget needs.

Historical pavement condition and structure data relating to periods before reconstruction of a road are not required for pavement management. The data should however be archived in order to be available for possible research on pavement performance models.

Actual costs of projects should be stored for both first and second order levels (see section 7.7). As-built historical measures data are stored against actual km distances. The data may be used to update pavement surface and structure type data and to determine the cost effectiveness of the measures over time. The capturing of historical data is an important part of the feedback and updating process in a PMS.

3.5 DATA REQUIRED FOR PROCESSING

These data consist of the constants used in the following PMS calculations:

- Visual condition indices (e.g. distress weights)
- Maintenance and rehabilitation measures that can be used
- Pavement performance prediction (constants used in the models)
- Unit costs for each M&R category and measure.

The weights and procedures used to determine the visual condition indices and measures are discussed in Chapter 6. The pavement performance prediction constants are regression equation constants used to describe pavement performance over time. The constants and models used to predict pavement performance are normally agency specific.

Cost data are required for the calculation of -

- project cost estimates, and
- excess road user costs.

Cost data required for project cost estimates consist of either unit costs per M&R category or unit cost per M&R measure (e.g. cost per m² of 13mm single seal) (refer to section 7.7).

Excess road user costs are calculated using a formula (see section 6.4.4). The constants used in the formula are based on the current costs of various items (e.g. petrol price). These constants should therefore be stored in a format that can be updated, as and when new data become available.

3.6 OTHER DATA

These data consist of information used in data base management. The organisational information relates to the PMS data structure, for example the districts belonging to a region are identified. This information is used in the presentation of PMS information.

The administrative data are used in the management of the data base. The following types of data are included:

- User access privileges,
- Back-up records,
- Security checks on files,
- Look-up tables used during data input,
- Data used in data verification etc. (also see Chapter 5).

4. ROAD CONDITION SURVEYS

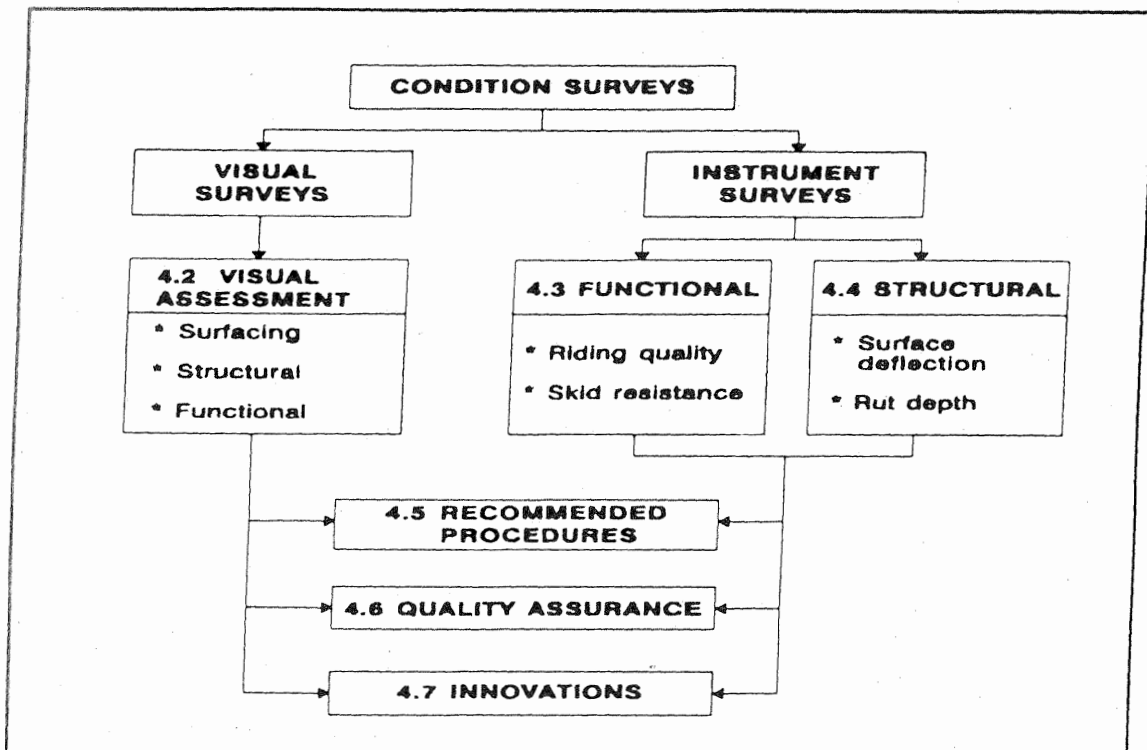


Figure 4.1: Flow diagram of Chapter 4

4.1 GENERAL

Visual assessment is widely used as a measurement of the pavement's surface, structural and functional condition. This is the most common method of road condition assessment in South Africa because of its cost effectiveness (also see section 4.7). Instrument surveys are used to supplement visual assessment information.

Instrument surveys are objective measurements of the pavement's structural and functional condition. Riding quality and skid resistance are functional condition indicators and deflection bowl measurements are indicators of structural condition. Although rutting is an indicator of both functional and structural condition, it is discussed under structural instrument surveys in this document. These instrument surveys are not absolutely necessary for the initial establishment of a PMS, but could be added in phases as enhancements to the basic system.

Although traffic surveys (including weigh-in-motion surveys) do not provide information on the condition of a pavement, traffic data are essential for the analysis of PMS condition data and are also used in the prediction of future pavement conditions. To ensure acceptable quality of traffic data it is therefore important to perform the surveys according to standard guidelines and specifications as set out in the TRH 16 and TMH 3 documents.

Figure 4.1 provides a graphic presentation of the contents of Chapter 4.

4.2 VISUAL ASSESSMENT SURVEYS

4.2.1 CSRA visual guidelines

In South Africa visual assessment of distress is mostly done via a "windshield" survey from a slow-moving vehicle including at least three stops per pre-defined assessment segment. Although this method has an element of subjectivity, thorough knowledge and use of the criteria and procedures outlined in TMH 9 will greatly reduce the subjectivity. The National Standard for the identification and collection of visual pavement distress data for flexible paved roads was published in TMH 9: "Pavement Management Systems: Standard Visual Assessment Manual", 1992.

The manual outlines assessment procedures and the required road segment information data. In addition, different distress types are classified and detailed descriptions of the extent and degree, including illustrations, are given for each distress type. The TMH 9 publication is a companion document to this publication.

4.2.2 Execution and frequency of assessments

The visual assessments for each road segment are recorded on a standardised assessment sheet for input into the PMS. Examples of visual assessment forms are shown in TMH 9.

The frequency of visual assessment depends on the size of the organisation and the amount of the funds available. In the initial stages of a PMSs implementation, annual visual assessments over chosen segments or the whole network are desirable. It is important to conduct the visual assessment for each pavement segment at the end of the wet season and over the same month for every visual assessment. This will generally ensure that the historical condition trends are consistent.

If an annual assessment of the network is not feasible the following criteria, in order of importance, may be used as a basis to determine the frequency of the visual assessment of a road segment:

- The functional classification;
- the region - in a road network that has been split into regions to facilitate the sequential annual visual assessment of each region, normally one region per year;
- the rate of condition deterioration; and
- the maintenance, rehabilitation and construction history.

4.3 INSTRUMENT SURVEYS: FUNCTIONAL

4.3.1 Riding quality

In southern Africa the most commonly used objective measure of the pavement's functional condition is riding quality or pavement roughness. Roughness is viewed in terms of the distortion of the pavement surface, which contributes to an undesirable or uncomfortable ride. A measurement and analysis method for quantifying distortions of the pavement surface is therefore required (Haas, 1994). Two types of measuring systems are available in South Africa.

The first type consists of the Response Type Roughness Measuring Systems (RTRMS), such as the Linear Displacement Integrator (LDI) and the PCA road meter (TRH 6, 1985), which measure the displacement between the vehicle body and the axle.

A second type of roughness measuring system is the profilometer. This system is fast becoming the standard for roughness measurement throughout the world. The profilometer system measures the road's roughness profile, which is then converted into a measure of riding quality. Approximate numeric relationships between the various riding quality scales are given in section 6.4.

4.3.2 Skid resistance

Skid resistance does not affect the pavement condition directly but can have a significant influence on the rate of accidents. Data may be used to indicate the need for resurfacing to improve skid resistance.

Three types of equipment are widely used in South Africa, as described in Table 4.2. The SCRIM (Sideways-Force Coefficient Routine Investigation Machine) device is the most common method used to measure skid-resistance conditions at a network level, and existing standards are based on its measurements. All measurements are conducted on a wet surface. Refer to TRH 6 (1985) for a description of the SCRIM.

TABLE 4.2: SKID RESISTANCE MEASURING EQUIPMENT AND THE USE THEREOF

EQUIPMENT	CONDITIONS SIMULATED BY THE EQUIPMENT	UNITS OF MEASURE
SCRIM	High speed skid resistance	Sideways-force coefficient SFC ₁₀₀
Brake-force trailer	Stopping distance of fully locked wheels	BFC
Pendulum tester	Slow speed skid resistance	PSV

It should be noted that fluctuations in skid resistance can occur on a seasonal basis, (Rogers, 1991).

4.4 INSTRUMENT SURVEYS: STRUCTURAL

4.4.1 Surface deflection

Currently, all practical non-destructive evaluations of pavement structural capacity are performed with deflection measuring devices. The three most widely used deflection devices in South Africa are the Benkelman Beam, the Travelling Deflectograph and the Falling Weight Deflectometer (FWD). The Benkelman Beam is a static load device and the deflectograph is an automated version of the static load beam device travelling at a speed of ± 3 km per hour. The FWD is a dynamic impulse load device and provides the closest simulation of traffic loading conditions.

The relationship between the maximum deflections obtained from the Benkelman Beam and the FWD are linear and highly correlated, but the ratios vary between 0,6 and 1,35 for different pavement types. In the absence of relationships derived specifically for a pavement type, it is recommended that the maximum deflections be equated. No relationships exist for the other deflection bowl parameters.

Deflection bowl parameters may be used to define the relative structural condition of a pavement, as explained in section 6.3. However, relative comparisons of individual parameters should be conducted only for pavements with similar structures and stiffness profiles. This problem is overcome by the Structural Stiffness Index (SSI), which combines the Maximum Deflection (Y_{max}) and Base Layer Index (BLI) parameters into a combined index.

4.4.2 Rut Depth

Information on rut depth may be used as an indicator of structural deterioration and as an indicator of a safety problem. This information may be used to identify projects for rut filling. Rut depth surveys can be conducted manually, by using a 2 m straight edge and measuring the maximum deviation from a straight line, or through automated methods by measuring the horizontal road profile across the wheel path over a width of at least 2 m. The two most common automated rut measuring devices in South Africa are the CSIR Spoorsnyer and the Rutmeter. The recently developed High Speed Profilometer (CSIR) also provides a transverse profile from which the rut depth may be determined.

4.5 TESTING PROCEDURE AND DATA STORAGE GUIDELINES

Certain testing procedures and data storage guidelines are recommended to ensure an acceptable quality of data for condition and trend analysis, as well as for use in pavement performance analysis. These recommended guidelines are presented in Table 4.3. The following are comments on these guidelines:

- Frequencies

Although certain frequencies are recommended, these are obviously subject to fund constraints. The actual frequency used should not exceed the maximum. Under the circumstances as stated for "additional", more frequent testing than the recommended frequency could be undertaken. "T4/T5" indicate roads with high traffic volumes. Skid resistance testing is only performed based on the visual assessment ratings or on sites of frequent accident occurrences. A formalised system should be established to request skid testing when required.

- Procedure

Riding quality, surface deflection and rut depth measurements are normally taken in one direction only, with the exception of freeways, where both directions may be specified. Where applicable, the required wheel path(s) is/are indicated, with the outer wheel path preferred if measurement of both is not possible.

- Data storage

This section indicates first at what interval the data should be stored and secondly the data items to be stored.

TABLE 4.3: SUMMARY OF RECOMMENDED GUIDELINES FOR SURVEY TESTING PROCEDURES AND DATA STORAGE

SURVEY FACET (See section 4.5)	SURVEY TYPE				
	VISUAL ASSESSMENT	RIDING QUALITY	SKID RESISTANCE	SURFACE DEFLECTION	RUT DEPTH
Frequency:					
- Recommended	Annual	2 years	As required	3 years	3 years
- Maximum	2 years	3 years	-	5 years	5 years
- Additional (a)	-	T4/T5	Accident site	Condition deterioration	Visual rating trigger
(b)	-	After treatment	Visual rating	-	-
- Time of year	End wet season	Same season	-	End wet season	-
Procedure:					
- Specified survey direction	-	Essential	As required	Essential	Essential
- Lane	All	Slow	As required	Slow	Slow
- Wheel path	Full width	Both	Outer	Outer	Both
- Test interval	Segment	Continuous	Continuous	200 m to 500 m (minimum = 6 tests per section)	20 m
Data storage:					
- Stored per	Segment	100 m	20 m	Point	20 m
- Date	Yes	Yes	Yes	Yes	Yes
- Unit of measure	-	Yes	Yes	Yes	Yes
- Direction of measure	-	-	Yes	-	-
- Data items	All ratings	Average/100 m	Average/20 m	All measurements	Measurement
- Other data	-	-	-	Temperature Pressure Test load	Length of straight edge

4.6 QUALITY ASSURANCE

It is essential to introduce a system of quality assurance for all condition surveys. This applies equally to visual assessments and instrument surveys. The systems should consist of both calibration procedures before the surveys commence and quality checks during and after the surveys.

4.6.1 Visual assessments

4.6.1.1 Types of errors

Experience has shown that both systematic and random errors occur in visual assessment rating. Systematic errors must be removed from the rating procedures since they introduce a bias. Random errors tend to average out at a network level. The following systematic assessment errors may occur in rating:

- Leniency error : This refers to the constant tendency of a rater to rate too high or too low.
- Halo effect : This refers to the tendency of raters to force the ratings of a particular mode of distress in the direction of the overall impression of the item rated. For example a rater may not consider bleeding to be a problem and may therefore rate all bleeding distress too low.
- Central tendency error : This refers to the fact that raters hesitate to give extreme judgements of the visual condition observed; therefore, ratings tend towards the mean. This means that the 2, 3 and 4 ratings are mostly used instead of the full spectrum from 1 to 5.

In general, the aforementioned systematic errors can be minimised by -

- the proper training and instruction of raters;
- the appropriate selection of cues - i.e., the TMH 9 rating scale from 1 to 5; and
- the anchoring of cues to well-defined physical stimuli (i.e., the TMH 9 detailed description of distress types).

The selection and anchoring of the cues is addressed in the TMH 9, Visual Assessment Manual. The training and instruction of the raters should be addressed in an annual calibration programme.

4.6.1.2 Calibration of visual assessment

At present, in South Africa, annual calibration workshops are held by all the major rural road authorities. The following elements should be included in the calibration session:

- A review of changes in the definitions, forms and manuals;
- a review of slides illustrating the rating scale of the various modes of distress;
- a practice group rating session of several different sections of road;
- a practical rating session of about 10 segments with various surface types and conditions rated independently by each assessor; and
- a review of the results of the practical session with the aim of calibrating the visual ratings of the trainees with the anchor cues, provided in the TMH 9 manual.

The primary objective of a training programme is to obtain consistent visual assessments with an acceptable level of bias. Even if the same assessors are used each year for the visual rating, calibration programmes are necessary, because there is a natural tendency on the part of raters to develop systematic errors in visual ratings. Field assessment teams should also be visited during the initial weeks of the execution of visual ratings in order to reduce the possibility of systematic errors.

4.6.1.3 Quality assurance during surveys

The various types of quality assurance approaches that can be used are discussed below.

a) Random checking

The controlling body randomly checks 10 to 15 per cent of all assessments to ensure that the assessments were done correctly and in accordance with TMH 9. In cases of total unreliability, all assessments should be repeated. Minor editing is often done during this process.

Self-checking should also be done by the executing body on a random or planned basis. In cases where one rater is consistently in error throughout the data base, the assessments could be adjusted accordingly.

b) Statistical approach

At the start of the assessment, all raters rate the same segments, normally about 10 to 20 segments. A statistical mean of the calculated condition indices (section 6.2.2) is determined for each road and individual indices are compared with the mean. Alternatively, control ratings on the 10 to 20 segments are done by an experienced panel and the individual condition indices are compared with those of the panel. This procedure is used as an acceptance test for the assessors.

Some authorities allow for about 5 per cent of the network to be separately assessed (cross checked) by at least two raters or executing bodies. Each rater or executing body is checked by at least two others. (Note that checking raters generally assess the segment more strictly than the original rater.) This procedure is used as a quality check on the actual assessments.

c) Recommended combined approach

Only accredited assessors are acceptable. To be accredited, an assessor should be well-versed in the use of TMH 9. (This could be checked through a special calibration course.) At the start of a new assessment period, all assessors rate the same segments, normally between 10 to 20. These segments are selected to cover a wide range of conditions. Results of assessments are compared statistically as described in (b). Assessors whose ratings show unacceptable deviations from the mean are not used for further assessments.

The checking of assessments by the executing body, as described in (a) should still be done before data are stored in the data base.

A small percentage (approximately 3 to 5%) should be double assessed, but only by the best accredited raters or client panel, to ensure continuous compatibility of assessments. This should be statistically well controlled and roads should be selected, from previous data, to cover a wide range of conditions.

Final control should be done through panel inspections, mostly only on roads identified for action by the PMS programme or regional engineers.

d) Comparison of degree and extent ratings

In addition to the comparison of assessments based on condition indices as described above, the assessments could also be compared on the basis of the individual degree and extent ratings. This is done to determine problems on the rating of particular distress types.

4.6.2 Instrument surveys

Instruments used for surveys should be in good working condition. Before a survey is started they should be calibrated and tested for repeatability and accuracy according to the manufacturers specifications and/or internationally accepted procedures. The frequency of calibration should be at least once a year, but more frequent calibration may be required depending on the usage of the equipment.

An acceptable test should also be performed after each survey to ensure that the equipment retained the calibration settings during the survey. If possible, checks should also be made during the survey.

4.7 INNOVATIONS IN INSTRUMENT SURVEYS

Many technology advances are being made in the development of pavement condition survey equipment. These developments affect all areas of condition survey described in this Chapter. Some of the recent innovations, which are in various stages of development, include the following:

- Distress surveys (Haas, 1994)

Manual surface distress surveys have several drawbacks including the hazard of being on the road, variability between raters, and the cost of the crews performing the slow-speed inspection. These factors have encouraged the development of automated techniques for evaluating pavement distress. Available equipment ranges from laptop/notebook computers (automated data collection forms) to video and film photography of the pavement surface. However, all working methods to date still require some degree of human intervention in the process of identifying and quantifying the distress types. Research into and development of equipment to replace the human observer continues. Owing to the rapid development of products in this area, those interested in equipment and methods for automated distress evaluation will need to access the most current information on the subject.

• Longitudinal and transverse profiling

Throughout the world, response type road roughness measuring systems (e.g. LDI) are being replaced by high speed profilometers. The modern profilometer measures the actual pavement surface profile and has some major advantages, including the following (Haas, 1994):

- Determination of actual profiles.
- Ability to handle large amounts of data automatically.
- Flexible operating speed (up to 120 km/h).
- Ability to detect and analyse long wavelengths (especially important for airport runways and high-speed highway traffic).
- Excellent repeatability.

In addition to the longitudinal profile, the transverse pavement profile can also be measured through a non-contact profiling system using closely spaced laser or ultrasonic beams and sensors on a transverse bar fitted to the vehicle. The transverse profile may be used to estimate rut depths.

• Skid resistance

The measurement of texture depth through the use of laser technology on high-speed profilometer, may be used as an indicator of potential skid resistance problems.

• Subsurface surveillance

Technology advances in the application of radar has led to the development of ground penetrating radar (GPR) equipment. The objective of the equipment is to improve the quality and speed of the collection of subsurface data. Current technology enables the collection of pavement layer thickness data, the detection of moisture levels, the detection of moisture induced stripping of asphalt and voids in pavement layers to be done at speeds of up to 70 km/h. The accuracy of the data is at present limited by the evaluation software.

5. DATA MANAGEMENT

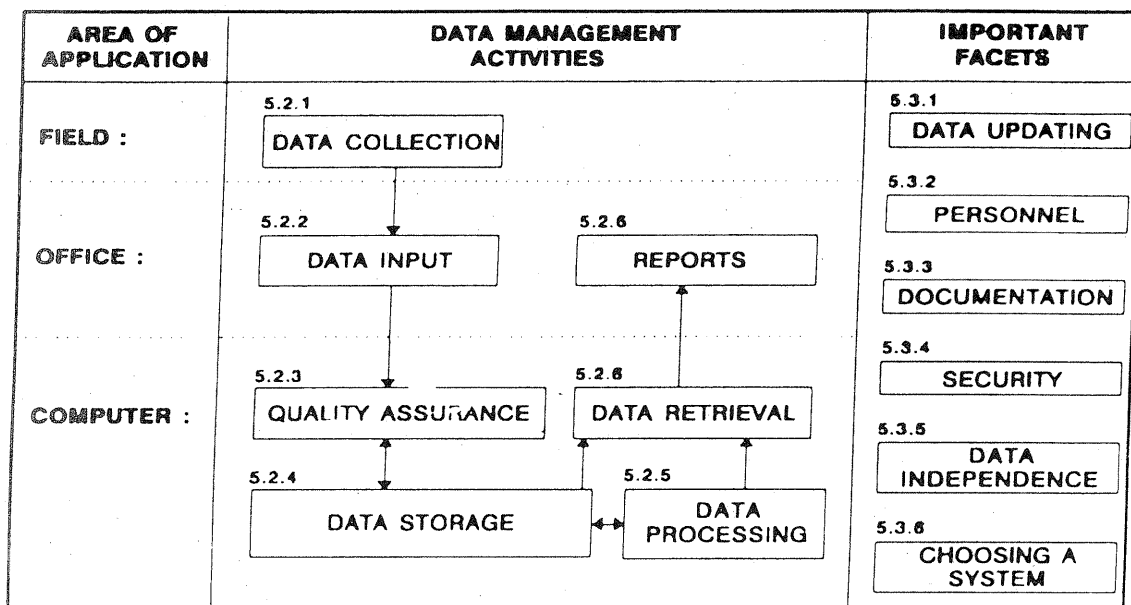


Figure 5.1: Flow diagram of Chapter 5

5.1 INTRODUCTION

For the purposes of this document, data management is defined as the total process of data handling, including the following:

- Field data collection.
- Data input into the computer PMS data base.
- Computer data handling, including verification, storage, processing and retrieval.

These data management activities are discussed in this Chapter, together with a few related important facets. Figure 5.1 provides a graphic illustration of these activities and facets.

5.2 DATA MANAGEMENT ACTIVITIES

5.2.1 Field data collection

There are two methods of recording visual assessment data in the field. The common practice in South Africa at present is to record the visual assessment ratings on standard data collection forms, as shown in TMH 9. The advantage of the form is that it can be used as a scratchpad during assessments, for example to record the number of occurrences of a distress type on a segment by making dots under the appropriate severity for each occurrence. In future this method of recording visual assessment data will be replaced by Automated Data Capturing (ADC) devices such as palm-held computers. Although ADC devices may reduce data-capturing errors and increase efficiency, the scratchpad advantage will be lost.

Data collected through instrument surveys are normally recorded electronically, directly into computer-based files.

5.2.2 Data input

The input of field data into the computerised PMS data base may involve one or more of the following three activities:

a) Interactive data entry

Data are interactively entered into a data base via an input screen using a data-base manager system. To make data input easier, the data-base manager software is used to design the input screen to look the same as the data collection form. The data may also be printed out in the same format as a hard copy of the survey data for checking and record purposes.

b) Data import

Data import is used to transfer data to the PMS data base from existing data bases or externally produced files (i.e. ADC device files). Most data-base manager systems will check each imported record being imported for errors.

c) Data transformation

Transformation is a function that writes a value into a PMS data-base file, based on values in one or more source data-base files. This form of data entry is used to transform raw data in the PMS data base or data from other management systems into a useful form for the PMS. For example, the transformation of traffic data from a Traffic Counting Management System for use in PMS.

5.2.3 Data quality assurance (data verification)

The quality of data affects the integrity of the entire PMS. Poor quality input data will result in poor quality outputs, irrespective of the amount and quality of computation performed by the PMS software. Data quality assurance is therefore imperative. Data quality assurance (or data verification) is the implementation of mechanisms that ensure data characteristics, such as validity, accuracy and integrity (FWHA, 1991).

Data quality assurance is an ongoing process. It begins with field checks during data collection, validity checks during data input, validity checks during and after data processing, and data integrity checks on a periodic basis.

5.2.3.1 Validity

Data validity mechanisms check if the given data fall within the expected range of values. Validity checks are carried out during data input and after data processing. The methods for checking validity are as follows:

- * Look-up tables used during interactive data input. These provide a range of feasible data values for the user to choose from.
- * Specification of maximum and minimum field values or sizes during interactive screen input of data. This facility is provided by most data-base managers.
- * Programs that are run after data input and processing to check that the data fields and values are within specified limits.

Data quality assurance can also be enhanced by using knowledgeable technical staff in the data input process. This could serve as an additional validation measure to avoid the input of meaningless data.

5.2.3.2 Accuracy

Accuracy means that data values must represent, as closely as possible, the actual situation at the indicated position and time. There are two types of data accuracy checks. The first checks the units in which the data are measured. For example, one data source might measure rut depth to the nearest millimetre, whereas another will measure to the nearest centimetre.

The second check is to ensure that observed and processed data values are as close as possible to a realistic situation. For example, the ratings of two different types of distress can be checked for conflicting data, i.e. if a rating of severe for bleeding and a rating of very good for skid resistance are in conflict. A typical data verification routine that is based on the TMH 9 data is presented in section A.2 of the Technical Addendum (Yellow Pages).

5.2.3.3 Integrity

It is good practice to avoid data redundancy (or the repetition of fields), since this may lead to lack of data integrity (DRTT, 1994). Data integrity means that whenever two data elements (values or names) in the same or different files represent the same fact, they must be equal. For example, if the length, width and area of a road section are stored in separate fields, the product of the first two must be equal to the area. Mechanisms to check data integrity are normally built into the data-base manager. Common data integrity checks include the following:

- * Checking that road names are spelled correctly.
- * Checking on the number of records in each file to ensure no data have been lost.
- * Checking for the possible duplication of records in each file.
- * Checking that the records in key fields, which are used to link files in a relational data base, are the same.

5.2.4 Data storage

Duplication of data in the PMS data base must be avoided. Where possible data should not be stored in more than one system in the total RMS (see Figure 1.2). Data should be stored in a well-structured data base, designed to group data elements together according to importance, frequency of updating and data type.

Data importance refers to the need for data security or for the maintaining of back-up copies. Importance may range from "scratchpad" or working data for which there is little concern if lost, since it can be regenerated very quickly, to "critical" data which needs to be backed up as soon as it is captured or updated.

Frequency of data updating may vary from condition data, which are updated annually to inventory data such as pavement width, which will be updated only if the road is reconstructed to a new width.

Different data types such as traffic counts and pavement structure should be stored in separate data files.

The data management plan should also include the storage of historical data. Separate archive files are normally recommended, but cognisance should be taken of the value of the information and appropriate steps should be taken to maintain and preserve the files. (Haas, 1994)

5.2.5 Data processing and analysis

Management of the data through the process of data processing and analysis requires these processes to be well defined, tested and documented to ensure that the processes are understood, that the results are reliable and that they meet the requirements defined in the quality assurance procedures.

5.2.6 Data retrieval and reporting

The management of data retrieval (queries) and reporting should ensure that casual users of the PMS software ask the right question to get the right answer. Two different users may want the same information from the PMS data base, for example the condition statistics for primary asphalt surfaced roads in Region A. The data retrieval process should make users ask the right questions to get the same answer. This can be achieved through predefined standard reports and forced filters.

5.3 IMPORTANT DATA MANAGEMENT FACETS

Effective management of the data base is essential for efficient storage, processing and retrieval of PMS data. Important facets of data management are data updating, personnel, documentation, data security, data independence and the choice of a data-base management system.

5.3.1 Data updating

Well-documented and consistent data updating procedures must be instituted as an important component of data management, in order to ensure good quality data. The frequency of data updating is dependent on the time cycle of PMS activities and the importance of the data to PMS operations and data processing. The data updating procedure must be executed at least annually. Some advanced networked systems update data on a daily basis.

A data updating system should be instituted within the organisation. The system should include standardised forms to collect data changes. The data types that need to be updated are described in Chapter 3. Prior to updating, the existing data files should be archived and stored on external storage mediums. An example of a form used for the collection of "as-built" data is shown in Figure 5.2.

5.3.2 Personnel

The four broad classes of personnel involved in the management and use of a PMS data base are (FHWA, 1991) the following:

- Data-base administrator
- Application programmers
- End users
- Support personnel

These classes of personnel have different levels of interaction with the PMS data base and their access to the data is controlled by the password system (section 5.3.4).

5.3.2.1 Data-base administrator

Data-base administrators are the people in control of the total system. They have the highest level of access to the data base. Typical tasks performed by the administrator are -

- * defining what data are stored in the data base;
- * defining and implementing data-base security systems;
- * defining data validity checks;
- * deciding data storage structures;
- * monitoring data-base performance; and
- * co-ordinating and communicating with users.

5.3.2.2 Application programmers

These are personnel that write and maintain application programs to access and process data in the PMS data base. They have limited access to the PMS data and normally work with a dummy set of data.

5.3.2.3 End users

End users range from frequent to casual users. Their access to the PMS data base is controlled by a password system and is related to their level of expertise. Access may range from edit to read only. Casual users are normally restricted to producing standard reports. Frequent users have access to procedures, such as system queries, to produce customised reports.

5.3.2.4 Support personnel

The level of access of support personnel to the data base is between that of the administrator and the end users. These personnel help enter PMS data, maintain backup copies of data and perform system support roles.

5.3.3 Data documentation

Each of the fields in a data-base file should be documented in a data dictionary with respect to the meaning, unit of measure, format, source use, relationships and security considerations (FHWA, 1991) (see also section 2.4.4).

5.3.4 Security

5.3.4.1 Passwords

Data-base security, in the form of passwords (user I.D.), is built into data-base manager systems. The purpose of the password system is to prevent unauthorised access to the data base and to protect against data loss. The passwords security system may be structured to allow different levels of access to data. Examples of user access levels are -

- read only (casual users)
- edit only
- data deletion
- data base packing and restoration (system manager).

5.3.4.2 Back-up

Back-up procedures are instituted to ensure that data can be restored to the data base in the event of data loss. Back-up frequency is influenced by -

- data importance;
- the extent of data changes; and
- the frequency of data changes.

The data base should be archived annually and stored as the official data for that year.

5.3.4.3 File checks

A check is made for file access and data file changes on a periodic basis. The dates are then recorded in a security file. This information can be used to initiate back-up procedures based on the frequency of file access or data changes.

5.3.5 Data independence (Deighton, 1994)

5.3.5.1 Storage

An important rule in data storage is that the data must be placed in the data base independent of any perceived application. The main reason is that if the data is transformed into management sections (uniform sections) and placed into the data base in that form, no changes can be made to the management sections without going back to the original raw data and repeating the transformation process.

If the data is stored independently, the data can be updated without any reference to management sections. This facilitates the ease and efficiency of the data updating process. In addition, if the data-base manager system has a dynamic segmentation feature, the data can be analysed according to any management sections, as and when required by the user. For instance, different management sections can be used for traffic and maintenance treatment analyses.

5.3.5.2 Dynamic segmentation

Dynamic segmentation is the most important feature of the PMS data-base manager software. Dynamic segmentation is the ability of the system to cross-reference data describing one set of data with the data describing another set of data. For example, the data describing roughness, rutting and traffic can be split into different management sections (uniform sections) and these sections can then be related to one another during the analysis process.

In addition, the dynamic segmentation facility enables roadway data from different management systems to be combined for PMS use, provided there is a common referencing system. Therefore, data can be stored in different management sections in each of the systems, in accordance with the systems' needs.

5.3.6 Choosing a data-base management system

A data-base management system (DBMS) provides a mechanism to manage data. It should be able to perform this function effectively according to accepted norms, including those discussed in this Chapter. To select a computerised system the following important criteria should be considered (DRTT, 1994):

- * The system should be able to handle the volumes of data calculated within acceptable time periods;
- * it should present an intuitive interface to the end-user;
- * staff should be available who can support it and its application;
- * the system should be able to operate across a computer network;
- * it should provide some kind of concurrency control, so that users can share data without introducing inconsistencies;
- * data-retrieval procedures should be simple and effective;
- * the supplier should be reputable and well-established;
- * the system should operate efficiently, and
- * it should be appropriate to the needs of the road authority.

It is important to note that the cost of DBMS (and the computer hardware) will in many cases be insignificant compared with the cost of collecting and managing the data.

PAVEMENT MANAGEMENT SYSTEM - AS BUILT DATA

ACTIVITY CATEGORY:		ROUTINE MAINTENANCE		PERIODIC MAINTENANCE		SPECIAL MAINTENANCE		REHABILITATION		NEW CONSTRUCTION		X		
ROAD NO.	SECTION NO.	FROM (km)	TO (km)	LANE	LAYER DESCRIPTION	LAYER THICK. (mm)	MATERIAL QUALITY (TRH 14)	BINDER/ STAB. AGENT	NEW/ REWORKED LAYER	YEAR	ACCURACY INDICATOR	CONTRACT NO.	CONTRACTOR	CONSULTANT
12	1	0.0	6.8	All	Surfacing	40	AC	Bitumen	N	1993	A	C123	ABC	XYZ
				All	Basecourse	150	G1		N	1993	A			
				All	U/Subbase	150	C3	Cement	N	1993	A			
				All	L/Subbase	150	C4	Cement	N	1993	A			
				All	USSG	150	G7		N	1993	A			
				All	LSSG	150	G9		N	1993	A			
				All	Subgrade	300	G10		N	1993	A			
2	3	13.0	23.5	All	Surfacing	13/8	S2	Bitumen	N	1994	A	C124	DEF	RST
				All	Basecourse	125	G2		N	1994	A			
				All	Subbase	150	C4	PBFC	N	1994	A			
				All	USSG	150	G7		N	1994	A			
				All	LSSG	150	G9		N	1994	A			
				All	Subgrade	150	G10		N	1994	A			

(Codes should be printed on the back of the form)

Figure 5.2: Example of typical as-built data collection form

6. PAVEMENT CONDITION ANALYSIS

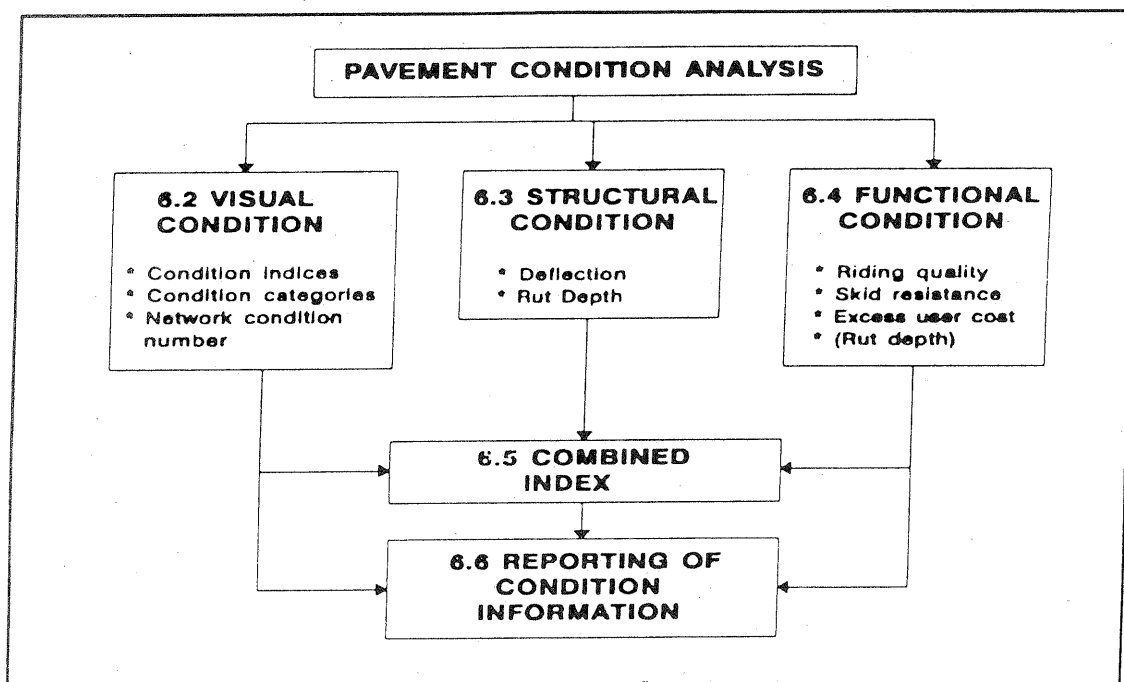


Figure 6.1: Flow diagram of Chapter 6

6.1 INTRODUCTION

The determination of the current pavement condition is the first step in providing management with decision support information. Pavement condition information is used at network level for the -

- * evaluation of present pavement condition;
- * evaluation of the change in pavement condition over time;
- * determination of maintenance and rehabilitation needs;
- * ranking of candidate projects;
- * establishment of maintenance and rehabilitation strategies;
- * prediction of pavement performance; and
- * optimising of maintenance and rehabilitation funds.

The use of pavement distress data at project level will depend upon its detail, quality and accuracy (refer to section 10.5.2). Normally more detailed measurements are used at project level.

Pavement condition analysis begins with the processing of condition data collected through either visual assessments or measurements. The condition analysis can be classed into the following three categories:

- **Visual condition analysis**

This analysis is based on data that can be collected through visual assessments, and may include a subjective rating of the functional condition items, e.g., road roughness (riding quality). This condition data is also referred to as pavement distress data.

- **Measured structural condition analysis (capacity)**

This analysis is normally based on non-destructive testing of the pavement and would give an indication of the structural integrity of the pavement and/or the number of repetitions of a standard axle that a pavement can carry.

- **Measured functional condition analysis**

The functional condition deals with the road user facets, namely riding quality (road roughness), rutting and safety (skid resistance).

Most of the pavement condition information can be provided through analysis of good quality visual assessment data. The use of the generally more expensive instrument survey condition data at network level will depend on -

- the importance of the roads (acceptable risk of failure);
- the cost of rehabilitation (including traffic accommodation);
- the type and level of decision to be made based on the data; and
- the cost of the survey and the resources available.

6.2 VISUAL CONDITION ANALYSIS

6.2.1 Condition indices : General

The visual condition analysis is performed on pavement distress data collected through visual assessments of the pavement surface. The data collection methods are described in section 4.2.

The method of analysis combines the visual pavement condition data for individual distress types into an index representing the general pavement condition. The index is only a representation of the "as-is" condition of the pavement, irrespective of the importance of the road and does not take traffic or functional classification of the road into account. The calculation of the pavement condition index requires the selection of a weighting factor for each type of distress.

In addition to the general visual condition index, other related indices may also be calculated, such as -

- pavement indices based only on certain distress groupings, e.g., surface distress index, structural distress index; or
- itemised pavement distress indices e.g., rut index, crocodile cracking index, etc.

Although it is possible to have different rating scales for different condition indices, it is advantageous to establish one unique rating scale for all indices (i.e. 0 to 100). This would facilitate better communication between the various PMS users. It is also important that the users know how, when and why to use the various types of condition indices.

A condition index has several useful applications, including the following:

- As a relatively simple way to communicate the health of the system or individual roads to management, planners and politicians;
- as a parameter to compare the general condition of different road networks;
- to indicate the rate of deterioration of individual pavements segments;
- as a factor in a priority rating method;
- as a fast technique for estimating average costs to maintain or rehabilitate a candidate project, e.g., pavements with an index of 50 will on average require "x" rand to repair.

The use of condition indices has limitations and the indices should therefore be used with discretion.

6.2.2 Visual condition index calculations

Various methods of calculating the condition indices are available and were used by the major road authorities in the past. These methods were investigated by the Committee for Compatibility of Pavement Management Systems with the objective of determining an acceptable method that would produce results that have a good correlation with the judgement of an expert panel of raters.

The proposed formula for calculating the visual condition index (VCI) is given in equations 6.1 to 6.3. To further improve the correlation of the VCI with engineering judgement, modifications to the formula are being investigated. These modifications are presented in section A.3 of the Technical Addendum (Yellow Pages).

$$VCI_p = 100 \left\{ 1 - C * \left[\sum_{n=1}^N F_n \right] \right\} \quad \dots\dots\dots (6.1)$$

where:

VCI_p	=	Preliminary VCI	
F_n	=	$D_n * (E_n) * W_n$	 (6.2)
n	=	Visual assessment item number (Table 6.1)	
D_n	=	Degree rating of defect n	
		Range :	0 to 4 for functional defects
			0 to 5 for other defects
E_n	=	Extent rating of defect n	
		Range :	Default 3 for functional defects
			0 to 5 for other defects

W_n = Weight for defect n (Table 6.1)

$$C = 1 / \left[\sum_{n=1}^N F_n(\max) \right]$$

$F_n(\max)$ = F_n with degree and extent ratings set at maximum.
Where two or more options are available per distress, e.g. aggregate loss, use the average W_n for the calculation of $F_n(\max)$.

Equation (6.3) is applied to transform the VCI_p to a standard percentage scale.

$$VCI = (a * VCI_p + b * VCI_p^2)^2 \dots \dots \dots (6.3)$$

where:

$$\begin{aligned} a &= 0,02509 \\ b &= 0,0007 \\ VCI_{\max} &= 100 \\ VCI_{\min} &= 0 \end{aligned}$$

Factors a and b have been derived from processing condition data collected through an expert panel throughout South Africa. As indicated in the TMH 9 document, not all visual assessment items listed in Table 6.1 are considered essential for compatibility at network level. It is proposed however that for maximum national compatibility, deviation from the proposed default weight set should be kept to the minimum.

TABLE 6.1: PROPOSED WEIGHT SET FOR VCI FORMULA

ITEM NO.	ASSESSMENT ITEMS	WEIGHT (W _n)
1	Texture	0
2	Voids	0
3	Surfacing failures	6,5
4	Surfacing cracks	5,0
5 A	Aggregate loss (Active)	4,0
5 N	Aggregate loss (Non-Active)	2,0
6	Dry/Brittle	3,0
7	Bleeding	3,0
8 N	Cracks : Block/Stab (Narrow spacing)	8,0
8 M	Cracks : Block/Stab (Medium spacing)	6,0
8 L	Cracks : Block/Stab (Large spacing)	5,0
9 N	Cracks : Long/Slip (Narrow spacing)	4,5
9 M	Cracks : Long/Slip (Medium spacing)	4,5
9 L	Cracks : Long/Slip (Large spacing)	4,0
10	Cracks : Transverse	4,5
11	Cracks : Crocodile	10,0
12	Pumping	10,0
13	Rutting	8,0
14	Undulation/Settlement	4,0
15 S	Patching (Small)	8,0
15 M	Patching (Medium)	8,0
15 L	Patching (Large)	8,0
16	Failures/Potholes	15,0
17	Edge breaking	3,5
18	Riding quality	5,5
19	Skid resistance	3,0
20	Surface drainage	3,0
21	Unpaved shoulders	3,5

6.2.3 Condition categories

The reporting of the condition of a paved road network for upper management should be through the use of condition categories. The condition indices of the road network should be grouped into one of the five condition categories shown in Table 6.2. The table also indicates the colours that should be used when reporting the condition category information graphically in the form of pie or bar charts. Typical examples of the charts are presented in section 6.6.

TABLE 6.2: CONDITION CATEGORIES

DESCRIPTION OF CATEGORY	CONDITION INDEX RANGE	COLOUR CODE
Very good	$85 \leq VCI \leq 100$	Green
Good	$70 \leq VCI < 85$	Blue
Fair	$50 \leq VCI < 70$	Yellow
Poor	$30 \leq VCI < 50$	Orange
Very poor	$0 \leq VCI < 30$	Red

At national level, the condition statistics may be reported at the following three levels only:

- Good (including very good) : $70 \leq VCI \leq 100$
- Fair : $50 \leq VCI < 70$
- Poor (including very poor) : $0 \leq VCI < 50$

6.2.4 Network condition number

The network condition number (NCN) has been developed as a simplified way to represent the condition of a road (sub)network in a single number. The NCN is closely related to the condition indices (section 6.2.2), and the condition categories (section 6.2.3) are therefore sometimes applied to the NCN to classify the overall network condition. It is proposed however that the applicability of the condition category limits to the NCN should first be confirmed through a calibration process. The major use of the NCN is twofold, i.e. -

- to compare the overall condition of two or more subnetworks with one another; and
- to monitor the change in condition of a network over time. For example, a drop in the NCN over time may indicate that too little money is spent on road maintenance and vice versa.

The NCN is an average visual condition index for the (sub)network, weighted for the condition and length of each segment. The NCN is calculated using equation 6.4, together with condition weights presented in Table 6.3. The weights ensure that the NCN has a high sensitivity for changes in the condition of poor to very poor condition segments.

Equation (6.4) gives the formula for the calculation of NCN:

$$NCN = \frac{\sum_{i=1}^I (VCI_i * L_i * W_i)}{\sum_{i=1}^I (L_i * W_i)} \quad \dots \dots \dots (6.4)$$

where: I = Number of segments in (sub)network
 VCI_i = Visual condition index of segment i
 L_i = Length of segment i
 W_i = Condition weight corresponding to the condition category of segment i (Table 6.3)

TABLE 6.3: CONDITION WEIGHTS FOR NCN CALCULATION (PRELIMINARY)

CONDITION CATEGORY CLASSIFICATION OF SEGMENT i	CONDITION WEIGHT (W_i)
Very good	1,0
Good	1,2
Fair	1,8
Poor	2,7
Very poor	4,0

6.3 STRUCTURAL CONDITION ANALYSIS

6.3.1 General

The analysis of the structural condition of pavements at network level is performed on surface deflection and/or rutting measurements. The data collection methods are described in section 4.4.

The analysis and presentation of the results may vary from a statistical processing of the measurements to the calculation of a structural condition index, as described in sections 6.3.2 and 6.3.3.

6.3.2 Analysis of deflection measurements

6.3.2.1 Statistical analysis of data

The deflection basin measurements may be used to define uniform sections. The percentile values for each uniform section can then be used to classify the pavement section into structural stiffness categories. This method of analysis does not provide information on remaining life under existing traffic loading but does indicate relative changes in structural stiffness in a network or along a route.

6.3.2.2 Structural stiffness index

At present there is no unified approach for establishing a structural stiffness index. It is essential that such an index should provide an indication of the remaining life of the pavement, based on the number of axle load repetitions the pavement can withstand and the predicted future axle loading. Various methods of determining the remaining life at network level are under development or investigation at present. The deflection basin measurements derived from FWD testing are normally analysed by linear elastic or empirical methods to determine layer stiffnesses and thereafter remaining life. Linear elastic methods require relatively detailed pavement data (e.g. layer thicknesses) for the analysis which, in many cases, are not available at network level. Empirical methods using the FWD basin parameters in the direct prediction of structural capacity are suited for use in cases where only limited pavement data are available at network level in pavement management systems. The accuracy of the results may however not be adequate for use at project level.

A proposal for the calculation of a Structural Stiffness Index (SSI), based on the predicted remaining life is presented in section A.4.1 of the Technical Addendum (Yellow Pages). One of the methods of determining the remaining life, which has been developed in South Africa and is currently being evaluated, is summarised in section A.4.2 of the Technical Addendum (Yellow Pages). The method is based on the FWD basin parameters.

6.3.3 Analysis of rut depth measurements

The extent and magnitude of rutting is an indication of the pavement's structural integrity and functional condition. Rutting severity can be converted into an index and combined as part of the visual, functional and structural indices. As a separate distress indicator, rutting severity can be used as a flag or trigger value for maintenance and rehabilitation action.

Table 6.5 provides rut depth severity levels that could be used as flags in action decision trees or used for graphical presentation of the rut depth data.

TABLE 6.5: RUT DEPTH SEVERITY LEVELS (TRH 12, 1985)

ROAD CATEGORIES	EXTENT (% OF LENGTH)	RUT DEPTH FOR SEVERITY LEVEL (mm)		
		D1	D2	D3
A	5	< 15	15 - 20	> 20
B	10	< 15	15 - 20	> 20
C	20	< 15	15 - 20	> 20
D	25	< 15	15 - 20	> 20

Where:

The severity level (mm) for a section of road is determined from a cumulative distribution graph, based on the extent defined for the particular road category.

- D1: Sound condition : There is no requirement for maintenance on the evidence of the condition parameter.
- D2: Warning condition : The pavement is approaching a severe state of distress, but is acceptable at present.
- D3: Severe condition : Based solely on the evidence of the particular condition parameter, requires remedial action.

The severity levels based on functional considerations (water standing in the rut) may require adjustments depending on the road alignment and cross section.

6.4 FUNCTIONAL CONDITION ANALYSIS

6.4.1 General

The functional requirements of a pavement are the required standards of those properties of the pavement that affect the service it provides to the road user. They are predominantly those that govern his comfort, safety and speed of travel (TRH 6, 1986). Three of the most important features are riding quality, skid resistance and surface drainage. Surface drainage is at present being assessed only through visual assessments. The processing of riding quality and skid resistance data is further discussed in this section.

6.4.2 Riding quality

Riding quality is used in PMS as one index of the functional condition of a pavement and a determinant of excess user costs. Riding quality can be combined as part of a visual functional index, or used separately as a trigger value or flag for maintenance and rehabilitation actions.

TABLE 6.6: RIDING QUALITY SEVERITY LEVELS (TRH 12, 1985)

ROAD CATEGORIES	EXTENT (% OF LENGTH)	RQ PER SEVERITY LEVEL (PSI)		
		D1	D2	D3
A	5	> 3,0	2,5 - 3,0	< 2,5
B	10	> 2,5	2,0 - 2,5	< 2,0
C	15	> 2,0	1,5 - 2,0	< 1,5
D	50	> 2,0	1,5 - 2,0	< 1,5

Where:

The severity level (PSI) for a section of road is determined from a cumulative distribution graph, based on the extent defined for that particular road category.

- D1: Sound condition : There is no requirement for maintenance on the evidence of the condition parameter.
- D2: Warning condition : The pavement is approaching a severe state of distress, but is acceptable at present.
- D3: Severe condition : Based solely on the evidence of the particular condition parameter, requires remedial action.

Riding quality (or road roughness) can be reported on any one of three scales in general use in the world today. For compatibility with international standards, the use of the IRI scale is recommended. These scales are the following:

- * International Roughness Index (IRI): The IRI is defined by the average rectified slope (ratio of accumulated suspension motion to the distance travelled) of a standard quarter-car (one wheel) simulation for a travelling speed of 80 km/h. It is computed from surface elevation data collected by either a topographical survey or mechanical profilometer. The IRI is expressed in units of mm/km (Paterson, 1987) (0 excellent, 20 very poor).

- Quarter-car Index (QI): The QI is measured by means of a linear displacement integrator (LDI) which measures and sums the displacements between the rigid axle and the body of a vehicle (Van der Merwe and Grant, 1980). (0 excellent, 270 very poor).
- Present Serviceability Index (PSI): The PSI is a five-point scale (0 very poor, 5 excellent) quantifying the subjective rating of riding quality by a panel of experienced highway users (TRH 6, 1985).

The approximate numeric relationships between PSI, IRI and QI are given in Table 6.7 and these are expressed diagrammatically in Figure 6.2.

TABLE 6.7: CONVERSION FORMULAE FOR RIDING QUALITY DATA

CONVERSION	FORMULA
PSI to QI	$QI = 94,104 - 57,804 \times \ln(PSI)$
PSI to IRI	$IRI = 7,436 - 4,132 \times \ln(PSI)$
IRI to QI	$QI = 14 \times IRI - 10$

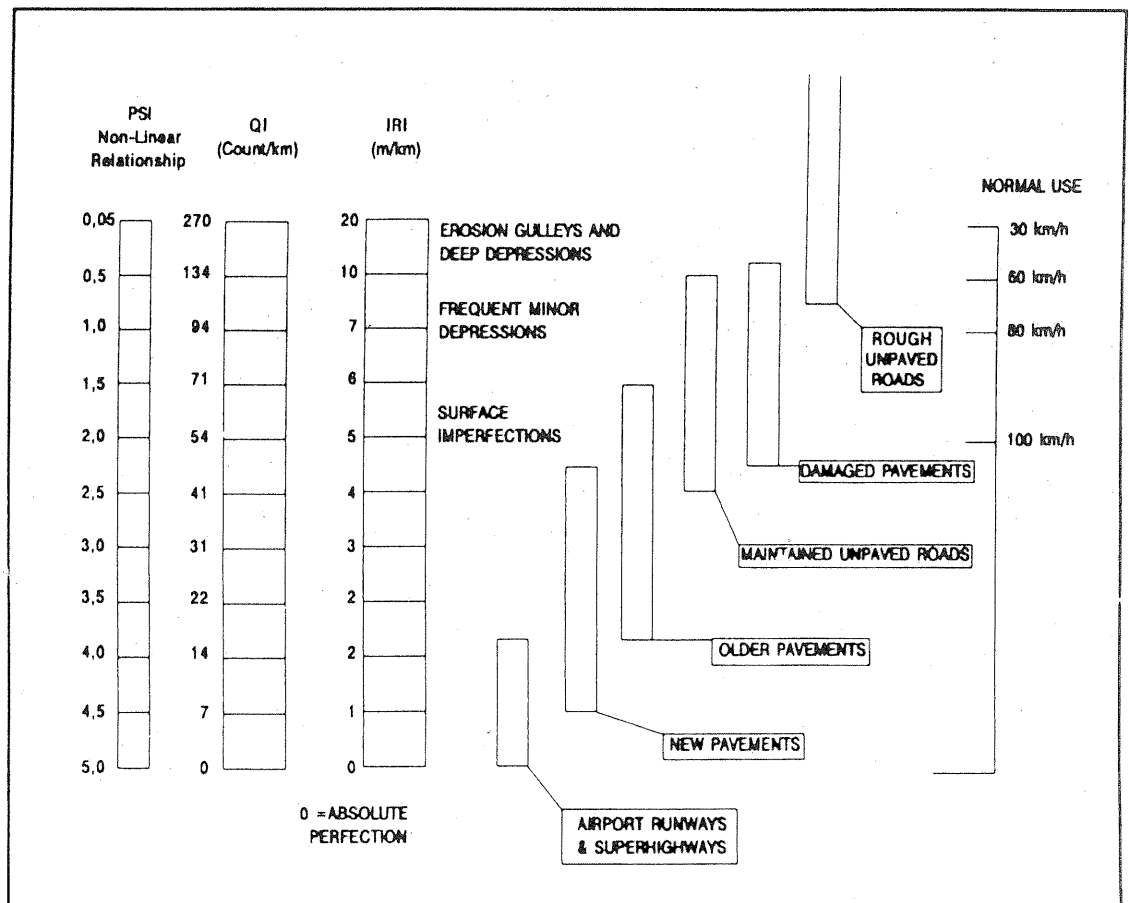


Figure 6.2: Scales of road roughness (Based on World Bank, 1986)

6.4.3 Skid resistance

No categorically unacceptable (severe) or warning limits are specified for skid resistance. Many interacting elements combine to establish a hazardous condition on a highway and skid resistance is only one such element. Factors such as road category, traffic volumes, traffic speed and difficulty of road situation should be taken into account. If classification of skid resistance is undertaken it should be rather in terms of appropriate levels of risk for typical situations requiring further investigation to reduce a level of risk. Potential guidelines for the classification of various levels of risk for certain sites is presented in section A.4 of the Technical Addendum (Yellow Pages).

6.4.4 Excess user costs owing to road roughness

6.4.4.1 Background

Guidelines for the calculation of vehicle operating costs (VOC), as affected by road roughness, were provided by the CSIR in a document "Guidelines on the Economic Evaluation of Rural Roads in Developing Areas of Southern Africa, March 1988", which had been prepared for the Development Bank of Southern Africa (Schutte, 1988).

One of the factors influencing the decision to undertake rehabilitation work is the generation of Excess User Costs (EUC) on a road section, owing to poor riding quality. EUC can be defined as the additional vehicle operating costs that would not have been experienced on the road if it had had a good riding quality. The riding quality (or road roughness) value above which EUC is generated has been defined as 40 (on a QI scale) or approximately 2,6 (on a PSI scale).

6.4.4.2 EUC calculations

EUC is calculated as the difference between the VOC at the actual measured riding quality (if > 40 QI) and the VOC at a riding quality of 40 QI. VOC can be calculated for three terrain types and for four vehicle types. The formulae for the calculation of EUC for use at network level in PMSs have been reduced however to include only vehicle types and riding quality as variables.

The annual EUC is calculated as presented in section A.6.1 of the Technical Addendum (Yellow Pages). A method of calculating an EUC index is under evaluation at present and is also presented in section A.6.1. The EUC index can be used for classifying EUC into categories or in combination with other condition indices. It is extremely important to indicate the base date of the input costs whenever EUC are reported.

Proposals for the classification of EUC into categories through the use of an EUC index are presented in section A.6.2 and A.6.3 of the Addendum.

6.5 COMBINED INDICES

An Overall Pavement Index (OPI) can be calculated from a combination of indices, such as the visual condition index and other indices based on field measurements (e.g. riding quality index and structural stiffness index). To calculate an OPI, the following should be taken into account:

- i) A relative weight factor must be assigned to each contributing index. The weight factor is chosen relative to the contribution the distress attribute makes to the overall pavement condition.
- ii) A uniform rating scale (0 to 100) should be used for all indices.
- iii) In order to maintain the same rating scale, the sum of the weight factors for all indices should be one.
- iv) The OPI can be calculated by summing the products of each index and the appropriate weight factor.

An example of an OPI is given in equation 6.5.

$$OPI = a.VCI + b.RQI + c.SSI \quad \dots\dots\dots (6.5)$$

where:

OPI = Overall Pavement Index
VCI = Visual Condition Index
RQI = Riding Quality Index (could be replaced by EUCI)
SSI = Structural Stiffness Index
a, b, c = Weight factors
1 = a + b + c

A problem with the combining of various indices into one is that, for example, where only one index is in a poor condition category, the combined index may still be classified as good overall, and the severe condition could therefore be overlooked.

6.6 REPORTING OF PAVEMENT CONDITION INFORMATION

6.6.1 General

The condition of the road pavement has to be reported to various levels of management. The reporting of the condition information must therefore be adjusted to suit the particular needs of the end user. This section provides typical examples of ways to present condition information graphically.

6.6.2 Visual condition (pavement distress)

The unprocessed assessment data (degree and extent ratings) can be presented per segment on the field assessment form or listed for a number of segments in a spreadsheet format with all the ratings for each road segment presented per line. The severity and extent of each distress item can also be shown visually, as presented in Figure 6.3. These data formats can be used for field control, for panel inspections or for input to project level evaluation.

For higher management level use a graphical summary of individual distress types can be prepared per subnetwork to indicate predominant distress types (Figure 6.4).

Condition indices can be reported in various formats ranging from lists, indicating the condition index per segment, to graphical presentations, indicating visual condition against distance (Figure 6.5) or change in visual condition over time for a particular road segment (Figure 6.6).

The reporting of visual condition per condition category is normally done in the following four formats using the colours defined in Table 6.2 where applicable:

- * Pie/bar charts summarising condition for one network (Figure 6.7).
- * Pie/bar charts comparing conditions between subnetworks (Figure 6.8).
- * Comparison of the annual condition classification of a road network over time (Figure 6.9).
- * Computer generated (GIS) maps presenting the condition category of each road segment in the standard colour.

The Network Condition Number (NCN) can be presented in the following two formats:

- * A presentation of the NCN per subnetwork to compare the condition of individual subnetworks with each other (Figure 6.10).
- * A presentation of the NCN per annum, used to monitor the change in condition of a network over time (Figure 6.11).

6.6.3 Structural condition

One or more deflection bowl parameters plus the structural condition index can be presented graphically along the length of the road, together with an indication of other relevant data (Figure 6.12).

The structural condition of a road (sub) network can be presented in summary on a pie chart similar to that for the visual condition categories (Figures 6.7 and 6.8), but using the SSI categories.

Rutting information can also be shown directly along the road length or summarised using the severity levels (D1-D3) defined in Table 6.5.

6.6.4 Functional condition and EUC

A typical example of riding quality results, together with the corresponding excess user costs, is shown in Figure 6.13 in the same formats as used for the visual condition. The excess user cost can also be presented as an EUC index or in EUC categories.

6.6.5 Combined information

To obtain an overall indication of the condition of a specific road, the results of various condition evaluations can be combined into one bar chart (Figure 6.14).

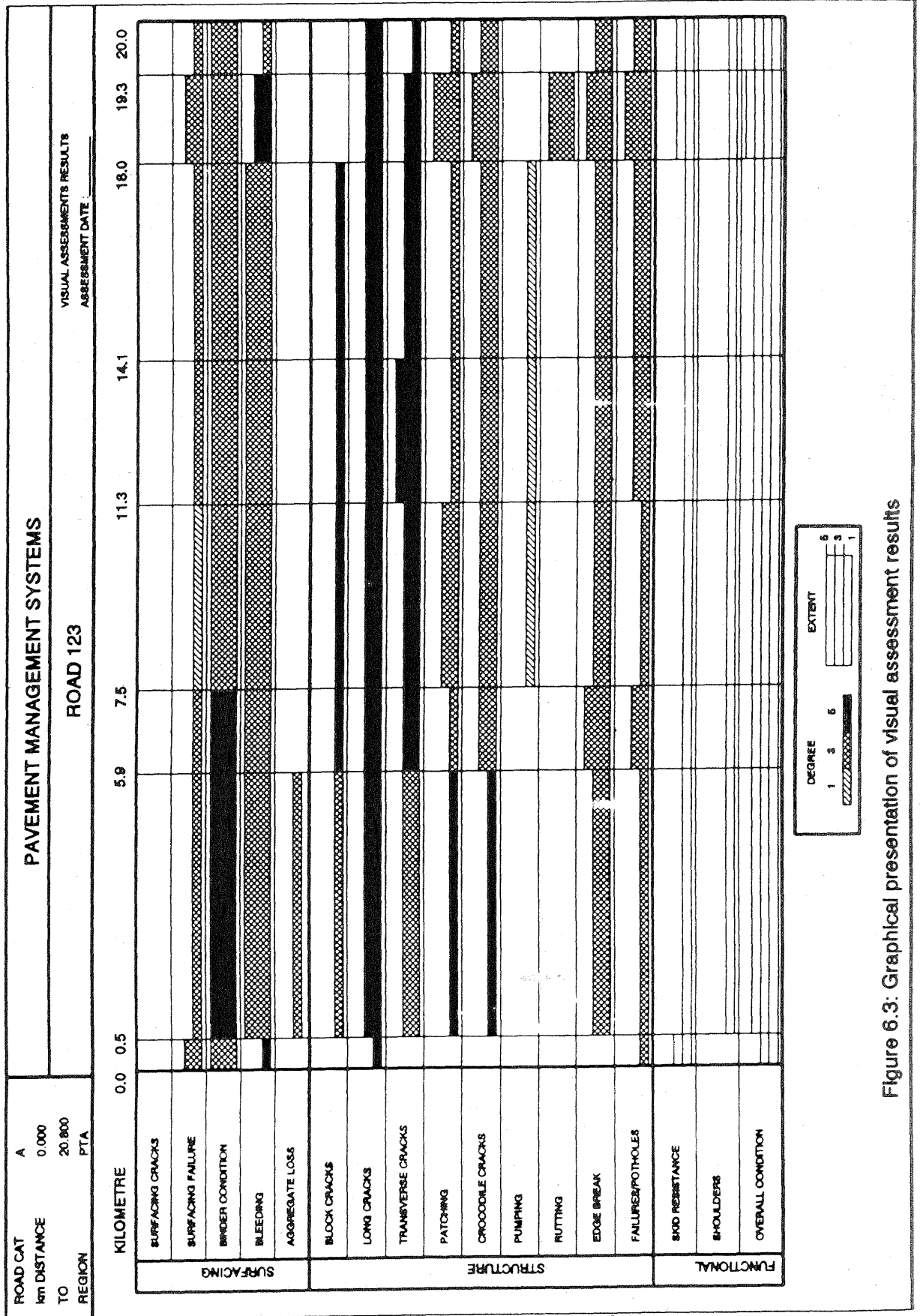


Figure 6.3: Graphical presentation of visual assessment results

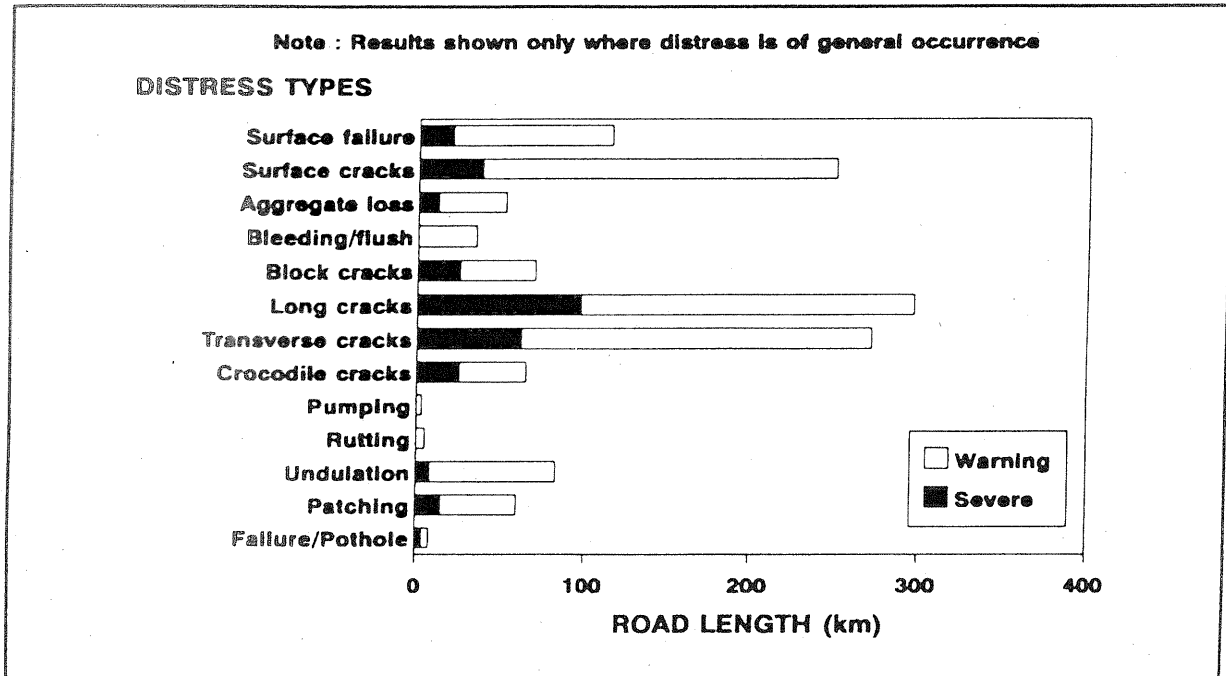


Figure 6.4: Distribution of significant distress

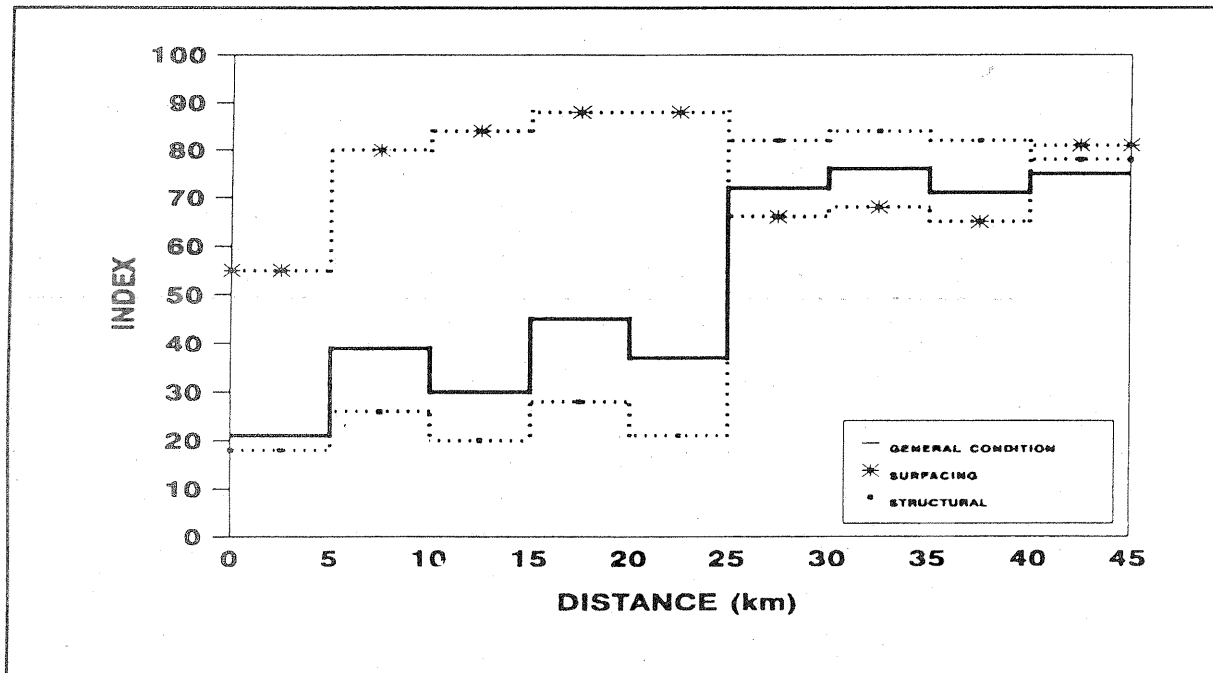


Figure 6.5: Condition indices per road length

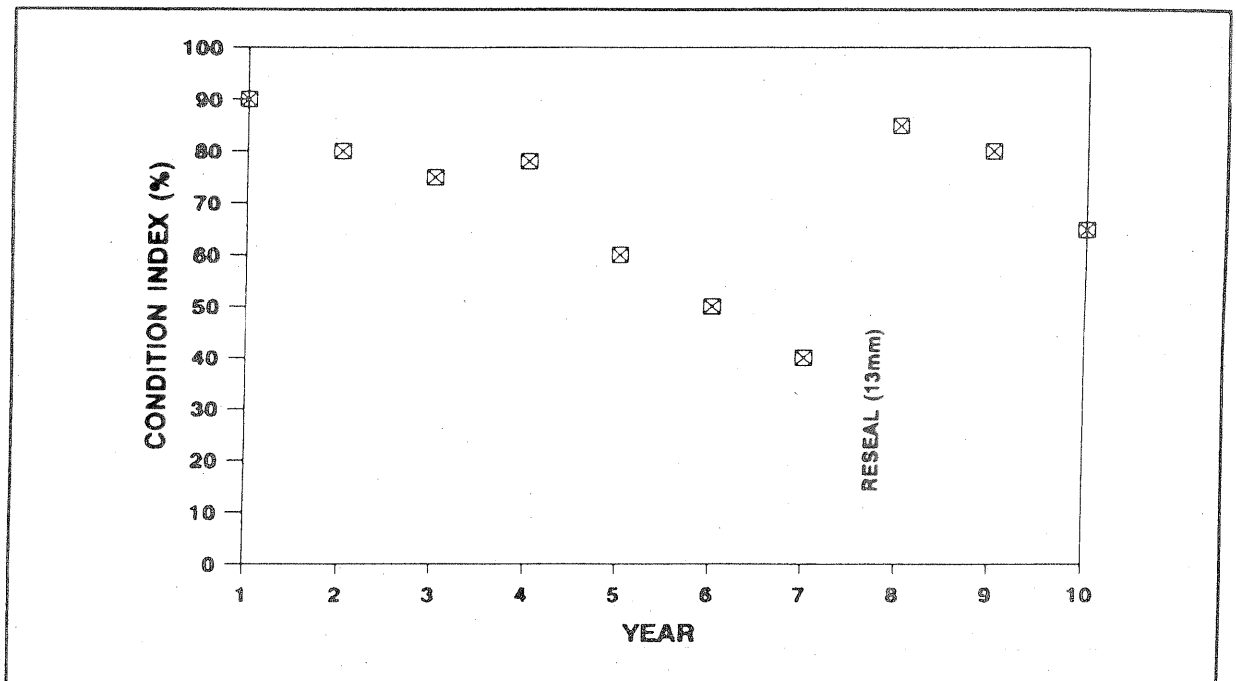


Figure 6.6: Change of VCI over time for a section of road

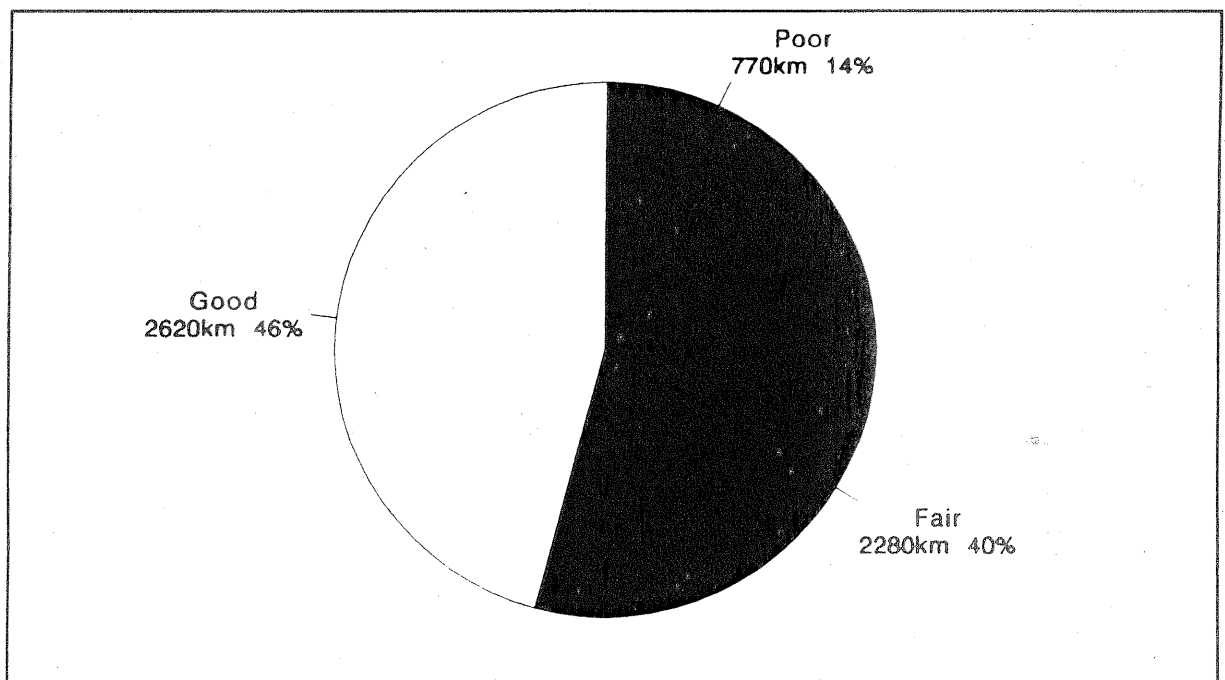


Figure 6.7: Condition classification of a road network

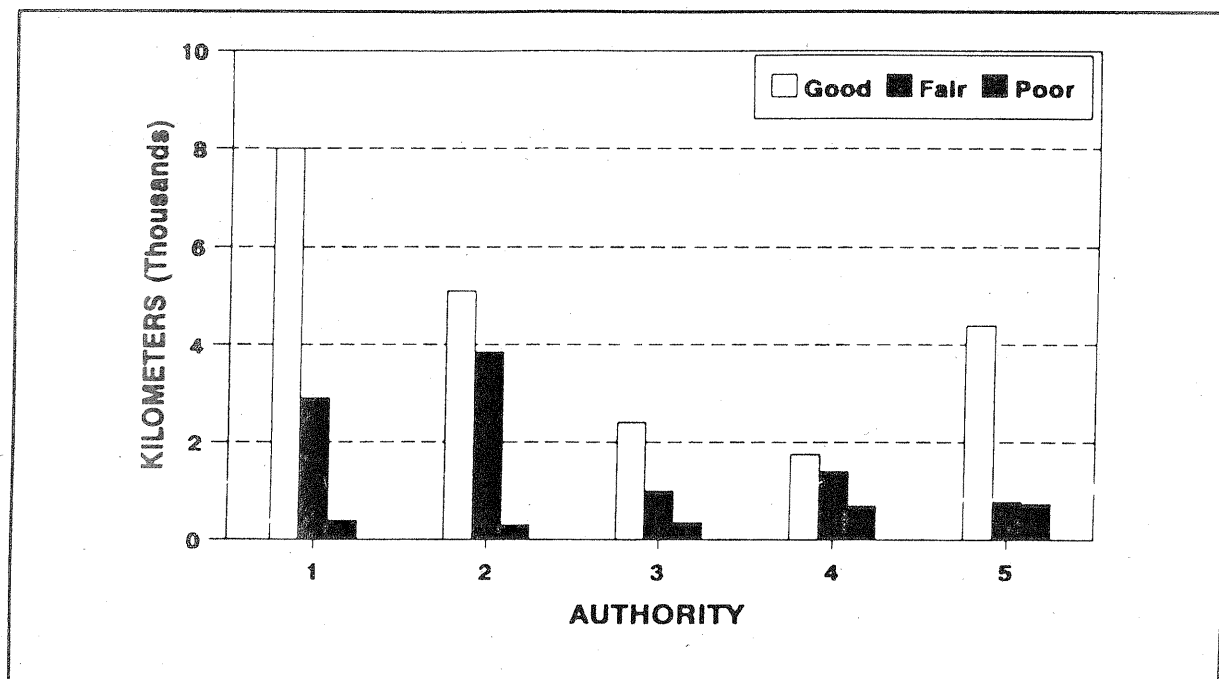


Figure 6.8: Condition classification per subnetwork

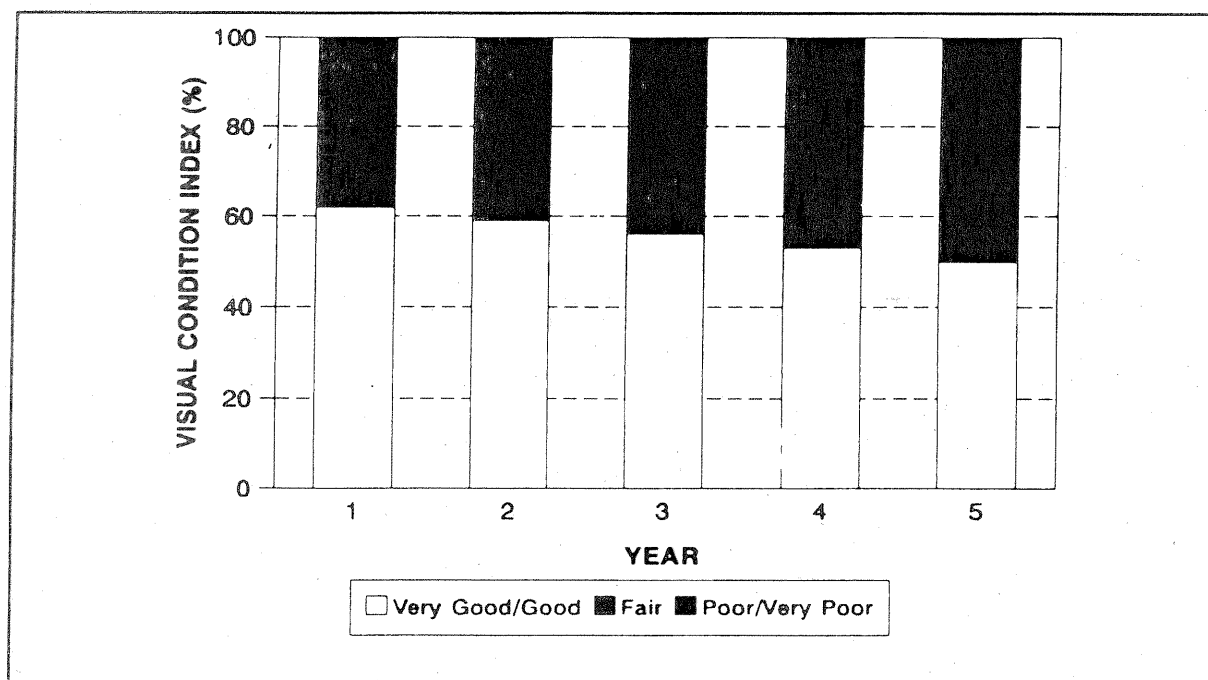


Figure 6.9: Change in road condition for the network

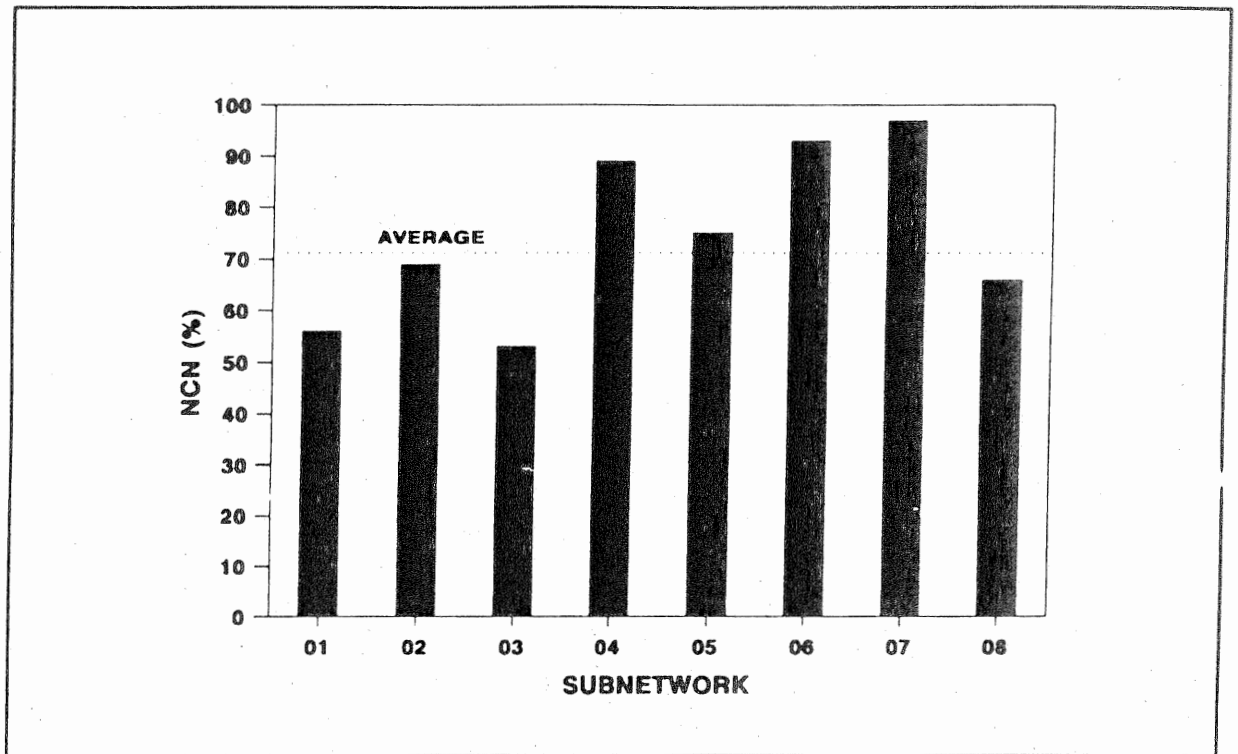


Figure 6.10: Comparison of network condition numbers

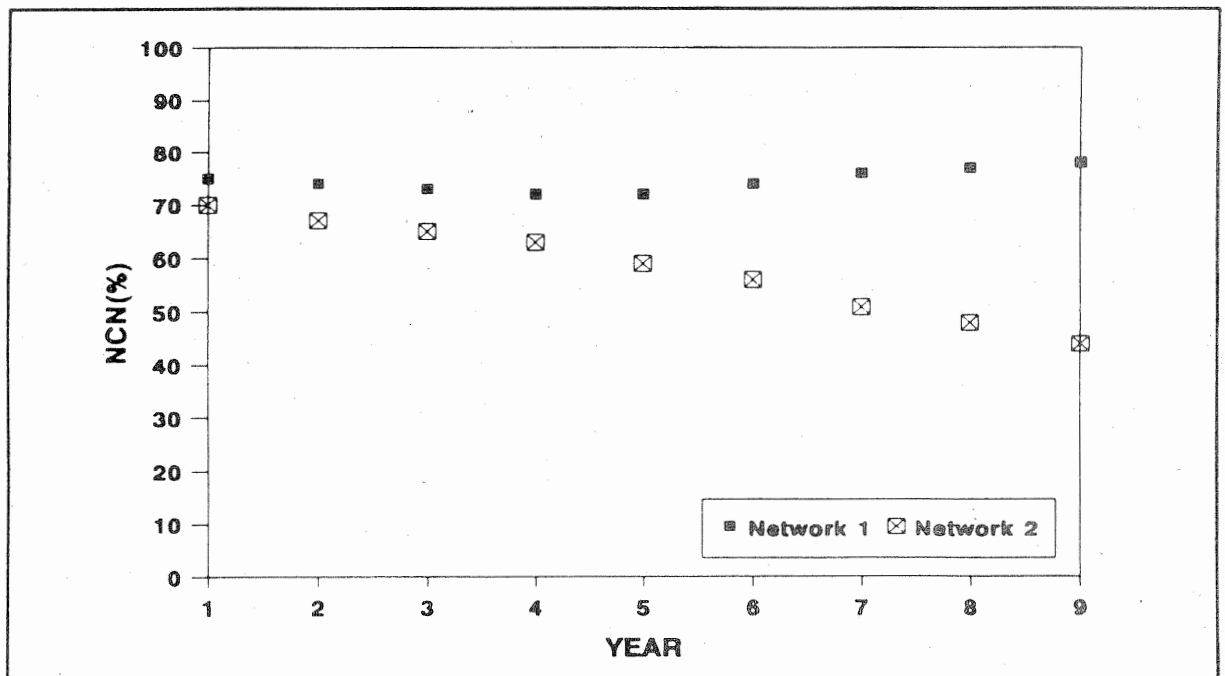


Figure 6.11: Network condition number over time

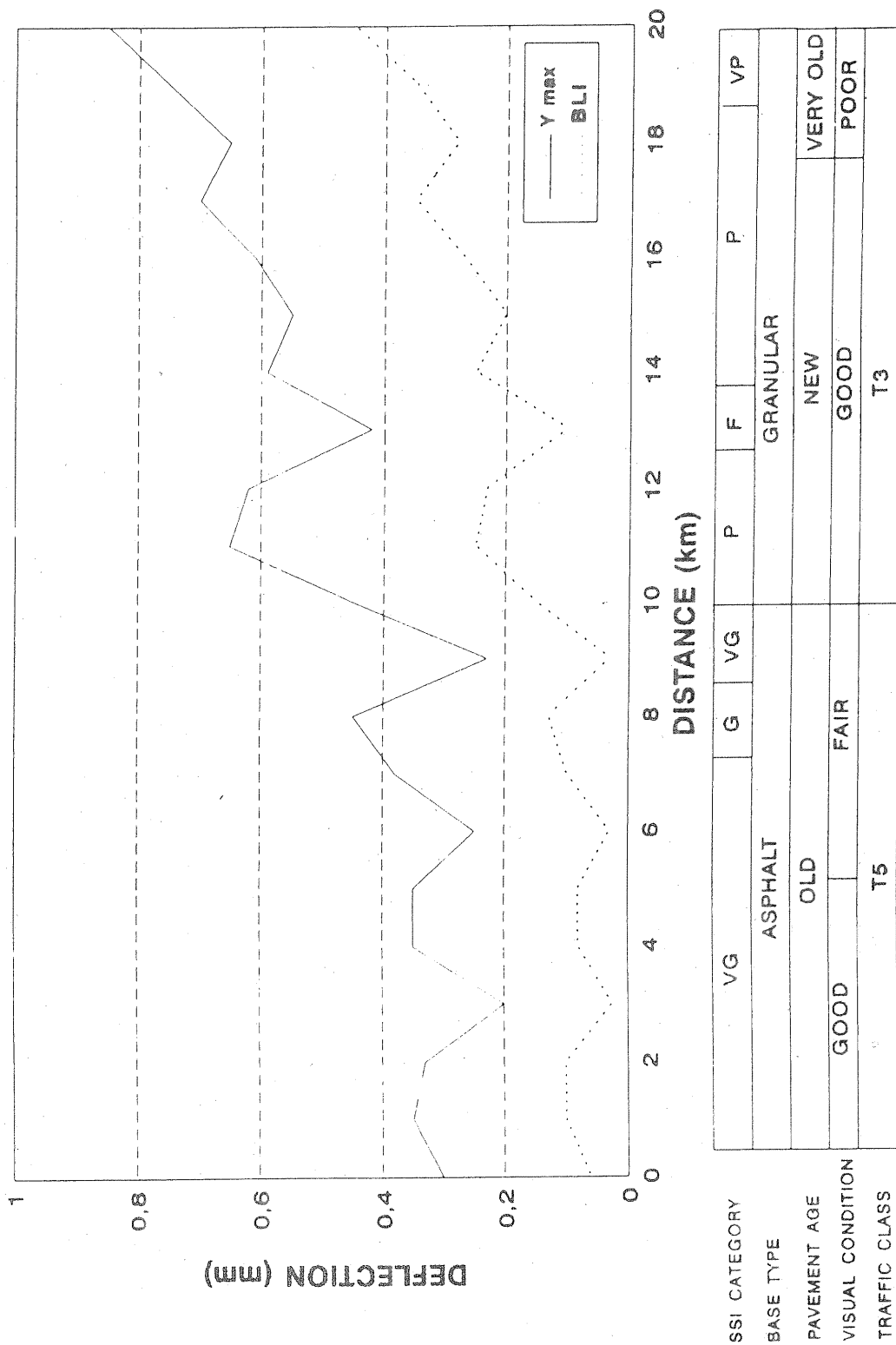


Figure 6.12: Deflection basin parameters

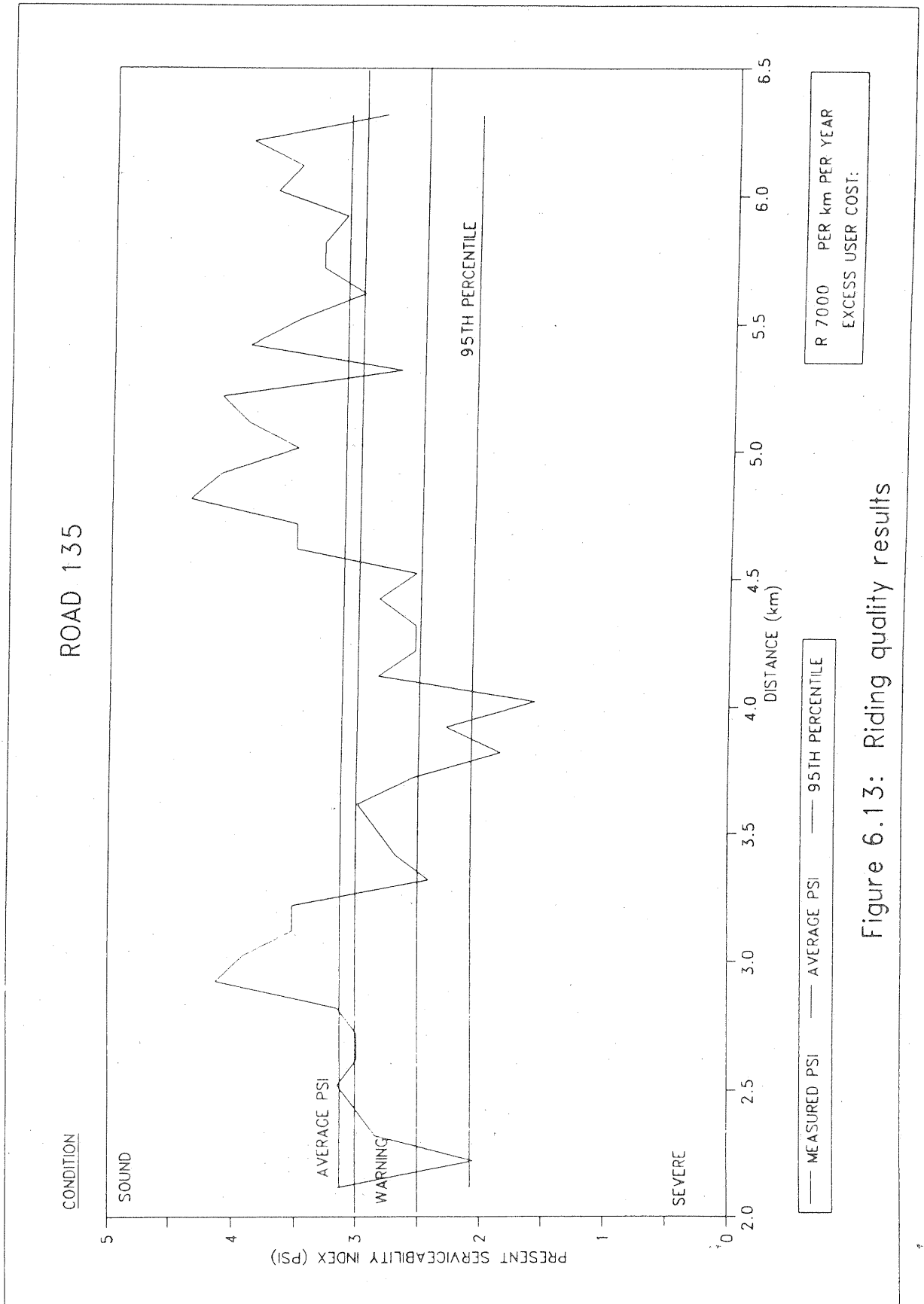


Figure 6.13: Riding quality results

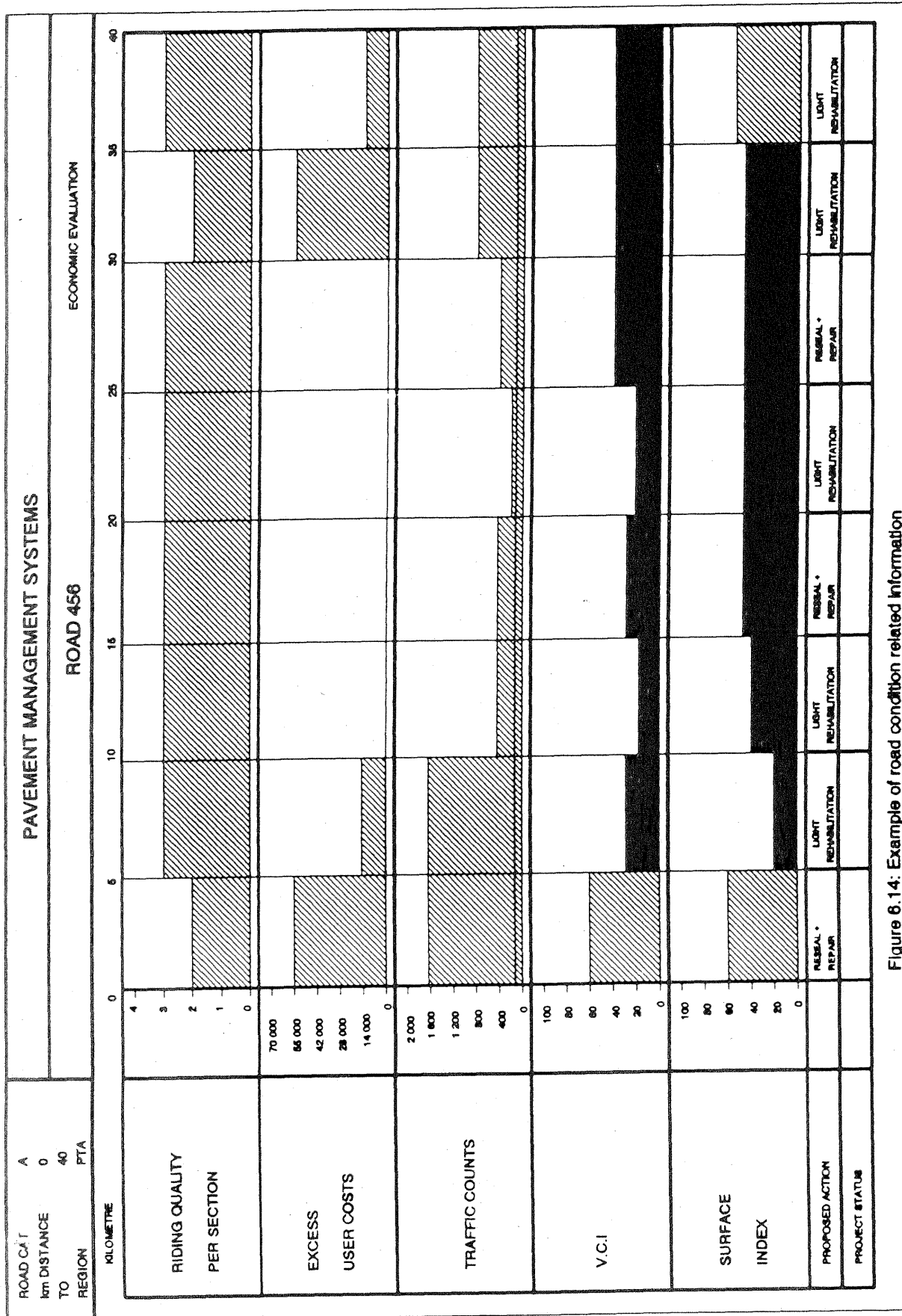


Figure 6.14: Example of road condition related information

7. DETERMINATION OF MAINTENANCE AND REHABILITATION NEEDS AT NETWORK LEVEL

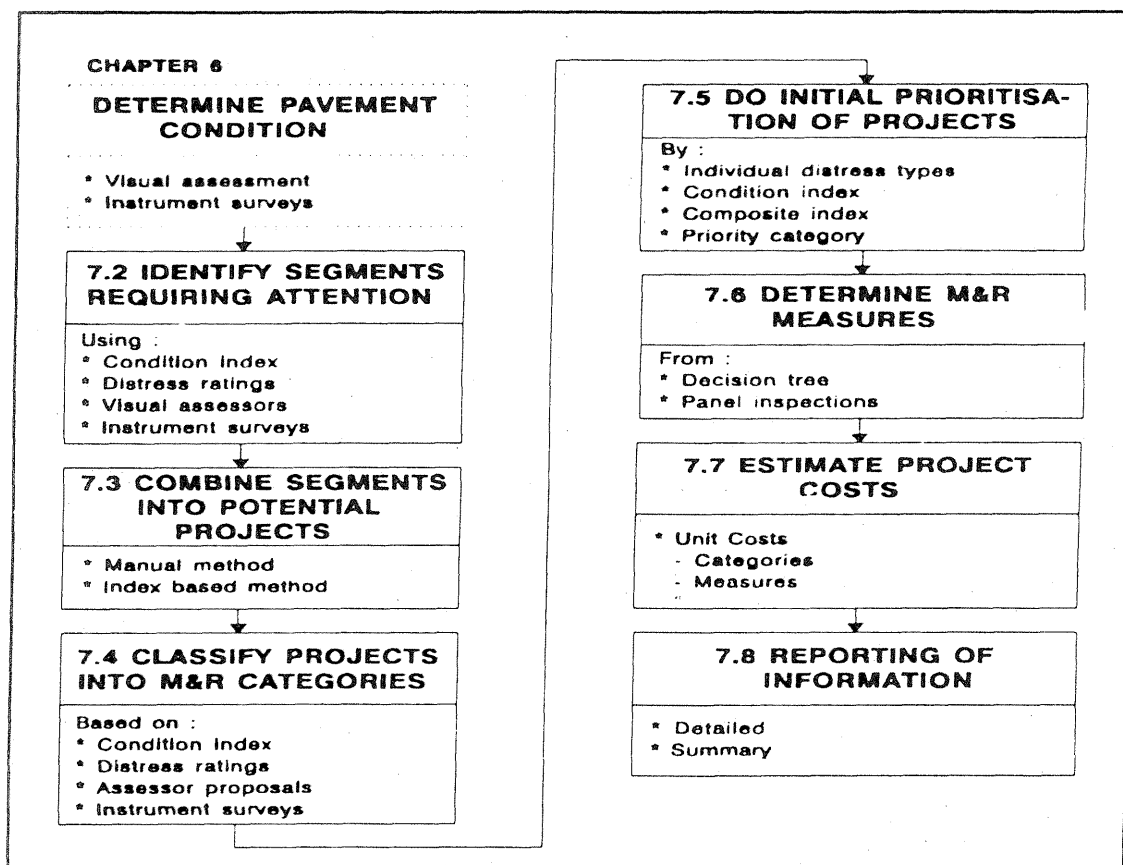


Figure 7.1: Flow diagram of Chapter 7

7.1 INTRODUCTION

The determination of network level maintenance and rehabilitation needs of the road network is the second step in the provision of decision support information to management. A PMS should therefore not only be able to identify road sections in need of repair but also have the ability to propose probable types of maintenance or rehabilitation actions (DRTT, 1994). This information is used at network level for the following:

- * The identification of road segments that should be considered for maintenance or rehabilitation work;
- * the determination of actions to be taken to improve or maintain the present pavement condition;
- * the estimation of the funds required for the maintenance and rehabilitation work;
- * the selection of road segments for inspection through panel inspections; and
- * the initial prioritisation of identified projects.

The maintenance and rehabilitation needs identified at network level can also be used at project level as one of the inputs into a multi-criteria analysis approach.

The determination of maintenance and rehabilitation needs is normally performed at two levels of detail, with each level also requiring some form of prioritisation to determine the urgency for taking action:

- **Maintenance and rehabilitation (M&R) categories**

The initial classification of the pavement need falls under one of the M&R categories. This classification is based primarily on pavement condition data with possibly some adjustments for other factors such as traffic volume, road importance, climate, etc. There are four M&R categories as defined in Table 3.15 (section 3.4.2.1).

- **Maintenance and rehabilitation measures**

Each M&R category can be further subdivided into M&R measures. The definition of the M&R measures is more detailed than that of the M&R categories. They can be determined either from more detailed analysis of the pavement condition data and other factors as mentioned above, or from detailed panel inspections. Table 3.16 (section 3.4.2.2) lists some of these measures.

The determination of the needs plus the prioritisation thereof must be integrated into the process of compiling a work programme. This Chapter outlines some of the initial steps in this process. These steps (to determine the M&R needs at network level) are presented in the flow diagram of this Chapter in Figure 7.1. These initial steps are based only on technical parameters and prioritisation criteria. The process described in this Chapter can therefore be implemented as a first basic step in the compilation of a programme. Economy based treatment selection and prioritisation methods are discussed in Chapter 9.

7.2 IDENTIFICATION OF SEGMENTS REQUIRING ATTENTION

Once the condition analysis of the pavement segments (as described in Chapter 6) has been completed, the next step is to identify the pavement segments that require attention. The identification process can consist of a combination of any of the following methods:

- a) **Condition index trigger:**
In this method a segment is triggered for attention if the condition index (or distress group index) is below a specified limit for that road.
- b) **Distress rating trigger:**
In this method a segment is triggered for attention if the degree and extent ratings for a certain distress type exceed the specified maximum values.
- c) **Visual assessor:**
The recommendations of the visual assessors can be used to identify segments for attention.
- d) **Instrument survey:**
Appropriate limiting criteria can be applied to the results of the instrument surveys, e.g. riding quality, rutting or surface deflection, to identify segments requiring attention.

The best results will be obtained by combining two or more methods in the identification process. The combination of methods (a) and (b) is recommended as a minimum requirement.

7.3 INITIAL COMPILATION OF POTENTIAL PROJECTS

7.3.1 General

The total road network has been subdivided into road segments for the purpose of effective visual evaluation and data management. The initial network level needs are therefore also produced per road segment. In practice, the rehabilitation and maintenance measures are, however, mostly applied to projects that are made up of a number of road segments or portions of segments.

The most accurate method of combining road segments into viable candidate projects is through a panel inspection as described in Chapter 8. Owing to restraints on resources, only the higher priority road segments are normally inspected during panel inspections. It is therefore necessary to do an initial compilation of potential projects based only on information in the data base. These initial potential projects can then be confirmed or amended during the panel inspection. Various methods may be used for this compilation of potential projects.

7.3.2 Manual compilation method

This method consists of a manual combination of segments based on a visual evaluation of PMS assessment data, such as shown in Figure 6.4, and of instrument survey results, as presented in Figure 6.13. This method will provide good results if performed by an experienced maintenance engineer. It can, however, be a relatively slow process and may not be practical for a very large network. In this method, segments that have been identified for attention and that are lying near each other are combined into one project if the condition and distress types are of a similar nature.

7.3.3 Index-based compilation method

In this method, a number of segments are combined into a potential project if, for all these segments, the condition or priority index is below a specified limit and all the indices are within a specified range of each other. An example of this situation is illustrated on the section of road between km 25 and 75 in Figure 7.2. Different priority or condition indices may be used in separate analyses to define the best project combinations. If the method relies on a combined index only, this could lead to discrepancies within the combined project.

This method can be performed through a computer algorithm. An example of the application of this method is given in section A.7 of the Technical Addendum (Yellow Pages).

7.4 METHODS OF CLASSIFYING PAVEMENT PROJECTS INTO M&R CATEGORIES

7.4.1 General

The information on the M&R categories has the following threefold application:

- a) At network level to obtain an indication of the road network needs in terms of both measures and funds. The funding needs can be determined through the application of average unit costs to each M&R category.
- b) As initial classification before panel inspections.
- c) As treatment types in network optimisation. Refer to section 9.5.4.

Each of the four M&R categories span a relatively broad range of measures as illustrated in Table 3.15 (section 3.4.2.1). The classification of the road segments into one of the M&R categories can be achieved with acceptable accuracy through theoretical algorithms based on various project selection criteria, including the following:

- * Overall project condition (distress index only or a performance index that takes such factors as traffic or road category into account).
- * Individual distress ratings plus riding quality and structural capacity indicators.
- * Rate of deterioration of the pavement condition.

The acceptable level of accuracy depends on the use of the results. An absolute accuracy level is, however, not expected from this M&R category classification, since the results are to be confirmed through further investigations (e.g., panel inspections) before final programming and implementation. Various methods can be used for the classification. Three of these methods are presented in sections 7.4.2. to 7.4.5.

To determine the appropriate M&R category for a potential project, it is recommended that each segment within the project limits be classified individually into an M&R category. An appropriate overall M&R category for the project is then selected, normally based on the category that has been recommended over the greatest length within the project limits.

7.4.2 Condition index trigger method

In this method, the value of one or more condition indices (e.g. visual condition, riding quality and/or structural stiffness index) are checked against specified limits on each condition index scale for each M&R category. The indices are checked in a predefined order. The road segment is then classified into the M&R category that is triggered first, based on the value of the appropriate condition index. For example, the rehabilitation category is selected if the visual condition index lies between 0 and 30. The trigger limits will vary according to various criteria including, for example, the importance of the road or the volume of traffic.

The accuracy of this method is not very high but it is very suitable for use in optimisation methods using deterministic prediction models (section 9.5.2.1), since the treatment selection is very simple. It is also suitable as only condition indices and not individual distress ratings are deteriorated over time in these optimisation methods. The lower accuracy of this method is due to the fact that it normally triggers only on a combined index and does not take individual distress items into account.

7.4.3 Distress rating trigger method

In this method, also referred to as a "decision tree" method, road segments are classified into M&R categories based on trigger values for condition indices plus trigger values for degree and extent ratings of specific distress items. An example of this method is described in section A.8 of the Technical Addendum (Yellow Pages).

This method, which is most widely used in South Africa at present, has a good accuracy since it combines the use of condition indices and individual distress ratings. A disadvantage of this method is that the classification of a road segment is, in some options, triggered by a single distress item only. An inaccurate rating for such an item could therefore lead to an incorrect classification.

7.4.4 Proposals by assessors

The classification of pavement needs as indicated by the assessors on the assessment sheet (see TMH 9) can also be used as an initial indication of M&R classification of the project. This method should only be considered however if the assessors have the necessary knowledge and experience in road maintenance to make a reliable judgement.

7.4.5 Instrument survey results

In addition to the specified trigger values for individual distress ratings as used in the distress trigger method, trigger values could also be specified for instrument survey results, and used where these results are available. The addition of these checks on instrument survey results will improve the accuracy of this classification method.

7.5 INITIAL PRIORITISATION OF PROJECTS

7.5.1 General

Once the potential projects requiring maintenance and rehabilitation work have been identified, the urgency for taking action must be determined, resulting in a priority list of potential projects. This must be done since it is seldom possible to implement all identified measures immediately owing to funding constraints. Based on management considerations and available funds, the prioritised list of potential projects can be cut down to a short list for panel inspections and further investigations.

Prioritisation can be defined as the process of ranking projects according to a given set of rules or guidelines. For generating a viable programme of projects, these rules must be of such a kind that they assist an organisation to achieve its overall goals and objectives.

A typical example of such a goal, and the corresponding rule, is the following:

Goal: The higher trafficked roads should generally be in a better condition than other roads in the network.

Rule: Traffic volumes must be included as one of the prioritising criteria, for example through the use of weight factors for each traffic category.

As with the classification of potential projects into M&R categories, it is recommended that the priority index for each road segment within a project be determined individually. The project priority is then determined as the weighted average.

7.5.2 Methods of initial prioritisation

For the initial prioritisation process, the project should be classified into an M&R category. The reason for this requirement is that the criteria (and sometimes the method) used for prioritisation are linked to the M&R category. For example, some of the criteria used for the prioritisation of periodic maintenance projects do not apply to rehabilitation projects.

Some typical non-economy based methods for initial prioritisation include:

a) Prioritisation by individual distress ratings or performance

In this method, individual distresses or performance characteristics may be used for prioritisation. For example, routine maintenance (e.g. crack sealing) projects may be prioritised by the degree and extent of the cracks only.

b) Prioritisation by a condition index

In this method, various distresses or performance measures are combined into a condition index. This index is then used to prioritise road segments.

c) Prioritisation by composite index

In this method, many facets may be combined to develop a function or composite index. The following are some of the elements that may be used to develop a priority index:

- | | |
|-----------------------|---------------------------------|
| - Condition index | - Climatic condition (rainfall) |
| - Traffic volume | - Age of surfacing |
| - Road classification | - Excess user cost |

The method recommended for initial prioritisation of potential projects is prioritisation by composite index (c). Examples of this method are shown in section A.9.1 to A.9.4 of the Technical Addendum (Yellow Pages).

7.5.3 Priority categories

The reporting to upper management of project priorities should be through the use of priority categories and not priority index values. The priority index of a project can be classified into one of four priority categories shown in section A.9.5 of the Technical Addendum (Yellow pages). The table also indicates the colours that should be used when reporting the priority category information in the form of charts or maps.

7.6 METHODS OF DETERMINING APPROPRIATE MAINTENANCE AND REHABILITATION MEASURES WITHIN POTENTIAL PROJECTS AT NETWORK LEVEL

7.6.1 General

Maintenance and rehabilitation (M&R) measure information is used at both network and project level. At network level it provides a more detailed classification of the actual anticipated measure for use in programming and budgeting. In the case of routine or periodic maintenance categories, the results may be accurate enough for implementation after confirmation through panel inspections. For the special maintenance and rehabilitation categories, however, the detailed measures will have to be determined through further detailed investigation and data analysis.

The determination of the detailed M&R measures in the routine and periodic maintenance categories can be done to a reasonable level of accuracy using algorithms based on good quality visual assessment data plus other data, such as existing surface type, traffic volumes, climate, surface and structural age.

An indication of the M&R measures in the special maintenance and rehabilitation categories may be obtained by processing other available network level data in addition to the visual assessment data. This data would include measurements of road roughness, rutting, skid resistance, pavement deflection, pavement structure, etc.

An example of a method to determine periodic maintenance measures is presented in section 7.6.2.

The alternative measures considered by a road authority for maintenance and/or rehabilitation usually represent current practice. These alternatives continue to change over time as new technologies become available, the experience of other authorities are reviewed and performance and cost-effectiveness is assessed. It is, however, important that all the feasible alternatives should be clearly identified by the agency, that provision should be made for adding to or deleting from existing alternatives and that procedures should exist for deciding which ones are feasible for a given situation (Haas et al, 1994).

Policy decisions regarding the use of specific remedial measures are made after years of experience, studies of cost-effectiveness and sometimes personal preference. This can be seen as a simple procedure to select the most appropriate maintenance and rehabilitation strategies. The following are examples of policies applied by some South African road authorities:

- Apply only asphalt on category A and B roads in the urban environment.
- Apply only asphalt on intersections or on roads surrounding shopping/industrial areas.
- Apply only sand seals if the traffic is less than 100 vpd.
- Slurry surfacings not allowed in wet climates.

In some cases road authorities have invested in personnel and specific equipment for certain maintenance or rehabilitation tasks, e.g. a city council has invested in asphalt pavers and a plant which produces a certain tonnage per day and has trained a team to do overlays. To optimise resources, the council has to keep the plant and the team busy - leading to a requirement that a specific length of the road network be overlaid each year. The cost of certain types of measures and the availability of specific materials, especially in remote areas of South Africa, can also influence the typical remedial measures of road authorities (DRTT, 1994).

7.6.2 Trigger method (Decision tree)

This method is applied most effectively to the periodic maintenance category, although it could also be applied to the special maintenance category where extensive patching and/or cracksealing is followed by a reseal. An example of the method for identifying more detailed reseal types in the periodic maintenance category is illustrated in section A.10 of the Technical Addendum (Yellow Pages). The example has been taken from the PMS of a regional authority and has been compiled to suit the conditions applicable to that road network and those management considerations.

The method can be customised further for local conditions based on the following:

- * The voids in the existing surface. A surface with many voids may require an application of diluted emulsion before resealing.
- * The type of seals and binder can be specified based on availability and local requirements.
- * Measures may be adjusted for local climatic conditions.
- * Traffic classes could be further subdivided into or replaced by road categories.

7.6.3 Panel inspection

The panel inspection, as described in Chapter 8, is an essential step in the implementation of maintenance and rehabilitation measures. In cases where reliable data are not available on network-level data bases, or reliable M&R measure algorithms have not been developed, the panel inspection must be used to determine the more detailed M&R measures.

7.7 UNIT COSTS FOR M&R CATEGORIES

7.7.1 General

Through the application of standard PMS unit costs to each of the M&R categories it is possible to calculate total budget need statistics at network level. These standard PMS unit costs could also be used for quick cost estimates of identified projects before a detailed investigation is carried out.

The use of a standard methodology to determine the unit cost for each M&R category will ensure the availability of compatible network-level information on fund requirements, which could be used for strategic planning of road maintenance at provincial and central government level. This section presents two methods for the determination of PMS unit costs for the M&R categories. Unit costs can be influenced by various factors and care should therefore be taken in determining unit costs to ensure that the costs are a true reflection of the total expected cost for the specific environment, authority and project size.

7.7.2 Unit costs per M&R category based on typical contracts

This method requires the establishment and maintenance of a data base containing contract values of past maintenance and rehabilitation projects. If sufficient data are available, typical unit costs for each M&R category can be obtained from this data base. The following must be taken into account when capturing the contract value of each project:

- * Classify the project according to the appropriate M&R category.
- * Remove the cost of all non-pavement related activities from the contract value.
- * Retain the cost of establishment, traffic accommodation and line marking.
- * Record the following:
 - Date of tender.
 - Region in which project lies.
 - Road category.
 - Traffic class.
 - Road type.
 - Total paved area (m²)
 - Tender amounts for all reasonable tenderers.

Although this method is relatively simple and easy to apply, high variations in typical unit costs per M&R category may be expected. This may be due to the absence of recent M&R projects in certain regions and/or the variation in quantities per activity for different projects.

7.7.3 Unit costs per M&R category based on pre-defined activities

In this method unit costs per M&R category are based on preselected typical (default) quantities per kilometre of road length for all relevant activities that would normally occur in each M&R category. Unit costs per activity (e.g., reseal, patching, etc.) are then obtained from a data base of recent contracts. These costs are applied to the default quantities to calculate standard unit costs per M&R category. These standard unit costs can be adapted for various project types based on, for example, the pavement base type, the traffic class and the traffic lane.

The method of calculating standard unit costs per M&R category based on preselected activities and quantities for each M&R category, requires more effort to establish initially. However, once it has been established and calibrated, it is easy to update and will provide more consistent and compatible M&R unit costs for use in pavement management systems and for other cost estimates.

7.8 REPORTING OF MAINTENANCE AND REHABILITATION INFORMATION

7.8.1 General

The maintenance and rehabilitation measures have to be reported for various users, each with his particular need. The needs vary from technical input required for panel inspections to statistical summaries for the top management.

Normally, fund allocation should be done per road class. This will ensure that target condition levels per road class set by management can be pursued effectively and will also reduce the chance of funds going only to high volume and/or major class roads that have high priorities owing to their importance. Reporting results per road classification is therefore important.

7.8.2 Detailed reports

These reports are used for panel inspections and programming of work. Typical information that should be included in these reports is shown in Table 7.1. Information on proposed M&R categories and priorities can also be shown graphically along the length of the road (Figure 7.2).

7.8.3 Summary of results

Information on network level maintenance and rehabilitation needs must be presented in summarised format for use by top management. This should be in tabular and graphical format. Typical examples are shown in Figures 7.3 and 7.4.

7.8.4 Cost per condition category

A useful information item for quick estimates of project costs based on condition only is the average maintenance and rehabilitation cost per m² for each condition category. This is calculated by adding the estimated costs of all road segments in each condition category and dividing this total by the area of all the segments in that condition category. An example of the result is shown graphically in Figure 7.5.

TABLE 7.1: EXAMPLE OF TYPICAL PRIORITY LIST FOR LIGHT REHABILITATION PROJECTS

ROAD CLASS: L1

YEAR: 1993

ROAD NUMBER	START	END	CONDITION INDEX		TRAFFIC CLASS	ROAD CAT.	AVERAGE RIDING QUALITY (PSI)	EXCESS USER COST R/km	ANNUAL DROP IN VCI	PRIORITY INDEX (RPI)	PROJECT COST (Rm)	CUMULATIVE COST (Rm)
			LOWEST	AVERAGE								
P123	0,0	9,2	23	26	T2	B	2,6	58 000	5	20	2,0	2,0
P456	0,0	6,1	43	43	T4	A	3,1	10 000	20	31	1,1	3,1
D345	0,0	5,1	44	44	T3	A	2,9	62 000	13	32	1,2	4,3
D789	0,0	10,9	53	43	T1	C	2,8	12 000	6	45	1,6	5,9

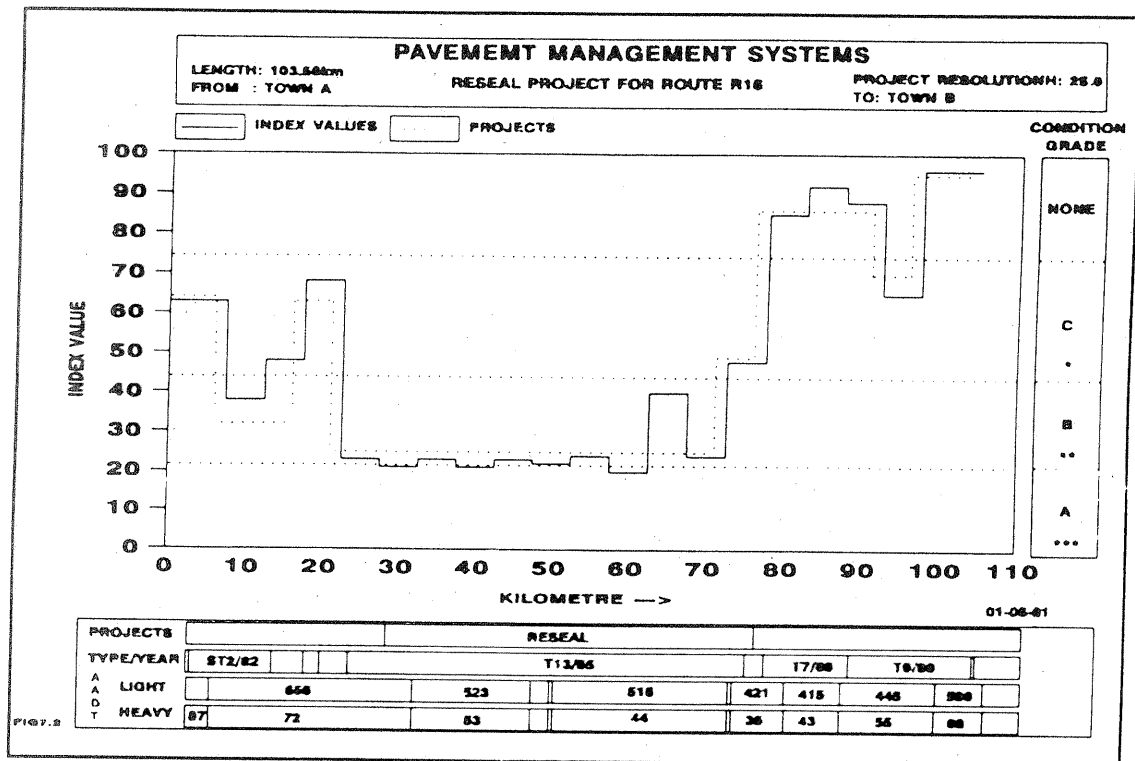


Figure 7.2: Condition indices and selected project for Route R16

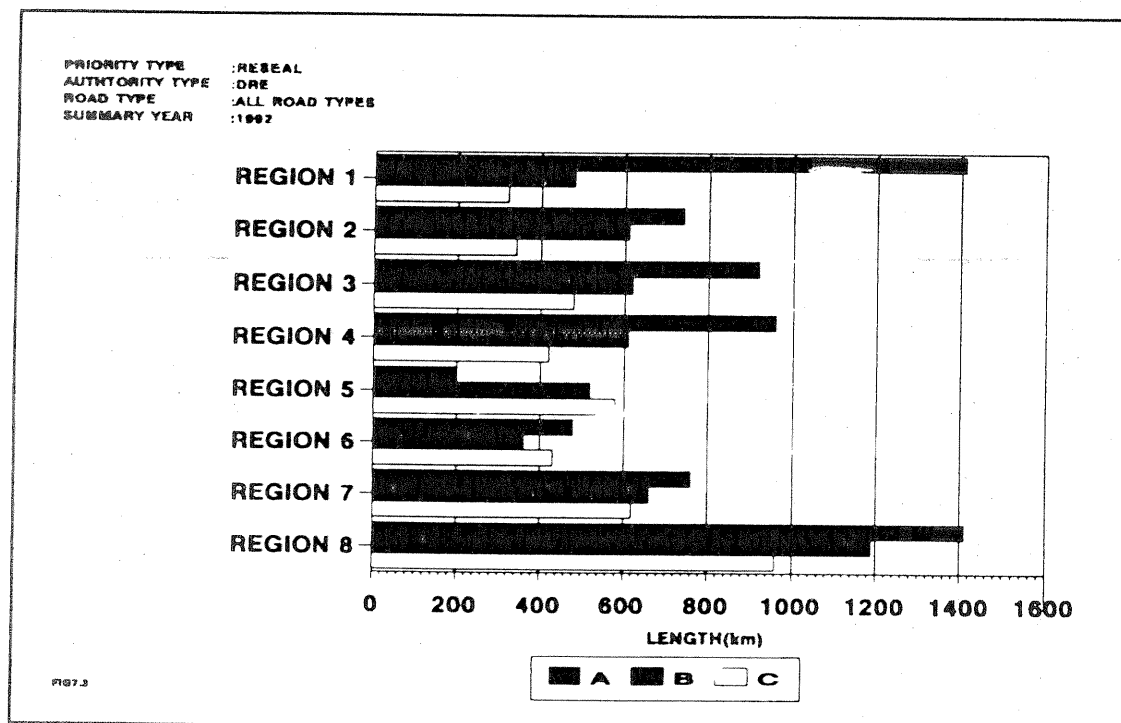


Figure 7.3: Distribution of priority categories in various regions

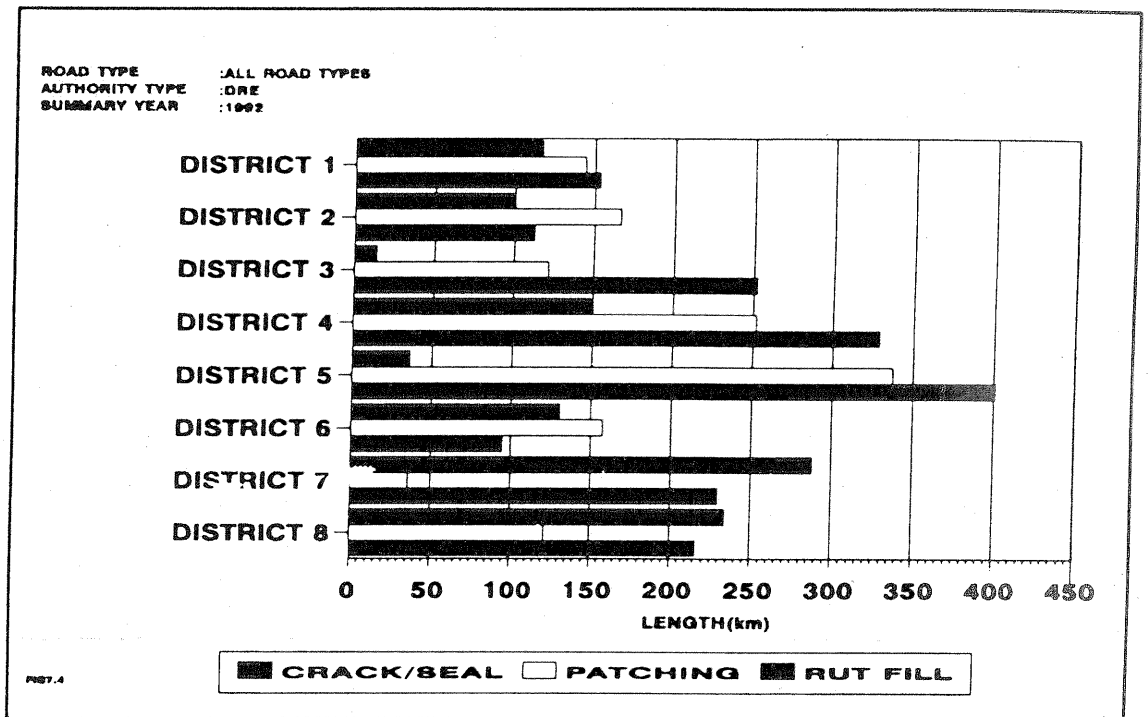


Figure 7.4: Distribution of various routine maintenance needs per district

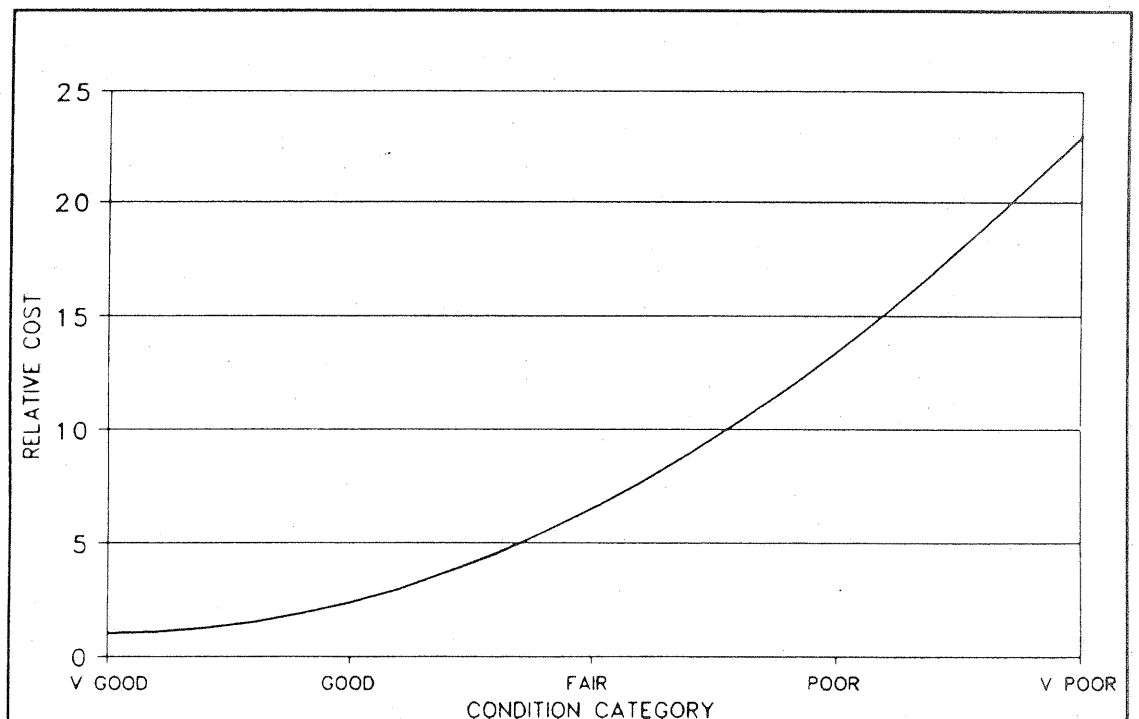


Figure 7.5: Average cost of M&R measures per condition category

8. PANEL INSPECTIONS

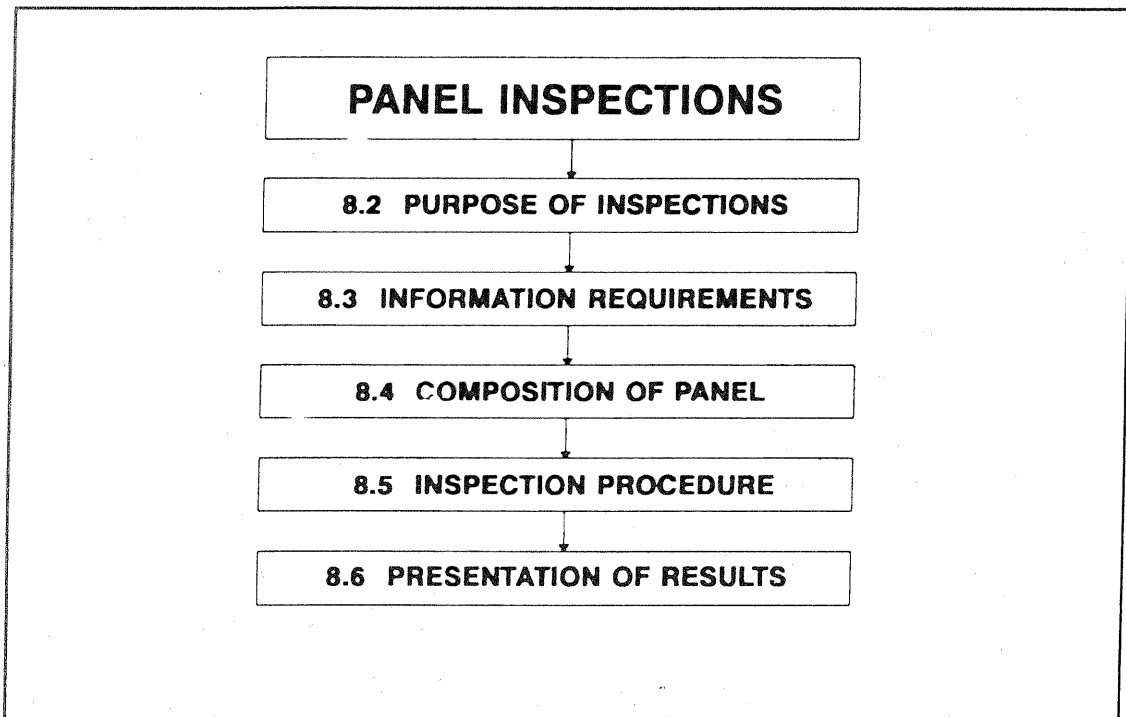


Figure 8.1: Flow diagram of Chapter 8

8.1 INTRODUCTION

The maintenance and rehabilitation needs of the road network are initially determined from the analysis of the pavement condition data, as described in section 7. Some of the network-level condition data are however aggregated data collected per road segment (e.g. visual assessment data). The results of the network-level data analysis for the determination of measures should therefore be confirmed through further investigation before programming and implementation.

The first step in the further investigation is the panel inspection. As discussed below this inspection may be the final confirmation of actions to be taken for projects in the routine and periodic maintenance categories. The projects in the special maintenance and rehabilitation categories will, however, require further investigation (e.g. material sampling and testing) before a final decision can be made.

8.2 PURPOSE OF THE PANEL INSPECTION

The role which the results of the panel inspections will play within the overall planning of the network maintenance and rehabilitation programme depends on various facets, including the following:

- PMS procedures

In some organisations consultants are appointed to do initial and detailed evaluations and to make proposals on the type of seal or other action to be taken. The purpose of the panel inspection is then primarily to confirm the priority (urgency) of the project, based on the visual evaluation by the panel plus any external factors known to the panel. This priority will then be used to programme the projects for further investigation by consultants.

- M&R category

The type of action to be taken on a road and the related cost may influence the need for further investigation. For example, it may be possible to confirm the need for an application of a diluted emulsion spray or slurry owing to aggregate loss through a panel inspection only, since the active distress can be assessed visually. At the other extreme rehabilitation projects will require further detailed investigation before final programming and execution can take place.

- Importance of the road

The importance of a road will also have an influence on the need for further investigation. An important road with high traffic volumes is much less forgiving of potential problems, both physically and politically, than a low volume, unimportant road.

Based on the abovementioned facets, panel inspections can have one of the following two main objectives:

- a) Results used for prioritisation only:

In this case the projects are prioritised for further investigation. Normally panel inspections of important roads and/or projects in the major M&R categories will have this objective.

- b) Results used for final programming:

The panel inspection of less important roads and/or projects in the minor M&R categories (e.g. reseal) could have this objective. The purpose of these inspections is to confirm the M&R measure (e.g. type of seal), to determine the type of pre-treatment and to determine the urgency for action (priority).

Where a seal is required as a holding action until funds become available for a rehabilitation measure, it may be possible to place projects into both rehabilitation and periodic maintenance categories.

Two further objectives, in addition to the abovementioned objectives, are also important. The first one relates particularly to road networks that have been subdivided into maintenance districts or regions. In these cases it is important to ensure uniformity in decision-making through head office representation in panel inspections. The second objective is to determine the exact limits of the proposed projects.

It should be noted that it is not the primary purpose of the panel inspection to check the accuracy of the PMS data. However, it could be used for spot checks.

8.3 INFORMATION REQUIRED FOR PANEL INSPECTION

The information required for a panel inspection can be classified into essential and desirable information. Examples of typical outputs that can also be used for panel inspections are presented in section 6.6 (e.g. Figures 6.4, 6.6 and 6.13) and Figures 8.2 to 8.4.

8.3.1 Essential information

The following information is classified as essential information to make appropriate decisions during panel inspections:

- a) Visual assessment data, consisting of individual distress ratings, preferably on assessment forms. If available, graphical presentation of the information along the length of a road will provide added benefit.
- b) Condition and priority indices as well as type of action proposed by PMS algorithm.
- c) Most recent riding quality results.
- d) Daily traffic volumes, including number of heavy vehicles.
- e) Pavement type, seal type and seal age.
- f) Programme of approved (committed) projects.
- g) Road network map.
- h) Unit price for types of seals (for final programming only).
- i) Excess user cost category (for final programming only).

8.3.2 Desirable information

In addition to the essential information, the following desirable information will lead to more accurate results from the panel inspections :

- a) Pavement layer structure data, including layer thicknesses, material types and quality.
- b) Date of (re)construction.
- c) Most recent annual routine maintenance costs.
- d) Historical information on application of reseals and diluted emulsions.
- e) Historical riding quality data.
- f) Present and historical deflection and rut data.
- g) Historical condition data to determine rate of deterioration.

- h) Rainfall data (climatic information).
- i) Non-pavement related factors that may influence priority (e.g., capacity problems).

8.4 COMPOSITION OF PANEL

To achieve the most benefit from a panel inspection, the following should be taken into account for the composition of a panel.

- a) Person(s) with local technical knowledge who can provide input with respect to maintenance history, any past occurrences and environmental influences that are of relevance.
- b) Person(s) with local management knowledge with regard to the future of the road, political influences, etc.
- c) Knowledgeable person(s) in the technical field who can assess the urgency of the action to be taken and who can provide input regarding the type of seal required for the given situation.
- d) On rehabilitation inspections, knowledgeable person(s) who can provide an indication of potential problems other than pavement related factors, such as dangerous junctions, etc., that may be addressed during rehabilitation work.
- e) Person(s) who will attend all panel inspections within a road authority to ensure uniformity of approach and decisions.

Based on the above considerations, the typical panel should include at least a representative from the region, from the PMS section and from the materials section. The total panel could, however, consist of -

- the Regional/District Engineer or his representative;
- the District Road Superintendent;
- a representative from the PMS section;
- a representative from the materials section;
- the person responsible for seal designs in the region;
- the person responsible for the approval of seal designs.

It is essential that all panel members should understand fully the objectives of the panel inspections and be familiar with the predefined guidelines and procedures. The panel members should be aware of departmental policies and any problems that have previously been encountered with specific types of reseals, etc. In addition, the extent to which standards can be lowered, e.g. resealing within the travelled lanes only, should also be known.

All panel members should be communicative people so that co-operation can be achieved in discussing the various problems encountered during the inspections. A chairman should be appointed to ensure that the objectives of the inspections are achieved and to facilitate the process of achieving co-operation.

8.5 PANEL INSPECTION PROCEDURE

The procedure should be of such a kind that it allows sufficient time to obtain an overall impression of the specific projects, while at the same time being fast enough to assess all the projects envisaged within as short a time as possible.

The inspection should not entail filling in too many forms. Inspections should be carried out as soon as possible after completion of the visual assessments, and preferably after the rainy season. The procedure should consist of the following steps:

- a) **Preparation :** All available information listed in section 8.3 should be made available to panel members before the inspection so that they can familiarise themselves with it. Panel members must also receive and study the objectives of and guidelines to panel inspections.
- b) **Pre-inspection meeting :** The PMS representative should convene a pre-inspection meeting in each region to discuss the proposed list of roads for panel inspection. The list of roads may be reduced owing to prior inspections or to external factors that make implementation not possible.
- c) **Briefing session :** The inspections should start with a briefing session by the chairman to discuss plan of action and inspection procedures and to obtain any feedback from panel members based on the information provided. Steps b) and c) may be combined.
- d) **Safety :** Arrangements with traffic authorities should be made in advance if protection is required. Reflective jackets must be worn by all panel members. The vehicle used must be fitted with a yellow flashing light and a large sign on the back with the words "ROAD SURVEY".
- e) **Vehicle :** The size of the panel should be limited to 8 persons so that all can fit comfortably into a microbus. This will facilitate discussion between members of the panel.
- f) **Inspection stops :** There should be at least two stops per project to examine the road surface. These stops should be on representative sections and the number of stops will depend on the size and number of these sections.
- g) **Consistency of decisions :** To promote consistency of decisions, it is recommended that decisions be made according to a decision diagram. Notes should be made of the reasons for deviating from the diagram. An example of such a diagram is included in section A.10 (Yellow Pages).
- h) **Recording of decisions :** The following information should be recorded where appropriate:
 - * Road and section number
 - * Start and end km
 - * Width of application

- Lanes to be treated (e.g. all lanes, excluding shoulders)
- Panel judgement of road condition category
- Type of measure (e.g. type of binder and stone size on reseal inspections)
- Pretreatments required (reseal inspections)
- Urgency classification
- Reasons for decisions
- Further action required (e.g. skid measurements)
- Photographs of typical problems is a useful record, particularly for rehabilitation projects.

8.6 PRESENTATION OF RESULTS

The results of the panel inspection are used for further investigation, programming and budgeting. The results must therefore be presented in a format that will assist decision-making in these three respects. An example of a form that could be used during inspections is presented in Figure 8.4.

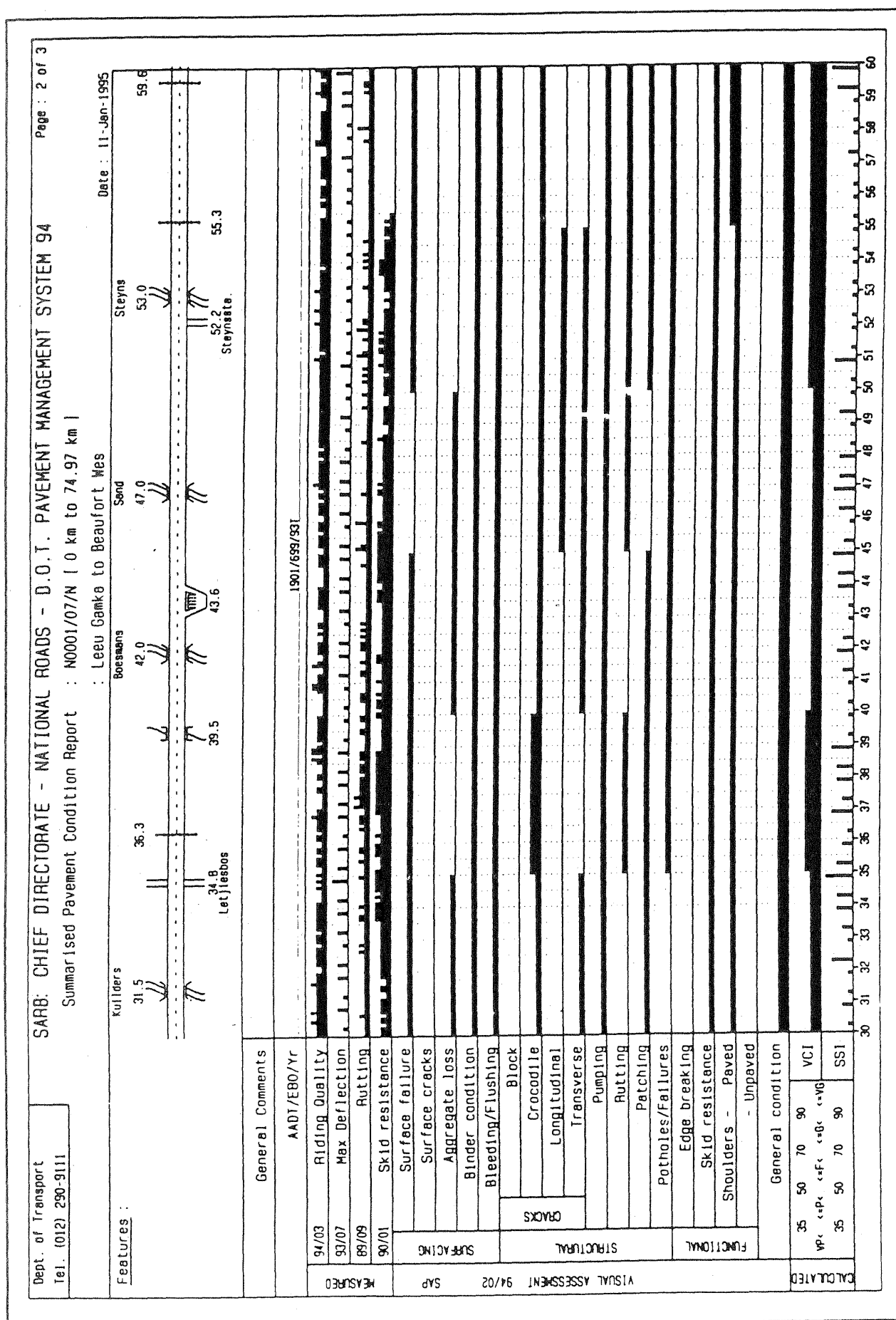


Figure 8.2: Example of pavement condition summary

UPDATED : 01/95		START KM : 0		END KM : 43.53		LENGTH (KM'S) : 43.53		START : DWARS ID WEG		ROUTE : N0003	
								END : BUCCLEUCH		SECTION : 12N	
FEATURES	INTERCHANGE	X									
	T-JUNCTION (L)	+									
	(R)	T									
	CROSSING	+									
ROAD TYPE											
Reserve Median											
53.9m											
15.0m Wisselend											
4.0m											
3.0P											
1.0P											
SECTIONS	SHOULDERS	LEFT									
		RIGHT									
CLIMBING LANES	LEFT										
	RIGHT										
LANES											
2x3.7m											
3x3.7m											
3x3.7m											
4x3.7m											
TOPOGRAPHY/CLIMATE											
GOLWEND/MATIG											
KILOMETRE DISTANCES											
10											
20											
30											
40											
TRAFFIC T-Count AADT/EBO/YR											
B-Estimate											
18329/1372/90T											
30790/1768/90T											
62440/1829/90T											
64000/1840/90T											
65368/1813/90T											
58000/1490/90T											
ROAD RENEWAL	Description/	6									
	Date/	5									
	Consultant/	4									
	Contractor/	3									
	Contract no	2									
		1									
COMPLETION DATE											
05/76											
03/77											
05/77											
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PANEL INSPECTION FORM

Road No.		Date	/ /
From Description		km	
To Description		km	
Project Status			

VCI:

Too Low

Correct

Too High

PROPOSED M&R CATEGORY

Routine Maintenance	
------------------------	--

Periodic Maintenance	
-------------------------	--

Special Maintenance	
------------------------	--

Rehabilitation	
----------------	--

PROPOSED M&R MEASURES

Patching

L

G

Crack Seal

L

G

Seal Type

Stone Size

Binder

Layer Work

Shoulder Work

Subsoil

Climbing Lanes

Geometry

FURTHER INVESTIGATION

District

Consultant

H/Office

PRIORITY

E. Urgent

Urgent

Important

L. Important

Omit

REMARKS

Figure 8.4: Example of a panel inspection form

9. PRIORITISATION AND OPTIMISATION

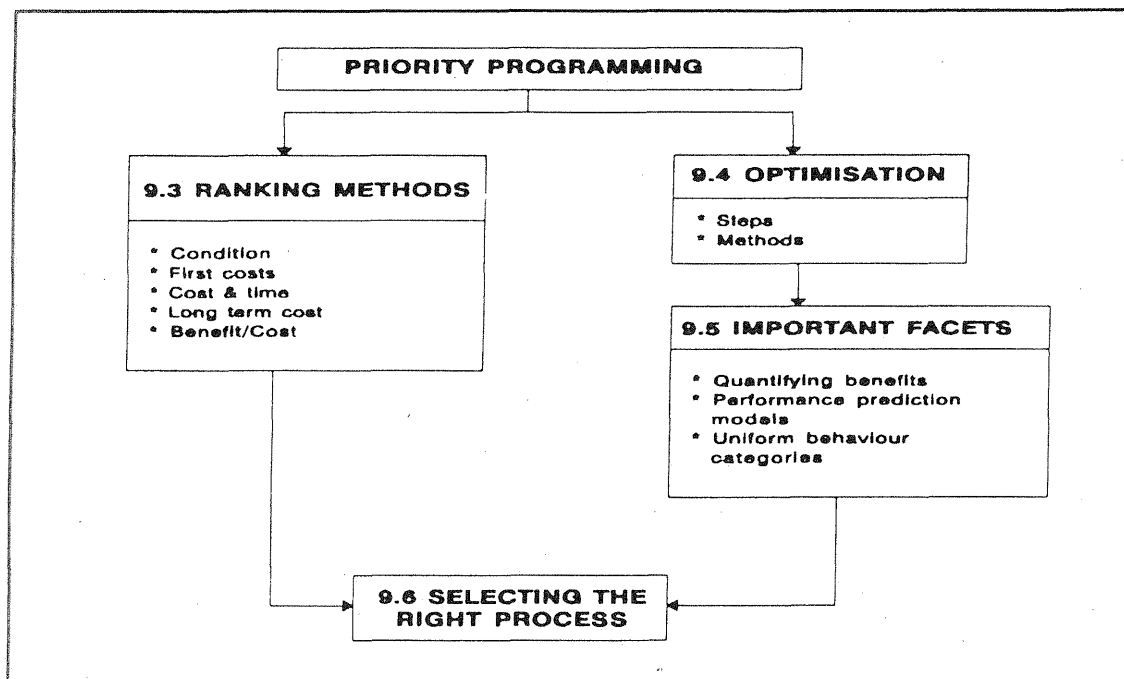


Figure 9.1: Flow diagram of Chapter 9

9.1 INTRODUCTION

One of the key components of pavement management is the comparison of investment alternatives (pavement needs) within some funding constraints. Generally, the goal is to provide the greatest benefit in network condition for the funds expended (Haas et al, 1994; Smith, 1992). The result of the comparison should be information from which a maintenance strategy and a prioritised programme of work can be compiled.

In Chapters 6 and 7, procedures have been described that will help to determine the present pavement condition, the maintenance and rehabilitation needs, and the initial prioritisation of potential projects; all based on network-level PMS data. These procedures provide good results for short- to medium-term planning periods and can be implemented with relative ease in the initial stages of a phased PMS development. The procedures are, however, based only on the present conditions and do not take future pavement deterioration into account. Limited projection of future conditions may be possible, based on traffic projections, pavement type and historical condition data. However, by not formally including the projected pavement performance in decision-making, the maximum benefit may not be achieved for a given budget level.

In this section, improved procedures for the selection and prioritisation of maintenance and rehabilitation projects are presented as an enhancement to the basic PMS system described in the previous chapters. As no accepted current practice is at present established in South Africa, these procedures are presented, in overview, as potential methods that could be further developed and used where appropriate. Figure 9.1 presents the subjects covered in this Chapter.

9.2 PRIORITISATION

Prioritisation is defined as the process of determining the urgency for attention that a project requires, while project ranking is defined as the process of drawing up a list of projects for execution, based on the predetermined priority. Prioritisation procedures can vary from simple subjective ranking to sophisticated mathematical programming. Whatever type of programming is used, it should be directed to answering the following the questions:

- * Which projects should be selected?
- * What measure should be applied?
- * When should the measure be applied?

Various methods can be used to determine priorities for programming the work. These can range from simple ranking (prioritisation) procedures to true optimisation methods which can simultaneously consider and evaluate all possible combinations of the three questions above. Thus prioritisation and optimisation are not necessarily the same thing and will in many cases not give the same answer. Table 9.1 summarises the various classes of methods plus their advantages and disadvantages.

Although the results of the higher class methods are in theory closer to the optimal solution, these results are dependent on the reliability and accuracy of the inputs and the performance models. The achievement of acceptable reliability and accuracy in these fields is currently still a problem.

**TABLE 9.1 : DIFFERENT CLASSES OF PRIORITY PROGRAMMING METHODS
(HAAS, 1985)**

NO	CLASS OF METHOD	ADVANTAGES AND DISADVANTAGES
1	Simple subjective ranking of projects based on judgement	Quick, simple; subject to bias and inconsistency; may be far from optimal
2	Ranking based on parameters, such as condition, serviceability, deflection, etc.	Simple and easy to use; may be far from optimal
3	Ranking based on parameters with economic analysis	Reasonably simple; should be closer to optimal
4	Optimisation by mathematical programming model for year-by-year basis	Less simple; may be close to optimal; effects on timing not considered
5	Real optimisation using heuristics and marginal cost-effectiveness	Reasonably complex; can be used in a microcomputer environment; close to optimal results
6	Comprehensive optimisation by mathematical programming model taking into account the effects of project timing	Most complex; can give optimal program (Max. of benefits)

9.3 RANKING METHODS

Once projects have been identified and evaluated through panel inspections, a short list of projects is available for programming over the planning period. Depending on the information that is further available, an appropriate ranking method can be applied to compile a priority programme of projects.

It is often assumed that a ranking system will automatically lead to "fixing the worst first" (Smith, 1992). However, there are many ways that ranking can be applied, including considering benefits and costs. Figure 9.2 shows various types of ranking using increasing volumes of information to arrive at project ranking (Lytton, 1994). The more information used in the ranking method, the more likely it is to provide a carefully reasoned and economical priority programme. The types start with the most basic ranking method that uses only the current condition of the road network to the method that incorporates future benefit projections.

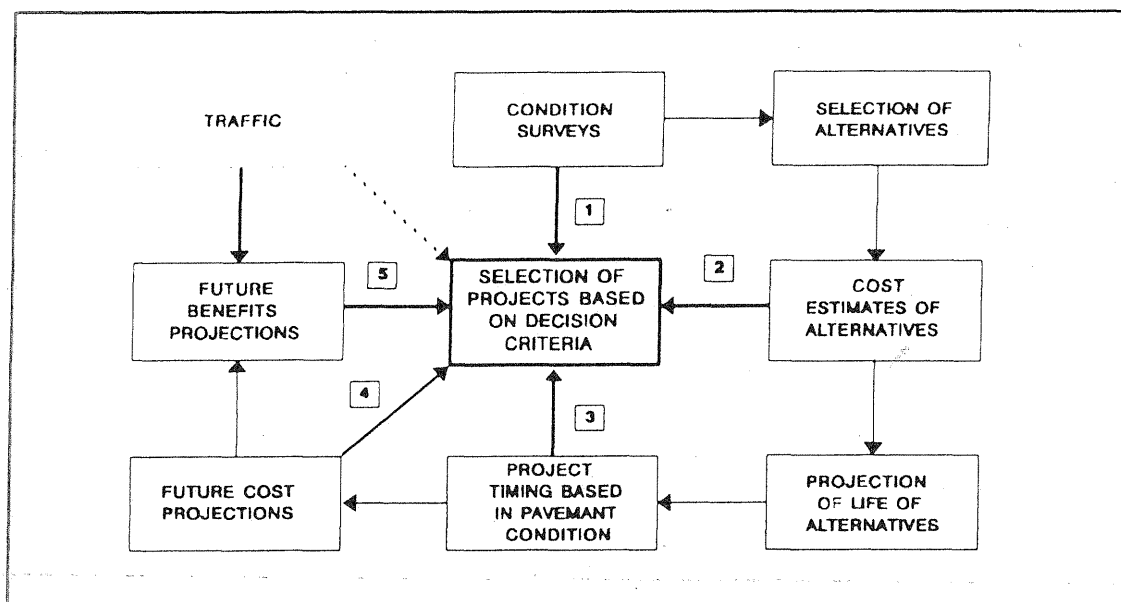


Figure 9.2: Ranking methods (Lytton, 1994).

9.3.1 Condition ranking (Method 1)

The non-economic condition based prioritisation methods have been summarised in section 7.5. These methods could generally lead to a "worst first" approach. To limit this effect, the ranking of projects should be done individually for each M&R category; that is, after the appropriate prioritisation method has been applied to all projects in each M&R category. By providing funds for each M & R category separately, the problem of doing only worst projects first will be substantially reduced.

A further improvement of this method is to subdivide each list further, based on the functional road classes. Appropriate decision criteria can then be applied to each class of road.

9.3.2. First cost ranking (Method 2)

In this method, the projects which can be repaired for the lowest cost per kilometre are selected first. This method does not consider the impact on future condition and addresses only agency costs and not user costs. This method can be modified in the following ways:

- * Find the lowest first cost to provide some set level of present condition;
- * group projects together per condition category and do ranking per condition category; or
- * group projects together per road category and do ranking per road category.

In the unmodified format, this method could lead to a process of doing the "best first" and also doing the low volume roads first.

9.3.3. Cost- and time-based ranking (Method 3)

The first cost ranking method may be extended to include the projected effective life of the alternatives (actions). The interval after application of a certain action within which the same condition (VCI) re-occurs can be used as the effective life of the action. The projects are then ranked based on the lowest cost per year of projected life. An example of this method which includes user costs, as used by an authority, is presented in section A.11 of the Technical Addendum (Yellow Pages).

If the pavement is not currently in need of attention, the time in the future may be estimated when action will need to be taken, provided that pavement deterioration models are available. The time when action is required is determined by threshold criteria that define a minimum acceptable pavement condition.

9.3.4 Long-term cost ranking (Method 4)

In this method the total net present cost of repairing each section is calculated based on a specified analysis period and including estimates of all future maintenance costs and salvage value. The costs can be in present values or equivalent uniform annual costs if varying analysis periods are used.

This method considers future agency costs, but fails to consider user costs or benefits.

9.3.5 Benefit / Cost ranking (Method 5)

Benefits obtained from repairing each section of pavement are determined over a selected analysis period in monetary terms using, for example, vehicle operating costs. The benefits are defined as the reduction in vehicle operating costs minus user costs, such as traffic delays during construction, and environmental costs, such as noise pollution. The costs, calculated over the same analysis period, include construction costs plus future maintenance and rehabilitation costs. It is important to keep costs and benefits separate.

The costs and benefits may be in present values or equivalent uniform annual costs. The projects that provide the greatest benefit for the funds expended are considered the best choice. Projects may be ranked in order of decreasing benefit-cost ratios or increasing internal rate of return (IRR). Examples of procedures that can be used to calculate the costs and benefits include the CB-Roads (SARB, 1994) and HDM-III (Watanatada, 1987) models. These procedures are applied mostly to rehabilitation projects.

The optimisation steps include the following:

PROCESS DEVELOPMENT:

- 1) Select an appropriate optimisation method based on available information and resources.
- 2) Define uniform behaviour categories for the pavement performance modelling.
- 3) Define and calibrate performance prediction models which will be used to predict the future condition of pavements, based on both the do-nothing option and the treatment (measure) option.
- 4) Define appropriate M&R alternatives and select a method to determine alternative treatments (measures) and costs, based on the pavement condition and other decision criteria.
- 5) Establish an objective for the optimisation process. This normally falls into one of the following two categories:
 - Minimise the overall cost of the year's programme; or
 - maximise the benefit that is derived from the expenditure of the available funds.
- 6) Formulate a mathematical model which is an explicit statement of the objective to be achieved. This also includes a set of constraints, which may be financial, physical or institutional.

PROCESS EXECUTION:

- 7) As with ranking, optimisation requires data on the current condition of the road network, from which the future conditions are predicted and appropriate measures are selected.
- 8) Define the constraints (e.g. funding) that apply to the planning period under consideration and the standards of acceptance for various pavement condition parameters.
- 9) Determine the optimum solution through the application of an optimisation procedure.
- 10) Repeat the optimisation execution process for various constraint levels and/or standards of acceptance to determine impact on optimum solution.

9.4.2. Optimisation methods

Various optimisation methods can be used to perform the optimisation. These are mathematical programming models that are applied to the specified objective function (step 5) to select alternatives that satisfy the function, within the stated constraints. These mathematical models, in order of increasing complexity include the following:

- Linear programming
- Non-linear programming
- Integer programming
- Dynamic programming

9.4 NETWORK OPTIMISATION

Network optimisation is a higher level of decision support. In general, it uses system analysis concepts and mathematical models to allocate resources in an optimum (efficient) manner, (Smith 1992, Haas 1994).

Not all optimisation is true optimisation. Some methods provide only approximations of the optimum result. It may be desirable however to use an approximate method if it provides good approximations quickly. However, an inefficient approximating optimisation method may result in project selections that are less cost-effective than some of the better ranking methods (Lytton, 1994).

Optimisation can be used at two planning levels, namely strategic and tactical, as discussed in Chapter 10. However, it is difficult to produce from network optimisation project priority lists that will be easily accepted for tactical planning. The most appropriate application of network optimisation is at strategic planning level to determine optimum budget levels for each M&R category through impact analyses.

The optimisation process has been described in detail in various publications (e.g. TRB, 1985, 1987, 1994). It is recommended that a study of the appropriate literature be made before commencing with the development of this process. This document will provide only a brief overview of the process with reference to some important facets to be considered in optimisation.

9.4.1. Optimisation steps

The process of optimisation is summarised in two phases, namely process development and process execution as shown in Figure 9.3.

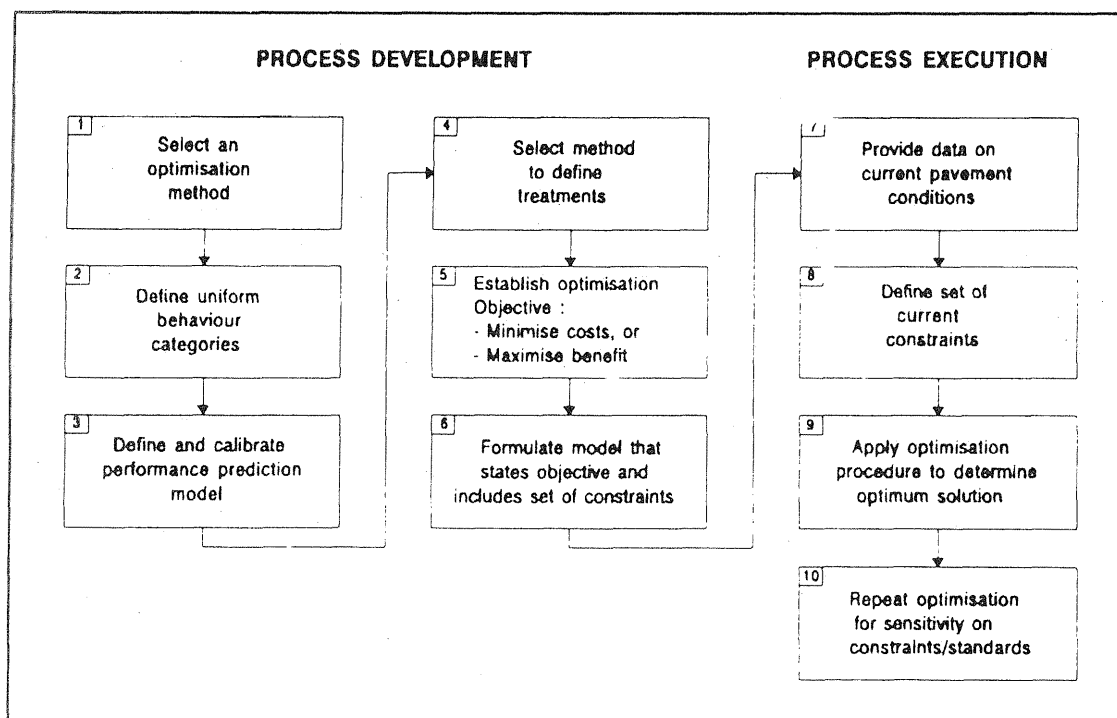


Figure 9.3: Flow diagram of optimisation steps

In addition to the above-mentioned optimisation methods there are also heuristic methods. Heuristic methods are approximations of true optimisation methods. These methods arrive at answers that are close to the true optimal solution, but they do so much quicker. However, they have limitations and cannot guarantee accurate results. They are often used because of the size limitations of problems that can be dealt with using true optimisation methods (Smith, 1992).

Marginal cost-effectiveness and incremental cost-benefit analyses (Shahin, 1985) are examples of approaches which can be used as heuristic methods. This type of approach has been shown to give near optimum results (FHWA, 1991) and unlike true optimisation techniques, it does not require the use of macro computers for networks with a large number of sections.

9.5 IMPORTANT FACETS OF OPTIMISATION

Various facets need to be considered in the development of the optimisation process. This section highlights some of these important facets that could be attended to even before the formal introduction of the process.

9.5.1 Quantifying benefits

As indicated in the optimisation steps (section 9.4.1), it is important to quantify the benefits to be derived from the application of measures (funds). The benefits of publicly financed projects are not simple to define, or calculate, and if done incorrectly the results may be misleading. The benefits derived from available funds can be classified into the following two broad categories:

- * User benefits; and
- * engineering benefits.

The road engineers tend to place greater emphasis on engineering benefits, while funding agencies emphasise user benefits.

9.5.1.1 User benefits

In general, user benefits are difficult to define and most measures of user benefits are subjective. User benefits may be based on savings in the following items when a road is improved (Smith, 1992):

- * Travelling time;
- * vehicle operating costs;
- * accident costs (safety), and
- * user comfort costs.

The most objective measure of user benefit is vehicle operating costs. Vehicle operating costs are directly related to riding quality and are quantified in terms of excess user costs (section 6.4.4). Current practice is to use savings in excess user costs as a measure of user benefit.

9.5.1.2 Engineering benefit

The primary measures of engineering benefits are also referred to as non-cost benefits (effectiveness). The effectiveness value is normally more easily determined and is used as a surrogate for the user benefits. These benefits, which are all related to user benefits in the long term, include the following:

- * Gain in condition indices;
- * remaining life; and
- * area under the deterioration curves.

The effective benefit may be multiplied by some traffic volume factor representing usage, which better represents the effectiveness of the treatment for the user public (Smith, 1992).

a) Gain in condition indices

Condition indices are a utility measure of a road or road network's condition. Indices commonly used in South Africa are described in section 6. Engineering benefit, due to an applied maintenance or rehabilitation measure, can be measured by the gain in the road condition indices. The effective benefit of an applied measure or set of measures is the gain in value of the respective indices divided by the cost of measures. Road network condition indices are commonly used measures of the effectiveness of budgets and of their derived benefits.

The gain in condition index is the only one of the three measures of benefit that does not require a pavement performance prediction model, since it refers only to the immediate gain at the time of application of the measure.

b) Remaining life

Remaining life is generally defined as the time from any selected condition until the pavement is projected to reach a designated terminal condition level (FHWA, 1991). Remaining life can be based on ratings of individual distress types or a combined condition index, e.g. VCI.

Although remaining life is better than just a change in condition, since it makes a prediction of how long the pavement will last, it does not indicate how the condition will change over time.

c) Area under the curve

This method projects the condition over time (without further treatment) until it reaches a designated terminal level as shown in Figure 9.4.

The effective benefit of a treatment is the area under the deterioration curve (Figure 9.4), divided by the annualised cost of the measure over the deferred maintenance period. The effective benefit of a measure can be adjusted to take into account the traffic carried by a road, by multiplying it by a function of AADT.

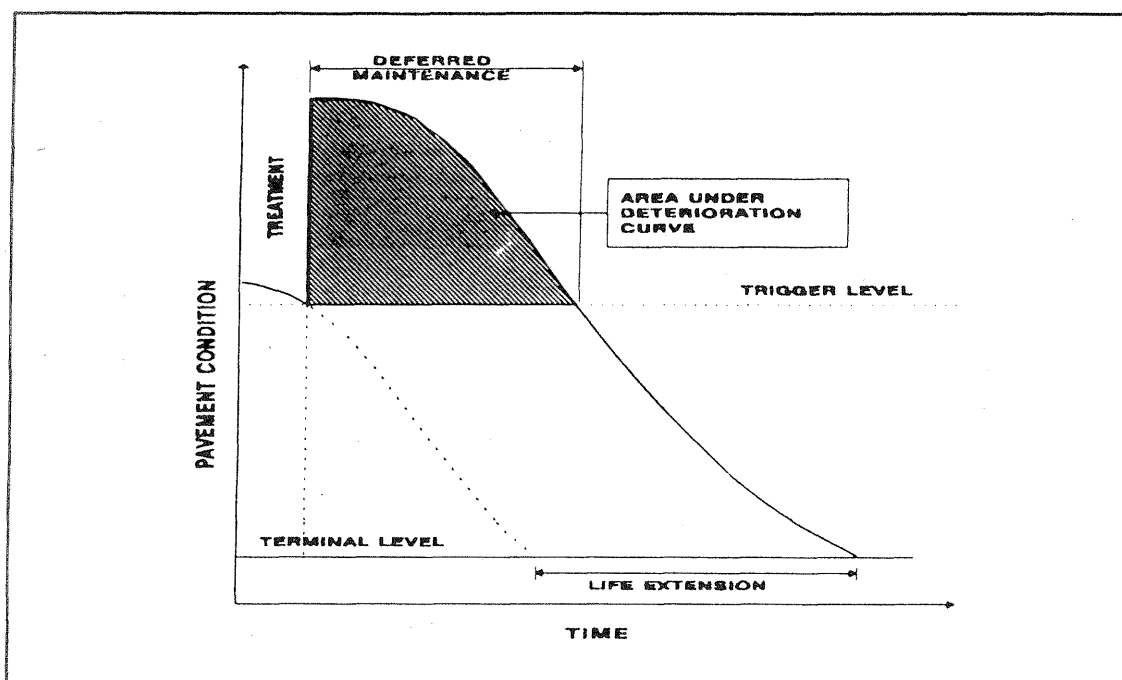


Figure 9.4: Depiction of area under deterioration curves

9.5.2 Pavement performance prediction models

Pavement performance prediction models are used to predict the future pavement conditions, as required in the optimisation process (section 9.4.1). Pavement performance is a measure of how adequately a pavement fulfils its purpose and is often defined as a function of the serviceability - time history of the pavement (SARB, 1993). Prediction models can be classified as either deterministic or probabilistic.

9.5.2.1 Deterministic models

These models generally project pavement conditions and are developed from empirical or mechanistic empirical models which do not explicitly consider uncertainty. Future performance owing to deterioration and maintenance activities is therefore assumed to be certain. Empirical models are derived using regression analysis or other mathematical techniques for curve-fitting on empirical data. Mechanistic-empirical models are those in which the primary response predicted by a mechanistic model is correlated with a traffic or weather cumulative variable at a prescribed level of distress (Smith, 1992).

a) Sigmoidal curve

One form of empirical model is the regression derived sigmoidal (S-shaped) curve. This curve describes the deterioration in condition over time or under traffic using a predefined equation. The shape of the sigmoidal curve is derived by -

- * using the sigmoidal equation to perform regression analysis on historical condition data; or
- * using a panel of experts to derive values for the sigmoidal equation shape coefficients if insufficient historical data are available.

The sigmoidal curve is given in Figure 9.5 and briefly explained in section A.12 of the Technical Addendum (Yellow Pages).

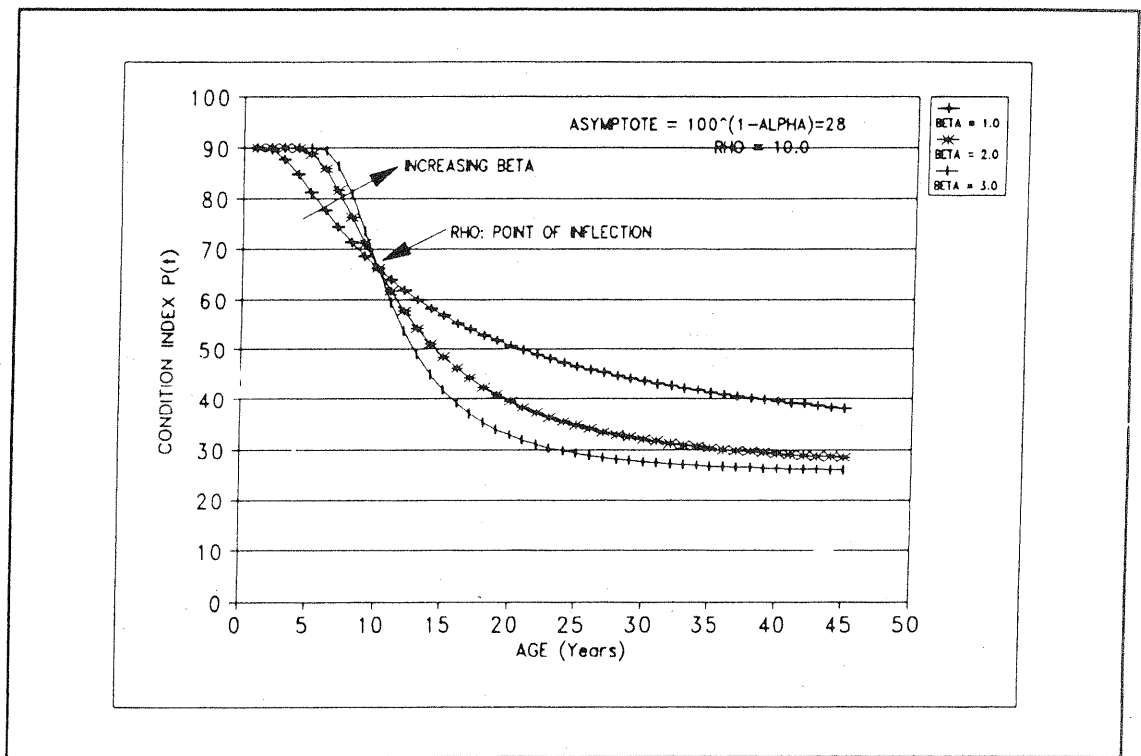


Figure 9.5: Sigmoidal pavement deterioration curve (SARB, 1993)

b) The prediction of road deterioration with HDM-III

The World Bank's HDM-III study is a most comprehensive study on deterioration and maintenance effects (Watanatada, 1987). HDM-III was developed as a tool to determine the best maintenance policy by calculating the total transportation cost of a road over the entire lifespan under different maintenance strategies. The prediction of road deterioration and the effects of maintenance are modelled in the deterioration / maintenance submodel of HDM-III. The deterioration is calculated as the incremental change in roughness during each analysis year as a function of the current condition, cumulative traffic, environmental factors and various other pavement parameters. The effects of maintenance are applied at the end of the specific analysis year before the simulation of the next year takes place (SARB, 1993).

Despite the complex nature of the HDM-III models it is possible to incorporate these models into a pavement management system. Although the HDM-III performance models have been statistically estimated and structured on mechanistic principles from a large data base, Paterson (1987) has pointed out that calibration for local conditions may be inevitable. This requirement is due to differences in some influential factors that were not varied in the original experimentally designed study. These factors include the local climate, material types and construction techniques. The HDM-III deterioration models allow for local calibration through calibration coefficients included in the model. These "scaling" factors increase or decrease the deterioration rate of the predictive models (Van Wyk & Louw, 1994). Work on the calibration of the HDM-III models has been undertaken in South Africa (Kannemeyer, 1994 and TPA Consortium, 1994).

The HDM-III model was designed to analyse projects and small road networks. It therefore has some limitations on how it may be used. Two of the uses of the HDM-III are given below:

- A possible use for the HDM-III model could be the calibration of other models which use a combined index of condition.
- A road network matrix has been developed to facilitate HDM-III analyses of entire road networks. It provides a method of modelling the road network to study the effect of policy changes throughout the network. This process is explained in the reference (Vincent et al, 1994).

A companion model was developed for use with the HDM-III model to aid users in the selection of optimal strategies. The Expenditure Budgeting Model (EBM) is an optimisation program used for selecting optimal strategies under multi-period budget constraints.

9.5.2.2 Probabilistic Models

Pavement performance predictions have considerable uncertainty, since they are affected by a large number of factors, many of which have not been included in most performance models. Not all factors have been well established and several factors have unpredictable variability. By using probabilistic concepts, the probability of reaching a given condition over a specified period is used to determine future needs (Smith, 1992). The probabilities are also a function of the envisaged maintenance action over the period. Existing probabilistic prediction models are based on Markovian and Bayesian modelling techniques. The probabilistic Markov approach is described in various papers (Rhode 1992, Smith 1992) and a summary from Smith (1992) is presented here.

The Markov approach comprises two primary elements, the transition probability matrix and the condition at a certain point in time. The transition probability matrix defines the event of a pavement's condition moving from one state to another over time. The transition probability matrices for specific time intervals can be multiplied together to describe the progressive deterioration of the pavement from one time interval to another.

The Markov approach described above is discrete; consequently, it defines the condition of a road at a certain point in time, which is dependent on the time interval used in the analysis.

One of the basic elements of the Markov process is that it has only a one-step memory. This means that projected future condition is only a function of the current condition. The way that the pavement reached the current state has no impact on the projected future condition. In other words, past performance has no impact on projecting future performance. Semi-Markov processes can address this by auditing age as a part of the consideration in the transition matrices. Predictions of deterministic models, such as the HDM-III model, can also be used in the compilation of transition probability matrices. An advantage of the probability-based models is that the experience and engineering judgements of pavement engineers and field supervisors can also be used to develop probability-based prediction models.

Linear and dynamic programming approaches are normally used to formulate the optimisation models for Markov processes. Standard operations research texts describe how to formulate the linear programming models for Markov processes.

The Markov formulation of projected performance addresses the basic problems of uncertainty in future conditions known to exist in pavements. This can be for both future condition without treatment and future condition with treatment. It can be formulated to handle the timing of treatments as well as the selection of treatments and sections.

Although the Markov process has been used in pavement management, it is limited as regards the number of factors that can be considered for each pavement. It is computationally complex and requires a large amount of computer capacity and time. This limits the size of the problem that can be addressed and requires mainframe computer analysis. The Markov concepts are more complex to describe to management than deterministic processes.

9.5.3 Uniform behaviour categories

Normally a requirement for both pavement performance models and transition matrices in probabilistic models is the definition of uniform behaviour categories. The division of pavement sections into these categories is achieved by using pavement parameters that have a significant influence on pavement behaviour. The following three parameters have been proposed in the S.A.R.B. Research Report No. PR 92/466 (SARB, 1993):

- * Pavement structure (e.g. asphalt, cemented, granular bases);
- * pavement surface type (e.g. weak, average or strong seal and asphalt);
- * climatic region (e.g. moderate/dry or wet).

These data categories have been defined in Chapter 3. The sensitivity of pavement performance to these, or other pavement parameters, can be determined by statistical methods.

All pavement sections in a road network should be divided into one of the predefined uniform behaviour categories (24 in the above example). The prediction of the future condition in the optimisation process for a road network will then require only a performance curve or transition matrix for each category, and not for each separate road section.

9.5.4 M&R strategies

An important facet is to define the appropriate M&R strategies to be used in the optimisation process. The definition of a strategy should include the following elements:

- * The selection of an appropriate set of M&R measures used by the authority, together with the unit costs.
- * The grouping of these measures into M&R categories as the optimisation process at network level would not normally work with detailed alternatives such as the type of reseal (e.g. 13 mm bitumen single seal). Similar types of measures should be grouped together into categories and the unit cost of the category would be an average weighted according to the usage frequency of each measure.
- * The definition of appropriate condition criteria for the selection of measures and the determination of criteria trigger limits based on appropriate standards.
- * The definition of subsequent treatments based on the future predicted condition after application of the first treatment could also be added.

9.6 SELECTING A PROCESS

Smith (1992) made the following recommendations on selecting a process:

As with many other pavement management decisions, there is no right or wrong process to use. The final decision on whether to use ranking, multi-year ranking, or optimisation and the processes used in the one selected should be based on the management process being supported. The level of sophistication of the personnel to use the PMS, the size of the network, the stability of the workforce operating the system, and the attitudes of those using the system should all be considered in selecting the best approach.

It may be best to start simply with the aim of increasing the level of sophistication as the level of training increases in the agency staff. This requires planning for the updating of the software and suggests modularisation in programming so that individual pieces can be replaced with new algorithms over time. In addition, since the higher-level systems depend more heavily on models, the system could be started with a simple selection process and increase in complexity and accuracy as the performance projection models are improved over time.

10. NETWORK-LEVEL BUDGETS, PROGRAMMES AND PLANS OF ACTION

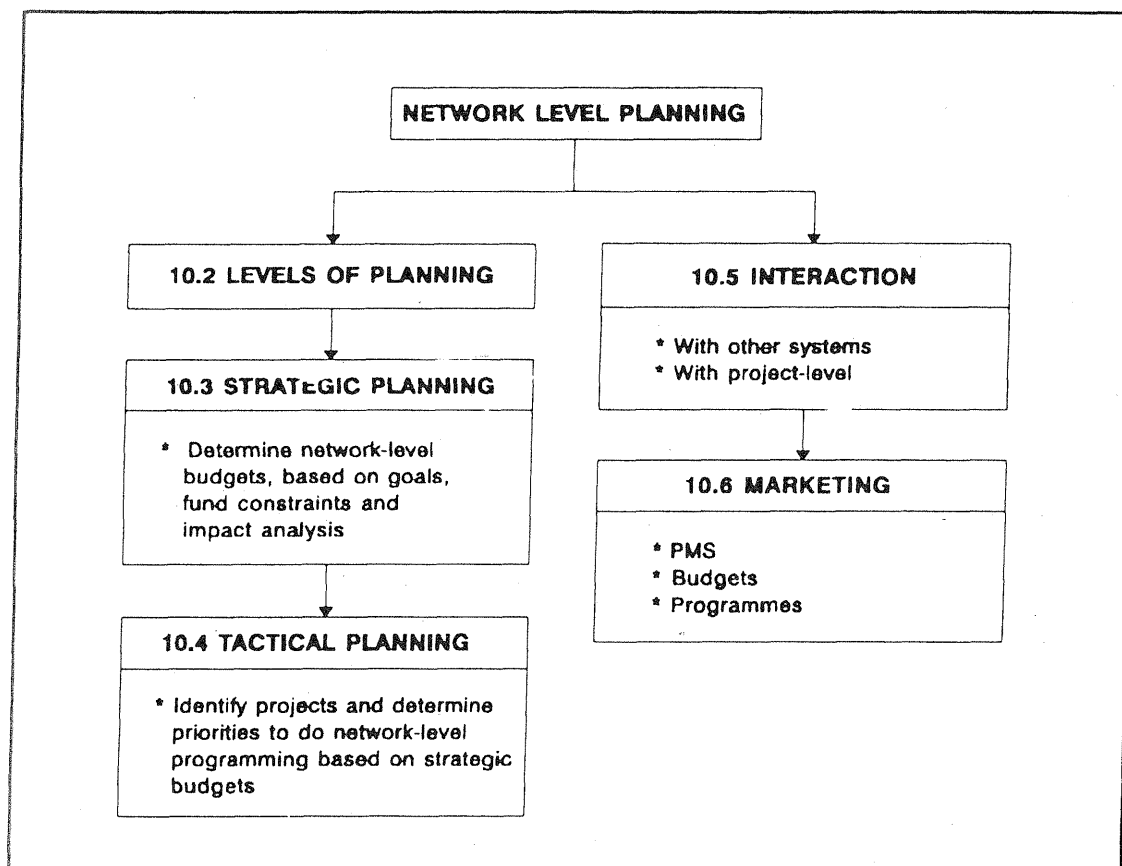


Figure 10.1: Flow diagram of Chapter 10

10.1 INTRODUCTION

The preceding sections of this document have described the various components of a PMS that are required in order to collect, process and analyse pavement data to produce information that can be used in the pavement management decision-making process. With the objective in mind of providing the best pavement condition for the money spent, the effective use of the available information to decide on network-level budgets, programmes and plans of action is a very important part of a successful pavement management process.

This section provides guidelines on the selection of projects for network-level programmes, the compilation of budgets and the interaction with project-level plans of action, as well as the marketing of programmes to decision-makers to ensure that sufficient funds are made available so that the programmes can be executed.

Figure 10.1 presents a flow diagram of the subjects discussed in this Chapter.

10.2 LEVELS OF PLANNING

Good planning is required for the effective operation of a road network. The planning function can be subdivided into three levels of planning which can be defined as follows (Curtayne et al, 1983):

Strategic Planning is long-term planning in order to determine the policy and resources required to fulfil the aims of the organisation. In this case, to assess the costs of alternative policies and their effect on the level of service provided by the road network and to secure the resources for the most attractive policy. This can best be achieved through a network optimisation process.

Road maintenance and rehabilitation policies should be based on a strategic approach where certain targets are set for the future for the whole or portions of the road network. The following are examples of such targets:

- * The maximum percentage of a road network in a poor and very poor condition;
- * the maximum percentage of a road network below a desired level of serviceability (based on riding quality);
- * a minimum network condition number (NCN) for a road network;
- * a maximum excess road user cost (EUC) per kilometre travelled for a road network; or
- * maximum resurfacing cycles for the various surfacing types.

One or more of these targets can be complemented by the use of a specified (approved) set of maintenance and rehabilitation alternatives, which should be updated periodically to ensure maximum cost-effectiveness (Haas, 1994).

Tactical Planning is short-to-medium-term planning by which the actions and their timing are specified in accordance with the aims, policy and resources of the organisation. Such planning is used to identify deficiencies in the network, to generate alternative solutions to these deficiencies and to prioritise and optimise the scheduling of the projects in accordance with available resources (funds).

Operational Planning (which includes design) is a project-level activity not covered by this document. The design for each project involves the preliminary design and detailed design in accordance with the project alternative which best fits the available budget and is generally a compromise between economy and the level of service provided to the road users. Operational planning also involves the detailed scheduling of projects and activities within projects, together with detailed project budgeting.

10.3 NETWORK-LEVEL BUDGETS

Network-level budgets are defined as budgets based on strategic plans and M&R policies, using network-level PMS information. These budgets address the total funding needs per M&R category over a medium-to-long-term planning period, but do not provide detailed budgets for specific projects. Figure 10.1 shows a flow diagram of the major steps required to determine network-level budgets. These steps form part of the strategic planning function.

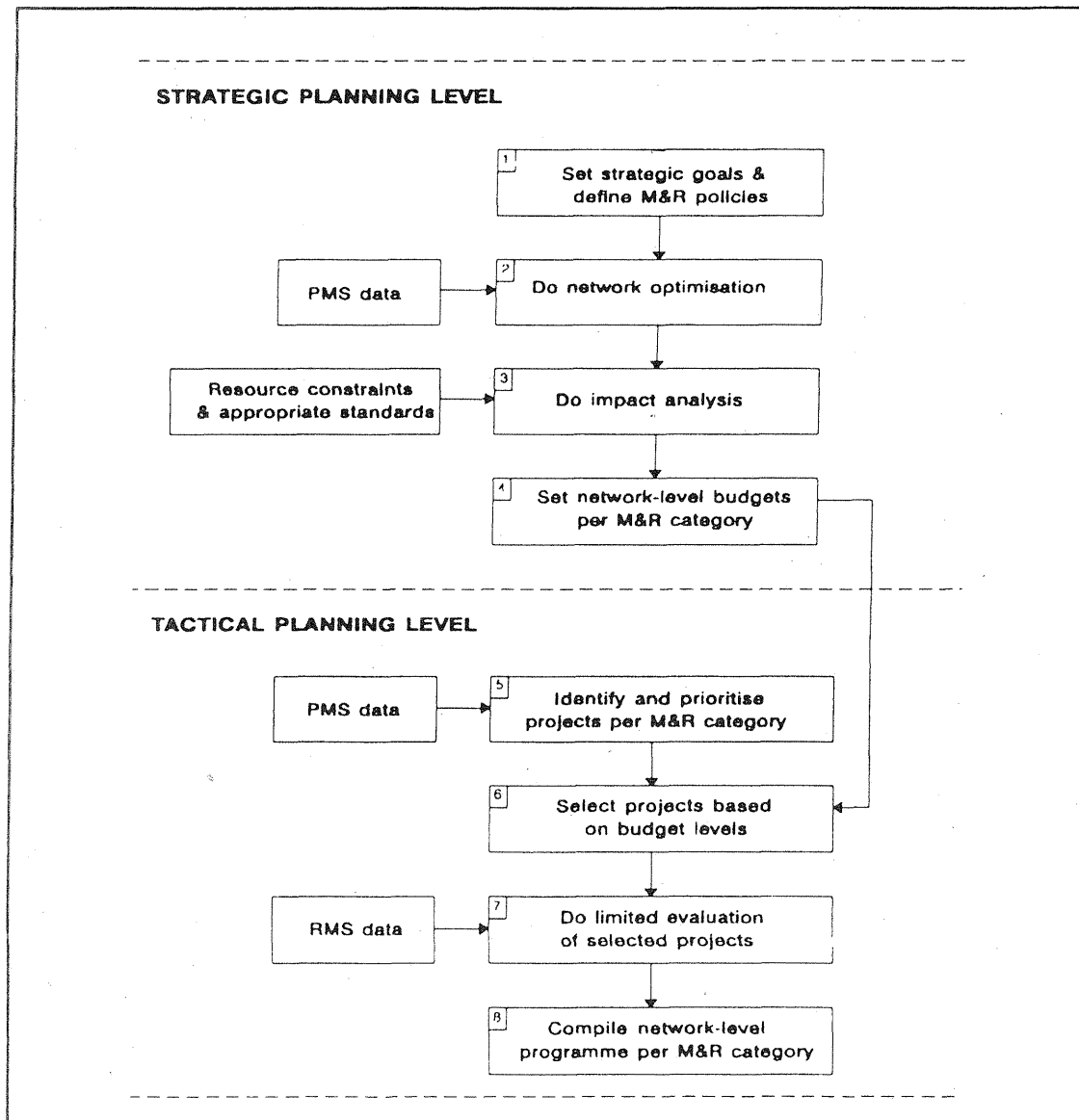


Figure 10.2: Major steps in determining network-level budgets and programs

The major steps shown in Figure 10.2, that are required to compile network-level budgets can be summarised as follows:

Step 1: Set strategic goals and policies

In the first step strategic goals and M&R policies must be set as described in section 10.2.

Step 2: Do network optimisation

Network optimisation is performed to determine the most efficient manner of resource allocation. The optimisation process uses the current and predicted condition of the road network (PMS data) and determines the required funding levels to achieve the strategic goals under the current M&R policy.

Step 3: Do impact analysis

In most cases the resources available will be insufficient to achieve the required optimum funding levels. An impact analysis using the optimisation procedure must then be performed using various levels of annual resource (e.g. funding) constraints. Typical outputs from funding impact analyses are presented in Figure 10.3 to 10.6 at the end of this Chapter (Deighton, 1994). From the analyses it will be possible to determine the optimum split of available funds between the various M&R categories and also show the impact of changes in funding levels on the future network condition.

Step 4: Set budget levels

Based on the results of the impact analysis and budget constraints, network-level budget proposals can be prepared which should address the following facets (Hobbs, 1987):

- * The proposed annual expenditure for the planning period (e.g. 5 years);
- * the proposed division of these funds between the M&R categories;
- * the anticipated future conditions and funding needs based on the proposed budget;
- * alternative budget scenarios and the corresponding implications.

This information is used by the decision-makers to decide on network-level budgets.

10.4 NETWORK-LEVEL PROGRAMMES

Network-level programmes are defined as programmes based on the network-level budgets, using network-level PMS information that may have been enhanced by limited additional evaluation. These programmes are prepared for the short to medium term (5 years) for each M&R category, and list specific projects with network-level cost estimates. The major steps required to compile network-level programmes are shown in Figure 10.2. These steps form part of the tactical planning function.

Step 5: Identify and prioritise projects

The first step is to identify the potential projects in each M&R category using the PMS data. These projects are then prioritised based on one of the methods described in Chapter 9. This can also include prioritisation by optimisation, although difficulty may be experienced in using the detailed outputs of the probabilistic techniques.

Step 6: Do project selection

Based on the prioritisation in step 5 and the budget levels defined in the strategic planning phase, the appropriate projects for the planning period are selected.

Step 7: Do limited evaluation

The limited evaluation could range from only panel inspections in the case of periodic maintenance projects to cost benefit analyses (to determine IRR), in the case of more expensive measures. During this step, allowance should also be made for non-pavement related work identified by other systems. The priority and cost estimates should be adjusted accordingly.

Step 8: Compile programmes

The results of the evaluation of the projects are used to compile network-level programmes for the planning period, ensuring that cost estimates are within the annual network-level budgets. Annual network-level budgets are finally revised, based on the network-level programmes for each M&R category.

10.5 INTERACTION WITH OTHER SYSTEMS AND LEVELS**10.5.1 Interaction with road network management systems**

The programming of maintenance and rehabilitation projects should not be done in isolation from other road management subsystems. The outputs of these subsystems must be managed in a co-ordinated way to maximise the overall utility of the road network. Figure 1.2 (Chapter 1) shows how the different subsystems within a total road management system should be combined for overall priority determination and programming.

10.5.2 Interaction with project-level

Project-level work falls in the design phase of planning (section 10.2). The TRH 12 (1985) document provides guidelines for the execution of the project-level phase. During this phase more detailed information is gathered and analysed, together with various project alternatives, to establish the design which best fits the available funds.

The interaction of the PMS with project-level activities includes the following facets:

- a) The provision of the following current and historical data from the PMS data base for use in project-level analysis:
 - * Pavement condition (visual and instrument measurements);
 - * pavement structure and maintenance history (the detail of network-level data is limited);
 - * traffic volumes and axle loadings (data may be in traffic counting system);
 - * unit costs of M&R measures.

- b) The feedback of the following information from the project level to the PMS data base:
- As-built maintenance and rehabilitation data;
 - as-built unit costs of M&R measures;
 - performance and effectiveness of pavement designs and previous M&R measures.

Procedures must be established to ensure efficient and effective interaction in both directions between network- and project-level activities. Refer also to section 11.3.

10.6 MARKETING OF THE PROGRAMME

10.6.1 Introduction

The pavement management process does not end with the provision to top management (or the political decision-makers) of the pavement condition information, budget requirements and proposed work programmes. In many cases reports are not read or understood, and the various departments within an authority all make financial demands for ever-increasing shares of the total budget. It is therefore essential that a plan should be drawn up to market the proposed network-level budget and work programme to decision-makers. The marketing of the PMS itself may also be required.

10.6.2 Factors influencing the marketing plan

A number of factors should be taken into account when considering how to market. These include the following:

a) Availability of PMS resources

If PMS resources are made available annually either through obligation or because decision-makers think it is a good thing, only limited marketing of the PMS may be required. However, if the PMS is in its implementation or upgrading phase, a substantial portion of the marketing plan should be used to market the benefits of the system.

b) Technical knowledge of the decision-makers

The technical knowledge of decision-makers may vary from technical department heads to elected political officials that may not fully understand the need for systematic maintenance. It is important to present information in a format that is compatible with the technical knowledge of the target audience.

c) Interest of decision-makers

Where the decision-makers also have interests in non-road related activities (e.g. health, police, etc.), the marketing plan should highlight reasons why the required road funds should not go to other services. In the case of elected officials, short-term thinking may be important to them (election or re-election). Marketing should take this into account, as over-emphasis of long-term goals and results may have little impact.

10.6.3 Marketing of PMS requirements

Before commencing with the marketing plan, the objective should be clearly defined and the concerns of the decision-makers understood. Taking these two items into account, an overall marketing plan should include the following elements:

- a) A continuous customised road maintenance awareness campaign. The goal of such a campaign will be to make staff, the decision-makers and the public aware of the need for road maintenance, as well as actual maintenance activities. Through regular newsletters, press releases, site visits, etc., awareness of road maintenance needs and road deterioration factors may be increased.

- b) An annual road condition report, providing information on pavement conditions, maintenance needs, programmes and budget proposals. The report should preferably be presented in at least three volumes.

Volume 1: An executive summary providing information for executive management and political decision-makers. Information should be provided only in summarised format, particularly in graphs.

Volume 2. The road condition report providing more detail (in statistical format) for middle management. The executive summary may also be included as the first few pages of this report.

Volume 3: A separate volume may be provided, with detailed information in listings, to be used by middle management and operational staff.

- c) Visual presentations of the information contained in the reports should be made to the upper- and middle-management levels. The opportunity should be used to ensure that the important facets of the report are understood. Items that could form part of the presentation (and the report) include the following:

- * Why a PMS? (Where the PMS is not generally accepted.)
- * The size and characteristics of the road network.
- * Pavement condition. Present condition as well as change over time. Use concept of remaining service life and show how many years are left in the road system.
- * Strategic goals and M&R policies.
- * Funding needs based on the strategic plan.
- * Consequences of various budget scenarios.
- * Condensed programme of work.
- * Conclusion in which important facets are highlighted.

- d) Marketing of the PMS should be done at all levels of management, both up and down, to ensure overall acceptance of the system.

10.6.4 Important facets of PMS presentations

The following facets should be considered when preparing presentations (verbal or written) to decision-makers (TRB, 1994):

- a) Define an objective for the presentation

Keep the objective in mind and make sure the presentation supports the objective. The major objective would normally not be to market the PMS, but to show why funds are required and the impact of reductions in funds.

- b) Credibility

Build the credibility of the PMS. This includes the credibility of the information, system and procedures. Inaccuracy of information can undermine funding requests. It is therefore important to screen all data before they are made available to any user. Ensure that there is support within the organisation. If staff do not believe in the system they can destroy it. Develop support from the bottom.

- c) Address questions that decision-makers may have

These questions will vary from organisation to organisation, but some basic questions could include the following:

- * Are sound and rational policies used for design, construction, maintenance and rehabilitation?
- * Is a sound and accepted basis used for characterising condition?
- * Pavement conditions - current, trends, predicted and desirable.
- * Is a rational basis used for allocating funds and other resources?
- * What portion of funding requests is crucial?
- * What are the benefits to be gained from the expenditure?

- d) Correct use of information

Make sure that users fully understand and are aware of the correct use and application of the PMS information.

- e) Keep it simple

When using technical terms, such as condition indices, explain the term in an appropriate manner. For example, for laymen indicate that roads in a good condition category normally only need preventive maintenance, in a fair category, normally something like a reseal, while a road in a very poor condition would normally require reconstruction. Highlight the relative costs of these measures and explain what is meant with each measure.

f) Preparation

In the preparation of the presentation try to find out background information about the audience from people that know them. Determine the issues that are important to the audience. If possible use public affairs staff. Do not use methods blindly that were successful for somebody else, since they may not work in all situations.

g) Concepts that can be used

A number of concepts can be used to support fund requests, namely -

- * compare total value of assets with funds spent on maintenance (%);
- * compare current expenditure (R/km) with historical expenditure or expenditure on national and adjacent road networks;
- * use remaining service life concept to show percentage of network past critical level;
- * based on the average life cycle of the present surfacings, show how many kilometres should be resurfaced annually.

h) Understand the political process

The political process and realities must be understood and proposals must be worked out within realistic constraints. It should be realised that maintenance projects normally do not have any political excitement and that sound pavement management sometimes defies common perceptions.

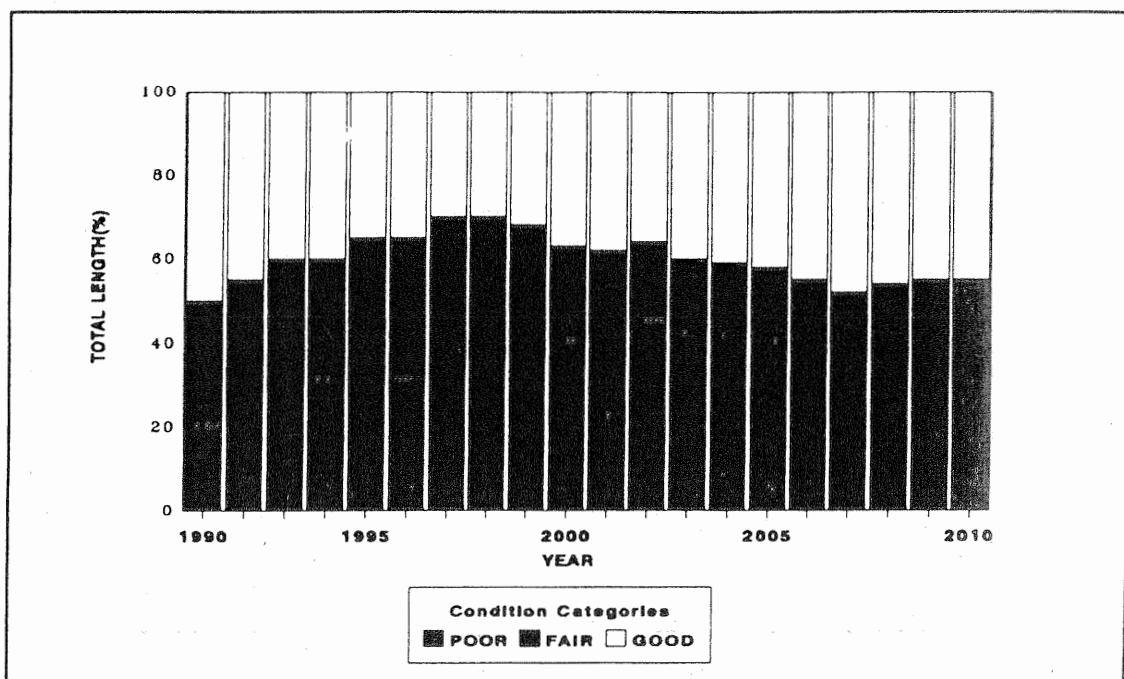


Figure 10.3: Example of predicted condition distribution report

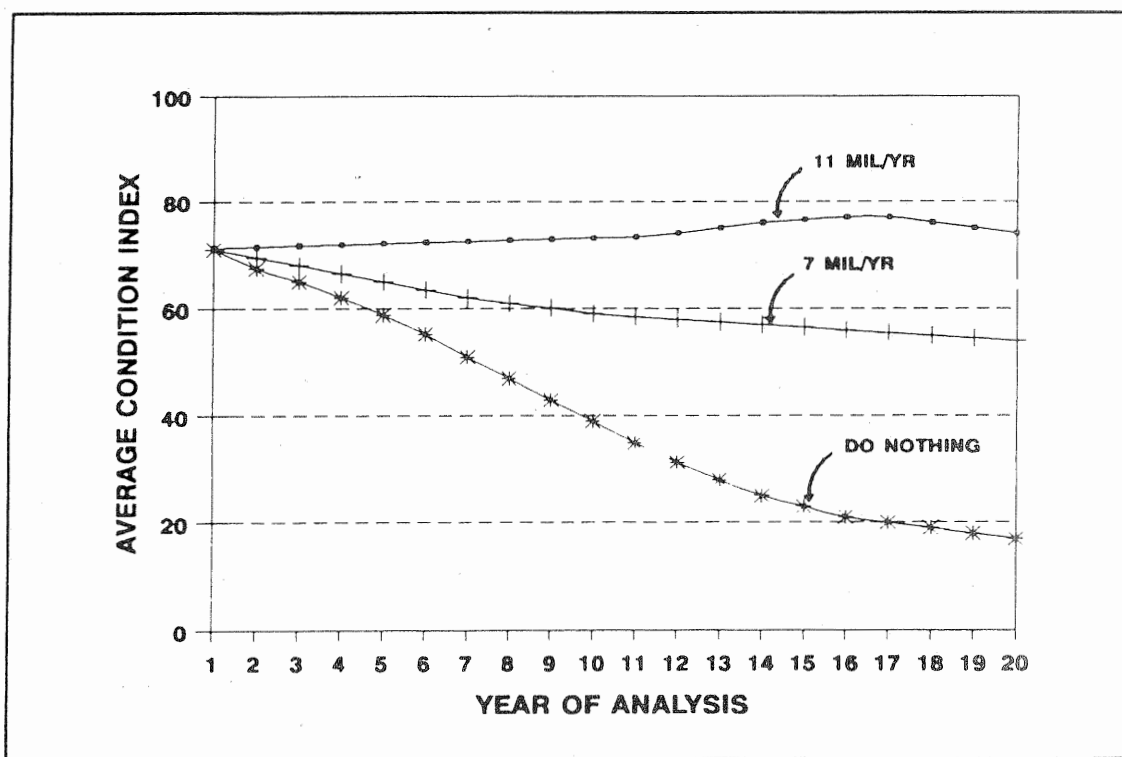


Figure 10.4: Average condition report

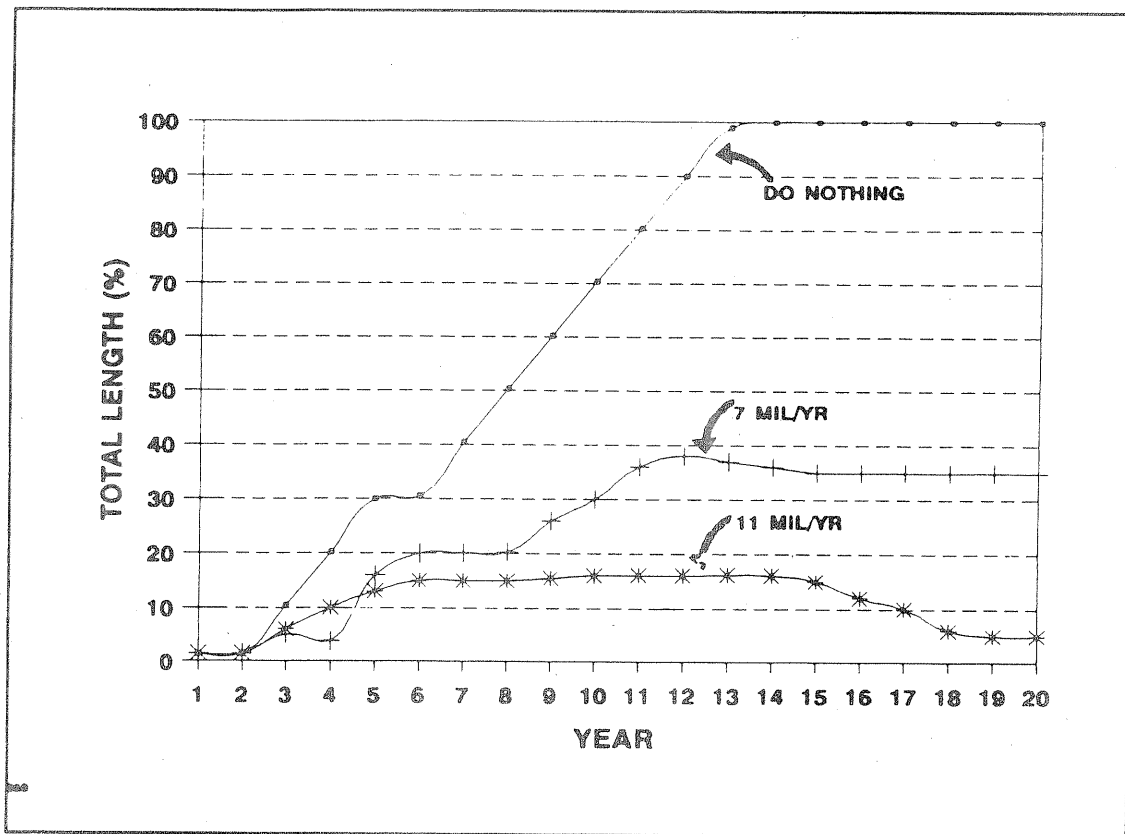


Figure 10.5: Backlog report

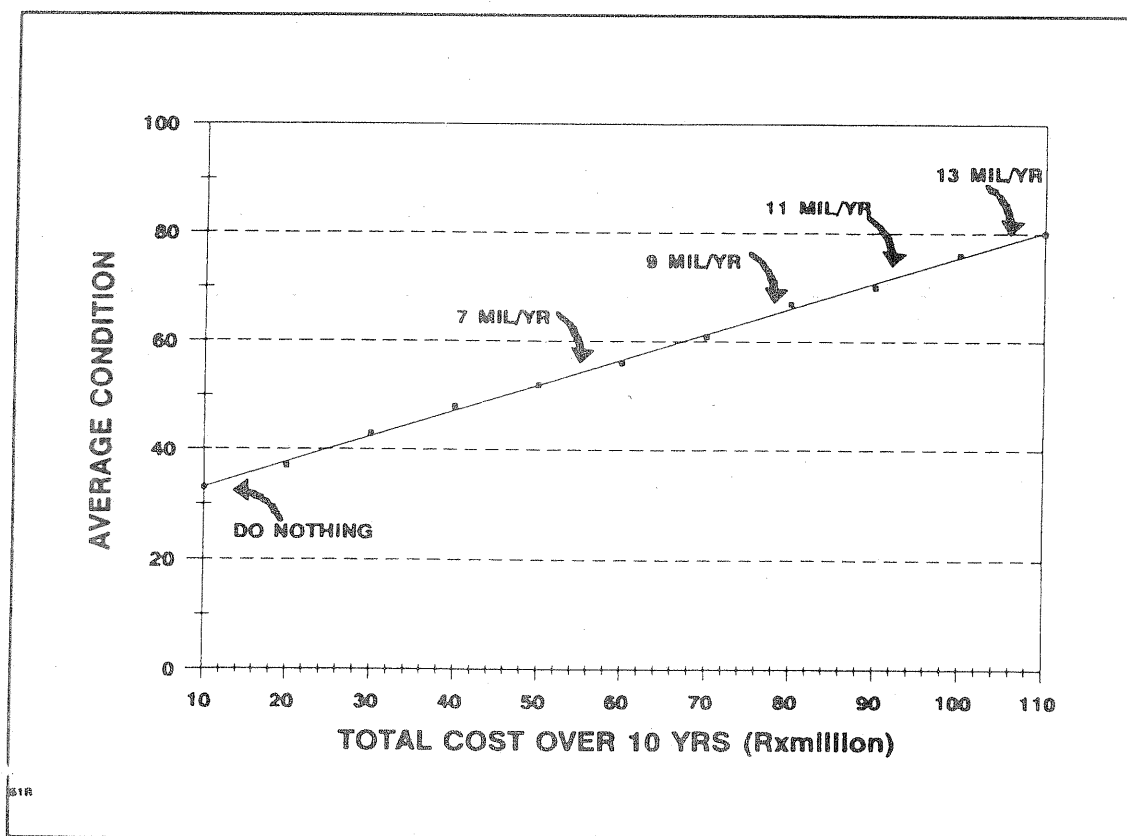


Figure 10.6: Funding impact curve

11. DATA UPDATING, FEEDBACK AND SYSTEM UPGRADING

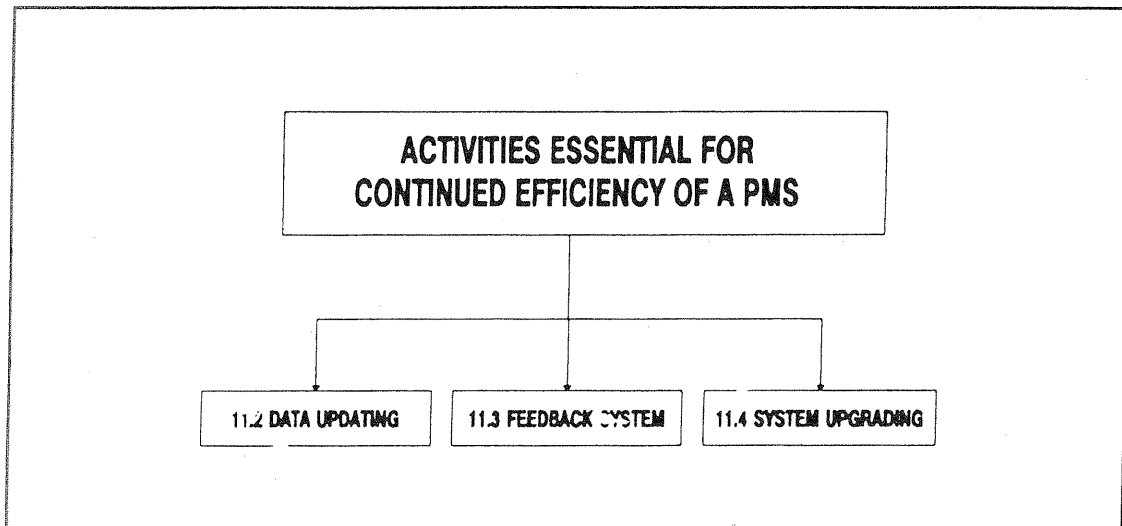


Figure 11.1: Flow diagram of Chapter 11

11.1 GENERAL

The systematic acquisition and updating of data and the ability to use this data in an efficient manner is a valuable aid to improving pavement technology. The quality of pavement management is largely dependent on the quality of the supporting technology and gathered information. To define and quantify the validity of a management system, a well-organised feedback system is a vital part of a complete pavement management system (Haas, 1978).

The purpose of this Chapter is to define and discuss the processes of data updating, feedback and system upgrading. In the literature these terms are often used to describe different processes. To avoid misinterpretation of these concepts they are defined as follows:

- Data updating

Data updating is defined as the process of collecting data on all changes to the road network and saving this data in the PMS data base. This process applies in particular to road definition and inventory data which are not automatically updated, as is normally the case with condition data. Examples of data that should receive particular attention include as-built construction, maintenance and cost data.

- **Feedback system**

A feedback system is defined as a system that provides data specifically for the updating of performance models, treatment selection algorithms or PMS procedures. The data can also be used in system upgrading.

- **System Upgrading**

System upgrading is defined as the implementation of improvements to existing PMS operations, policies or organisational structures that were identified through the initial needs survey or through review and analysis of the system (AASHTO, 1985).

11.2 DATA UPDATING

A short summary of important facets of data updating is presented in section 5.3.1. The reference to data updating in this section is provided to highlight the difference between data updating and feedback.

11.3 FEEDBACK SYSTEM

Many pavement management systems operate with the same procedures, assignment processes and projection models with which they were implemented. To ensure that adequate and reliable information is available for improvement of these facets a formal, documented feedback system should be implemented as part of the pavement management system. The system should provide feedback on particular facets of the PMS, namely -

- the comparison of actual pavement conditions with projected pavement conditions based on performance models;
- the effectiveness of maintenance and rehabilitation measures, and
- the effectiveness or suitability of present PMS procedures and activities.

11.3.1 Performance models

The purpose of the feedback system with regard to the PMS performance models is to compare the actual conditions with those projected by the PMS models.

Pavement management systems can be used with projection techniques and models, based only on limited information available at implementation date. However, for a system to become fully adopted and used, it must provide reliable projections. The feedback process provides information on how reliable past estimates have been and provides information to improve future estimates (Smith, 1992).

Performance model feedback processes are not generally program elements, but rather a manual process by which the personnel responsible for operating the pavement management system update the projection algorithms and assignment processes on a recurring basis. However, certain expert systems are available with so-called "self learning" abilities. These programs have their own programmed model performance feedback systems to update performance models and, therefore, improve the reliability of future performance estimates. There are a number of methods to adjust performance models and future projections. The most generally used are regression analysis and Bayesian methods.

11.3.2 Effectiveness of design, construction and M&R measures

In many road authorities, certain pavement designs, construction methods and M&R measures are used regularly without adequate monitoring of their effectiveness for various conditions. This could lead to the continual use of designs, construction methods and measures in conditions that are not appropriate.

Condition data collected at network level should provide adequate information to analyse the impact of some project level decisions (Peterson, 1987). The overall performance of various designs, material types and construction processes under similar or different conditions can be compared with predicted performance. This can be used to update network- and project-level treatment selection, as well as network-level performance projections. It will also help to determine the most cost-effective designs, material types, construction methods, maintenance treatments and rehabilitation strategies (Smith, 1992).

Feedback should go not only to the PMS data base but also to various other sections within the road authority, including the design, materials and construction sections. The information can be used to update or modify existing policies, specifications and standards.

11.3.3 Overall PMS activities

The procedures and resources defined for the execution of the various activities in a pavement management system should not be considered fixed. A system should be implemented to provide feedback on inefficiencies and problems in all the PMS areas including the following:

- Organisational structure;
- available resources;
- road network size;
- policies; and
- procedures.

Although the need for feedback on PMS activities is greatest in the period following the implementation or upgrading of the PMS, it is a process that must be maintained continuously.

Feedback on PMS activities is best obtained through two complementary methods:

- * Periodic reports

The providers of PMS data and the users of PMS information should provide short pro-forma reports annually on the efficiency of or problems with PMS activities. This will provide valuable data for the identification of facets that require improvement or change.

- * User committee

The establishment and regular meeting of a user committee provides a forum for the presentation and discussion of PMS matters. Matters requiring attention may be prioritised for attention, based on benefit and cost implications.

11.4 SYSTEM UPGRADING

As stated in the definition, system upgrading is the implementation of improvements to existing PMS elements. The improvements (system upgrading) may be grouped into three categories:

- **Phased implementation**

Some improvements form part of the long-term implementation of identified needs which are addressed in a planned manner as part of an overall programme.

- **Improvement of system deficiencies**

Certain deficiencies in a PMS system can be identified through a feedback system, as described in section 11.3. Through the review and analysis of these deficiencies, the implementation of improvements can be planned. An effective feedback system will ensure that users are involved in upgrades and this will make them feel part of the system and they will therefore accept the results more readily.

- **Improvements to keep up with changing capabilities and needs**

Data collection techniques, computer capabilities, system processes, etc., change continually. PMS user needs may also change because of changes in network size, organisational structure, etc. To accommodate these facets, improvements to the PMS system will be required.

System upgrading must be a continuous active process and its success depends mainly on the effectiveness of the implemented feedback system. Without continuous upgrading of the PMS, including the manuals, it will very soon become stagnant and useless to the user that, for instance, may have adopted new maintenance and rehabilitation techniques and methods.

Care should be taken, however, to avoid too frequent changes since this may frustrate system users who feel that once they have learnt the system, it is changed. Training is also essential to assist system users to understand the changes (Smith, 1992).

11.5 CONCLUSION

In this section the general processes of data updating, feedback and system upgrading were discussed and defined. From the information given it is evident that these processes are of vital importance to ensure that pavement management systems are efficient and a reliable management tool and source of information.

A. TECHNICAL ADDENDUM

A.1 INTRODUCTION

Various facets of the pavement management process are at present still under development in South Africa, and current recommended practice does not exist in all facets of PMS. Many proposed techniques and procedures are, however, currently being evaluated. This addendum incorporates some of these proposals to facilitate the evaluation process and encourage comments on these proposals before a decision is made on their possible incorporation into the final document. Care should therefore be exercised when the techniques are used since they have not yet been accepted as current practice.

The proposed methods are presented with a reference to the relevant section in the main document to which they refer.

A.2 TYPICAL TMH 9 DATA VERIFICATION ROUTINE

An example of a typical verification routine to check the accuracy of TMH 9 visual assessment data is shown in Table A.2.1.

TABLE A.2.1: EXAMPLE OF TMH 9 DATA VERIFICATION ROUTINE

VERIFICATION ITEM	CONDITION RATING		CONTROL ITEM	CONFLICTING CONDITION RATING		ERROR MESSAGE
	DEGREE	EXTENT		DEGREE	EXTENT	
A: SURFACE						
Texture	5	-	Bleeding	≥ 4	≥ 4	10
Texture	5	-	Skid resistance	≥ 3	-	11
Texture	1	-	Skid resistance	0	-	11
Voids	1	-	Skid resistance	0	-	12
Voids	5	-	Bleeding	≥ 3	≥ 2	13
Voids	5	-	Skid resistance	4	-	12
Patching	≥ 4	≥ 4	Riding quality	0	-	14
Binder	≥ 4	≥ 4	Bleeding	≥ 4	≥ 4	15
Bleeding	≥ 3	≥ 3	Skid resistance	≤ 1	-	16
B: STRUCTURE						
Crocodile cracking	≥ 4	≥ 4	Riding quality	0	-	20
Pumping	≥ 4	-	Block, long, transverse and	0	-	21
Rutting	≥ 4	≥ 3	crocodile (Error if all ratings are nil)			
Rutting	≥ 4	≥ 3	Block, long, transverse			
Undulation	≥ 3	≥ 3	Surface drainage	0	-	23
Undulation	≥ 5	≥ 3	Riding quality	0	-	24
Patching	≥ 4	≥ 4	Riding quality	< 2	-	25
Failure	≥ 3	≥ 3	Surface drainage	0	-	26
			Riding quality	≤ 2	-	27
			Riding quality	≤ 2	-	28

TABLE A.2.2: TYPICAL ERROR MESSAGES

ERROR MESSAGE NUMBER	MESSAGE
10	Texture conflicts with bleeding
11	Texture conflicts with skid resistance
12	Voids conflict with skid resistance
13	Voids conflict with bleeding
14	Patching conflicts with riding quality
15	Binder condition conflicts with bleeding
16	Bleeding conflicts with skid resistance
20	Crocodile cracking conflicts with riding quality
21	Pumping conflicts with cracking
23	Rutting conflicts with surface drainage
24	Rutting conflicts with riding quality
25	Undulation conflicts with riding quality
26	Undulation conflicts with surface drainage
27	Patching conflicts with riding quality
28	Failures conflict with riding quality

A.3 MODIFIED VISUAL CONDITION INDEX CALCULATION METHOD (Refer to section 6.2.2)

The method presented in this section is the same as the method presented in section 6.2.2, with the exception of the following two items:

- * An extent weight factor (Y_n). The purpose of this factor is to provide a weighting to the extent rating for distress types. This is considered important where the extent rating of the defect is more important than the degree rating, for example in the case of failures.
- * A small degree factor (S_n). The purpose of this factor is to reduce the contribution of certain defects to the total index value when their degree rating is small. For example, bleeding or rutting with a severity rating of 1 or 2 is not considered a significant problem.

The proposed formula for calculating the visual condition index is given in equation A.3.1:

$$VCI_p = 100 \left\{ 1 - C * \left[\sum_{n=1}^N F_n \right] \right\} \quad \dots\dots\dots (A.3.1)$$

where:

VCI_p	=	Preliminary VCI
F_n	=	$D_n * (E_n \wedge y_n) * W_n * S_n \dots\dots\dots (A.3.2)$
n	=	Visual assessment item number (Table A.3.1)
D_n	=	Degree rating of defect n Range : 0 to 4 for functional defects : 0 to 5 for other defects
E_n	=	Extent rating of defect n Range : Default 3 for functional defects : 0 to 5 for other defects
y_n	=	Extent weight for defect n (Table A.3.1)
W_n	=	Weight for defect n (Table A.3.1)
S_n	=	Small degree factor for defect n = 1 for degree ratings > 1 (functional defects) or degree ratings > 2 (other defects) Else = S_n (Table A.3.1)
$D_n * (E_n \wedge y_n)$	=	12 maximum, for functional defects. = 25 maximum, for other defects.
C	=	$1 / \left[\sum_{n=1}^N F_n(\max) \right]$
$F_n(\max)$	=	F_n with degree and extent ratings set at maximum.

Equation A.3.3 is applied to transform the VCI_p to a standard percentage scale.

$$VCI = (a * VCI_p + b * VCI_p^2)^2 \quad \dots\dots\dots (A.3.3)$$

where:

a	=	0,04
b	=	0,0006
VCI	=	100 (maximum)
VCI	=	0 (minimum)

TABLE A.3.1: DEFAULT WEIGHT SET FOR VCI FORMULA

ITEM NO.	ASSESSMENT ITEMS	WEIGHT (W_n)	SMALL DEGREE FACTOR (S_n)	EXTENT WEIGHT FACTOR (Y_n)
1	Texture	0	1	0
2	Voids	0	1	0
3	Surfacing failures	6,5	1	1,2
4	Surfacing cracks	5,0	1	1,1
5 A	Aggregate loss A	4,0	1	1,1
5 N	Aggregate loss N	2,0	0,8	1,0
6	Dry/Brittle	3,0	0,5	0,9
7	Bleeding	3,0	0,5	1,0
8 N	Cracks : Block/Stab N	8,0	1	1,2
8 M	Cracks : Block/Stab M	6,0	1	1,0
8 L	Cracks : Block/Stab L	5,0	1	1,0
9 N	Cracks : Long/Slip N	4,5	1	1,2
9 M	Cracks : Long/Slip M	4,5	1	1,0
9 L	Cracks : Long/Slip L	4,0	1	1,0
10	Cracks : Transverse	4,5	1	1,0
11	Cracks : Crocodiles	10,0	1	1,3
12	Pumping	10,0	1	1,3
13	Rutting	8,0	0,5	1,0
14	Undulation/Settlement	4,0	0,5	1,0
15 S	Patching S	8,0	0,8	1,2
15 M	Patching M	8,0	0,8	1,1
15 L	Patching L	8,0	0,8	1,1
16	Failures/Potholes	15,0	1	1,3
17	Edge breaking	3,5	0,8	1,0
18	Riding quality	5,5	0,8	1,0
19	Skid resistance	3,0	0,5	1,0
20	Surface drainage	3,0	0,5	1,0
21	Unpaved shoulders	3,5	1	1,0

A.4 STRUCTURAL STIFFNESS INDEX (Refer to section 6.3.2.2)

This section describes a method to determine the structural stiffness index (SSI) based on the remaining life of a pavement, as determined from surface deflection measurements.

A.4.1 GENERAL SSI CALCULATION

Once the remaining life has been determined from surface deflections through any selected method, the SSI is determined from the conversion function given in Figure A.4.1. The classification of the SSI into condition categories is also given in Figure A.4.1. The range of index values in each category is presented in Table A.4.1.

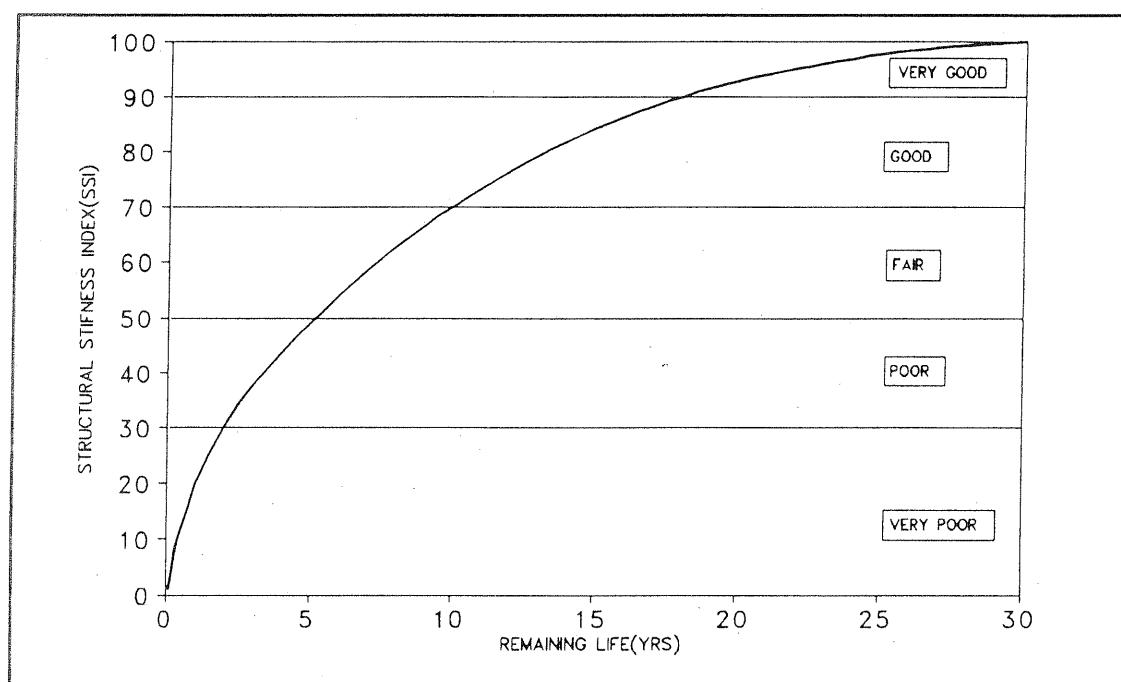


Figure A.4.1: Determination of SSI from remaining life

TABLE 6.3: STRUCTURAL CLASSIFICATION OF A PAVEMENT ACCORDING TO THE STRUCTURAL STIFFNESS INDEX (SSI)

STRUCTURAL STIFFNESS CATEGORY	SSI RANGE	REMAINING LIFE RANGES (Years)
Very good	$85 \leq \text{SSI} \leq 100$	Long term (> 15)
Good	$70 \leq \text{SSI} < 85$	(10 - 15)
Fair	$50 \leq \text{SSI} < 70$	Medium term (5-10)
Poor	$30 \leq \text{SSI} < 50$	(2 - 5)
Very poor	$0 \leq \text{SSI} < 30$	Short term (< 2)

A.4.2 AN EXAMPLE OF A METHOD TO CALCULATE THE SSI

This section describes a method to determine the structural stiffness index based on the FWD basin parameters. The method is at present being evaluated. Elements of the method require further research and development, as described in the SARB research report PR 91/325. The method uses the Y-max and BLI deflection basin parameters in the direct prediction of structural capacity (and then remaining life). These parameters have been related to the structural capacity through previous field observations and test results.

Calculation of the structural stiffness index (SSI) consists of the following steps, which are also depicted in Figure A.4.2.

1. Normalised falling weight deflectometer (FWD) measurements are used to calculate maximum deflection (Y-max) and base layer index (BLI). Surface deflection measurements should also be adjusted for asphalt temperature on thick asphalt surfaced roads.
2. The Y-max and BLI calculated in Step 1 are used with equations A.4.1 to A.4.6. to estimate the allowable E80s of the pavement section for both Y-max and BLI ($N_{Y\text{-max}}$ and N_{BLI} , respectively). These are preliminary equations at present and they are to be verified by further research:

a) Granular base:

$$N_{Y\text{-max}} = (2,43 \times 10^{17})(Y\text{-max})^{-4,252} \quad \dots\dots\dots (A.4.1)$$

$$N_{BLI} = (1,17 \times 10^{15})(BLI)^{-3,807} \quad \dots\dots\dots (A.4.2)$$

b) Asphalt base:

$$N_{Y\text{-max}} = (1,135 \times 10^{16})(Y\text{-max})^{-3,831} \quad \dots\dots\dots (A.4.3)$$

$$N_{BLI} = (1,263 \times 10^{14})(BLI)^{-3,519} \quad \dots\dots\dots (A.4.4)$$

c) Cemented base:

$$N_{Y\text{-max}} = (3,122 \times 10^{15})(Y\text{-max})^{-3,676} \quad \dots\dots\dots (A.4.5)$$

$$N_{BLI} = (4,408 \times 10^{13})(BLI)^{-3,401} \quad \dots\dots\dots (A.4.6)$$

3. By using the available information on the average annual daily traffic (AADT), percentage growth rate and percentage heavy vehicles, together with the values of $N_{Y\text{-max}}$ and N_{BLI} determined in step 2, the estimated remaining life is calculated for both $N_{Y\text{-max}}$ and N_{BLI} through equation A.4.7.

$$L_{Y\text{-max}} \text{ or } L_{BLI} = \frac{\log\left[\frac{N_e \cdot (0.01.i)}{365E \cdot (I + 0.01.i)} + 1\right]}{\log(I + 0.01.i)} \quad \dots\dots\dots (A.4.7)$$

Where

N_e	=	Allowable Equivalent 80 kN axles; That is, N_{Y-max} and N_{BLI} determined in step 2.
E	=	Equivalent daily E80s at start of projection period.
i	=	Expected/Observed growth rate (%) over design period.
L_{Y-max}, L_{BLI}	=	Remaining life (in years) predicted by Y-max and BLI, respectively (Maximum : 30 yrs).

4. The remaining life estimates of Y-max and BLI are used in equation A.4.8 to calculate SSI values for Y-max and BLI (SSI_{Y-max} and SSI_{BLI} , respectively). The equation is illustrated in Figure A.4.1 (section A.4.1).

$$SSI_{Y-max}, SSI_{BLI} = \sqrt{\frac{(0,82 + 448,54 \cdot X)}{(1 - 0,02 \cdot X + 0,0011 \cdot X^2)}} \dots\dots\dots (A.4.8)$$

Where:

SSI_{Y-max}, SSI_{BLI}	=	Structural stiffness index for Y-max and BLI.
X	=	Remaining life (yrs) L_{Y-max} and L_{BLI} from equation A.4.8.

5. The final SSI is calculated as the average of SSI_{Y-max} and SSI_{BLI} .

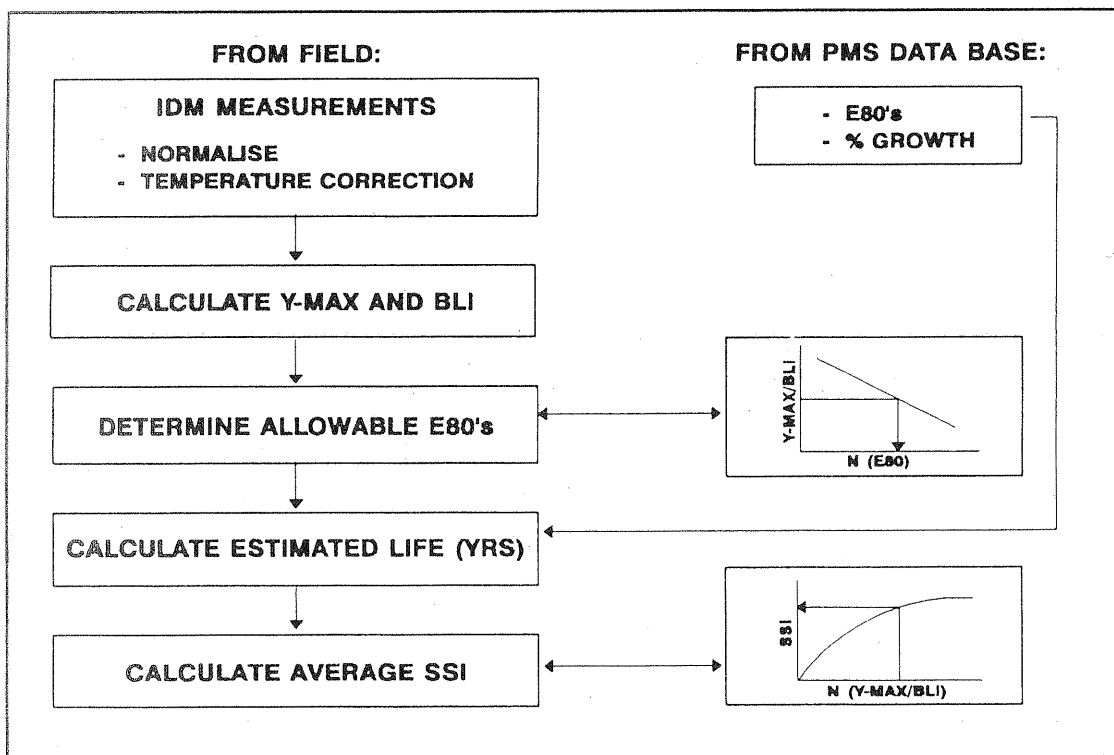


Figure A.4.2: Flow diagram of steps to calculate structural stiffness index

A.5 INVESTIGATORY SKID RESISTANCE LEVELS (Refer to section 6.4.3)

This section presents potential guidelines for the classification of appropriate levels of risk for typical site categories. Table A.5.1 provides guidelines for skid resistance levels below which routine surface investigation should take place. Based on Rogers (1991).

TABLE A.5.1: GUIDELINES FOR INVESTIGATORY SKID RESISTANCE LEVELS FOR DIFFERENT CATEGORIES OF SITE

SITE CATEGORY	INVESTIGATORY SKID RESISTANCE LEVEL (SFC @ 50 km/h)						
	0,30	0,35	0,40	0,45	0,50	0,55	0,60
Very difficult (VD)							
Difficult (D)							
Average (A)							
Easy (E)							
Very easy (VE)							

Typical descriptions of site categories listed in Table A.5.1:

VD: Approaches to traffic signals, traffic circles, pedestrian crossings and similar hazards on main roads.

D: Gradients steeper than 10% (longer than 50 m).

A: Bends with radius < 250 m (speeds > 70 km/h); gradient > 5% (longer than 50 m), approaches to and across major junctions; and single carriageway (minor junctions).

E: Dual carriageway (all purpose) with minor junctions; single carriageway (non-event sections).

VE: Dual carriageway (all purpose; non-event sections), motorway (mainline).

For each of the categories the risk rating could be aggravated by factors such as high traffic volumes or unauthorised pedestrian crossings. For these cases the site category could be upgraded to a higher level, depending on the severity of the aggravating factor.

A.6 METHOD OF CALCULATING EXCESS USER COST (Refer to section 6.4.4)

This section presents a simplified version (under review at present) of the original EUC equations for use at network level in pavement management systems. It uses only riding quality as a variable. The latest cost constants available which are presented here are based on 1991 costs. When updated constants from the CSIR become available they should be used. It is important to indicate the base date whenever EUC are reported.

A.6.1 EUC equations

The general format of the EUC equation is as follows:

$$EUC = 365 [EVOC (C) + EVOC (B) + EVOC (L) + EVOC (H)] 10^{-3} \dots\dots (A.6.1)$$

Where:

EUC	=	Annual excess user cost in rand per kilometre per annum.
EVOC	=	Excess vehicle operating costs for four types of vehicles: cars (C), buses (B), light trucks (L) and heavy trucks (H)
EVOC(C)	=	$A_c * (QI_E - 40) * (\text{No. of cars})$
A_c	=	A cost constant calculated each year based on the costs of fuel, tyres, depreciation and maintenance of cars.
QI_E	=	Measured road roughness on a QI scale for EUC applications (see explanation below).

Based on the outline above, the annual EUC per kilometre for a specific section of road should be calculated from equation A.6.2:

$$EUC_x = 365 F_s (QI_E - 40) [(A_C N_C) + (A_B N_B) + (A_L N_L) + (A_H N_H)] 10^{-3} \dots (A.6.2)$$

Where:

EUC_x	=	Annual excess user cost per kilometre in rand
X	=	Base year. It is important to state the base year when reporting EUC since costs are related to the year used for the input costs.
A	=	Cost constants for cars, buses, light and heavy trucks. To be updated annually to allow for changes in input costs. Values published by Transportek for 1991 are as follows: $A_c = 214,5; A_B = 1248,8; A_L = 1239,8; A_H = 2046,4$
N	=	Daily number of vehicles (cars, buses, light and heavy trucks). This is in both directions with the measured road roughness applicable to both directions.

QI_E = The average value of all road roughness measurements which have a QI value greater than 40.

F_s = (Number of measurements above 40 QI) / (Total number of measurements)

To calculate the total annual EUC for a road segment, the result from equation A.6.2 must be multiplied by the segment length.

A.6.2 EUC index

To transform the EUC into an index for reporting or for use in combination with other indices, the following equation is proposed:

$$EUCI = \frac{I}{(0,01 + 0,0502 X - 0,0804 X^2 + 0,0678 X^3)} \quad \dots\dots\dots (A.6.3)$$

Where:

$EUCI$ = Excess user cost index

X = EUC_n / EUC_{BASE}

EUC_n = Excess user cost of road section "n"

EUC_{BASE} = Excess user cost as calculated for the base road conditions defined as: $QI = 60$; $AADT = 4000$; % Heavy = 10% (Buses 1%, light trucks 5%, heavy trucks 4%)

A.6.3 Classification of EUC

The EUC can be reported as the actual value (rand) per road segment. For comparing different projects with each other, the value should be expressed as rand per kilometre. As the EUC is dependent on input costs (e.g. fuel costs), which may vary from year to year, fixed limits for the EUC categories based on actual values cannot be used for the classification of EUCs.

To classify EUCs into categories the EUC must first be transformed into the EUC index described in section A.6.2. The index can then be used to classify the EUC, as shown in Table A.6.1. These EUC categories can be used in visual presentations, such as charts, and in colour codes on road condition maps.

TABLE A.6.1: CLASSIFICATION OF EUC

EUC CATEGORY	EUC INDEX RANGES	EUC RANGES (Approximate (1991) rand per kilometre per year)			
Very low	$85 \leq EUCI \leq 100$			$EUC \leq 5\,000$	
Low	$70 \leq EUCI < 85$	$5\,000 <$		$EUC \leq 12\,500$	
Medium	$50 \leq EUCI < 70$	$12\,500 <$		$EUC \leq 40\,000$	
High	$30 \leq EUCI < 50$	$40\,000 <$		$EUC \leq 100\,000$	
Very high	$0 \leq EUCI < 30$	$100\,000 <$			

A.7 EXAMPLE OF INDEX-BASED PROJECT COMPILATION METHOD (Refer to section 7.3.3)

The objective of this method is to rationalise sets of point data into uniform and continuous sections. This method uses two algorithms, namely a smoothing algorithm and a stepping algorithm. The algorithms first smooth data values to diminish the effect of sharp spikes or dips, and then group sets of points using an areas method to create uniform sets complying with a specified bandwidth.

a) Smoothing algorithm:

The raw data is broken up into small segments e.g. 500 m links. Raw data for groups of links is then smoothed using advanced, high-quality statistical methods. An example of an equation used to smooth a set of 9 data points is as follows:

$$SD(i) = \frac{W1*RD(i-4) + W2*RD(i-3) + \dots + W9*RD(i+4)}{W1 + W2 + \dots + W9}$$

where

SD(i)	=	The smoothed data point
W(1-9)	=	Weightings
RD(i)	=	Raw data points

b) Stepping algorithm:

The second step in the compilation of projects involves the stepping algorithm. A resolution or bandwidth is specified by the user, e.g. 10 VCI points. Using the first smoothed data point as the reference, all data points falling within the bandwidth are grouped together. This group of points forms a recommended project, the start and end points of which could differ from the start and end points of the visual assessment segments. Weighted averages of other data such as traffic, riding quality, pavement structure, etc., are then assigned to the recommended project.

A.8 METHOD OF CLASSIFYING ROAD SEGMENTS INTO AN M&R CATEGORY

(Refer to section 7.4.3)

Distress rating trigger method

The classification is done through the following steps, starting with the rehabilitation category (Table A.8.1):

- i) Compare the relevant index and distress ratings with the specified trigger values for all options within the category under consideration.
- ii) If the required index trigger value plus at least one set of distress trigger values are met, then the road segment is classified into that category.
- iii) If no match is found, go to the next category.
- iv) Repeat steps i) to iii).
- v) If no match is found in any category, classify the segment as "do nothing".

If available, the deterioration rate of the pavement condition can also be used in classification. This can be done by extending the average deterioration rate of the index value over the past two years for a further short period (e.g. 3 months). The road segment is then re-classified if the next lower index trigger value is passed.

TABLE A.8.1: DEFAULT VALUES FOR DISTRESS RATING TRIGGER METHOD

TRIGGER ITEMS	M&R CATEGORIES										
	REHABILITATION		SPECIAL MAINTENANCE		PERIODIC MAINTENANCE			ROUTINE MAINTENANCE			
	I	OR II	I	OR II	I	OR II	OR III	De	Cs	PATCH	
OPTION: PAVEMENT INDEX RESEAL INDEX	≤ 30	≤ 50 AND D, E ≥	≤ 40	≤ 70 AND D, E ≥ PLUS: D, E ≥	≤ 65	≤ 80 AND D, E ≥	D, E ≥	D, E ≥	D ≥	D ≥	
2 Voids								FEW to MANY			
3 Surface failures				3,3		3,3		AND		4	
4 Surface cracks				3,3		3,3 OR 2,4	4,4	2,3 or			
5 Aggregate loss				4,3(A)		4,3(A)	4,4(A)	3,3 or			
6 Binder condition								4,3			
7 Bleeding				4,4		4,4	5,4				
8 Block/Stab cracks		5,4 (N)		3,3 (M, N)		3,4 (N, M)			3		
9 Longitudinal crack				3,3 (M, N)		3,3 (N, M)			3		
10 Transverse crack						3,4			3		
11 Crocodile crack		4,4		3,3		4,3	4,4			3	
12 Pumping		5,4		3,3							
13 Rutting		5,4				4,3				4	
14 Undulation		5,4				4,4					
15 Patching		4,4		3,4						4	
16 Failure/Pothole		4,4		3,3		3,4				3	
17 Edge breaking										4	
18 Riding quality		4		4							
19 Skid resistance				4		4					

LEGEND: PI = Priority Index (Section 7.4);

De = Diluted Emulsion;

Cs = Crack sealing;

Patch = Patching

D, E = Degree, Extent

A.9 INITIAL PRIORITISATION BY COMPOSITE INDEX : EXAMPLES OF METHODS (Refer to section 7.5.2)

This section provides a few examples of methods that can be used for the initial prioritisation of potential projects through the use of a composite index. The methods have not yet been proved in practice and it is therefore recommended that calibration of the indices be undertaken before the methods are implemented fully.

A.9.1 Example of method for doing initial prioritisation of special maintenance and rehabilitation projects

The following criteria are combined into the rehabilitation priority index:

- * Modified visual condition index (section A.3).
- * Coefficients to adjust the visual condition index for -
 - traffic class;
 - road category;
 - climatic condition;
 - excess user cost category; and
 - Rate of pavement deterioration measured in the VCI.

$$RPI = 100 (VCI/100)^x \quad \dots\dots\dots (A.9.1)$$

where:

- RPI = Rehabilitation priority index
 = 100, maximum (no urgency for action)
 = 0, minimum (urgent need for action)
 VCI = Visual condition index (section A.3)
 x = (1 + t + r + c + e + d) defined in Table A.9.1
 = 1,6 maximum
 = 0,9 minimum

TABLE A.9.1: EXAMPLES OF REHABILITATION PRIORITY INDEX ADJUSTMENT COEFFICIENTS

TRAFFIC CLASS	t	ROAD CATE-GORY	r	CLIMATE	c	EUC CATE-GORY	e	ANNUAL VCI DROP OVER LAST 2 YEARS	d
T1	-0,10	D	-0,05	Dry	-0,05	V. Good	-0,05	≤ 5	0,00
T2	-0,05	C	0,00	Moderate	0,00	Good	0,00	5 - 10	0,05
T3	0,00	B	0,05	Wet	0,05	Fair	0,10	10 - 20	0,10
T4	0,10	A	0,10	Very Wet	0,10	Poor	0,20	> 20	0,20
T5	0,20					V. Poor	0,30		

A.9.2 Initial prioritisation of periodic maintenance projects

The following elements are combined into the reseal priority index (SPI):

- * Reseal index, SCI (calculated using the VCI formula in section A.3, but using reseal weights in Table A.9.2).
- * Coefficients to adjust reseal index for -
 - traffic class;
 - road category;
 - climatic condition;
 - age of seal; and
 - rate of deterioration in reseal index.

$$SPI = 100 (SCI/100)^x \quad \dots\dots\dots (A.9.2)$$

where:

- SPI = Reseal priority index
 = 100, maximum (no urgency for action)
 = 0, minimum (urgent need for action)
- SCI = Reseal index determined as for VCI but with Table A.9.2.2 weights
- x = (1 + t + r + c + a + d) defined in Table A.9.2.1
 = 1,6 maximum
 = 0,9 minimum

TABLE A.9.2.1: EXAMPLES OF RESEAL PRIORITY INDEX ADJUSTMENT COEFFICIENTS

TRAFFIC CLASS	t	ROAD CATE-GORY	r	CLIMATE	c	AGE OF SEAL	a	ANNUAL SI DROP OVER LAST 2 YEARS	d
T1	-0,10	D	-0,05	Dry	-0,05	New	-0,15	< 5	0,00
T2	-0,05	C	0,00	Moderate	0,00	Inter.	-0,05	5 - 10	0,05
T3	0,00	B	0,05	Wet	0,05	Old	0,05	10 - 20	0,10
T4	0,10	A	0,10	Very Wet	0,10	Very Old	0,10	> 20	0,20
T5	0,20								

TABLE A.9.2.2: EXAMPLE OF A WEIGHT SET FOR RESEAL INDEX (SCI)

ITEM NO. (n)	VISUAL ASSESSMENT ITEM	WEIGHT (W _n)	EXTENT WEIGHT FACTOR (Y _n)	SMALL DEGREE FACTOR (S _n)
1	Texture	0,0	0	1
2	Voids	0,0	0	1
3	Surfacing failures/Patching	8,0	1,3	1
4	Surfacing cracks	8,0	1,3	1
5A	Stone loss [A]	7,0	1,2	1
5N	Stone loss [N]	2,0	1,0	0,2
6	Dry/Brittle	5,0	1,0	0,2
7	Bleeding	4,5	1,0	0,2
8N	Cracks: Block/Stab [N]	8,0	1,3	1
8M	Cracks: Block/Stab [M]	6,0	1,1	1
8L	Cracks: Block/Stab [L]	5,0	1,0	1
9N	Cracks: Long/Slip [N]	6,0	1,2	1
9M	Cracks: Long/Slip [M]	5,0	1,0	1
9L	Cracks: Long/Slip [L]	4,0	1,0	1
10	Cracks: Transverse	5,0	1,1	1
11	Cracks: Crocodile	9,0	1,4	1
12	Pumping	10,0	1,3	1
13	Rutting	0,0	0,0	1
14	Undulation/Settlement	0,0	0,0	1
15S	Patching [S]	5,0	1,3	0,8
15M	Patching [M]	5,0	1,1	0,8
15L	Patching [L]	5,0	1,1	0,8
16	Failures/Potholes	6,0	1,2	1
17	Edge breaking	0,0	0,0	1
18	Riding quality	0,0	0,0	1
19	Skid resistance	7,0	1,0	0,5
20	Surface drainage	0,0	0,0	0
21	Unpaved shoulders	0,0	0,0	0

A.9.3 Initial prioritisation of diluted emulsion projects

Prioritisation should be done by distress for this measure. The priority is not calculated, but classified into one of four categories based on the presence of voids, aggregate loss and binder condition, as shown in Table A.9.3.1.

TABLE A.9.3.1: CLASSIFICATION OF PRIORITY FOR DILUTED EMULSION

BINDER CONDITION	AGGREGATE LOSS (ACTIVE)			
	Degree ≥ 3 & Extent ≥ 2 (Severe)	Degree = 2 Extent ≥ 2 (Moderate)	Degree = 1 Extent ≥ 3 (Moderate)	Degree = 1 Extent 3 (Slight)
Degree ≥ 3 (Dry)	***	**	**	*
Degree = 2 (Fair)	***	**	* ** if voids = many	-
Degree ≤ 1 (Good)	***	* ** if voids = many	*	-

Note: Increase stars by one if surface age is "old" or "very old".

- *** = Top priority
- = Lowest priority

A.9.4 Initial prioritisation of routine maintenance projects

Routine maintenance projects for paved areas are divided into two subcategories, namely crackseal projects and patching projects. A priority index is calculated for each of these subcategories using the following items:

- * Crackseal index (CCI) or Patching index (PCI) (calculated with the modified VCI formula in section A.3, but using the weights in Table A.9.4.2).
- * Coefficients to adjust the indices for -
 - traffic class;
 - road category;
 - climate; and
 - rate of deterioration of index.

$$CPI = 100 (CCI/100)^x \quad \dots\dots\dots (A.9.3)$$

$$PPI = 100 (PCI/100)^x \quad \dots\dots\dots (A.9.4)$$

where:

- CPI = Crackseal priority index
 PPI = Patching priority index
 = 100, maximum (no need for action)
 = 0, minimum (most urgent need for action)
 CCI = Crackseal index determined as for the VCI, but with Table A.9.4.2 weights
 PCI = Patching index determined as for the VCI, but with Table A.9.4.2 weights
 x = $(1 + t + r + c + d)$ defined in Table A.9.4.1.
 = 1,6 maximum
 = 0,9 minimum

TABLE A.9.4.1: EXAMPLE OF CRACKSEAL/PATCHING PRIORITY INDEX ADJUSTMENT COEFFICIENTS

TRAFFIC CLASS	t	ROAD CATE-GORY	r	CLIMATE	c	ANNUAL INDEX DROP OVER LAST 2 YEARS	d
T1	-0,10	D	0,00	Dry	0,00	< 5	0,00
T2	-0,05	C	0,00	Moderate	0,00	5 - 10	0,05
T3	0,00	B	0,05	Wet	0,05	10 - 20	0,10
T4	0,05	A	0,10	Very Wet	0,15	> 20	0,15
T5	0,10						

TABLE A.9.4.2: EXAMPLES OF A WEIGHT SET FOR CRACKSEAL AND PATCHING INDICES (CI/PI)

ITEM NO.	VISUAL ASSESSMENT ITEM	WEIGHT (Wn) CRACKSEAL	WEIGHT (Wn) PATCHING	EXTENT WEIGHT (Yn)	SMALL DEGREE FACTOR (Sn)
1	Texture	0	0	0	0
2	Voids	0	0	0	0
3	Surfacing failures/Patching	0	5	1	0,5
4	Surfacing cracks	5	0	1	0,2
5A	Stone loss [A]	0	0	1	0
5N	Stone loss [N]	0	0	1	0
6	Dry/Brittle	2	0	1	0
7	Bleeding	0	0	1	0
8N	Cracks : Block/Stab [N]	7	5	1	0,5
8M	Cracks : Block/Stab [M]	10	0	1	0,5
8L	Cracks : Block/Stab [L]	10	0	1	0,5
9N	Cracks : Long/Slip [N]	7	5	1	0,5
9M	Cracks : Long/Slip [M]	10	0	1	0,5
9L	Cracks : Long/Slip [L]	10	0	1	0,5
10	Cracks : Transverse	10	0	1	0,5
11	Cracks : Crocodile	2	10	1	0,8
12	Pumping	0	6	1	1,0
13	Rutting	0	5	1	0
14	Undulation/Settlement	0	0	1	0
15S	Patching [S]	0	8	1	0,5
15M	Patching [M]	0	8	1	0,5
15L	Patching [L]	0	8	1	0,5
16	Failures/Potholes	0	12	1	1,0
17	Edge breaking	0	6	1	0
18	Riding quality	0	0	1	0
19	Skid resistance	0	0	1	0
20	Surface drainage	0	0	1	0
21	Unpaved shoulders	0	0	1	0

A.9.5 Priority categories

The reporting to upper management of project priorities should be through the use of priority categories and not priority index values. The priority index of a project can be classified into one of four priority categories shown in Table A.9.5.1. The table also indicates the colours that should be used when reporting the priority category information in the form of charts or maps.

TABLE A.9.5.1: PRIORITY CATEGORIES

CATEGORY	PRIORITY INDEX (PI) RANGE	COLOUR CODE
D (Possible)	$70 \leq PI \leq 100$	Green
C (Desirable)	$50 \leq PI < 70$	Blue
B (Recommended)	$30 \leq PI < 50$	Yellow
A (Top Priority)	$0 \leq PI < 30$	Red

A.10 EXAMPLE OF TRIGGER METHOD ALGORITHM TO CLASSIFY PAVEMENT NEEDS INTO M&R MEASURES (Refer to section 7.6.2)

This section presents an example of an algorithm used to determine M&R measures. The algorithm is illustrated in Figure A.10.1. The prescribed conditions in Figure A.10.1 are defined by number below.

PRESCRIBED CONDITIONS FOR THE REPAIR MEASURE ALGORITHM

A.10.1 Very poor riding quality with cracking

PSI $\leq$ 1,5 and [Extent Block Cracks
+ Extent Crocodile Cracks
+ Extent Failures
+ Extent Patching] $\geq$ 6

A.10.2 Severe rutting

Degree Rutting $\geq$ 4 and Extent Rutting $\geq$ 4.

A.10.3 Severe cracks

DEFECT		D $\geq$	E $\geq$
Block/Stabilisation Cracks	Narrow	3	4
	Med/Wide	3	4
Transverse Cracks		3	4
Crocodile Cracks		3	3
Failures		3	3
Patching (All sizes)		3	3
Pumping			3
Cracks *			5

* Cracks : Degree = (Degree Block Cracks + Degree Crocodile Cracks + Degree Failures + Degree Patching)/N

N = Number of above defects with degree $\geq$ 1.

: Extent = Extent Block Cracks + Extent Crocodile Cracks + Extent Failures + Extent Patching.

A.10.4 Warning riding quality

Road Classification = A or B and PSI $<$ 2,3

or

PSI $<$ 2,0

A.10.5 Poor visual condition

Road Classification = A or B and $VCI \leq 50$

or

$VCI \leq 40$

A.10.6 High reseal need

Reseal Need Index ≤ 70 .

A.10.7 Fine or medium texture

Texture = 1 or 2, or 3, or W12, or W13, or W23, or W123.

A.10.8 Warning cracks

DEFECT		D $\geq$	E $\geq$
Surface Cracks		2	3
Block Cracks	Narrow	2	3
	Med/Wide	3	3
Transverse Cracks		3	3
Crocodile Cracks		2	3
Patching (All sizes)			3
Pumping			3
Failures			3
Cracks *		2	4

* As defined in 3 above.

A.10.9 Fine texture

Texture = 1 or 2.

A.10.10 Medium texture

Texture = 3 or W12, or W13 or W23 or W123.

A.10.11 Slight cracks

DEFECT		D	D ≥
Surface Failures		≤ 2	3
Surface Cracks		≤ 2	3
Aggregate Loss	Active	≥ 1	2
Dry/Brittle		≥ 2	3
Block Cracks	Narrow, Medium	≤ 2	3
Crocodile Cracks		≤ 2	3

A.10.12 Warning bleeding

Degree Bleeding ≥ 3 and Extent Bleeding ≥ 3.

A.10.13 Few voids

Voids = 1 or 2, or W12, or W13, or W23, or W123.

A.10.14 Very few voids

Voids = 1 or W12 or W13 or W123.

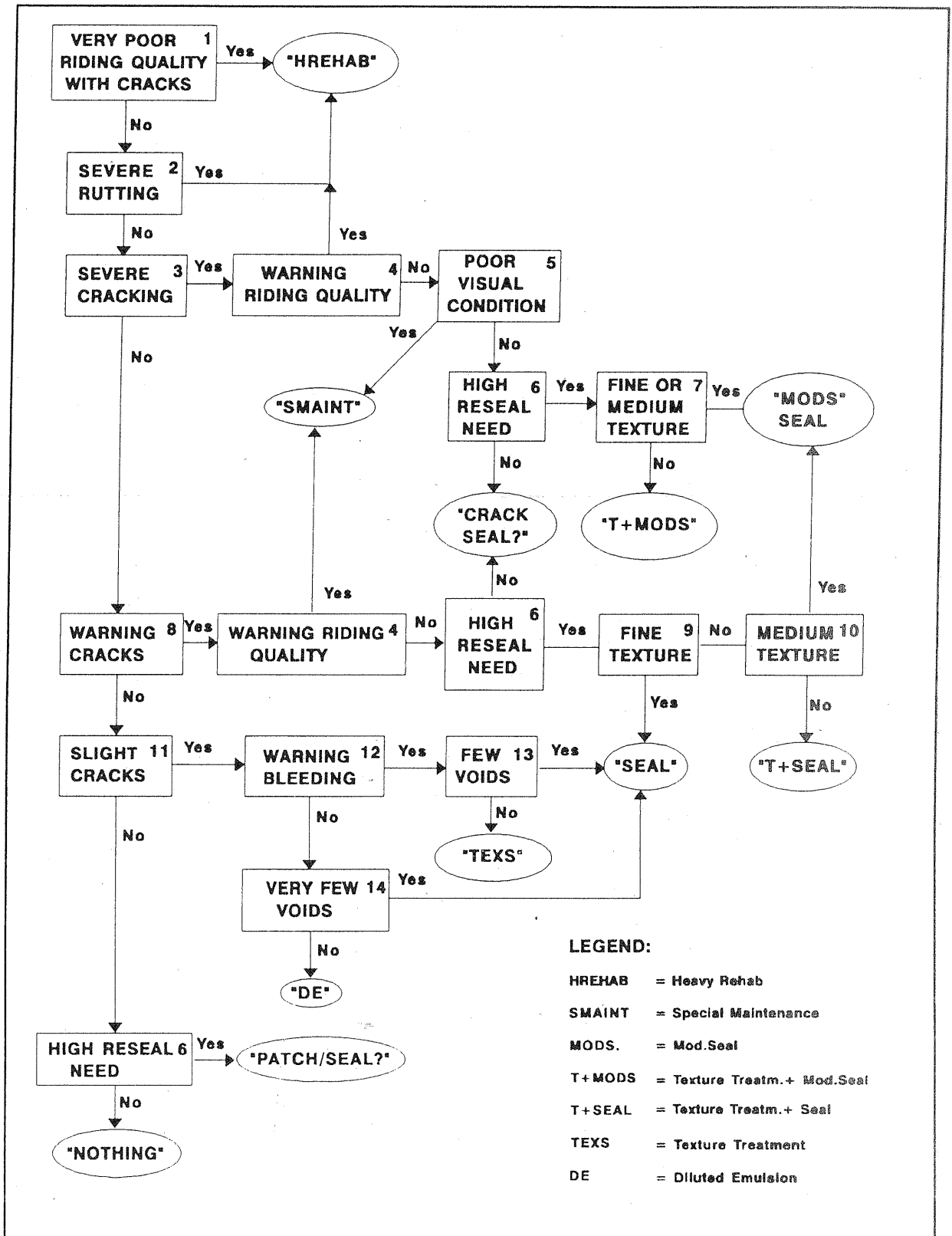


Figure A.10.1: Flow diagram for pavement repair measures

A.11 EXAMPLE OF PROJECT RANKING METHODS (Refer to section 9.3.3)

A.11.1 Ranking of rehabilitation projects using the V-value

Potential rehabilitation projects are ranked using the V-value, with the biggest V-value at the top of the list.

$$V = U + M - R \quad \dots\dots\dots (A.11.1)$$

where:

- V = Net rehabilitation value per km per year of V-value.
- U = Excess user cost (per km per year) that is related to riding quality and traffic as defined in section A.6.1.
- M = Normal pavement related maintenance cost in R/km.
- R = Annual capital recovery cost in R/km of average type of rehabilitation.

A.12 EXAMPLE OF DETERMINISTIC MODELS (Refer to section 9.5.2.1)

A.12.1 Sigmoidal curve

The sigmoidal curve illustrated in Figure 9.5 (section 9.5.2.1) is calculated from equation A.12.1.

$$P(t) = c (1 - \alpha \cdot \exp [- \rho/t]^\beta) \quad \dots\dots\dots (A.12.1)$$

- where:
- P(t) = Value of the condition index
 - t = Age of the pavement (time)
 - ρ = Rho, a shape coefficient defining the point of inflection in the S-Curve (related to the life of the pavement).
 - β = Beta, a coefficient controlling the shape of the curve (i.e. the rate of deterioration) by defining the steepness of the curve.
 - α = Alpha, a coefficient defining the asymptote of the curve (minimum level to which pavement is maintained).
 - = (100 - asymptote)
 - c = Maximum practical value of condition index after construction.

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