

A MAINTENANCE CONTROL SYSTEM  
FOR RURAL ROADS

by

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DECLARATION BY CANDIDATE

I, Peter Charles Curtayne, hereby declare that the work presented in this thesis is my own and that it has not been submitted for a degree of another university.

*P. C. Curtayne*

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TO

MY PARENTS

CHARLES AND GRACE CURTAYNE

## PREFACE

The presentation of this work as a thesis requires some explanation. This is, first, because it covers a period of some 13 years of activity and many of the ideas that were novel or innovative at the time are now generally accepted in the current state of the art. Secondly, during this period I have been assisted by several colleagues whose contributions are inextricably coupled with my own. Lastly, a large proportion of the effort centred on the implementation of pavement management systems rather than on furthering their theoretical bases. This course was chosen because in South Africa the level of implementation was so far behind what was technically possible that it was pointless to continue to build models "in the air" when the foundation on which they could be developed was lacking.

It should be noted however, that notwithstanding the valuable contributions of colleagues, it has been my responsibility to provide the motivation, discipline and basic methodology for implementing the pavement management systems. In actually carrying out the implementations my original ideas could be tested and developed and in this way structures were obtained that could meet the practical requirements of operational systems. At the same time many of the problems that beset the implementation and successful use of such systems could be investigated. A substantial body of expertise and three operating systems have resulted directly from these efforts. These achievements have lead a number of other road authorities to consider the adoption of similar systems. Discussions with researchers from other countries substantiated our experience that the various practical problems of implementation have lead to what appears to be a singular underutilization of available technology. This to my mind justifies the prominence given to findings in this area of work.

Over the years I have documented the ideas, techniques, implementation proposals and findings that emanated from this work in a number of papers and research reports. It should be noted that in several cases, although I was the main contributor to the writer of a paper, I was

listed as a co-author. This was done to assist road authorities in demonstrating the achievements that had been obtained in practice. In certain other cases the author was an assistant working under my guidance on this project. These comments are offered to clarify the nature of my contribution to the literature referenced in this thesis and to explain its historical perspective.

Aside from these general comments, some comments regarding the contribution of specific topics discussed in this document are set out below to indicate its suitability as material for a thesis of this type:

- (a) During the course of this work considerable attention was given to providing a conceptual framework for pavement management systems within which the objectives, requirements and problem areas could be explained. My current view of a systems formulation for pavement management is given in Chapter 2 of this document. This analysis has evolved through experience gained from the implementation the various systems and as a result the areas requiring attention in the development of a pavement management system are identified. Naturally many other authors have made similar observations to these expressed here. I have, however, not found it practical or necessary to acknowledge all of these contributions (except where their ideas have been borrowed directly), since this formulation has evolved in parallel to the work of others and, to my mind, still contains several unique features.
  
- (b) An illustration of the design and implementation considerations is contained in a description of the development of a pavement management system for a rural road authority (the Cape Provincial Administration). Emphasis is given to the efficient communication of basic information about the condition of the network to assist in the decision making processes of pavement management. A simple algorithm was developed to indicate the relative urgency of rehabilitation projects on economic grounds. The stage has now been reached where it is appropriate to investigate more advanced optimization models for prioritizing the projects. Since none of the

existing published procedures was found to be suitable a new formulation with novel features is presented.

- (c) During the early part of the study it was my responsibility to propose a standard definition of terms for describing pavement condition and to introduce a suitable instrument for measuring riding quality. (These are fundamental requirements of pavement management systems.) The suggested terminology was produced at a time when nothing comparable was available and it has subsequently been accepted for general use in South Africa. A modified version of the PCA roadmeter was built and calibrated by 1976 and since then has been used to measure riding quality as a service to road authorities. Reference is made to this work.
- (d) Road user costs in general and riding quality in particular are central to pavement management evaluations, yet there are a number of philosophical and practical problems in incorporating them in the analysis. What I consider to be interesting and original thoughts in dealing with these problems are presented here.
- (e) Although this study has concentrated on the identification and scheduling of maintenance projects, the design of maintenance (particularlyly rehabilitation) treatments is an integral part of pavement management. Some contributions I have made in the development of a pavement rehabilitation design procedure are noted.

# CONTENTS

	PAGE NO.
CHAPTER 1 INTRODUCTION AND MOTIVATION	
1.1 Definition and scope of pavement management systems	1 - 1
1.2 Background to rising importance of pavement management	1 - 5
1.3 Motivation for research and objectives for this thesis	1 - 12
1.4 Layout of thesis	1 - 16
CHAPTER 2 ANATOMY OF PAVEMENT MANAGEMENT SYSTEMS	
2.1 Use of systems engineering techniques	2 - 1
2.2 General systems concepts	2 - 3
2.3 Technical level of a pavement management system	2 - 7
2.4 Operational level of PMS	2 - 23
2.5 Organization level of PMS	2 - 36
2.6 Summary	2 - 41
CHAPTER 3 GENERAL STATUS OVERSEAS	
3.1 Outline of the history of PMS development	3 - 1
3.2 Situation in North America	3 - 7
3.3 Situation in the United Kingdom	3 - 14
3.4 Situation in Europe	3 - 16
3.5 Situation in Australasia	3 - 19
3.6 Summary of situation overseas	3 - 21
CHAPTER 4 DEVELOPMENT IN SOUTH AFRICA	
4.1 Introduction	4 - 1
4.2 System for the Department of Transport	4 - 2
4.3 System for the City of Johannesburg	4 - 13
4.4 System for the Cape Roads Department	4 - 30
4.5 System for the Transvaal Roads Department	4 - 33
4.6 Other road authorities	4 - 35
4.7 Future prospects	4 - 39
CHAPTER 5 DETAILS OF PMS FOR CAPE TRUNK ROADS	
5.1 Introduction	5 - 1
5.2 Data included in the system	5 - 1
5.3 PMS data processing configuration	5 - 7
5.4 Data outputs	5 - 10
5.5 Preliminary algorithm for determining maintenance requirements	5 - 21
5.6 Implementation considerations	5 - 28
5.7 Future developments	5 - 33



Contents (cont.)

	Page No.
CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS	
6.1 Introduction	6 - 1
6.2 General situation regarding PMS implementation	6 - 1
6.3 Considerations for PMS development	6 - 2
6.4 Application of development considerations	6 - 4
6.5 Theoretical considerations for future application	6 - 5
6.6 Recommendations	6 - 6
REFERENCES	
APPENDIX 1 THE DESCRIPTION OF PAVEMENT CONDITION	
A1.1 Introduction	A1 - 1
A1.2 Visual assessment of distress	A1 - 3
A1.3 Surveillance equipment	A1 - 5
A1.4 Definition and calibration of riding quality measurements	A1 - 10
A1.5 Summary	A1 - 13
APPENDIX 2 INTERPRETATION OF RIDING QUALITY MEASUREMENTS	
A2.1 Introduction	A2 - 1
A2.2 Properties of the PSR scale of riding quality	A2 - 3
A2.3 Effect of riding quality on road user costs	A2 - 8
APPENDIX 3 NOTES ON THE ROLE OF ROAD USER COSTS IN PAVEMENT MANAGEMENT EVALUATIONS	
A3.1 Introduction	A3 - 1
A3.2 Components of road user costs	A3 - 4
A3.3 Suggested procedure for dealing with road user costs in a PMS	A3 - 7
APPENDIX 4 BRIEF REVIEW OF VARIOUS PAVEMENT MANAGEMENT SYSTEMS	
APPENDIX 5 NOTES ON THE DESIGN OF PAVEMENT REHABILITATION	
A5.1 Introduction	A5 - 1
A5.2 Suggested analysis framework	A5 - 2
A5.3 Relation to PMS data base	A5 - 4
POSTSCRIPT	

# C H A P T E R 1

## INTRODUCTION AND MOTIVATION

### 1.1 DEFINITION AND SCOPE OF PAVEMENT MANAGEMENT SYSTEMS

When this research project was initiated a maintenance control system was taken to mean a formal computer-based system by which the condition of the pavements in a road network can be recorded and analysed with a view to scheduling maintenance in the most cost effective way. During the intervening time the term "pavement management system" (PMS) has evolved. Through developments in this field it has become an accepted term which, although embracing the activities originally implied by "maintenance control systems", encompasses a much richer set of concepts and methodologies. In fact pavement management has been defined (Hudson et al, 1979) as the total range of activities required to provide the pavement portion of the public works programme. It is useful to consider the functions of pavement management in terms of business management concepts before defining the term PMS.

#### Functions of pavement management

The functions of management are well established in texts on business methods (see for example Hastings, 1974). The classifications used vary a little but for this purpose can be given as:

- goal setting
- planning
- organization
- control

One of the roles of a road authority can be considered as that of managing the pavements in the network in a way that meets certain criteria. Pavement management can accordingly be conveniently defined in terms of the above functions:

Goal setting involves specifying some long term objective about the condition of the pavements in the network that will take into account the needs of the public and the current and probable future budgets and general resources. This is then formulated as a policy under which the maintenance of the pavements is to be managed.

Planning involves deciding what actions to take with time that will be the most favourable to the specified goals. The purpose is to ensure that the necessary resources are arranged timeously and that the actions are performed in the correct sequence and are compatible with available resources. There are three levels of planning:

- (a) Strategic planning. This is long term planning in order to determine the type of resources required in the future and the most suitable approach to maintenance. This function will predict the effect of various approaches on the condition of the network and therefore interacts with goal setting and policy formulation.
- (b) Tactical planning. This involves the scheduling of maintenance activities over an immediate set programming period according to their urgency and the availability of resources.
- (c) Design. This determines the most suitable type of maintenance treatment to apply in each situation.

Note that the essential feature of planning is the ability to predict the consequences of various courses of action.

Organization involves establishing a suitable administrative structure to assist in the management functions and to carry out the various maintenance operations. It provides a chain of authority for directing the work and communication lines for co-ordinating the operations.

Controlling involves reviewing the actions and their consequences to determine whether the plans of the authority are being met. There are three aspects to be considered:

- (a) Supervision. This determines whether actions are carried out in terms of the policy of the authority.
- (b) Comparison. This compares the results of the various maintenance actions with what was expected from the original plan and assesses the degree of divergence.
- (c) Correction. Where the above divergence is too large this aspect instigates a change in the policy, plans or operational procedure in order that the goals of the authority are better met.

Note that the boundaries between these functions are not always clear and that there is a great amount of interaction among the various functions. Nevertheless this classification provides a useful framework for analysing the scope and objectives of pavement management.

Pavement management systems

In the broadest terms a system is defined as an object that processes things received as input into things regarded as output. From the point of view of pavement management a road authority can be seen as a system providing a quality of service from a given network of pavements. Input into this system are public requirements, finance and environmental aspects such as traffic and climatic impacts. This is illustrated in Fig. 1.1.

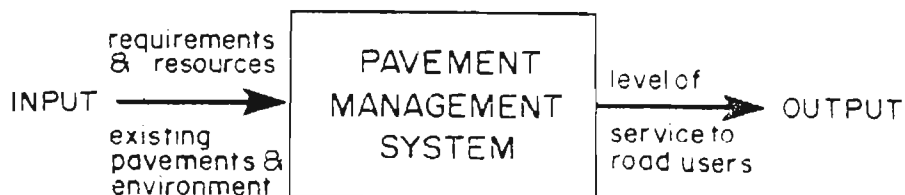


FIGURE 1.1

*REPRESENTATION OF PAVEMENT MANAGEMENT*

Pavement management is a natural function of a road authority and has obviously been operating since the first pavements were provided. The current implementation of PMSs therefore suggests a novel approach to this function which can be defined as follows:

A PMS is a set of procedures (usually computer based) used to assist a road authority in its pavement management functions, especially the planning functions, where such procedures are designed around the concept of pavement management as a system for which the objective can be given as optimizing the output (level of service) with regard to the input resources and constraints.

#### Aspects of pavement management considered in this thesis

The term "maintenance" used above is a generic term encompassing all treatments to the pavement that restore, improve, or preserve the pavement to a satisfactory condition. The various maintenance operations are discussed in Section 2.3. However they can be broadly classified as:

- (a) Routine maintenance (crack sealing, patching etc.)
- (b) Special maintenance (surface treatments, thin overlays)
- (c) Rehabilitation (thick overlays, partial reconstruction)

For reasons expounded in Section 2.3, this thesis concentrates on special maintenance and rehabilitation activities. It is therefore mainly concerned with the surfaced part of the rural pavement network. Routine maintenance is discussed insofar as it interacts with the other activities.

As the title suggests, this thesis deals more with the planning and controlling aspects of pavement management than with the organizational aspects, except for those organizational aspects that deal with the planning and control functions.

Furthermore, the identification of the (tactical or strategic) need for maintenance is considered rather than the design of the maintenance treatment itself. However some attention is given to the interaction of these aspects and to the requirements of the methodology for rehabilitation design.

Note finally that a PMS can be seen as part of a road management system. A road management system will consider additional aspects of improving a road network, particularly the upgrading of roads by virtue of their geometric properties and type of surface and the maintenance and improvement of structures and roadside furniture. Although development of a PMS will have to consider its relationship with the broader road management requirements, little attention has been given to this aspect in this thesis.

## 1.2 BACKGROUND TO RISING IMPORTANCE OF PAVEMENT MANAGEMENT

The last decade and a half have witnessed a marked increase in interest in pavement management. This has largely been the result of a shift of many authorities in developed countries from construction to maintenance issues.

### Developments overseas

In 1970 in the United Kingdom the Marshall Committee tabled their report indicating the prevailing paucity of accurate statistics regarding maintenance activities and recommending a formal approach to maintenance standards, costing and reporting (Ministry of Transport, 1970).

In the early seventies the Steering Committee for Road Research of the Organization for Economic Co-operation and Development (OECD) set up a group to determine maintenance needs for road networks in the face of the expected escalation of pavement maintenance requirements. Because of the complexity of the problem no easy solutions were possible. Their report (OECD, 1973) accordingly stressed the need to design an overall long term strategy that

combined maintenance, construction and traffic operation considerations and it sets out methods and approaches available at the time by which this might be achieved.

During 1974 sixty maintenance engineers from all over the United States attended a workshop to identify important highway research needs. Their report (Transportation Research Board, 1975) stated that:

"... maintaining the present network of highways during the future at an acceptable level for the safe and economic movement of people and goods will require a concentrated planning effort. This effort will require the utilization of manpower and resources paralleling what went into the development of the present highway network."

Raiken (1976) showed the rapid rise in maintenance expenditure in the USA in relation to the total highway expenditure. This is illustrated in Fig. 1.2. Yet despite the growing proportion of maintenance expenditure the level of maintenance is considered by many to be grossly inadequate. For example it has been suggested (The Road Information Program, 1981) that:

"An estimated 53 percent or some 1,03 million miles of the country's (USA) 1,95 million miles of paved roads require immediate attention .... nearly \$222 billion will be required."

During this period there was in fact a considerable shift in emphasis in research towards pavement management issues. The most notable empirical investigation was a \$16 million study of pavement behaviour and road user costs undertaken in Brasil (Wyatt et al, 1979). The rise in prominence of pavement management research has been evident in the literature as exemplified in the proceedings of the recent International Conference on the Structural Design of Asphalt Pavements held in Delft in 1982.

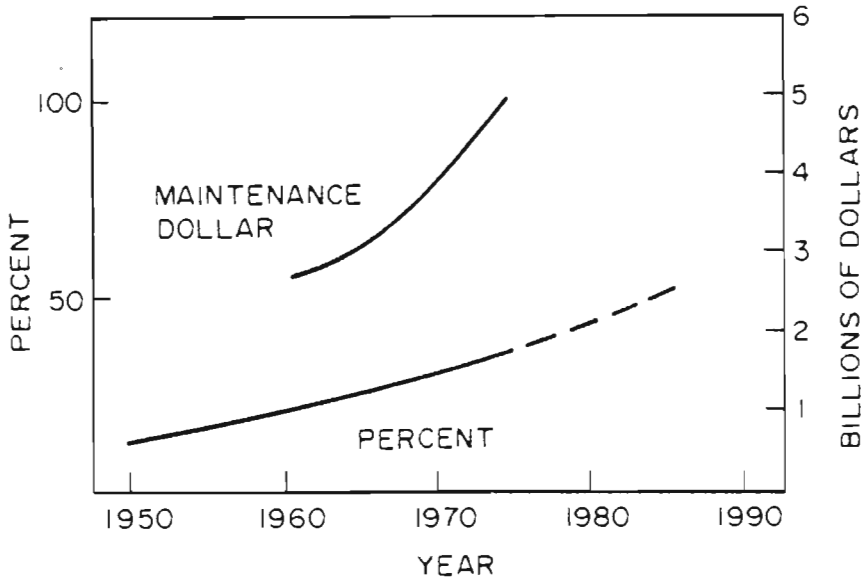


FIGURE 1.2

*MAINTENANCE COST AS A PERCENTAGE OF TOTAL  
USA HIGHWAY EXPENDITURE*

( After Raiken, 1976 )

The situation in South Africa

In South Africa there are four provincial authorities and one national authority who essentially control the rural road networks. The approximate size of these networks and the expenditure of the road authorities are given in Table 1.1. Also given in this Table is similar information for the metropolitan authorities with networks greater than 1 000 km and for the combination of smaller municipal authorities.

The replacement value of these roads in 1981 was estimated to be R22 000 million (The South African Road Federation, 1981). The growth of the rural road network is shown in Fig. 1.3. Note that the total number of kilometres of road has remained fairly constant over the last 20 years but that the proportion that has been surfaced has increased steadily and doubled over this period.



The total expenditure on rural roads over the previous decade is given in constant 1975 prices in Fig. 1.4 (mainly from Hamilton, 1982, but data interpolated where values unavailable). This shows that the maintenance expenditure has remained fairly constant over this time period and not escalated as might have been expected from the growth of the bituminized network. Note, however, that the meaning of these figures is not clear since the costing procedures and the activities classified under maintenance differ among road authorities (Nicoll, 1978). For example the Cape Provincial Administration (CPA) include partial reconstruction under their construction account, whereas the Department of Transport (DOT) include similar activities on national roads under their rehabilitation account. Moreover these data are for maintenance of the total network of gravel and bituminized roads. It is therefore difficult to estimate either the total expenditure on maintenance or the expenditure on each class of maintenance. It is also difficult to interpret the trend of maintenance expenditure over time. This can however be done for the total maintenance expenditure on the national road network which is a fairly young set of roads. (The pavements have all been constructed between 1965 and 1982.) Fig. 1.5 shows the rise in the maintenance costs as a

TABLE 1.1 : Size of rural and municipal road authorities \*

Type of authority	Roads Department	Total length of road (km)	Length of surfaced road (km)	Total road expenditure 1980/81 ('80) Rx10 <sup>6</sup>
Rural	National	2 000	2 000	187,0
	Transvaal	49 000	16 000	239,8
	Cape	72 000	17 000	153,9
	Natal	15 000	5 000	94,2
	OFS	48 000	7 000	71,9
Urban > 1000 km road	Johannesburg	2 800	2 500	48,0
	Durban	2 700	2 500	36,4
	Cape Town	2 200	1 900	21,0
	Pretoria	2 000	1 900	21,2
	P.Elizabeth	1 100	1 000	11,9
Municipal < 1000 km road	collective	32 000	24 000	220

\* After Hamilton (1982)

percentage of the total expenditure on national roads over the last 12 years. The rise is largely due to rehabilitation of the older pavements. This Figure illustrates the increasing importance of maintenance with the growth and aging of the network.

It would be reasonable to assume that the size of the road investment and the annual maintenance costs would justify the use of the most sophisticated methods of pavement management. However it was shown in a survey of 13 rural and urban authorities (Curtayne and Gordon, 1977) that there was considerable scope for improving the management of maintenance in this country. Most of the authorities accepted the importance of such improvements and a few had in fact initiated various improvements. Although this work has progressed to some extent, it is still sporadic and on a limited scale.

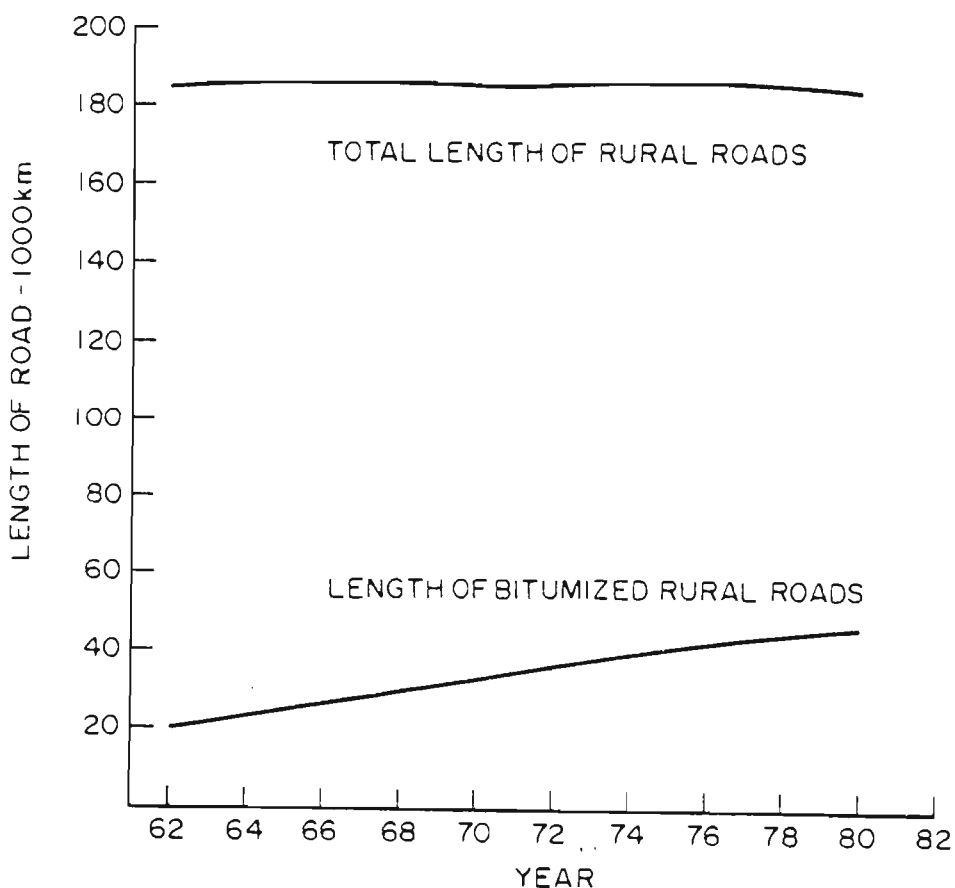


FIGURE 1.3  
*GROWTH OF THE RURAL ROAD NETWORK IN SOUTH AFRICA*

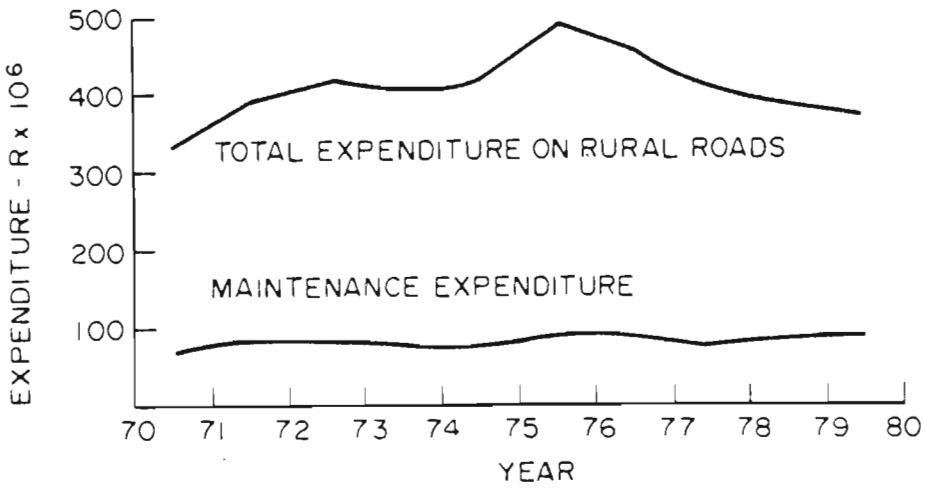


FIGURE 1.4  
EXPENDITURE ON RURAL ROADS IN CONSTANT 1975  
PRICES

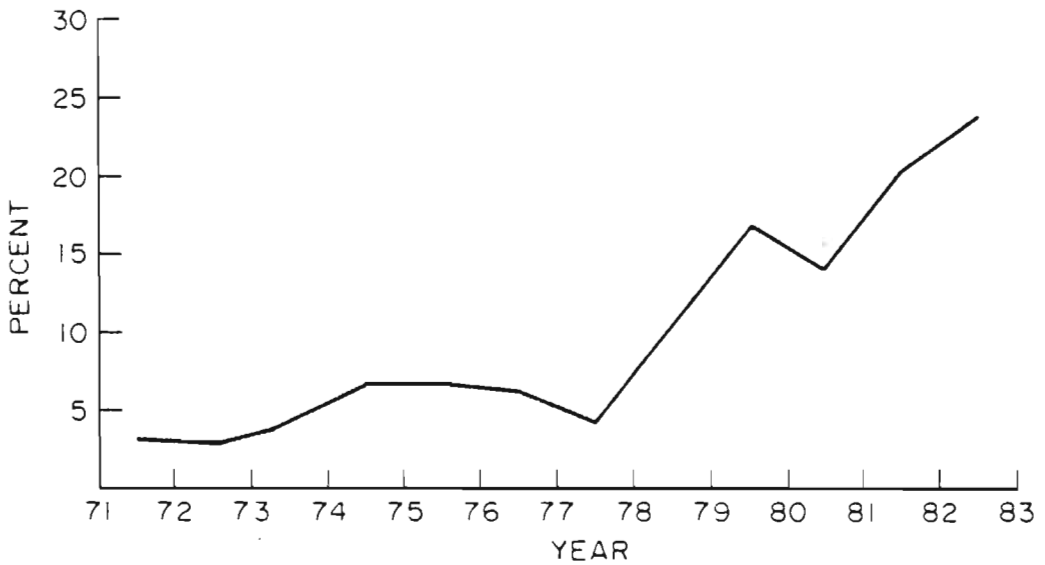


FIGURE 1.5  
MAINTENANCE EXPENDITURE ON NATIONAL ROADS AS  
PERCENTAGE OF TOTAL EXPENDITURE

A recent study (The South African Road Federation, 1981) showed that by considering average lives of various types of maintenance there is currently an under expenditure of maintenance in South Africa which is occurring to the detriment of the road user. This study recommended the use of work done overseas in pavement management to identify and plan maintenance.

At an important conference, Conference on Road Strategy for South Africa (held in Pretoria 15 & 16 April 1982 and attended inter alia by senior officers and executives of the road fraternity and financing authorities), various speakers expressed fears about the level of funding for pavement maintenance and its probable effect on the future condition of the pavements and road user costs. Curtayne and Visser (1982) at this conference pointed out the need for a formal procedure for assessing the state of the road network and identifying the maintenance requirements and their priorities. They showed that although many techniques were available and attempts were being made to introduce these techniques into some authorities, there was no coordinated unified approach among authorities by which needs could be formulated on a national basis. In summing up the proceedings of the conference the then Deputy Minister of Finance, Mr D W Steyn, agreed with these comments (Southern African Bitumen and Tar Association, 1982). He stressed the importance of preserving the capital invested in pavements and made a plea for further conferences to consider how pavement management systems can be developed on an integrated and co-ordinated basis.

#### Summary

The difficult financial climate both overseas and in South Africa for road authorities is causing concern about the maintenance of the road networks. This has highlighted the need for PMSs, first to make optimum use of available resources and secondly to assess objectively the consequences of given levels of funding so that these can be explained to the funding authorities. Although the condition of the road network is not as bad in the Republic as has been reported for certain other countries (e.g. the USA) there is still a body of opinion that the current level of maintenance is inadequate and will lead to deteriorating conditions.

In any event the need for a coordinated approach in South Africa for dealing with this problem is almost common cause. What is needed are clear guidelines as to how this should proceed. For this it is important to examine and build upon the work done overseas and locally.

### 1.3 MOTIVATION FOR RESEARCH AND OBJECTIVES FOR THIS THESIS

Interest in pavement management arose in the context of this work with the introduction, by the NITRR, of various surveillance instruments for measuring the condition of pavements in the early nineteen seventies. These were instruments for measuring riding quality, deflection and skid resistance. It was felt that these instruments could be used to monitor the condition of the network and together with information obtained from visual assessments the results could, if processed in a systematic manner, be used to identify current and predict future maintenance needs. The development of such a system formed the first proposal for this thesis in 1972.

Soon after this it was learned that the Commonwealth Bureau of Roads of Australia had investigated a nation-wide roads needs study which appeared to be along similar lines to the above proposal except that its scope was wider, including the upgrading of all aspects of the roads and bridges. It was further learned that the Main Roads Department of Western Australia was employing this approach to planning geometric improvements and maintenance of their roads (Kaesehagen, 1970). Since conditions in Australia appeared to be very similar to those in South Africa a visit was paid to that country in 1973 to investigate their methods and the results (Curtayne, 1975).

On the basis of these findings a scheme for a road management system for South Africa was suggested (Curtayne, 1974). This is illustrated in Fig. 1.6. This system centres on a computer based inventory. The heavy lines in the diagram indicate the main decision making cycle emanating from this data base. The other lines show the interaction with other functions.

This approach was adopted in 1974 by the Department of Transport as part of the information management system they were developing (Curtayne and Eaton, 1975).

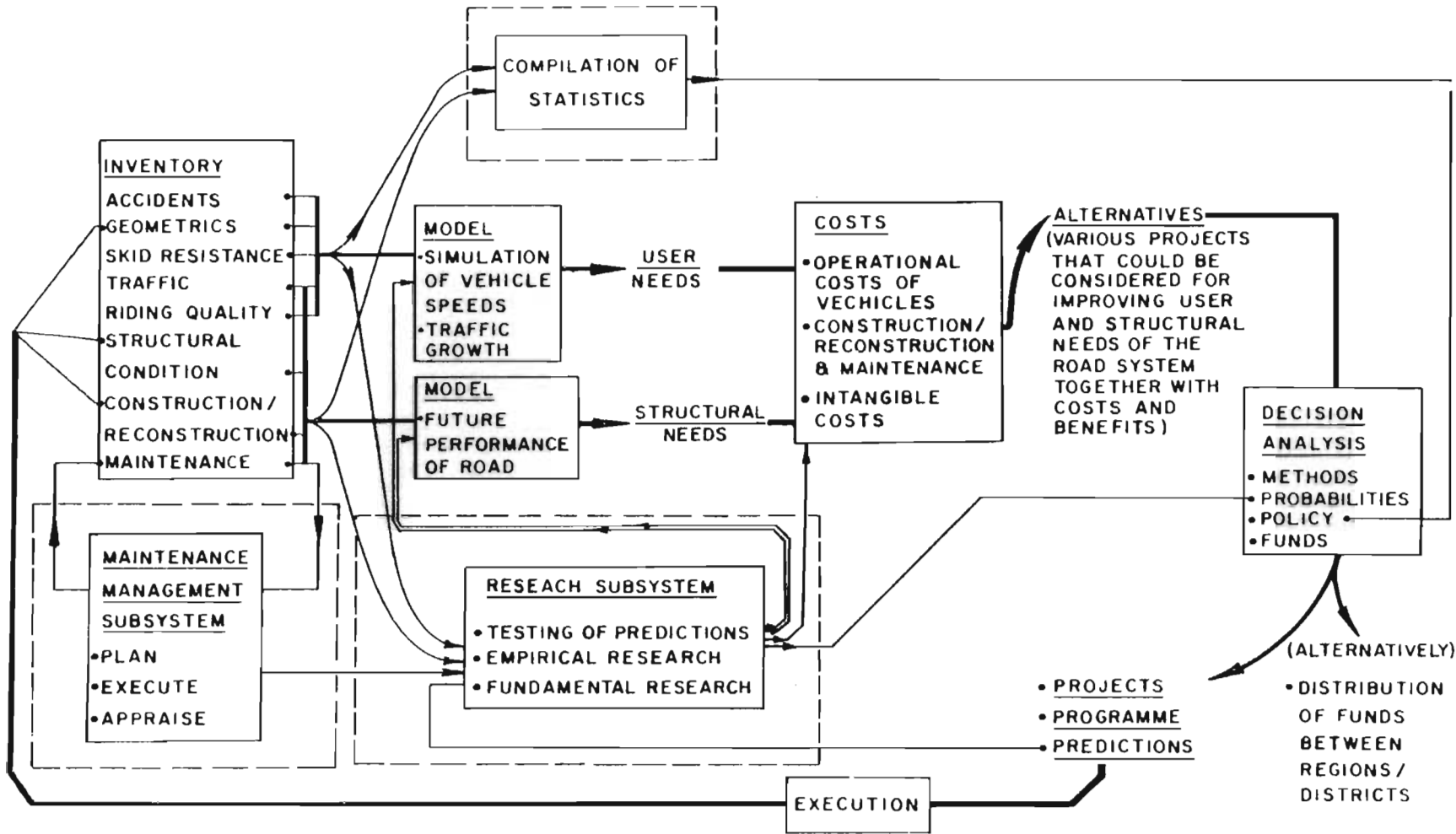


FIGURE 1.6

A PROPOSED ROAD MANAGEMENT SYSTEM

(After Curtayne, 1974)

One of the functions within the general scope of pavement management is the budgeting and control of routine maintenance. Although the principles for this aspect of maintenance management had been well established and in fairly wide use by the late nineteen sixties (Highway Research Board, 1968; Roy Jorgensen Associates, 1972), it appeared to have received only limited attention in South Africa. The survey of 13 South African authorities in 1976 included agencies with responsibilities varying from 40 km to 50 000 km of road. The survey was carried out to determine the type of management techniques being used both for routine and special maintenance. For all sizes of authority management was found to be based on traditional methods. Curtayne and Gordon (1978) summarized these methods and their shortcomings and showed that even simple improvements could bring substantial benefits.

A symposium attended by 13 rural and metropolitan authorities and the NITRR was held in 1978 to discuss the various innovations tried by different road authorities and to determine the level of common interest there was in this work (Curtayne, 1978a). It was decided as a consequence of this meeting that the NITRR would play a role of coordinating developments of pavement management and of disseminating the results. It would assist in implementation where possible and would prepare general guidelines for implementation based on this work. In terms of this the NITRR continued to assist with the implementation of the PMS for national roads and assisted with the development of a PMS for the Johannesburg City Engineer's Department (JCED) from 1976 to 1981. It also played a major role in the initiation of a PMS for the Cape Provincial Administration (CPA). All of these activities centred on the planning and control of special maintenance and rehabilitation activities. Mainly because of the lack of time and personnel little was done regarding the study of the management of routine maintenance activities except to take note of the successful work done by the JCED in this regard (Holtshousen and Curtayne, 1979).

An essential feature of a PMS is the ability to record the condition of pavements in a consistent and objective fashion at a reasonable speed. Considerable effort was made during the above

period to formulate the requirements of such measurements and to provide instruments and recording procedures for carrying out the work.

The above gives an overview of some of the main events and considerations that have prompted research on PMSs in a variety of specific topics. It was realized early in this work that further basic research was of little value unless at least crude versions of PMSs were operational. It was found however that although the necessary technology exists to operate a fairly sophisticated PMS, the creation of a system as a viable, integrated element of the organization presents many difficulties. The major effort has therefore been to assist in the above implementation activities and, in doing so, to identify the problems inhibiting the development and application of such systems.

The objectives of this thesis are therefore:

- (a) to provide a basic framework for analysing pavement management systems and determining their technical and practical requirements;
- (b) to briefly review the developments that have taken place overseas and locally in the techniques and implementation of PMSs;
- (c) to give a detailed account of the system being provided for the CPA in which particular attention is given to the implementation strategy and the techniques employed to obtain suitable communication between field and Head Office staff and computer analysis to carry out the planning and control of rehabilitation;
- (d) to propose a methodology for developing improved planning models for the CPA system and for taking road user costs into account;



(e) to provide general recommendations, based on the total experience of this work, to other rural road authorities contemplating their own system.

#### 1.4 LAYOUT OF THESIS

In the following chapter pavement management is analysed in more detail in terms of systems theory. The concept of performance of pavements is explained as is the objective of optimizing a maintenance strategy to take into account both the performance and the available resources. The various relations that have to be considered to develop a comprehensive optimization model are identified. However, the problem is shown to be too complex to be solved in closed form and therefore the approach is to subdivide it into aspects that can be studied separately and then co-ordinated.

Chapter 2 also discusses practical and organizational considerations for operating a PMS. Attention is given to the problems of communication and control of the PMS activities within the road authority and between the road authority and the public financing authority.

Chapter 3 gives a brief account of the status of PMSs overseas. An overview is given of the history of the development of PMS technology. Short descriptions of operating PMSs in various countries are given.

The status of PMS development in South Africa is outlined in Chapter 4. Details are given of the various PMSs that have been or are being developed by different road authorities. Some of the problems and achievements in the implementation of these systems are discussed and an evaluation is made of their future prospects.

A detailed account of the PMS for the rural Trunk Road network of the CPA is given in Chapter 5. Particular attention is given to the implementation strategy and to the preparation of outputs from the data base to facilitate communication regarding maintenance requirements. A simple algorithm being used provisionally to

determine the priority of maintenance projects is described and a proposal is given for the future development of an optimization algorithm incorporating a new pavement condition prediction model.

General conclusions emanating from this work are given in Chapter 6. From these results recommendations are offered for the implementation of PMSs for rural road authorities and for further research that would assist in improving the effectiveness of such systems.

The development and implementation of PMSs have entailed research into a variety of specific topics. Some aspects of this work are described in the appendices.

Appendix 1 describes the work done to provide methods for rating the condition of pavements. This involved the provision of a suitable terminology for classifying the various parameters to be used in describing the condition and the commissioning of surveillance instruments to measure certain properties. Particular mention is made of work done to provide instruments for measuring the riding quality of pavements and measures taken to provide a time-stable calibration procedure.

Two interpretations of riding quality are commonly used. One is in terms of a "present serviceability index" scale of comfort; the other is in terms of its effects on vehicle operating costs. In Appendix 2 it is shown that these two interpretations can be combined into a unified scale of riding quality.

The level of service that should be provided by a pavement network could be evaluated on economic principles. Ultimately, though, it depends on the quality the public is willing to pay for. An outline of a procedure is suggested in Appendix 3 for dealing with road user costs taking into account both public preferences and economic considerations.

Many pavement management planning algorithms have been reported in the literature and have been termed PMSs. They, however, differ greatly in purpose and design. A brief summary of the characteristics of the systems studied are given in Appendix 4 in the form of a Table.

Though this thesis deals predominantly with the strategic and tactical planning functions of pavement management, attention has been given, during the course of the study, to an approach towards the design of pavement rehabilitation and the role of the PMS data base in assisting the design procedure. Comments regarding this work are given in Appendix 5.

## C H A P T E R 2

### ANATOMY OF PAVEMENT MANAGEMENT SYSTEMS

#### 2.1 USE OF SYSTEMS ENGINEERING TECHNIQUES

Pavements are in themselves complex structures which can be designed in a large variety of ways. The pavement manager however does not only have to contend with the difficulty of determining the engineering requirements of single pavements; he has to consider the requirements of all the pavements simultaneously under conditions of a limited budget. He has to take into account engineering criteria as well as economic considerations for both the road authority as well as the road user. In arriving at the best strategy he has to make use of large amounts of information from a variety of sources. These few examples are given to illustrate the complex nature of the problem and the reasons for adopting a systems approach to the study of pavement management.

Since its inception in the early 1940s, the methodology of systems engineering has become increasingly popular for analysing complex technical and engineering problems. The salient feature of this approach is seeing the organization or apparatus under review as an entity (or system) with a well defined objective. All parts of the system can then be viewed within the perspective of how well they contribute to this objective. In particular, the requirements of the relationships between the parts (i.e. the flows of information, material or energy between them) can be assessed in these terms.

However the role of systems engineering does not end with the development of a mathematical model for calculating the best strategy. In his celebrated papers, Ackoff (1979a, 1979b) pointed out that the failure of operational research to be more effective in organizations was because they were preoccupied with the development of optimization models and not enough concerned with the way in which the results would be incorporated into the actual decision making process. Since all models are simplifications of reality,

they are inadequate in themselves for dealing with the complex set of problems ("messes") facing managers in dynamic situations. He suggested, inter alia, that for systems to be viable they should:

- supply a methodology for dealing holistically with problems, noting especially that:"no level of a multilevel system can be planned for effectively without involving every level of that system";
- be able to adapt rapidly to changing demands;
- allow interaction of the model with the decision maker and encourage the participation of those who will be affected by the decisions;
- consider the humanization problem of how to manage social systems to serve the purposes of their parts better while promoting the systematic objectives;
- consider the problem of how to serve the larger system of which they are a part better, in a way that promotes their own objectives.

The relevance of these observations to pavement management has been forcibly experienced in this study. Accordingly, this chapter sets out to analyse the role of pavement management in systems terms at three levels:

- (a) The technical level. At this level the most economic maintenance strategy under a given set of criteria is sought. (This is largely a problem of physics and traditional operational research.);
- (b) The operations level. Here attention is given to the way the pavement management functions are carried out within the organization, (This is a problem of management science.);
- (c) The organization level. Here the relationship between the organization in which the pavement management system operates (i.e. the road authority) and the public (and its representatives) is considered. (At this level there is an interface between technical and socio-political problems.)

This classification is after Petit (1967) but used somewhat differently. In a recent workshop on pavement management, Hudson and Haas (1981) used a similar type of classification though it also differs in detail.

The next section discusses some basic systems concepts. These are used in the following sections in which each of the above levels of a pavement management is analysed in turn.

## 2.2 GENERAL SYSTEMS CONCEPTS

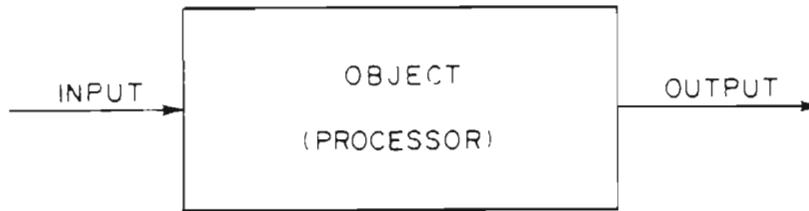
A broad range of systems concepts have been well established in the literature. (See for example Ackoff, 1971.) In this Section a few of these concepts are defined for use in describing PMSs.

An (object) system is defined as an ordered process (Betz and Mitroff, 1974). This means we identify an object, which can be considered to process certain input into some type of output. (See Fig. 2.1(a).) The input and output can have the form of information, energy or matter or combinations of these. Two types of inputs can be considered:

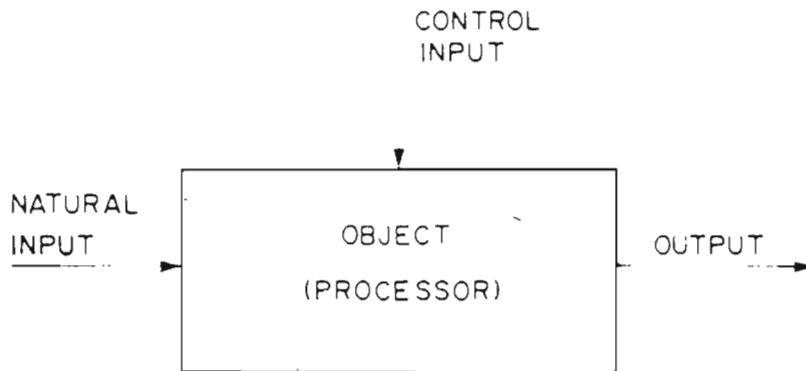
- (a) Natural inputs. These are the primary inputs under consideration which are processed into the outputs according to the current state of the object;
- (b) Control inputs. These are inputs that are considered to change the state of the object in order to modify the way the natural inputs are processed.

These inputs are represented in the way shown in Fig. 2.1(b).

Certain systems may produce no physical output and are said to be output closed. Such systems can still be purposeful in that the state of the object is of interest (i.e. can have a value). The output is then considered to be a description of the form (or state) of the object in terms of "morphological" variables as a function of some temporal variable.



(a) SIMPLE SYSTEM



(b) SYSTEM WITH CONTROL INPUT

FIGURE 2.1  
*SYSTEMS REPRESENTATIONS*

The output of a system can be regulated by observing the output (in relation to the input) and then adjusting the state or nature of the processor (or object) so that a more favoured relation is obtained. This is termed feedback control and is performed by a second system, the so-called controller (see Fig. 2.2.) If the controller operates according to some preset rules producing a state of equilibrium between input and output, its action is said to be homeostatic. If its action changes to accommodate new knowledge or objectives it is said to be adaptive.

A further characteristic of systems is that they can often be represented by a set of components (or subsystems) interconnected by their respective inputs and outputs. The controller in the feedback system can be thought to comprise a sensor (to detect the output values), an evaluator (to compare the output against decision criteria and select an appropriate action) and an activator (which applies this decision to the processor). (See Fig 2.3.) Conversely, the combination of all the elements in Fig 2.3 can be considered a higher order system as shown by the dotted line in the Figure.

The nature of the system can be determined empirically by observing the effect the natural and control variables have on the output. In this way the type of control required to obtain a desired output can be determined. In this case the processor is regarded as a so-called black box, i.e. its inner workings are not recognized. Another approach would be to present the system in terms of simpler subsystems for which the relations between input and output have been established. This is called an analytical or a mechanistic representation of the system and is said to explain the operation of the system. The benefit of this representation is that it can be used to predict the behaviour of the system beyond the bounds of experience (depending on how good the representation is and how well the nature of the subsystems is known.



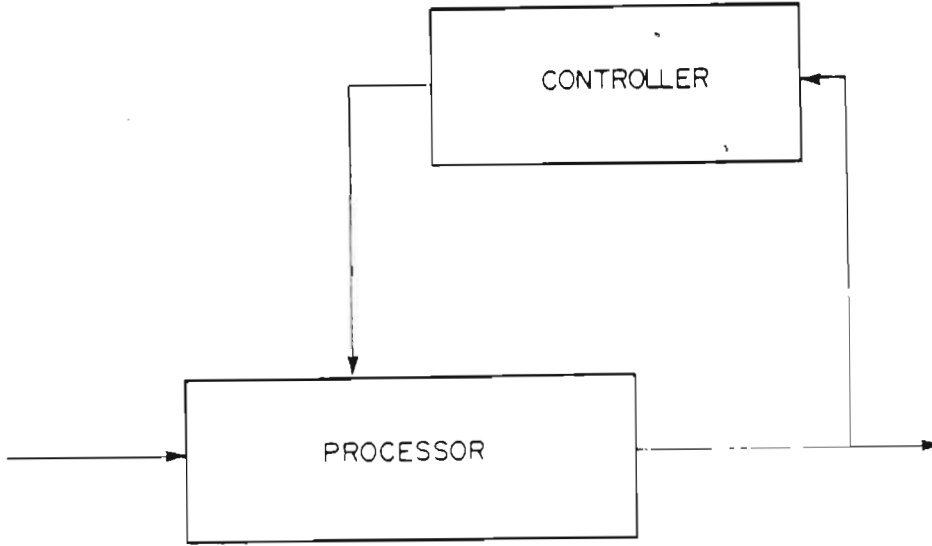


FIGURE 2.2  
*SYSTEM WITH FEEDBACK*

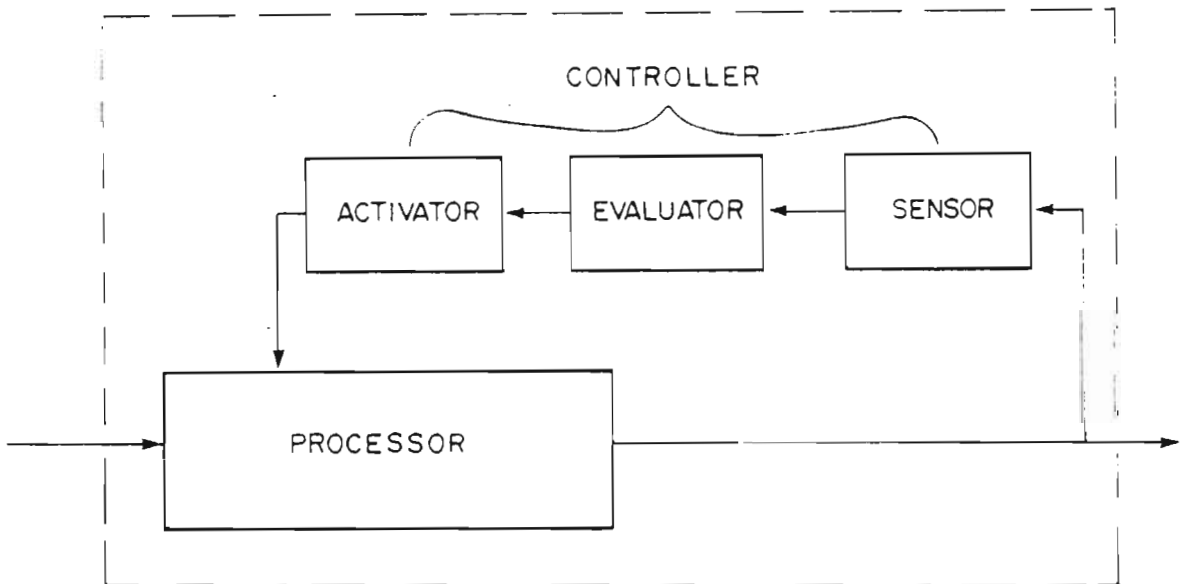


FIGURE 2.3  
*COMPONENTS OF A FEEDBACK SYSTEM*

### 2.3 TECHNICAL LEVEL OF A PAVEMENT MANAGEMENT SYSTEM

The pavement management problem at the technical level is to determine the optimum course of action to meet the objectives of the pavement network. A suitable representation of this problem is to regard the PMS as a feedback system to control the state of the pavements in the network. The purpose of this section, therefore is:

- to define a pavement as a system and to consider the concept of the value of this system;
- to define the object of a PMS and to identify the various relationships that must be taken into account in reaching this objective;
- to demonstrate the complexity of the optimization problem and how it is decomposed into sub-problems to be manageable;
- to show moreover the need for the PMS to be adaptable to qualitative issues, changing demands and improved knowledge about pavement behaviour.

#### The pavement system

A length of pavement can be considered to be an output closed system. Its state  $\psi$  is affected by the input of traffic and climatic forces. Any of numerous types of measurements can be made on the state of the pavement. The results of such measurements are called the condition  $c$  of the pavement (or some aspect of its condition). Examples include aspects of distress, deflection and riding quality. The measurements can be considered a function  $m$  that maps the state space  $\Psi$  onto the condition space  $C$ , i.e.:

$$m: \Psi \rightarrow C$$

The value of the vector  $c$  represents the output of the system at a point in time. The value of  $c$  changes because of the inputs to the system and the function of the condition with respect to the time domain  $T$  is said to be the behaviour  $b$  of the pavement, i.e.:

$$b: T \rightarrow C$$

This is illustrated in Fig. 2.4.

The purpose of a pavement is to provide a suitable riding surface to the road user. The value of the pavement at any point in time should therefore be seen in those aspects of its condition that contribute to the level of service to the road user. The measure of this is called the serviceability of the pavement.

Carey and Irick (1960) originally defined present serviceability as:

"the ability of a pavement to serve high-speed, high-volume, mixed traffic in its present condition".

As this definition was aimed at primary highway systems, a more general definition of serviceability might be:

the extent to which a pavement meets its functional requirements.

The main features of pavement condition that contribute to its serviceability are riding quality, skid resistance and surface drainage (Curtayne and Walker, 1972). (In urban situations environmental aspects such as noise generation, and aesthetic properties may also be important - see for example Karan and Haas, 1976.) However the serviceability concept arose from the the need to interpret the AASHO Road Test results (Highway Research Board, 1962) where the main consideration was the effect of traffic on riding quality. The well known "present serviceability index" (PSI) equation that was developed then related riding quality to measurable surface characteristics, namely longitudinal profile, rut depth, cracking and patching.

The development of the concept of serviceability was a watershed in the science of pavement engineering and can be considered to be the origin of the systems approach to pavement management. Unfortunately much confusion arose (and to some extent persists) in the intention and use of this term. The problem stems to a large extent from the irrelevant and misleading use of the cracking and patching terms in the PSI equation (Curtayne and Walker, 1972). The need for clarity on this matter is evident from the discussion below where it is seen that serviceability forms a central position in the evaluation process of a PMS.

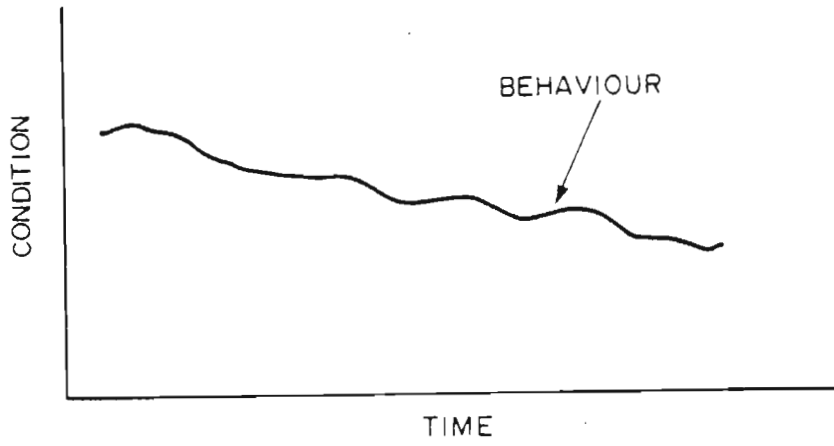


FIGURE 2.4  
*CONCEPTUAL REPRESENTATION OF BEHAVIOUR  
OF A PAVEMENT*

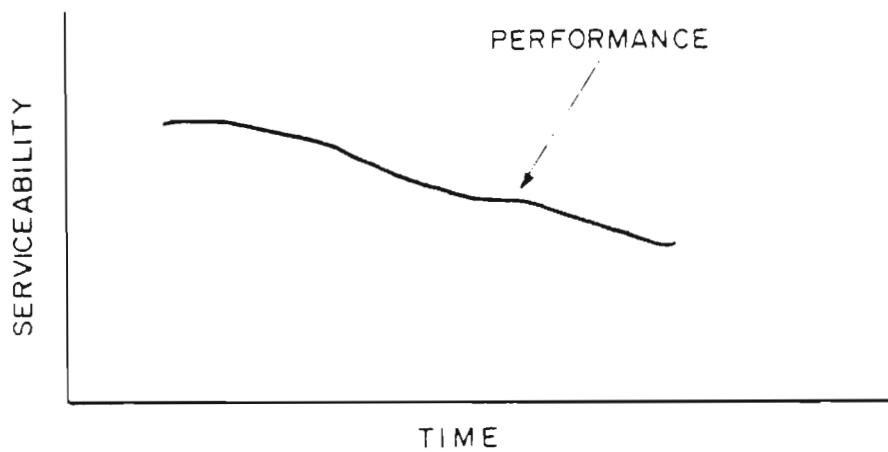


FIGURE 2.5  
*CONCEPTUAL REPRESENTATION OF PERFORMANCE  
OF A PAVEMENT*

Formally, the serviceability vector has components of riding quality, skid resistance and surface drainage (and aesthetic and environmental measures, if appropriate). Its vector space  $S$  is a subspace or projection  $\$$  of the condition space  $C$  :

$$\$:C \rightarrow S$$

The function  $p$  that gives the value of serviceability with time is called the performance of the pavement:

$$p:T \rightarrow S$$

This is illustrated in Fig. 2.5.

Pavements should be designed to provide a suitable level of service over a given period of time. Presumably the higher the level of service over this period (i.e. the better the performance) the greater the value of the pavement. To quantify this, a utility function  $u_1$  is required to map performance  $P$  onto a value space  $V_1$ :

$$u_1:P \rightarrow V_1$$

One formulation of this relation is the determination of the increase in road user costs arising from reduced levels of service. This is discussed in Appendix 2.

#### Pavement management system

Usually pavements providing better performance will cost more and it is a function of pavement management to balance the cost with value obtained.

Pister (1971) showed that pavement design should take into account the fact that the condition of the pavement will be controlled by periodically inspecting it and, if necessary, effecting some type of maintenance measure to restore or preserve its serviceability. The most economic design will be the one that incorporates both construction and future maintenance costs. This requires the ability to predict the behaviour of a given pavement. For this an empirical or a mechanistic model of the pavement system is needed.

As early as 1968 various analysts (Scrivner et al, 1968; Hudson et al 1968; Hutchinson and Haas, 1968) gave a systems representation of the design problem showing the relation between various inputs, pavement structure variables, decision criteria etc. This representation was prepared with a view to evaluating the design of new pavements by relating the performance of the pavement to its construction cost and the cost of future maintenance. The principles apply equally to the design of the maintenance of pavements. This kind of evaluation is therefore needed for each pavement in the network when deciding on the type of maintenance treatment required (if any) to preserve its serviceability.

A more generalized representation of a PMS is given in Fig. 2.6. The natural inputs to the network of pavements are the effects of traffic and climate on individual pavements represented by the function (with time)  $e$ . The output is the behaviour  $b$  of the respective pavements. Some aspects of the behaviour are monitored by the sensing system and presented as the modified function  $b'$ . From this an evaluation is made of the best maintenance programme under the constraints  $k$  imposed on the controller. These constraints have the form of budget and other resource limitations and the decision and other policy criteria. After this decision is made the chosen maintenance treatment  $m$  is applied to the relevant pavements. The monitoring of the pavements is an expensive operation. The expense is greatly affected by the frequency, detail and accuracy of measurement. Part of the evaluation exercise of the controller is to balance the cost of monitoring with the value of the information obtained for the purposes of the decision at hand. This is represented by the function  $n$ .

From the point of view of the people responsible for determining maintenance needs and carrying out the maintenance activities, the controller with the sensor comprise the system for managing pavements (i.e. the PMS). However outsiders could well view the pavement network as part of the system providing the service. This view is indicated by the dotted line in Fig. 2.6. Outsiders have no interest in the condition of the pavements other than its effect on the level of service provided. Their view of the output is therefore the performance  $p$  "filtered" from the behaviour.

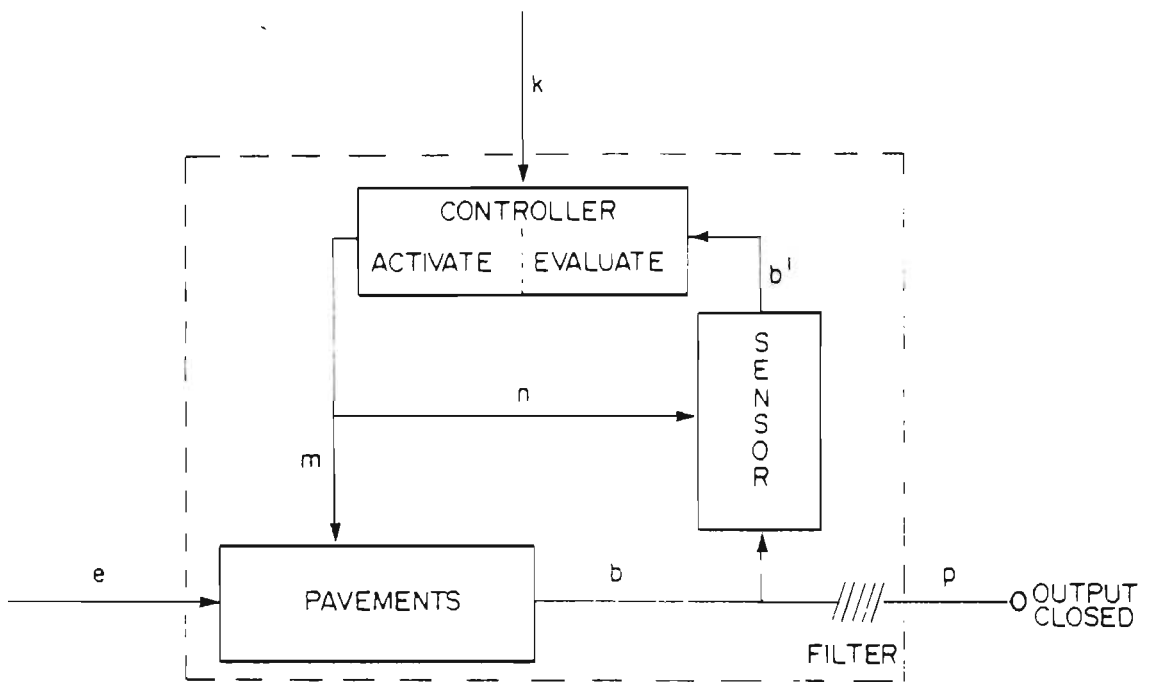


FIGURE 2.6

*BASIC COMPONENTS OF A PAVEMENT MANAGEMENT SYSTEM*

The object of PMS at the technical level can therefore be defined as the selection of a policy that will "optimize" the value of  $p$  with respect to the cost of the policy  $k$  in view of the input  $e$ . Internally (i.e. acting under given resources and policies) the problem can be seen as determining the optimum maintenance strategy  $m$  and monitoring strategy  $n$  given the constraints  $k$  and the prediction of the future input  $e$ .

#### Optimization evaluations

In approaching the above optimization problem it is helpful to consider the operation of the system in discrete time intervals. Suppose the time scale to be divided into a series of intervals by the points in time:

$$t_i, i=1,2,\dots$$

so that each interval  $i$  is bounded by  $t_i$  and  $t_{i+1}$ . Decisions are made at the particular points in time about actions for the following time interval based on information emanating from previous time intervals. This corresponds to the annual revision of the maintenance programme.

The input/output relation of the various components can be expressed as transformations with the notation:

$$Xy = z$$

interpreted as  $X$  operates on input  $y$  to give output  $z$ . The transformation operator  $X$  depends on the state of the processor. Similarly the notation:

$$qX_i = X_{i+1}$$

indicates that the control input  $q$  changes the transformation operator from its value  $X_i$  in the interval  $i$  to  $X_{i+1}$  in the time interval  $i+1$ .



The activity of the PMS can therefore be expressed by:

$$\begin{aligned}
 \psi_i e_i &= b_i \\
 S_i b_i &= b'_i \\
 k_i D_i &= D'_i \quad \dots \dots \dots \dots \dots \dots \dots (2.1) \\
 D_i b_i &= (n_i, m_i) \\
 m_i \psi_i &= \psi_{i+1} \\
 n_i S_i &= S_{i+1}
 \end{aligned}$$

where  $\psi_i$ ,  $S_i$  and  $D_i$  are the transformation operators for the pavements, the sensor and the controller for the time interval  $i$ .

The technical design object of a PMS is to derive an evaluation procedure  $D$  that will specify at time  $i$  values for  $n_i$  and  $m_i$  based on available information about the state of the pavements, current and future traffic conditions and subject to constraints implied by  $k_i$ . This requires:

- (a) Models to approximate relations (2.1) by which the effects of  $n_i$  and  $m_i$  can be estimated. The most important of these is the prediction of the behaviour of the pavements (change in condition) due to maintenance and traffic;
- (b) A decision rule that provides the criterion for choosing among alternatives. Conceptually this will involve three value functions:

- a utility function for performance (as discussed above):

$$u_1 : P \rightarrow V_1$$

- a cost function for the resources used:

$$u_2 : NxM \rightarrow V_2$$

where  $NxM$  = space of possible monitoring and maintenance strategies.

- a function that combines the individual values assigned to the performance and resource costs to an overall value:

$$u_3: V_1 \times V_2 \rightarrow V \dots \dots \dots \dots \dots \dots (2.2)$$

The interpretation of relation (2.2) is that the preferred course of action is one that will provide the highest value of  $v \in V$  subject to the constraints.

- (c) An algorithm to obtain values for  $n_i$  and  $m_i$  from the models of Relations (2.1) and the decision rule represented by Relation (2.2).

Algorithms have been provided for simplified cases that incorporate various assumptions and approximations of Relations (2.1) and use different decision criteria. A list of such algorithms used overseas is given in Appendix 4. However the magnitude and complexity of the PMS in practice prohibits an overall solution. The following factors illustrate the case:

- (a) The number of variables that can be taken into account in predicting the performance of a pavement under alternative maintenance strategies is very large. Hudson and McCullough (1973) identified 50 such variables. This in itself creates problems in the size of the model required, the processing time and the information that must be provided;
- (b) The PMS, however, does not deal with one pavement at a time but has to contend with all of the pavements in the network simultaneously. The values  $e_i$  and  $\psi_i$  for example can be considered as vectors with components;

$$e_{ij} \text{ and } \psi_{ij}, j = 1, 2, \dots, J$$

where  $J$  = number of separately considered lengths  
of pavement.

The maintenance requirements for each of these lengths have to be adjusted to comply with the available budget limits while maximizing the overall value of the system.

(c) There is a large variety of maintenance treatments that can be applied that differ greatly in cost and method of operation. The various categories of maintenance are listed in Table 2.1. (Different nomenclature and classifications have been suggested by other authors, e.g. Monismith (1979), however this roughly agrees with that accepted by the South African CSRA Subcommittee on Highway Materials in 1974.) Routine maintenance usually involves simple operations that are scheduled on a 2-6 week basis. Special maintenance activities are more sophisticated, larger undertakings and usually scheduled on an annual basis. Rehabilitation is usually a major undertaking requiring considerable planning and resources and is often scheduled on a five year basis. In each broad category of maintenance there is also a large range of options in the detailed materials design. (Consider for example the use of rubber, polymers, sulphur and fabrics in the design of surface seals.) Clearly the diversity in the types of maintenance greatly complicates the optimization problem.

TABLE 2.1 : Classification of maintenance types

Maintenance category	Types of maintenance
Rehabilitation	Partial reconstruction (removal and replacement of material on existing alignment) Thick overlays
Special maintenance	Thin asphalt overlays Surface treatment (seals, rejuvenators, fog sprays etc.)
Routine maintenance	Routine pavement maintenance (patching, crack sealing, etc.) Routine non pavement maintenance (mowing, painting, etc.)

(d) A large degree of uncertainty is inherent in the Relations (2.1). This is partly due to the variable nature of pavement structures and to the fact that many of the other relationships

are not well established. Therefore the effect of maintenance strategies has to be regarded as a stochastic process and the use of probability theory incorporated into the analysis. There is also a great deal of uncertainty about the decision criterion (2.2) which means that the meaning of optimization is not necessarily established. (This problem is discussed in Appendix 3.)

- (e) There are many ways to gather information about the pavement condition and a great range in the detail in which they may be obtained. Different kinds of information are required for different types of maintenance decisions. Some information is even obtained through subjective, non numerical channels of communication. Though valuable in the decision process, such information is not amenable to mathematical interpretation. Though the value of information can be established explicitly for certain simple problems (Howard 1966), it is difficult even to formulate the general problem in this case because of its magnitude and complexity.
  
- (f) Even if a theoretical solution based on the condition of the pavement can be obtained, this may not satisfy logistic constraints in executing them. In principle logistic considerations may be incorporated into the formulation of the problem, but in practice these may be difficult to define *a priori* or express in a mathematically tractable way.

This brief account illustrates that the dimensions of the problem, the uncertainties about many of the relationships and the difficulty of incorporating certain of the variables into the analysis prohibits a solution to the general optimization problem. When it is further considered that a solution procedure must be flexible enough to deal with changing circumstances (eg. changes in policy, additional knowledge of certain relationships) it is clear that a standard unified algorithm is insufficient for selecting the optimum maintenance programme.

One method of dealing with the problem is to decompose it into sub-problems dealing with specific aspects.

### Decomposition

The various maintenance activities can be grouped into three subsystems which are regulated by an overall control system (see Fig. 2.7). Each of these subsystems takes care of its own information needs and is responsible for determining the requirements of that category of maintenance in a way that will optimize that particular operation. Information from each of the subsystems is fed back to the overall controller which coordinates the separate functions.

The principles for managing routine maintenance are well established and have been set out in numerous articles on maintenance management and performance budgeting. (See especially Roy Jorgensen Associates, 1972.) The decisions in this operation are based on a set of simple standards which are used in the week to week planning and control of the work and for the annual budgeting. The budget and the standards are controlled by the overall controller. This system also informs the other subsystems about annual expenditure of routine maintenance on specific pavements as this will influence the planning of other maintenance categories.

Special maintenance is often also handled independently with the objective of keeping pavements sealed against the ingress of water and maintaining a skid resistant surface. Formal methods usually employ simple criteria relating to distress to schedule projects on an annual programme. The standards and budgets are again controlled by the overall controller and information about these activities are passed onto the subsystem for managing pavement rehabilitation.

The evaluation of pavement rehabilitation requirements, although still complex, is in this case undertaken under the assumption that routine and special maintenance are provided under known criteria. The prediction of pavement behaviour is therefore made simpler. The evaluation of pavement performance can also be made without regard to skid resistance since this will be considered by the special maintenance system.

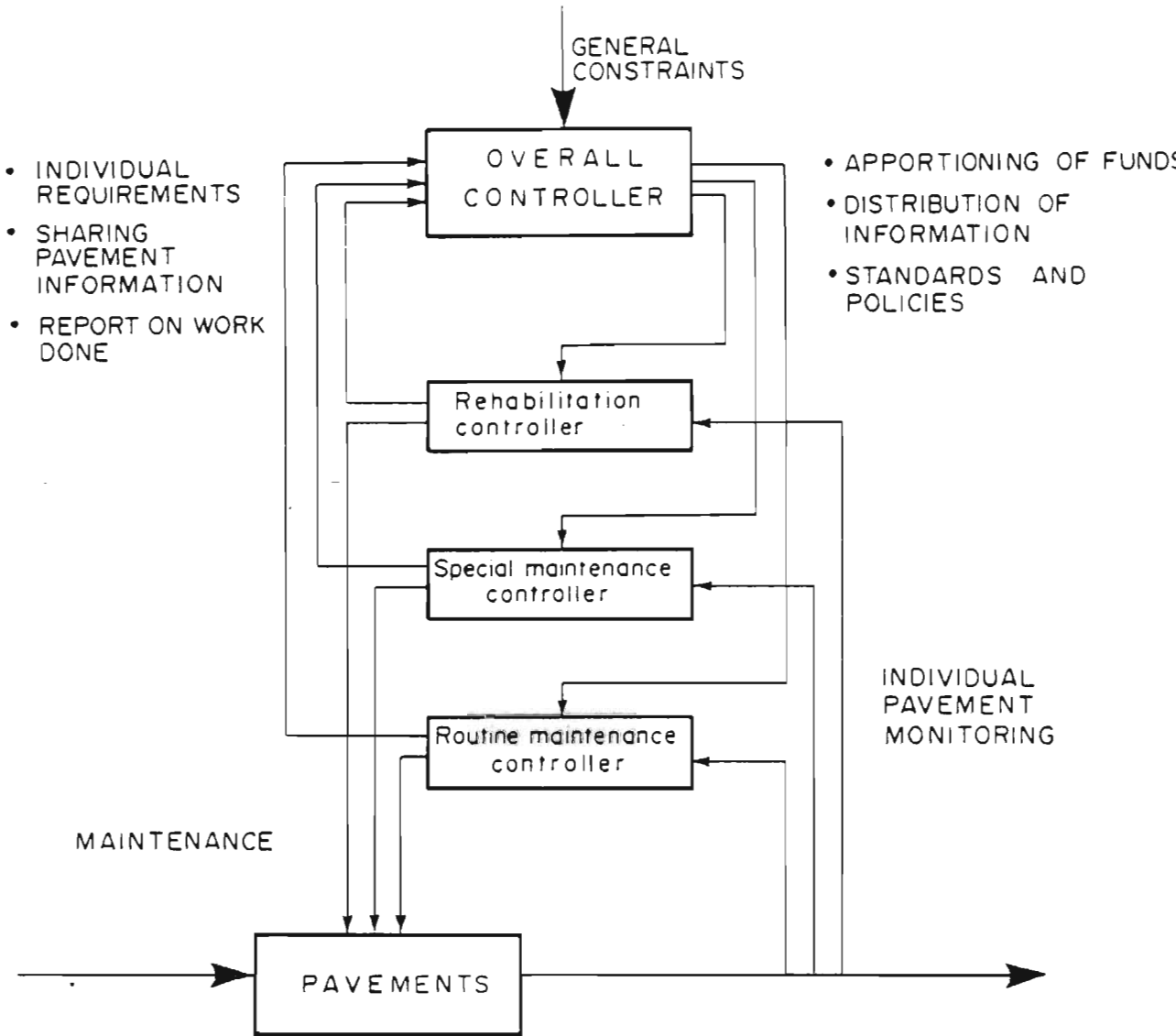


FIGURE 2.7  
DECOMPOSITION OF PAVEMENT MANAGEMENT CONTROL SYSTEM

Although it is simpler and more practical to decompose PMS in this fashion, it can naturally lead to sub-optimization of the system as a whole. This can be avoided to a degree by structured interaction between the various subsystems. Haas et al (1982) discussed an algorithm by which special maintenance needs are matched with rehabilitation requirements.

Because of this decomposition it is common for PMS development to concentrate on rehabilitation and (usually) special maintenance requirements, assuming that systems for the management of routine maintenance can be developed independently.

Another dimension of decomposition is to look at pavement management from the so-called "network" and "project" levels (Monismith and Finn, 1982; Hudson et al, 1979). The object of network level evaluation is to identify potential rehabilitation projects and schedule them by taking into account budget projections and predictions of their behaviour. Here sufficient information must be available with respect to the whole network to ensure that this is done realistically.

Pavement management evaluation at the project level is actually the design of the most appropriate rehabilitation measure which is obtained by evaluating the effects of alternative maintenance strategies (i.e. series of maintenance acts) over an analysis period. (The first act of the optimum maintenance strategy is the rehabilitation measure that should be chosen). To do this successfully information is required in much more detail than for network level evaluations but is only obtained for those pavements selected for rehabilitation.

The choice of project priority, type of rehabilitation and, ultimately, detailed materials design are not necessarily strictly sequential and final since evaluations made with additional information may affect earlier decisions (Curtayne and Servas, 1982). However, the general principle is that the first evaluations are made on network information and then more detailed information is obtained for more specific aspects according to the requirements of the problem.

The work reported in this thesis (see Chapter 5) has concentrated on planning for rehabilitation on needs at the network level. However Appendix 5 outlines a suggested approach for evaluations at the project level and discusses the interrelationship between these levels.

#### Adaptive property of PMS

In spite of the sophisticated optimization procedures available, the solutions are not necessarily accurate even for subproblems as many of the assumptions that are used to make the procedure tractable do not reflect the true physical situation correctly. As noted above many of the conditions and constraints on the maintenance operations are difficult to express in mathematical form but could be the determining factors in the choice of the maintenance programme.

These limiting factors mean that an appreciation of the principles included in the optimization is more important than the accuracy of the numerical solution. The solution can be seen as a first order approximation which must be adapted to the physical situation. Of particular importance is that decisions are made with a clear idea of the overall objective of the system and that some measure is available for assessing how well this objective is met. Managers should be able to interact with the models to determine how decisions were reached and to gauge the significance of deviating from "optimum" solutions.

The evaluation procedure must also be flexible enough to deal with changing conditions, policies and state of knowledge. Initially decisions will have to be made in the face of many uncertainties. As it is used the results of past decisions can be evaluated and the decision process improved. Particular attention should be given to facilitating the adaptive potential of the system. Provision should be specially built in to allow easy back analysis of alternative policies and maintenance strategies. As expressed by Ackoff (1979a):

"There is a greater need for decision making systems that can adapt effectively than there is for optimizing systems that cannot."



Road management systems

Finally, note that a PMS can be regarded as a subsystem of a more comprehensive road management system (RMS) in which the maintenance and improvement of all aspects of the road system are considered. The main activities requiring longer term project planning are:

- pavement rehabilitation;
- improving the geometric properties of existing roads;
- upgrading gravel roads to sealed roads;
- providing completely new facilities.

Ideally the RMS should provide an optimum strategy for all road management activities collectively. This would obviously be that much more complicated than the PMS requirement. The problem can be handled to some extent by decomposing it into subproblems for each of the activities along the lines discussed for the various maintenance categories. In this case, though, note must be taken of the interrelation between pavement rehabilitation and the improvement of geometric properties. This occurs because work to improve the road geometry will usually include improvement to the pavement and, conversely, when pavements are rehabilitated geometric improvements will be considered.

Various approaches to dealing with this problem can be adopted according to the circumstances and policy of the authority (see for example Fig. 1.6; National Association of Australian Road Authorities, 1981; Harral et al, 1979). Whatever method is used, provision must be made for the results of the PMS to be interfaced with the more general requirements of the RMS.

In the implementation of PMSs carried out in this study, the improvement of geometric properties was a minor consideration (for various reasons) consequently minimal attention was given to this question.

## 2.4 OPERATIONAL LEVEL OF PMS

The provision of a reasonable evaluation procedure is only one aspect of the development of a desirable PMS. The more important and often the more difficult task is to create a PMS as a viable subsystem that is integrated and unobtrusive in the general operations of the authority. The practicalities of introducing new techniques that involve additional or modified duties need to be analysed and dealt with. The basic requirements are:

- (a) to assign people and tools to various functions and
- (b) to establish suitable lines of communication; of information up the decision-making hierarchy, on the one hand, and of control directives down the hierarchy of responsibility on the other.

These have to be achieved in a way that protects the security and integrity of the information and that is compatible with the existing organizational structure. Note, for example, that no line of communication can be secure if there is not reciprocal authoritative control. Moreover, a line of authority for one function cannot work effectively in an opposite direction to that for another function. Other important considerations are:

- (a) The real decision making process of the authority must be recognized and information must be provided in a form that can be assimilated in that process;
- (b) The organizational structure of the PMS has to take into account human requirements of the individuals concerned.

These general considerations, obvious as they may seem, are not always easily achieved but are vital to the acceptance and effectiveness of PMSs. The use of systems engineering principles can greatly contribute to the analysis of pavement management and the successful development of a PMS. The exact nature of the resultant system will be specific to the characteristics (i.e. size, policy, resources etc.) of the authority concerned. However, this Section

offers some general operational considerations for the development of a PMS with respect to the following topics:

- the relationship between the PMS and top management;
- aspects requiring attention for obtaining, storing and using formal pavement data;
- human considerations in operating a PMS and the role of informal data in the decision making process;
- organizational considerations in the administration of a PMS.

#### The relationship between the PMS and top management

The function of the PMS discussed above is to identify maintenance requirements on the strength of information received about the network, to match the needs against the available resources in the form of a maintenance programme, to design suitable maintenance treatments and to bring the treatments into effect.

However the PMS is controlled by top management and thereby has the responsibility for providing feedback information to top management so that control can be made more effective in terms of the overall objectives of the road authority. This feedback loop is illustrated in Fig. 2.8. The type of information that should be supplied to top management includes:

- (a) an account of how pavement management resources were previously employed and an indication of the results in comparison with anticipated (promised) results;
- (b) summary of the proposed maintenance programme and decision criteria used in formulating the programme (for ratification by top management);
- (c) budget proposals for future years in order to ensure a satisfactory level of maintenance, i.e. a strategic plan. (This should include "what if" information, i.e. it should indicate what would be the consequences if higher or lower budget levels were adopted.)

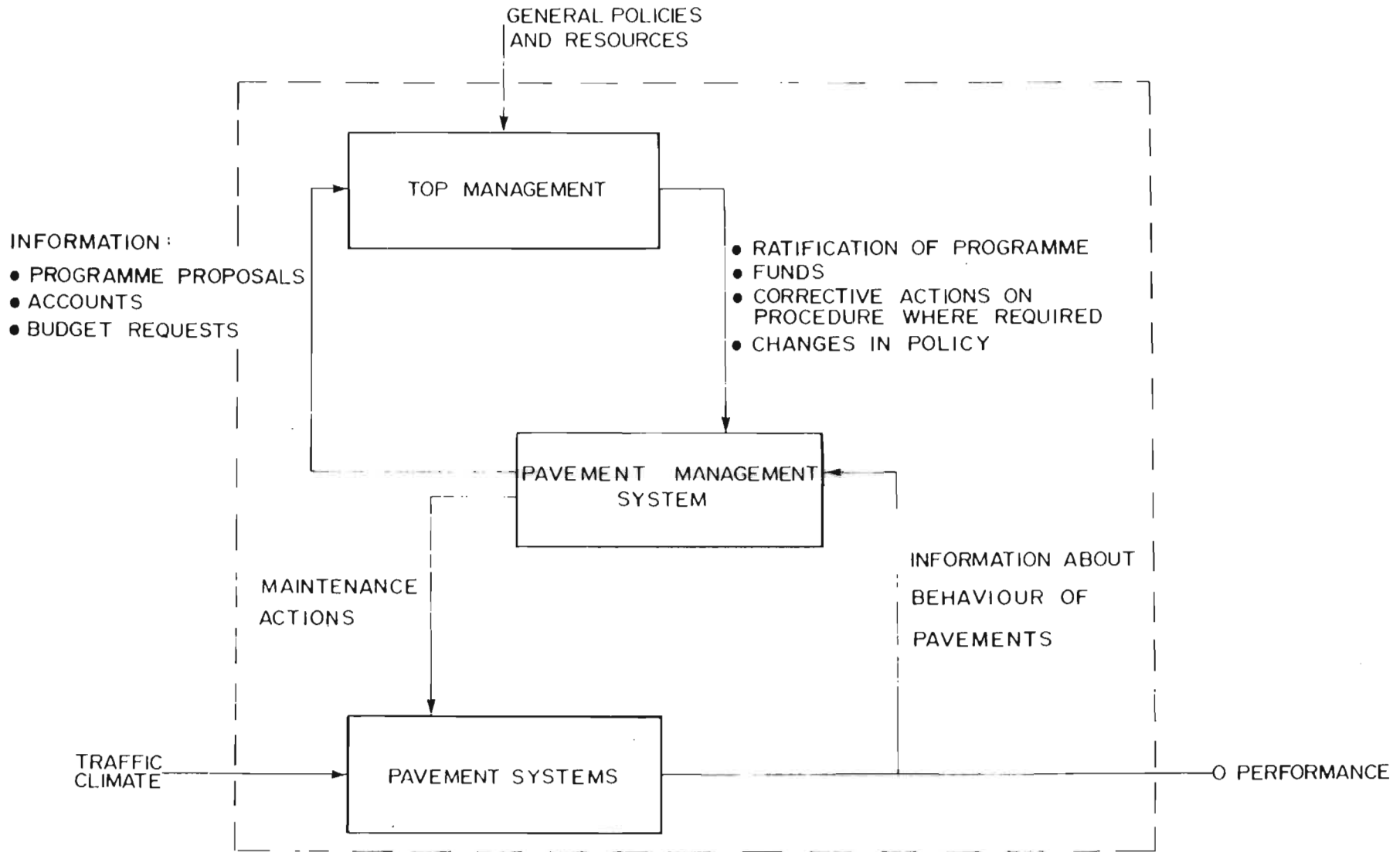


FIGURE 2.8  
 RELATIONSHIP BETWEEN PAVEMENT MANAGEMENT AND  
 TOP MANAGEMENT

Top management is controlled by the resources and policy constraints it receives from the public financing bodies. It has, within these constraints, to match the demands from the PMS against other demands for improving the road network, i.e. to view it in the wider road management context. (Other considerations, not part of the technical concern of pavement management, may also be considered at this level, eg. the necessity for deployment of funds in certain areas or the political importance of specific roads.) The other function of top management is to evaluate the operations of the PMS against standards of expectation to ensure that the PMS functions are being carried out correctly. If not, some type of corrective action is required. The output of the top management "subsystem" with respect to the PMS therefore comprises:

- (a) ratification of maintenance standards and programme (possibly amended);
- (b) resources for carrying out the maintenance activities and
- (c) corrective action where required to improve the operation of the PMS.

The more the output of the PMS can facilitate the functions of top management, the more they will appreciate its value and the more likely they will be to make the finance available for necessary maintenance work. Moreover corrective action or changes in policy are likely to be less arbitrary.

Note that from outside the road authority no distinction is made between top management and the PMS and the dotted line in the Figure indicates their view of the PMS in its widest sense.

#### Formal data requirements

A PMS in a certain sense is a dynamic decision support system that centres on a data base concerning the road network which is analysed by standardized algorithms that provide information about maintenance alternatives for decision making. This type of support system has been made possible by the rapid growth in the data storage and processing ability of the electronic computer.

The effectiveness of the use of the data base in a PMS depends on the type of hardware and software that are available and the care given to various important considerations in the management of the data. Some brief comments regarding the requirements of a data base are given in the following.

- (a) Types of data. Typical categories of data on a PMS data base are given in Table 2.2. Some of these data, such as geometric characteristics, relate to relatively fixed properties of the network, whereas others, such as pavement condition, are transient and have to be updated regularly to maintain validity. The manner and the amount of detail in which data are provided in each of these categories will be specific to the authority and will depend on their facilities for collecting data, the cost and the contribution of each item to their PMS objectives (i.e. the value of the data). Of central importance to the establishment of a data base is a suitable location referencing system by which data in the inventory can be reliably related to a location in the field. In a situation where alignment of roads can change and where milestones don't exist or are subject to repositioning, this factor requires serious attention otherwise it will not be possible to relate data collected over a number of years (Curtayne and Eaton, 1975).
- (b) Data requirements. Centralized numerical data, especially those stored on a computer, are abstracted from the field environment where their meaning and validity would normally be constantly reviewed with use. Deliberate measures must therefore be introduced to secure the meaning, integrity and reliability of the information in the data base. The meaning of condition data first of all requires a recognized way of describing the condition of pavements. (Considerable work was done in this regard during this study as a preliminary to the implementation of PMSs which is described in Appendix 1.) Secondly all data are provided via coding forms with the aid of documented coding instructions. Thirdly a data dictionary must be provided that strictly defines every item on the data base so that its meaning is preserved unambiguously. (As an illustration note that the

TABLE 2.2 : Data pertaining to pavement management

Class	Type	Examples of data items
Structure	Network definition	Routes Positions of nodes and link
	Pavement	Horizontal alignment Gradient Carriageway dimensions
	Maintenance	Previous special maintenance details Routine maintenance costs
Condition	Results from instrumented surveillance	Skid resistance Riding Quality Deflection Rut depth
	Visual assessment	Cracking patching Ravelling Drainage
Environment	Traffic	No. of vehicles per day Per cent heavy vehicles No. of equivalent 80 kN axles
	Climate	Köppen, Thornthwaite classifications Rainfall
Accidents	Severity	Number of injured, severity of injuries Number of vehicles, severity of damage
	Circumstances	Surface (wet or dry) Collision type

meaning of a deflection measurement may be obvious when the measurements were first taken and used but could be obscured with time so that it is not clear what instrument was used, whether the values represent single measurements or a statistic such as 95th percentile and whether they are seasonally adjusted or measured in a critical month or randomly during the year.) A second problem with mechanically processed data is that errors can occur that are difficult to detect. One method of reducing the number of errors is to test incoming data with

so-called validation programmes. These programmes check whether the data fall within prescribed ranges or whether they are at variance with data already in the data base and can therefore eliminate many punching and coding errors. A third problem is making the data base reliable in the sense that the data it contains is valid and current data. This can be assisted by data request programmes which inspect the data on the base and identify areas which require updating. These mechanical techniques may be supplemented by human control procedures.

- (c) Data storage requirements. The considerations for the way the data base is stored are the cost, its security (against loss, damage or theft), the ease of updating and retrieving data and its flexibility with regard to changing its structure. A large variety of sophisticated hardware and software is available for aiding the operation of a data base. The choice will be restricted by what is accessible by the road authority but there will often be a sufficient number of options to warrant a careful selection of the best alternative. Specialized software packages for this purpose are called data base management systems. Although they are very powerful, care is needed in their implementation and use.
- (d) Output requirements. The ease with which data are processed by computers often results in an overwhelming amount of printout being presented to the decision makers. This is often counter-productive since if they cannot assimilate the information easily they will tend to ignore it altogether. A separate type of output should be prepared for each defined application in which the data is summarized and clearly displayed for this purpose and not more data provided than are needed. Graphical techniques should be used as far as possible as they greatly assist the assimilation of information. Examples of output that have been used in this study are shown in Chapters 4 and 5.

#### Human considerations in PMS

The traditional method for identifying maintenance requirements in most rural authorities (at least in South Africa) is via their



decentralized administrative structure (Curtayne and Gordon, 1977). The road network is divided into a number of regions and the regional officers supervise the work carried out in their areas. Sections of pavements requiring maintenance are identified by field staff and recommendations are supplied to Head Office. The Maintenance Engineer from Head Office will collate these recommendations from the different regions (sometimes supplementing them with additional information) and inspecting a number of them with the regional staff. The Maintenance Engineer will then select pavements for the maintenance programme by taking into account the available resources, the relative needs of the regions and the policy of the authority.

The development of a PMS introduces a formal (coded) collection and interpretation of data stored on a centralized data base. The need for such formal methods has been discussed above. However, Stamper (1973) stresses that, when considering formal information systems, it is important not to overlook the informal system with which it must coexist. In informal systems communication takes place via a series of interconnecting groups. Much of the communication of such groups takes place through indirect means such as gestures, the shared background of experience of the local environment and common assent of attitudes. Often the symbols (words or numbers) used are only special refinements of the total information. Moreover, within a small group it is easy to maintain a common understanding of the objectives of their functions. This enables members to overcome unanticipated problems. Such flexibility is not possible in formal systems since they cannot be designed to allow for all contingencies.

Pavement management has traditionally operated reasonably successfully as an informal system and today such systems contain a wealth of experience, knowledge and patterned behaviour which will always be a part of PMS. An important contribution to the assessment of maintenance requirements is the local experience of pavement behaviour, the effect of alternative maintenance treatments and of problems peculiar to that region. Therefore in the introduction of formal systems care must be taken not to disrupt the hidden advan-

tages of the informal system. Equally important is to avoid having the informal system seen to be in opposition to the formal system, which it may discredit. Rather the formal system should be designed to assimilate and exploit the informal system.

In a similar vein, the introduction of a formal system should not threaten the job satisfaction of the field staff. Herzberg (1974) suggested that the motivating factors for workers are achievement, recognition, interesting and challenging work, responsibility and advancement. These are important considerations in the implementation of PMS. In the past the Maintenance Engineer relied on the field staff to make recommendations for the maintenance programme. This has been an important responsibility for which the experience and local knowledge of the staff have been well recognized. When formalizing the system there is the danger of degrading this function to a seemingly routine clerical procedure. This would reduce job satisfaction resulting in demotivation of the workers and ultimately leading to poor supply of data and the disintegration of the integrity of the formal system. The PMS should therefore be designed to re-enforce and enhance the role of the field staff rather than to detract from it.

To illustrate how the above comments may apply in the operation of a PMS, consider the following example of a decision making process for programming pavement rehabilitation. (This shown in Fig. 2.9.) Details of the pavement network are assumed to be stored on a data base. These are analysed (say annually) using computerized algorithms that demarcate lengths of pavement as suggested rehabilitation projects and give for each an assessment of the type and urgency of rehabilitation. This information is forwarded to the field staff who then make the final demarcation of the proposed projects and assessment of requirements in consultation with Maintenance Engineer. These modified projects are re-evaluated in terms of anticipated future budgets to produce a proposed rehabilitation programme for ratification by top management.

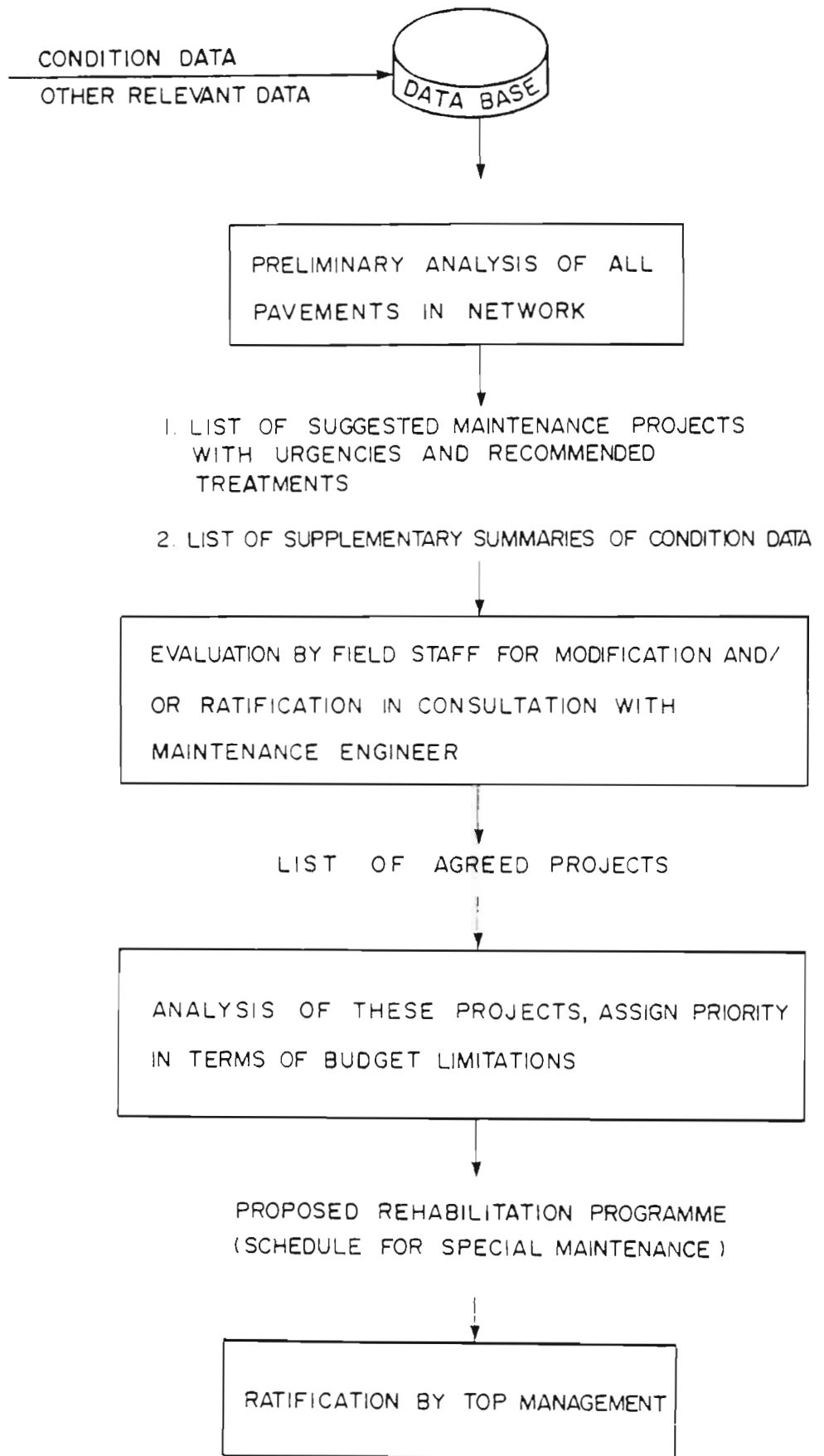


FIGURE 2.9

*DECISION MAKING PROCESS FOR REHABILITATION PROGRAMME*

This procedure has the advantage of combining formal analysis with field experience in a structured way. It gives the Maintenance Engineer the assurance that all sections are considered that are likely to require rehabilitation. It provides the field staff with the assurance that they are still the centre of the decision making process. However their participation is controlled in the sense that if they disagree with computed results they should either provide new information to modify the result or be able to argue why the computer algorithm is in error. This latter case provides a feedback process for tuning the algorithm.

This procedure has the further advantage that it provides a control on any data originating from field staff. If they have to assess the computed decision against recorded data and the conditions in the field, they can check whether the original data were correct and will be motivated to supply correct data in future. Examples of the application of these principles are illustrated in Chapters 4 and 5.

#### Organizational structure

The functions of pavement management have been expressed above in terms of systems diagrams. It would be convenient from an organizational point of view if these representations of sub-systems and links were to map directly onto the structural hierarchy of the authority. In practice, however, it is found that the PMS functions are distributed quite widely across the hierarchy. That is, there is no single division responsible for pavement management and most people concerned with pavement management are also active in other, unrelated, tasks.

The operations of collecting and storing pavement data and processing them via algorithms for evaluating rehabilitation strategies and programmes form one division of PMS. It is useful to refer to them as pavement management data processing (PMDP). The PMDP activities will normally be housed in one of the divisions of the authority and will be responsible for obtaining information from other sections involved in pavement management and for supplying

processed information to interested parties. The control of these communications can be complicated by the distributed nature of the PMS as a whole.

By way of illustration part of an organizational structure of a hypothetical road authority is shown in Fig. 2.10. The relevant sections are managed by the accountant, the materials, maintenance and contract engineers and the various regional engineers. These sections are under the control of the chief engineers and the director as illustrated. The PMDP function is housed here under the control of the maintenance engineer. The functions of the various sections with respect to pavement management and their relation to PMDP is as follows:

- (a) The accountant obtains cost information of routine maintenance carried out by the regional staff. Costs incurred on pavements can then be supplied to PMDP for storage on the data base;
- (b) The materials engineer is responsible for the design of new pavements, rehabilitation and special maintenance. He controls the materials laboratory and the surveillance instruments for measuring aspects (such as riding quality and skid resistance) of the condition of the pavements. He also determines the schedule for special maintenance and assists in assessing rehabilitation requirements. Certain details arising from all of these functions should be communicated to PMDP;
- (c) The maintenance engineer is responsible for setting and controlling standards and budgeting for routine maintenance. He also prepares the rehabilitation programme (with the assistance of the materials engineer and regional field staff) and controls the PMDP activities;
- (d) The contracts engineer arranges for the various new pavement and rehabilitation projects to be carried out on contract;
- (e) The regional engineers carry out routine maintenance and control contractual work in their areas. They report to the PMDP on certain aspects of condition of the pavements and on the maintenance work done.

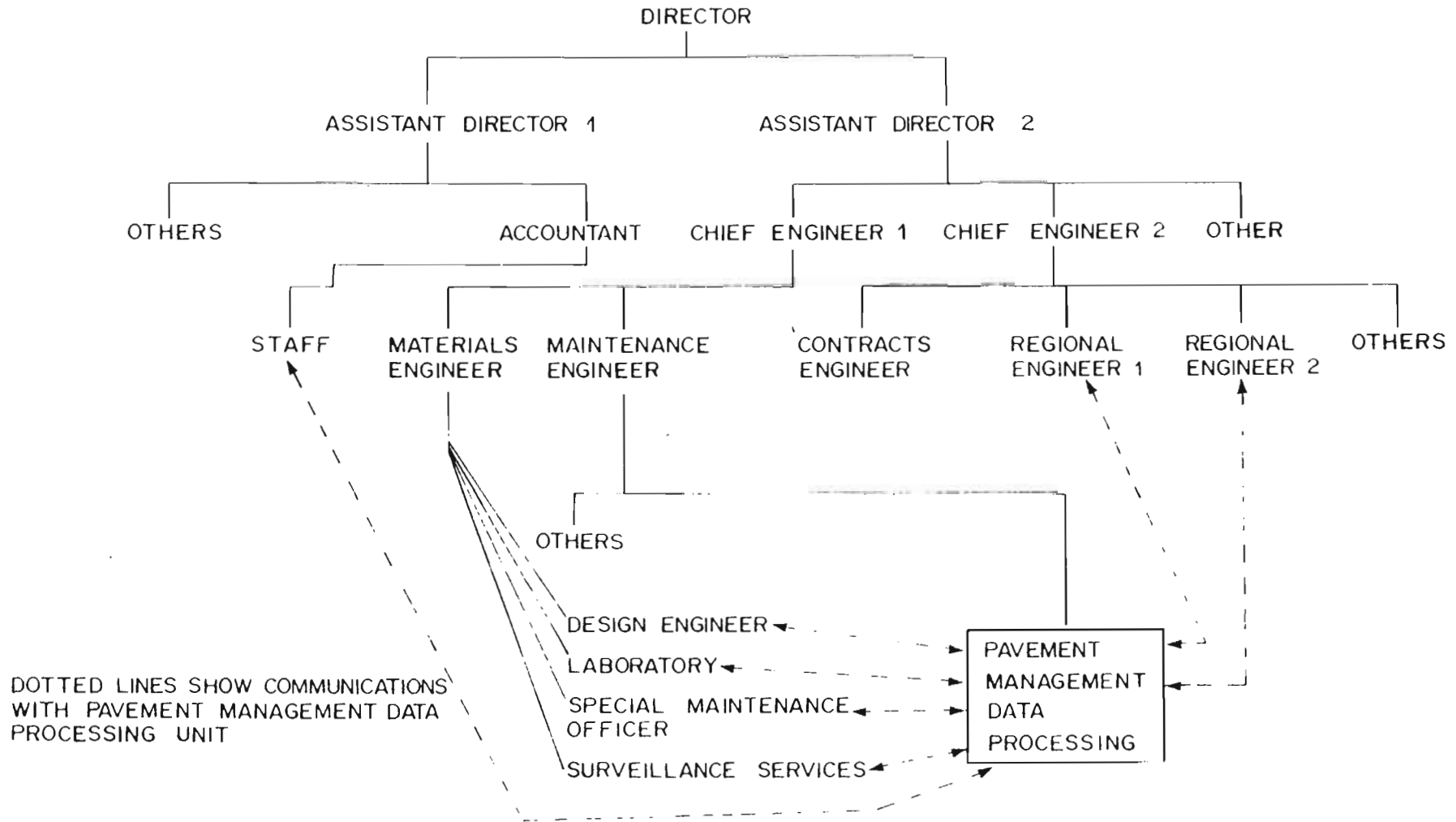


FIGURE 2.10  
PART OF AN ORGANIZATIONAL STRUCTURE OF A HYPOTHETICAL ROAD AUTHORITY

The dotted lines in Fig. 2.10 indicate necessary lines of communication with the PMDP across the hierarchical structure. Experience with PMSs has shown that problems arise when the PMDP officer is responsible for this communication without the authority for enforcing it by virtue of his position in the hierarchy.

Since it is clearly impractical to group all of the PMS functions in a single section it is important to establish these lines of communication as part of organizational policy with the requirements documented and the authority and responsibility vested at the apex of the two branches across which the communication must take place. For example in Fig. 2.10 it must be seen as the responsibility of Chief Engineer<sub>1</sub> to ensure that correct and timely communication takes place between the materials section and the PMDP unit.

In a similar way communication up and down the hierarchy must take place formally for which the requirements are laid down as organizational policy. Typical examples are:

- (a) an official manual setting out how the PMS should operate giving responsibilities, types of communication and the times they must take place;
- (b) standard forms by which data is to be communicated and manuals describing how they are to be completed;
- (c) an official requirement for the way in which the PMS should be used for strategic and tactical planning and design.

## 2.5 ORGANIZATION LEVEL OF PMS

The organization carrying out pavement management functions can be viewed as a subsystem of the higher order socio-political system it serves. This community has to decide on the manner it wishes to disburse its total earnings. The choices that need to be made (from the point of view of pavement management) are illustrated in Fig. 2.11. This shows that the level of funding provided for

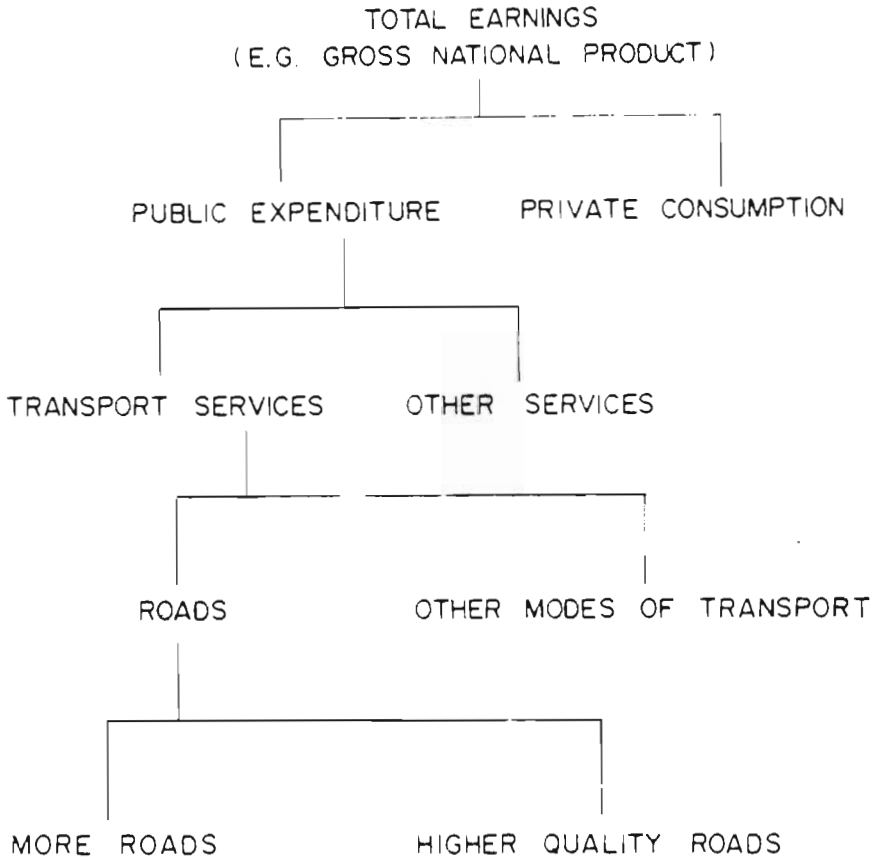


FIGURE 2.II

*HIERARCHY OF DECISIONS ON DEPLOYMENT OF FUNDS  
FROM THE VIEW OF PMS*



pavements reflects the proportion of its earnings the public is willing to pay for roads in relation to private consumption and other statutory services.

A suitable level of funding cannot be decided on simple economic costs (i.e. user, maintenance and capital cost) alone, because this may not represent the option most desired by the body politic in the face of many confounding issues. These issues include for example:

- the most desirable level of taxation;
- priorities in social services;
- the distribution of tax deployment (e.g. should poor areas of low tax contribution have roads as good as those in rich areas; should one form of tax, say fuel tax, be earmarked for a specific interest group, such as the road user?).

It is not possible for an administrator to decide on those issues according to his own ethical or political philosophy. They need to be resolved in the political arena according to the political processes adopted by the community. These processes encompass the widest scope of political activity including, for example, the action of interest groups, influential individuals, executive councils and parliamentary debate. The administrator can however assist in this process by providing suitable objective information.

Fig. 2.12 gives a systems representation of some of these ideas. The socio-political control system is a goal seeking system. It attempts to provide the highest benefit to the community from its service organizations through optimum use of its funds. Since there are no objective criteria for defining the highest benefit, this operation takes place iteratively. That is, funding and policy decisions are made, their effects experienced and the funding and policy modified. This process supposedly continues until the most satisfactory arrangement is achieved. However, this situation is never reached in practice because the system continually has to adapt to changing circumstances. These are changes in:

- community attitudes;
- economic conditions;
- physical environment;
- size and ability of service organizations.

The socio- political control system is therefore a dynamic system that perpetually seeks the most desired course of action.

The object of this representation is to identify the nature and purpose of the communication links between the control system and the service organizations. The most forceful information that is input into the control system is the direct experience of the public of the level of service obtained. This can be evaluated according to the satisfaction it provides in relation to the costs incurred. Auxiliary objective information is fed into the decision process, in the case of road authorities, by the way of work proposals, concomitant budget requirements and reasons for the proposals. These proposals are either accepted or modified and funds provided according to the perceived needs of the community.

The object is to provide information in the most meaningful way that will assist in this control process. Political councils provide at best a difficult decision making environment. Without a structured framework for evaluation, decisions may become arbitrary, dealing with particulars rather than with policies, and generate an inconsistent basis for directing the affairs of the service. The type of information that can be considered includes:

- a statement of policy giving, for example, standards of service aimed for (eg. minimum levels of riding quality);
- The current status with respect to those standards (eg. the total length of road below the minimum level of riding quality);
- justification of budget proposals in terms of these standards;
- "what if" statements regarding the effect on future maintenance costs, level of service and road user costs if the budget requirements are not met.

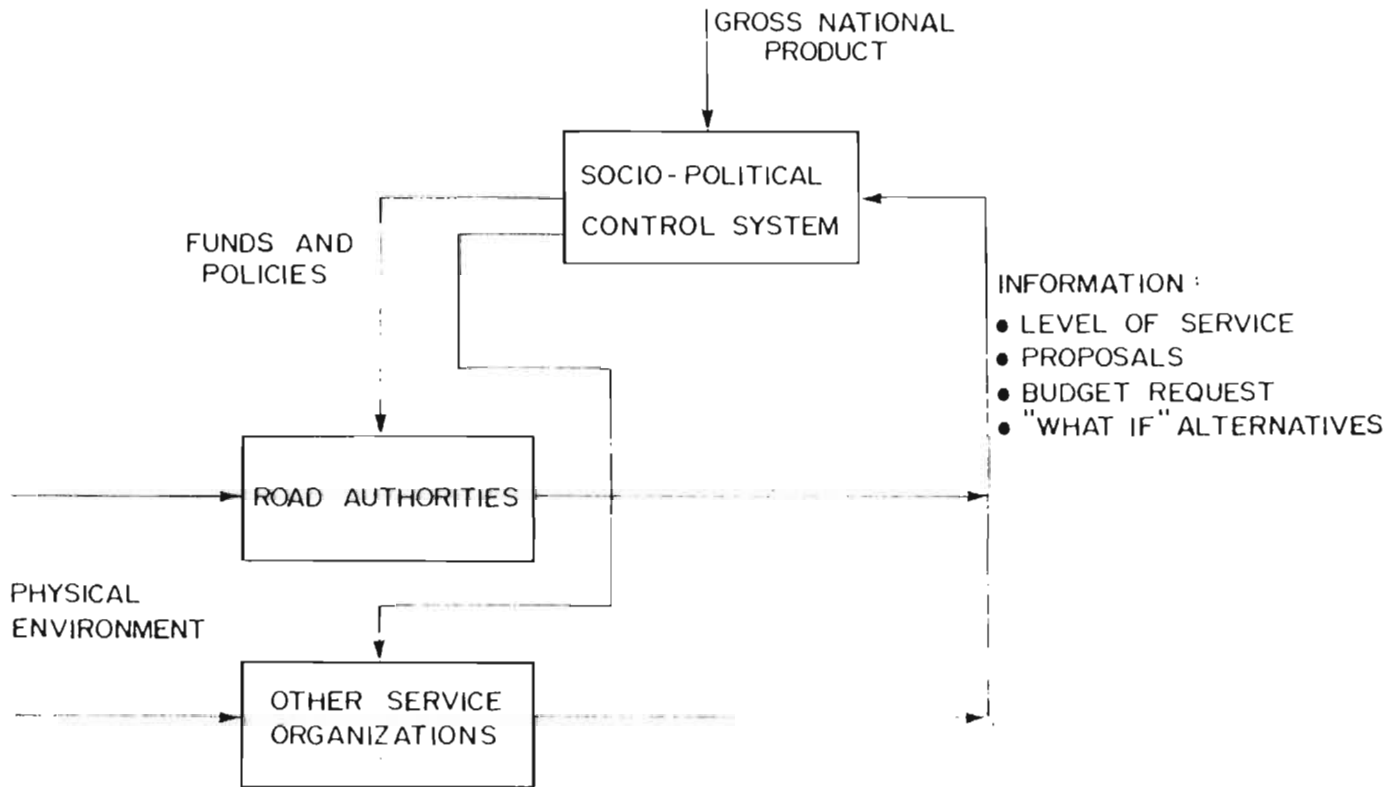


FIGURE 2.12  
 FEEDBACK CONTROL BY SOCIO-POLITICAL SYSTEM OF ROAD AUTHORITIES  
 AND OTHER SERVICE ORGANIZATIONS

The controlling body in evaluating this information should consider whether they can afford higher levels of service, whether they can face the consequences of a reduction in the budget or whether they should invest in order to obtain better service. As a result they should, along with the decided funding, provide general policy guidelines indicating a revision of the standards of service, an attitude to road user costs, the acceptable way of carrying out economic evaluations (specifying, for example the discount rate that should be used) etc. Further ideas as to how this may be achieved are given in Appendix 3.

Even if these ideals are not possible yet, the financing authority should get uniform - or at least comparable - information from the various road authorities in order to distribute money equitably. Perhaps care should be taken not to straight-jacket development at this stage by insisting on the type of system to be used. There is a need to try different ideas and approaches but this common goal should be recognized from the outset so that enough flexibility is maintained to move towards uniform reporting.

It is always difficult to make objective judgements about priorities between say hospital services and roads. However this method of presenting information should help to rationalize the decisions. An effort in this direction should encourage other organizations to follow suit. In fact in view of the current economic climate in South Africa and the Government's commitments, it appears that it will be increasingly necessary for road authorities to justify their budget requests in these terms to secure their funding.

## 2.6 SUMMARY

This chapter has attempted to synthesize the various aspects of pavement management to produce a holistic picture of the nature and purpose of PMS, It has been shown that the systems approach to pavement management involves pavement engineering, operations research, management science and aspects of socio-political science. The ultimate objective can be viewed as contributing to an improvement in the overall public good as defined by the body

politic and that the technology, organization and communication in a hierarchy of systems should be designed around this objective.

Many of the comments made may appear to range from the obvious to the unnecessarily academic yet experience in this study suggests for many of the difficulties in establishing viable PMSs. Similarly, the dearth of PMS implementation by road authorities overseas (Chapter 3) suggests that this applies equally to their circumstances. It is one thing to carry out a one-off analysis using sophisticated PMS techniques and another to integrate a PMS in a road authority in a way that adapts to changing circumstances and evolves with experience while maintaining a secure historic data base. Attention to data communication and control appears to be, by far, a greater immediate problem than the accuracy of the algorithms that determine maintenance requirements.

The diagrams in this chapter were used to illustrate the communication and control requirements of the various components of the PMS and to emphasise practical considerations. By way of a summary, a list of considerations against which the different aspects of a PMS development can be judged is given in Table 2.3. They are illustrated further in the description of the development of a PMS for a rural road network given in Chapter 5.

TABLE 2.3 : PMS development considerations

CLASS	ASPECTS	CONSIDERATIONS
Data types	Given in Table 2.2	Cost, contribution to PMS, practical aspects of collection
Computer environment	Hardware	Suitability, cost, accessibility, flexibility for future modification and expansion
	Data base management system	Cost, efficiency, data base design
	Operators	Assistance with programme development and maintenance, user control over operations.
Data input	Data definitions	Coding forms, guides
	Validations	Manual and automatic error checking
	Update procedures	Robustness with respect to data errors and break-downs
	Control	Security, integrity and completeness.
Models	Design Tactical planning Strategic planning	Interactive ability and participation of field staff; routine maintenance, special maintenance, rehabilitation; interface with geometric requirements; adaptive to changing demands, additional information etc., optimization ability; acceptance of road authority.
Data output	Listing of raw data	Method of extraction; suitability for: field staff, designers, middle management, top management, higher authority.
	Summarized data	
	Analysed data	
Operations	Data base administrator	Functions, authority
	Decision making	Policy, people, data requirements
	Control of PMS functions	Responsibilities, authority, communication channels
	Documentation	Data dictionary, manuals, guides, descriptions, policies

## CHAPTER 3

### GENERAL STATUS OVERSEAS

#### 3.1 OUTLINE OF THE HISTORY OF PMS DEVELOPMENT

Pavements have naturally been managed since the first roads were built. However, the science of pavement management or PMS, in its modern sense, has evolved over the past twenty five years and has only recently reached a level of prominence previously enjoyed by research into road building materials. This is the result of the accumulation of a number of factors which have been identified by Hudson et al (1979) and are set out in Table 3.1. Inspection of this Table shows that these factors can be grouped into two main categories:

- on the one hand the growing relevance of improved techniques for managing pavements;
- on the other the parallel development of such techniques.

The history of the development of PMS techniques can be traced by the following milestones.

##### (a) The concept of serviceability

As indicated in Chapter 2, the introduction of the concept of serviceability during the AASHO Road Test in 1962 can be considered the birth of the science of PMS. This concept was found necessary to interpret the analysis of the behaviour of the various test sections in a meaningful way. The view was taken that the ultimate objective of a pavement was to serve the road user and therefore the cheapest design that would successfully provide a satisfactory level of service should be chosen. This philosophy generated the subsidiary concepts of performance, design life, structural number and equivalent axle loads.

TABLE 3.1 : Factors providing impetus to pavement management system interest and development (After Hudson et al, 1979)

Year				Factor
1950	1960	1970	1980	
				1. Road building boom of 1950's and 1960's
				2. Developments in pavement technology, systems methods, information growth, data handling capabilities, computers, etc.
				3. Direct application of systems analysis to design component of pavement management
				4. Increased emphasis on management of existing network; i.e., rehabilitation and maintenance needs
				5. Recognition of direct effect of pavement condition on user costs
				6. Increased emphasis and capability in pavement monitoring as a management tool
				7. General growth in management methods and awareness
				8. Increased maintenance costs with decreased availability of funds (inflation)
				9. Energy and material shortages

(b) Considering future maintenance in pavement design

The evaluation of the AASHO Road Test results was done on the implicit assumption that pavements are designed to carry traffic over a finite time period (the design life) during which time the pavement receives no structural maintenance and after which the pavement has no value. Although these assumptions facilitated the analysis, they were clearly not in accordance with existing or desirable practice. Pavements are generally kept going through an indefinite number of "life cycles" during which the pavement deteriorates and is repaired



until the road is no longer required. By recognizing the restoration effects of future maintenance cheaper initial designs can be used to a degree that an overall saving can be achieved when both construction and maintenance costs are considered.

This view was incorporated in the FPS (Flexible Pavement System; the basis for which was set out by Scrivner et al, 1968) and SAMP (Systems Analysis Method for Pavements; founded in a parallel study of Hudson et al, 1968) series of programs. These representations regarded the performance of the pavement as an output of the pavement system and the expected traffic, climate and subgrade conditions as input. An overlay is supposed at the time at which the serviceability is predicted to drop below an acceptable level. The predictions were based essentially on results from the AASHO Road Test. Using these programs the total cost of various designs can be calculated and the most economic one chosen. This approach introduced the economic concepts of analysis period, discount rate and salvage value into the analysis and laid the basis for PMS evaluation at the project level.

(c) Consideration of variability in pavement behaviour

The variability of pavement materials has long been recognized and the uncertainty in the future behaviour of pavements was clearly demonstrated in the wide variation in the performance of replicate sections in the AASHO Road Test. An important advance in PMS development however was the introduction of these uncertainties explicitly in the analyses. Important instances of this are:

- the use of Bayesian decision theory as suggested by Hutchinson and Haas (1968);
- the introduction of reliability requirements in the VESYS II M pavement design model (Kenis, 1977);
- the use of infinite Markov processes for evaluating alternative rehabilitation strategies. (Smith, 1974; Smith and Monismith, 1976).

(d) The development of pavement feedback systems

Having to maintain increasingly large networks of pavements introduced a need to describe, measure and record the condition of pavements in a uniform way on a large scale. This was inspired and facilitated by three developments in the sixties and seventies, namely:

- the classification of the various manifestations of distress;
- the development of rapid measuring devices;
- the rapid growth in the capabilities of electronic computers.

The myriad of ways in which pavement distress occurs and the various terminology used to describe it, even within one authority, created a need for a standard nomenclature. Various attempts were made to present suitable classifications and coding procedures were drawn up by different authorities for recording distress (see e.g. Wingate and Peters, 1975).

The various devices for measuring pavement condition include the Dynaflect, SCRIM, a number of roadmeters for measuring riding quality such as the PCA roadmeter, GMR profilometer, Maysmeter etc. With the aid of microprocessors these instruments have evolved (or are being adapted) to record measurements at up to 80 km/h directly onto magnetic tape in a form that is amenable to placing on a data base.

The most dramatic development has been in the field of computer hardware and software. Martin (1978) has shown that the unit cost of computer processing and storage decreased by orders of magnitude over the past two decades and is expected to drop in the same way during the next decade.

(e) Investigation of user costs in relation to pavement deterioration

The International Bank for Reconstruction and Development in association with the British Transport and Road Research

Laboratories (TRRL) and the Massachusetts Institute of Technology developed a model, the "Highway Cost Model", to calculate the total costs of alternative pavement designs. (Moavenzadeh, 1972). Apart from considering the construction and maintenance costs, this model made the important innovation of explicitly recognizing the effects of poor pavement condition on the operating costs of vehicles using the facility. These costs include petrol consumption, maintenance and depreciation of vehicles etc. Two important experiments were conducted to provide data to calibrate this model.

The first was a study conducted by the TRRL in Kenya (Robinson et al, 1975) where the rate of deterioration of paved roads, mainly with cement treated bases, was studied as were the operating costs of vehicles on pavements having different levels of riding quality.

In an effort to broaden the breadth of this study to a greater sample of roads that included additional pavement materials and different environmental and economic conditions, a second major study was carried out in Brazil during the period 1975-1981 (GEIPOT, 1976). The results of this study are still being examined but they are expected to add substantially to our understanding of the consequences of alternative maintenance policies on road user costs.

(f) Network evaluation procedures

The availability of data regarding the pavement network and of efficient data storage and processing facilities promoted the development of computerized analytical procedures for identifying rehabilitation projects and determining their priorities. A variety of algorithms have been produced that range from the simple use of "deduct points" for different types of distress (see e.g. Sharma, 1978) to more sophisticated methods that take into account the future behaviour of pavements and budget constraints of the authority. These methods are based on

various types of dynamic programming such as infinite Markov programming (see e.g. Kulkarni et al, 1982) and integer programming (see e.g. Lytton et al, 1982).

(g) Structural analysis of pavements

A major contribution to the understanding of pavement behaviour, an essential aspect of PMS, has been the development of analytical (or mechanistic) methods of evaluating pavement structures. These procedures use the fundamental properties of materials to predict the behaviour of asphalt pavements and overlays. They are based on a large body of work over the last two decades, comprising materials testing and the formulation of analytical models and design procedures. A summary of these techniques and and state of development was given by Monismith and Finn (1977).

The situation today is that the principles of PMS are well established and accepted. Two text books have emerged recently setting out the theory and giving guidelines for implementation (Haas and Hudson, 1978; Roads and Transportation Association of Canada, 1977). Procedures such as SAMP have been used routinely for a number of years (Haas and Hudson, 1978) and many authorities throughout the world have some level of PMS development. A large number of agencies have emerged selling PMS services either to assist authorities in implementing their own systems or to provide the total service of collecting the pavement data and analysing them to give rehabilitation needs and priorities.

The following sections give an overview of PMS development in various countries. This is not intended to be a comprehensive exposition of the state of the art (since this would have needed personal contact with all the major agencies) but an illustration of the various approaches to PMS and the different levels of implementation.

### 3.2 SITUATION IN NORTH AMERICA

Despite the widespread interest in pavement management over the last decade in both the USA and Canada, relatively few instances of operational PMSs have been reported. However among the working systems there are some with highly developed data support systems and sophisticated optimization algorithms.

A review of the status of PMSs in North America was made at a workshop in Tumwater, Washington in 1977 (Terrel and LeClerc, 1978). Nine USA and two Canadian authorities presented overviews of the PMSs they had implemented or were in the process of developing. Hudson et al (1979) gave a summary of existing practice as indicated by the workshop participants. They concluded that although none of the authorities had the facility for determining an optimum strategy for the network as a whole, several of the agencies were able to prepare priority listings based on fixed standards of service and all of the agencies had some level of information for analysing pavements on a network basis. They also showed that the implementation of PMSs at the project level was more advanced than at the network level in that most of the agencies selected the type of rehabilitation by analysing the consequences of alternative maintenance strategies. However in 1977 the state of implementation among participants of the workshop was regarded to be low in relation to what is desirable and possible. If one considers that these authorities represented the most advanced users of PMS among the many North American agencies then clearly the general level of implementation can be assumed to have been much lower.

In two further workshops (conducted in Phoenix, Arizona, in May 1980 and in Charlotte, North Carolina, in September 1980; see Transportation Research Board, 1982) emphasis was placed on step-wise implementation of activities that were already known to be needed. That there was sufficient technology to proceed was evidenced by the fact that several states and federal agencies had working systems (notably California, Washington, Utah, New York, Arizona and the US Airforce). Guidelines were offered as to how

implementation should be carried out. It was estimated that funding of \$3,5 million (1980 dollars) would be required over the following 5 years to introduce these systems at the national level.

Despite the above comments some striking advances have been made in North America in both state and local authorities. Some aspects of important working systems are given below.

#### Arizona Department of Transportation

The network optimizing PMS in use by this Department was considered by Monismith and Finn (1982) to be the only one in use by a highway department in the USA that determines rehabilitation policy by considering an optimum distribution of alternative rehabilitation strategies on a network basis. This procedure calculates the most cost effective policy for maintaining the network at a level of service satisfying certain minimum requirements. The condition of the pavements is monitored in order to identify those sections that need maintenance in terms of the established policy. Full details of this system are given by Kulkarni et al (1982).

Its success is evident in its acceptance by the various district representatives and by the fact that additional funding was allocated to the Department for maintenance on the strength of information obtained from the system.

#### Washington State Department of Transportation

The approach adopted by this Department to optimize their maintenance programme is outlined in terms of the following steps:

- (a) The future behaviour of candidate pavement sections (projects) is estimated by extrapolating from information of past behaviour;
- (b) Based on this prediction, an optimum maintenance strategy (with respect to construction, maintenance and user costs) is determined by calculating the consequences of alternative valid maintenance strategies for each project;

(c) These projects are then ranked according to their value and scheduled according to this ranking but constrained by budget levels and the minimum level of service acceptable.

Details of this method are given by LeClerc and Nelson (1982). Although it is not a true optimizing procedure on a network basis, these authors considered this system to provide:

"a good solid framework for orderly analysis which, because of programming design, can be easily updated or modified to fit any new condition."

#### California Department of Transportation

The procedure of the PMS of this Department is to identify maintenance requirements (ie the type and urgency) from the results of biennial condition surveys. These requirements are determined by a decision tree process that leads to a type of maintenance that will suit all the modes of distress on a given pavement length. This is called the dominant strategy for the project. The procedure is illustrated as follows:

If maintenance treatments  $m_1$  and  $m_2$  are both suitable for treating distress  $d_1$  and  $m_2$  and  $m_3$  are suitable for  $d_2$  then  $m_2$  is the dominant strategy when  $d_1$  and  $d_2$  occur together.

The urgency of treatment is given in terms a "priority rating" which is established by a further set of rules. The maintenance programme is then compiled by scheduling projects according to their priority rating subject to budget and other constraints.

Further details of this system are given by Bartell (1978) and Kampe (1978). The decision rules constitute a maintenance policy. Although not optimized in the sense of the Arizona system this procedure does provide a formal basis for controlling the identification and scheduling of maintenance projects. It has the further advantage that the rules are easy to understand which makes them

adaptable to additional information outside the scope of the model. This procedure parallels that developed for national roads in South Africa described in the next chapter.

City of Palo Alto, California

A relatively simple PMS has been implemented for the City of Palo Alto. It centres on three separate computer files:

- (a) Pavement design and construction file giving the functional and physical characteristics of the streets;
- (b) Pavement maintenance history file containing a record of details of past maintenance;
- (c) Pavement physical condition survey file containing results of condition surveys in terms of details of distress on each street, a condition score based on these details and a field recommendation of the maintenance requirement.

The condition score is determined from deduct points allocated to the various types and severities of distress. If the score is between 65 and 75 the pavement is considered eligible for preventative maintenance and if below 65 for rehabilitation.

The type of maintenance is proposed via a decision tree type logic. (A typical branch of the tree is illustrated in Fig. 3.1) These suggestions are for assigning maintenance priorities only. The actual design can only be determined after more detailed testing. The priority for a particular maintenance treatment is assigned according to:

$$\text{priority score} = \frac{365 \times \text{daily traffic} \times \text{estimated life of treatment}}{\text{cost of treatment per unit length}}$$

Various outputs are prepared from the files to assist the engineer in planning and designing the rehabilitation.



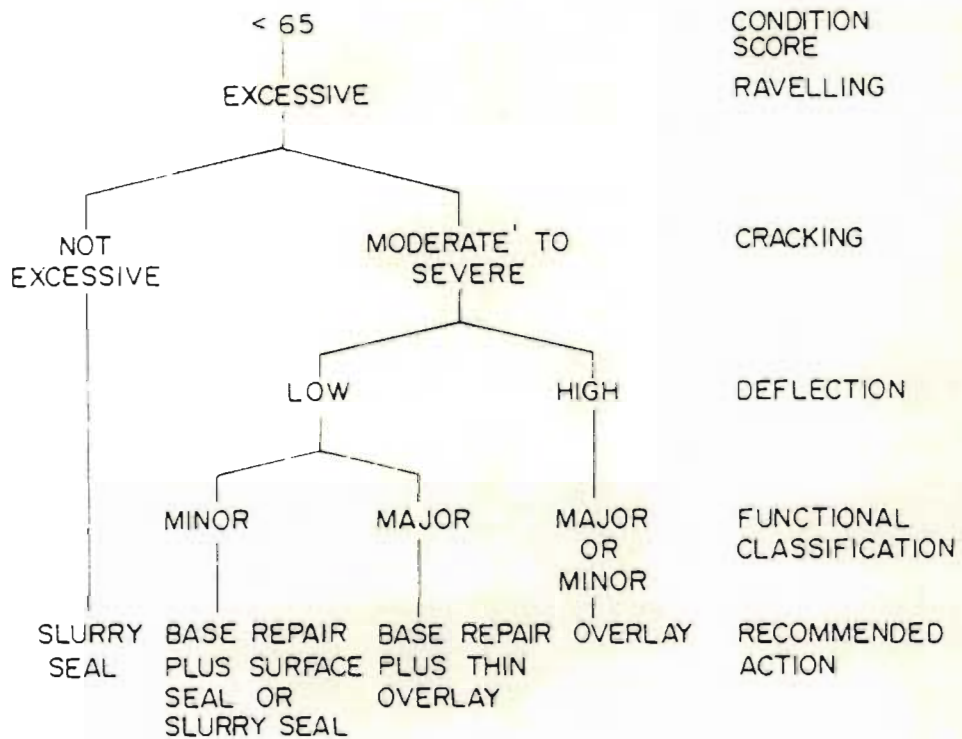


FIGURE 3.1

EXAMPLE OF A "DECISION TREE" PROCESS FOR  
DETERMINING MAINTENANCE TYPE

(After Monismith and Finn, 1982)

Further details of the system are given by Finn (1979) and by Monismith and Finn (1982). This development was considered an important first step which had the potential for evolving into a more comprehensive PMS.

In some ways the nature of this system is similar to that developed for the Johannesburg City Engineer's Department which is discussed in the following chapter.

#### Ontario Ministry of Transportation and Communication

This Ministry has introduced various elements of a PMS since the early 1960s (Phang, 1981). Of particular interest are a pavement information system and a computerized pavement thickness design system which were introduced in 1975.

The pavement information system is a computerized inventory comprising pavement condition data including:

- a pavement condition rating (which is a subjective rating of distress on a scale 0-100);
- riding quality;
- deflection;
- skid resistance.

These data were used (in 1980) to identify rehabilitation and preventative maintenance projects. However research was being conducted to improve the quality of the pavement condition data and to introduce optimizing procedures for planning rehabilitation.

The computerized pavement thickness design system is known as OPAC (Ontario Pavement Analysis of Costs). It is used interactively to obtain the most suitable design under constraints imposed by the user by considering initial capital expenditure, maintenance and user costs. The prediction of the performance of alternate designs is made considering traffic and environmental effects. The details of this system are given by Jung et al (1975) and Kher et al (1975).

### Commercial firms

Several commercial firms have begun offering pavement management services in North America. One such firm, Pavement Management Systems Limited, is based in Canada. It offers a comprehensive set of services which cover the monitoring of the network, identification of projects and assigning priorities to them as well as materials testing and design. Sophisticated monitoring equipment (including the ARAN unit, Dynaflect, Road Logger) are used and analysis is supported by a substantial range of software that makes extensive use of graphics in presenting the results.

Such firms are set up to evaluate a road network of a small authority and present them with a recommended rehabilitation programme. Note that even if the range of services is very wide, as in the case described above, they are still not a substitute for an on-going system, controlled and maintained by an authority, that provides a permanent inventory of the status and history of the network.

### Resume

This overview illustrates the range of approaches being taken in North America. Although the reported cases are inadequate as a sample for gauging the general level of implementation throughout the large number of big and small authorities, the indications are that:

- (a) Many authorities have some form of data base on which various features of the network are recorded;
- (b) Several authorities have network level evaluation techniques to assist in identifying and prioritizing maintenance projects;
- (c) Few of these have optimizing techniques to assist them in finding the most economic strategy or maintenance policy;

- (d) Overall there seems to be a growing awareness of the need for PMS type analyses and many authorities are looking towards improving their methods and in this are supported by commercial firms who either assist in implementation or provide pavement management evaluations on an ad hoc basis.

### 3.3 SITUATION IN THE UNITED KINGDOM

The development of PMS in the United Kingdom has its origins in the report of the Marshall Committee on Highway Maintenance (Ministry of Transport, 1970). The philosophy of this report (as summarized by one of the members of the committee, Harrison, 1973) was to propose a formal method for determining the level of funding required and controlling maintenance activities. Accordingly they attempted to define standards of maintenance to serve as a basis for planning work and to establish units of output to serve as a basis for assessing the costs of various maintenance activities and the evaluation of productivity.

The initial proposals for standards of maintenance are contained in Appendix I of the report. However to effect these standards a system is require by which data is collected, processed and evaluated. Two similar computer based systems were developed for this purpose:

- CHART by the TRRL (Wingate and Peters, 1975);
- MARCH by the "City Engineer's Group" (1975).

Originally the CHART system was confined to the consideration of visual distress of pavements, footways and kerbs. More recently mechanical measurements of riding quality, skid resistance and deflection have been incorporated (Thompson and Hatherly, 1982). The maintenance requirements are determined by a dominant treatment approach based on warning levels for the different types of distress. (Those currently proposed are given by Weller, 1980.) Deflection measurements can be used (especially for the more heavily trafficked roads) to estimate the remaining life of the

pavements and the amount of strengthening required. This evaluation follows the procedures described by Lister et al (1982). Minimum levels of skid resistance depend on the characteristic of the particular site (such as road geometry, visibility, traffic speed). Therefore a risk rating has to be assigned to each site against which the skid resistance can be evaluated.

Users of the CHART system insist that it is only an aid to decision making as the final choice of rehabilitation must take into account additional engineering, safety and environmental considerations. Hatherly (1978) has said that one of the most important functions performed by the system is to indicate to the engineer which lengths of road need not be considered further, allowing him to concentrate on those lengths that were shown to be deficient in some way.

Although there has been some scepticism among potential users of the system, it is now being used by a number of highway authorities in the United Kingdom, as well as by the Scottish Development Department, and has been adopted by the Department of Transport for the trunk road network in 1981/1982 (Thompson and Hatherly, 1982). The CHART system has also been used in nation-wide surveys to assess changes in the overall condition of the road network (Leech, 1979).

The basic CHART system is flexible enough to allow refinements to be added by individual authorities. This feature has been exploited, in particular by the Greater London Council who introduced graphic facilities for displaying sections of road of interest as an overlay for a road map (Hatherly, 1980).

The TRRL are investigating the use of data base management systems to improve updating and access facilities of the data (Weller, 1982).

Despite the advantages experienced from the system it is recognized that the decision criteria are arbitrary and that there is a need for a usable pavement maintenance optimization model and research to that end is in progress (Nicholas, 1979).

The Department of the Environment for Northern Ireland, Roads Service, controls all aspects of highway design and maintenance in its region. (In this respect it is unique in the United Kingdom.) This Department has chosen to adopt the MARCH program as the basis of its pavement management system (Snaith et al, 1982). MARCH, although a more coarse rating procedure, was considered easier to operate with unskilled staff and thereby more suited to their situation. A data bank has been developed to facilitate data handling. Apart from a few modifications and refinements (such as the use of curvature measurements) the approach is along the same lines as that adopted on the British mainland with the CHART system.

#### 3.4 SITUATION IN EUROPE

The following details about the status of PMS in Europe were virtually entirely obtained or inferred from the proceedings of the IXth International Road Federation World Meeting of 1981 and the 5th International Conference on the Structural Design of Asphalt Pavements held in 1982.

##### The Netherlands

Kellersman and Van der Klooster (1982) described a PMS that was being developed for the City of Amsterdam. This system centres on a road data bank in which the basic features of the road are recorded. It contains the coordinates of the ends of the 6 300 street sections so that these can be set out in the form of a map in which sections in poor condition can be highlighted. Superficial visual inspections are to be made biennially. These are to be supplemented with mechanical measurements of skid resistance and riding quality on the main routes. From these results sections of suspect condition are identified and a more thorough condition survey made. Pavements are selected for rehabilitation and the treatment is designed using further detailed tests such as the falling weight deflectometer. The information in the data bank will be able to show, in future years, to what extent the condition of the network

is improving or deteriorating as a result of the maintenance policy. This system started formally in 1981 and its different aspects are in various stages of development.

The Dutch Study Centre for Road Construction set up a working group in 1976 to develop a simple and efficient system for the maintenance of municipal streets and roads. The results of this study are described by Koning (1982). The proposed system uses visual and mechanical measurement of the condition of the pavements to determine maintenance needs in three categories:

- (a) Long term requirements (0-20 years) to adjust policy to ensure that suitable maintenance can be achieved in good time;
- (b) Medium term requirements (0-5 years) to assign priorities in order to schedule urgent maintenance according to available budgets;
- (c) Short term requirements (0-2 years) to contribute to the road managers' annual estimates of expenditure.

The prediction of behaviour on which these projections are made are currently based on analyses of subjective opinion. The proposed system has been applied to a municipal authority experimentally. The results were sufficiently good for the working group to recommend that it serve as a basis to get other municipalities started on PMS implementation.

#### France

A Preventative maintenance policy based, in particular, on periodic systematic surveillance of the French national roads was set up in 1972. Boulet and Gramsammer (1982) described the operational framework in which this policy is carried out. Three types of surveys are made:

- establishing the initial condition of new or reconstructed pavements;
- routine surveys of the condition of the network to identify pavements requiring attention;
- detailed surveys of selected sections to determine the maintenance requirement.

Pavements requiring maintenance are identified by considering structural, surfacing and serviceability needs. Threshold values for various types of distress, deflection and levels of service are given which define a deficiency in one or more of these aspects. From this analysis sections are defined that are uniform with respect to their need for maintenance. A further set of rules are then used to determine the type and urgency of maintenance or to indicate sections requiring more detailed analysis.

This procedure is supported by a comprehensive data bank that records road geometric properties, road furniture, pavement structure, surveillance results, traffic and accidents. Various aspects of these data can be displayed graphically on a map representation of the network.

Particular attention has been paid by the French Road Research Laboratories (Laboratoires des Ponts et Chaussées) to the development of instruments for measuring pavement condition. These are both the rapid instruments aimed at routine network surveys as well as the slower instruments for assessing requirements at the project level. An overview of these instruments, many of which are still in the development stage, are given by Boulet and Gramsammer (1982).

#### Sweden

According to Wallin (1981) the planning process of road maintenance by the Swedish National Road Administration is based on information in a data bank concerning the condition of pavements and structures. Data about the network relies on standard descriptions of condition and the use of sophisticated measuring devices (e.g. the



Saab Road Surface Tester for measuring pavement condition and the Mobile Road Survey System for measuring road alignment). The information from the data bank is used to produce a 5-year plan in consultation with the 24 county administrators.

### Resume

From the available evidence it appears that the systems for the countries described above constitute the most advanced level of implementation in Europe. Although not much use has been made of optimizing procedures (that include predictions of pavement behaviour) for scheduling projects considerable progress has been made in developing surveillance equipment and establishing data banks. Of central importance though is the clear indication of a growing appreciation of the need for improving the methods of pavement management in order to programme maintenance by economic criteria (incorporating user costs) from comprehensive and reliable data.

## 3.5 SITUATION IN AUSTRALASIA

### New Zealand

Wright and Major (1979) reported that the pavement condition of all New Zealand State Highways were being rated at least biennially. The ratings were in the form of quantified assessments of various types of visible defects according to the method set out by Stacey (1971). Different combinations of ratings for individual defects are used to indicate basecourse condition, surfacing fatigue, maintenance needs and overall condition. These indicators can be used to assess changes in pavement condition between inspections. In some Districts inspections of roads are made twice a year to assess maintenance needs directly. Assessments are made at 0,5 km intervals and are then costed and totalled for the District network. Although primarily instituted to determine resource requirements for routine maintenance, this procedure also assists in identifying areas needing special maintenance or rehabilitation.

Although these procedures were initiated in 1969, they were still, in 1979, not incorporated in a formal computerized system meeting basic PMS objectives. Wright and Major considered that the main need was to establish the correct balance between the different maintenance categories to provide a suitable level of service at minimum cost. Of central interest was to determine the most effective resealing frequency.

Over the past few years there has been an increased interest by the Ministry of Works and Development to systematize their pavement management. To some extent this has been encouraged by the more difficult economic situation and the desire of the Treasury to have quantified substantiation for budget requests (Paterson, 1983).

#### Australia

Porter and Armstrong (1979) reported that both the state and the local government authorities of Australia were investigating road condition procedures for use with a road inventory to establish road management systems for controlling the allocation of funds by "policy, specification and design".

The development of a suitable condition rating method for Australian conditions was a subject of research of the Australian Road Research Board. The first stage of the project was a review of methods in use internationally. On the basis of this, Porter and Armstrong (1979) favoured procedures that were simple to use and easily adapted to experience. The procedure already in use by the Country Roads Board, Victoria, was attractive from these points of view but was thought to be lacking in certain important aspects. This investigation was considered to still require a number of years study, but to ultimately result in:

- improved programming rationalization;
- the opportunity to analyse effects of different strategies;
- improvement in performance modelling, design, specification and construction techniques.

Recently several Australian urban authorities have become interested in implementing simple PMSs. A number of these have been introduced along the lines of that developed for the City of Johannesburg, described in the next chapter (Yeaman, 1982).

A notable development has been the road planning model, NIMPAC, of the National Association of Australian Road Authorities (1982). This model was developed to assign priorities among road improvement projects. It is based on a system used for planning in Western Australia (Kaesehagen, 1970) and further developed by the Commonwealth Bureau of Roads (Both and Bayley, 1976). The model uses simple predictions of pavement behaviour to determine the possible effect of pavement condition on the choice of priorities. A data base containing an inventory of the road features provides input to the model. Although containing typical aspects, this model does not operate as a PMS by their road authorities.

#### Resume

Although there has been **some** progress in introducing PMS techniques in Australasia, the general level of **implementation** appears to be low in relation to their recognized needs.

### 3.6 SUMMARY OF SITUATION OVERSEAS

There is a growing awareness, world-wide, of the need for improved pavement management and significant progress in the implementation of PMSs has been made by many authorities. Most of these have some formal method of measuring and recording the condition of pavements. A number use these data systematically for the strategic and tactical planning of pavement maintenance. There are also a few instances where this planning is being done using procedures that strive to optimize the use of resources.

However, in view of the PMS technology that is now available and the evidence of its successful **employment**, the state of implementation internationally falls far short of the established need and

capabilities of authorities. This points to the fact that technological developments of this type cannot be simply handed over to users (like a new tool) since it affects the way the organization operates. It suggests that managers need to be strongly motivated to interfere with their traditional, tried and tested, procedures and then are only likely to adopt new methods piece-meal, when substantial benefits are perceived and as the the numerous operational obstacles are overcome.

# CHAPTER 4

## DEVELOPMENT IN SOUTH AFRICA

### 4.1 INTRODUCTION

This chapter gives a brief account of the use, nature and, in some cases, the history of development of various PMSs in the major South African road authorities. These comprise the Department of Transport (DOT), the four provincial authorities (Transvaal, Cape, Natal and Orange Free State Roads Departments) and the City of Johannesburg. The areas of jurisdiction of these authorities is shown in Fig. 4.1.

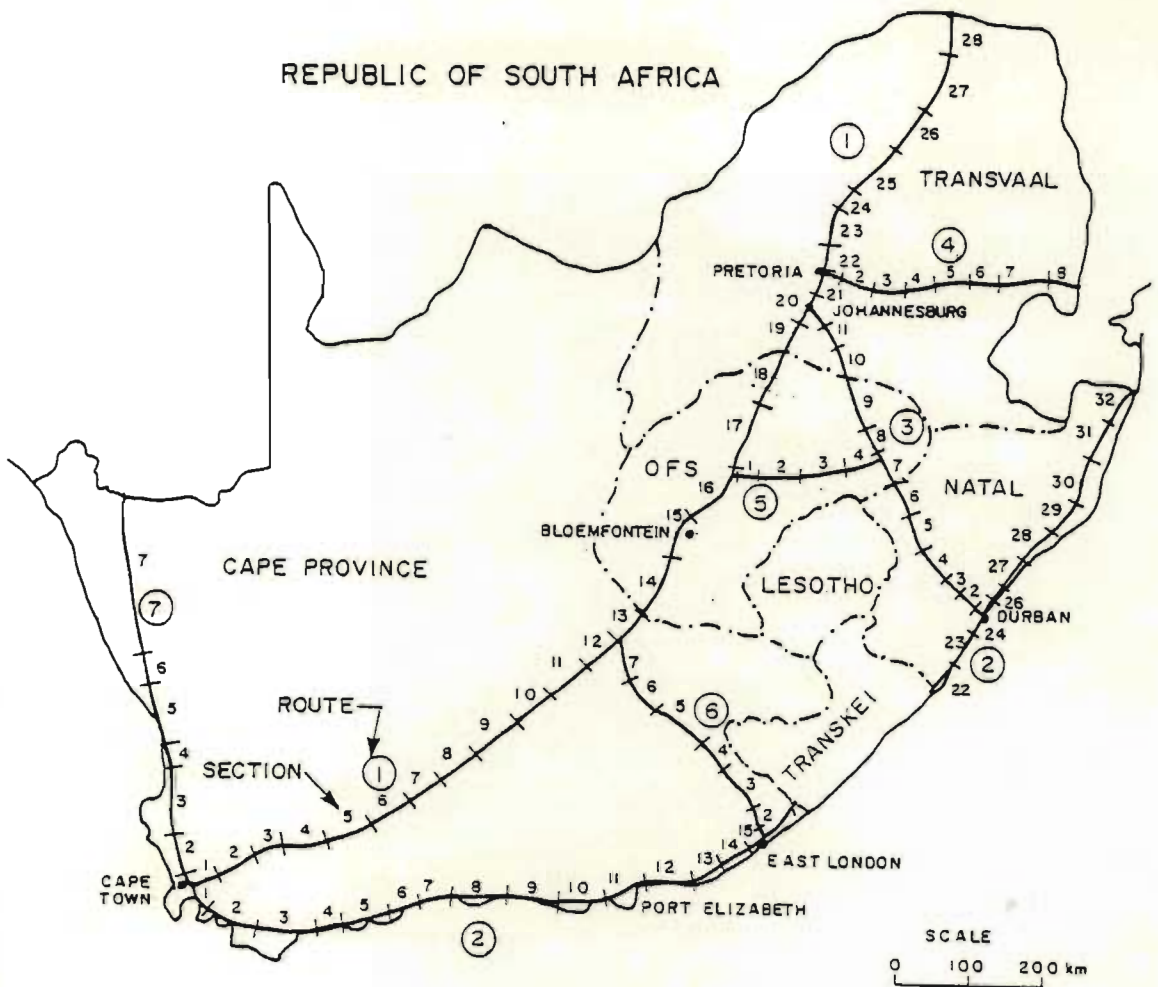


FIGURE 4.1 AREAS OF JURISDICTION OF VARIOUS SOUTH AFRICAN ROAD AUTHORITIES

The objects of this chapter are:

- to present a general overview of the status of PMS in South Africa, an evaluation of current use of these systems and the direction future developments are expected to take;
- to describe the results of the implementation activities which have formed a major part of this study (i.e. for the DOT, Cape Roads Department and the City of Johannesburg).

The information concerning the nature and operation of the various organizations have been obtained in consultation with their staff and are mostly contained in the publications referenced.

#### 4.2 SYSTEM FOR THE DEPARTMENT OF TRANSPORT

##### History of the national road network

The national road network dates back to 1935 with the passing of the National Roads Act and the creation of the National Roads Board for planning and financing a national network of roads. The development of the network increased steadily to nearly 10 000 km in 1970. In that year the National Transport Commission defined a new national road network of some 6 000 km (as shown in Fig. 4.1) which they proposed to build as a system of freeways. Only that part of the old network that had already been built to freeway standard and was suitably placed was retained. The rest was brought under the control of the provincial authorities. The rate of construction was, however, slower than was originally envisaged. By 1982 about 1 600 km had been constructed, although for 600 km only one carriageway had been built. It was then decided to redeclare certain lengths of the old network (about 600 km in all) as national road to link the new sections so that the national roads could be managed more realistically as a network.

Outline of the history of the PMS

In 1972 it was clear that the results of the various pavement monitoring equipment then being commissioned had to be incorporated into some structured form of retrieval and analysis to be useful. The first proposals of this type were the origins of this study. These were formalized in the form of the road management system shown in Fig. 1.6 as a result of a study tour of Australia in 1973 (Curtayne, 1974).

The DOT provided a particularly appropriate environment to initiate these ideas (especially those dealing with pavement management) because of the following peculiar features of the national road network:

- (a) The roads were of a high geometric standard. Therefore the problem of evaluating pavement requirements was not complicated by other road needs problems (except the necessity to add traffic lanes);
- (b) The roads were of a high structural standard thus representing a high investment per kilometre. They also had a prestige value which demanded that high levels of serviceability should be maintained. These features indicated a need for a high level of control over the structural integrity and serviceability;
- (c) The road system, being a homogeneous set of freeways, had the advantage that it was easy to use surveillance equipment on it and that all the pavements could be treated in a similar fashion;
- (d) Because the network was fairly new and of limited extent it was thought that it would be fairly easy to set up a new data storage and processing system.

The national roads therefore presented an opportunity to study an advanced approach to PMS on a relatively small scale without many of the complicating factors that would prevail with other road authorities.

The DOT agreed to proceed with a PMS but decided to incorporate it in the development of a more comprehensive management information system (MIS) designed and planned for a wide range of activities (Curtayne and Eaton, 1975). In 1974 implementation commenced for three of these activities, viz:

- project control and financial programming;
- road log and completion plan compiling;
- pavement management.

The control of development and computer programming was to be done by consultants but the specifications for the PMS were supplied by the NITRR.

By 1979, despite a substantial amount of computer programming, the development had been set back by a variety of problems which resulted in there not being any aspect of the MIS that was available to the end users. The DOT thereupon decided to terminate any further development. The NITRR, however, continued with the development of this PMS as a research project for the following reasons:

- There was considerable research interest in evaluating the models and forms of data presentations designed for the PMS;
- A large amount of data from surveillance instruments had been collected by the NITRR for the DOT and this system provided a suitable method for storing this information for research and for reporting to DOT on request.

This phase of work was completed in 1982 with the provision of a comprehensive pavement data set and all the required computer outputs. By this time many of the outputs were being used by the DOT and the usefulness of the features of the PMS had become clearer. However the computer environment (i.e. the use of the



SYSTEM 2000 data base management system operated through a computer bureau) turned out to be far more expensive than was warranted for this type of application. In view of these observations the DOT decided to:

- incorporate the PMS into their pavement management operations;
- seek a more suitable computer environment;
- make certain modifications and additions to the programs.

These activities are currently underway in a joint project of the DOT and the NITRR. Despite the many difficulties along the way the results that have been achieved are very promising and the experience gained has prepared the groundwork for all other PMSs in South Africa. Further details of the stages of development are given by Mitchell and Eaton (1977), Curtayne (1978b), Mitchell and Curtayne (1979) and du Plessis and Curtayne (1982).

#### Nature of the system

The PMS, in its current form, comprises a data set controlled by a data base management system, a suite of programs for validating and updating the data base and a set of application programs.

The types of data that are provided are given in Table 2.2. (Accidents are not being considered at the moment because of the difficulty in obtaining comprehensive and reliable statistics for the network.)

Validation and update programs perform a valuable function in identifying many errors in incoming data.

The application programs are of three types:

- listings of raw data, formatted for easy reference;
- summaries of data displayed, usually graphically, for rapid evaluation;
- analyses of present and future maintenance requirements.

Examples of some of these programs are given below:

(a) Fig. 4.2 shows a representation of the current condition of a Route/Section. The latest measured value of each of the condition parameters is given at 100 m intervals. These values are represented as a long line (severe condition), a short line (warning condition) or a dot (sound condition) according to whether they exceed critical limits defined for each parameter. (A blank indicates that no measurement has been taken.) The advantage of this representation is that many data can be shown very succinctly and that problem areas can be identified at a glance. In Fig. 4.2, for example, it is immediately clear that skid resistance is the only significant problem, apart from a short section where loss of stone has occurred.

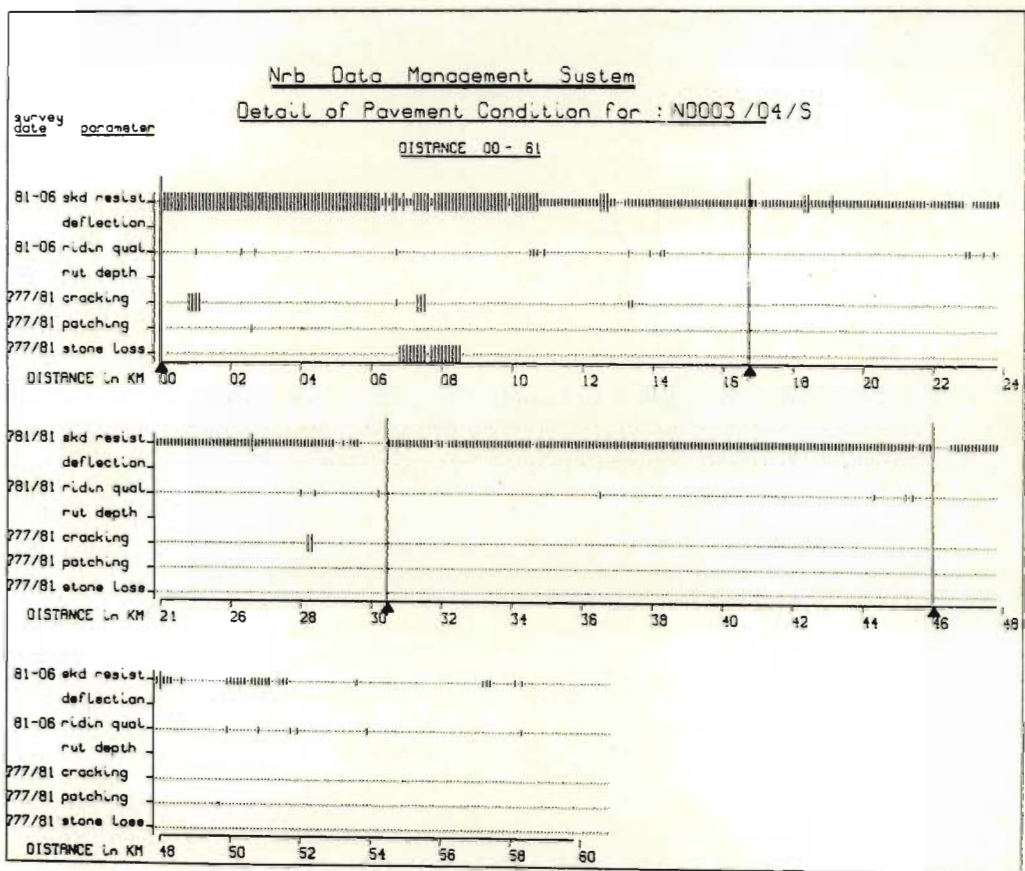


FIGURE 4.2 SUMMARIZED DISPLAY OF CURRENT CONDITION OF PAVEMENT

(b) A similar type of display is illustrated in Fig. 4.3. Here the history of successive measurements of each condition parameter is given. (Only part of the display is shown because of lack of space.) The feature to note here is that a deteriorating condition is easily identified by patches that become darker in an upward direction;

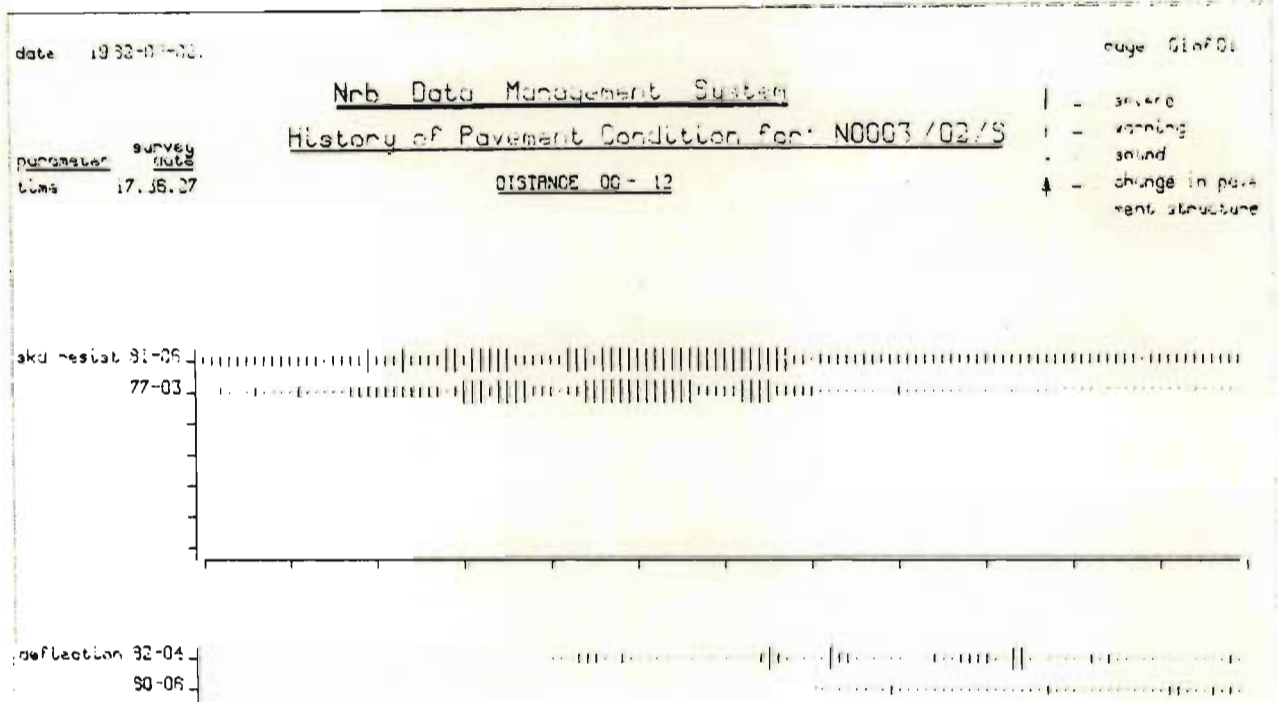


FIGURE 4.3 PORTION OF DISPLAY OF HISTORY OF PAVEMENT CONDITION

(c) Historic trends of mechanical measurements are also given as plots of average values every kilometre. Fig. 4.4 shows a comparison of two series of skid resistance measurements. Here the critical limits defining sound, warning and severe conditions are indicated by the dotted lines;

(d) An example of results from the algorithm for determining maintenance requirements is shown in Fig. 4.5. The type and urgency of maintenance is calculated for every 100 m element;

The urgency is given by the height the vertical lines, where:

Urgency 5 indicates maintenance must be done whatever  
the cost;

Urgency 4 indicates maintenance should be done as soon  
as possible;

Urgency 3 indicates maintenance could be done if  
convenient.

The elements are grouped according to their similarity regarding maintenance requirements thus determining maintenance projects at different levels of urgency. These are shown by the horizontal bars in the Figure.

A simplified schematic of that part of the algorithm for assigning maintenance requirements to 100 m elements is given in Fig 4.6. The full algorithm is given in detail by Rickwood and Curtayne (1978). As can be seen from the Figure the approach is that of a decision tree in which the dominant requirement for the various types of distress present are determined. This algorithm, although fairly complex, was drawn up in 1978 as a tentative proposal based on the opinion of a few researchers and engineers. It is now being reviewed by comparing the results of the model with inspections of pavements.

- (e) An algorithm has also been proposed to predict long term requirements of the network for strategic planning (Mitchell and Curtayne, 1979). This algorithm is based on average pavement behaviour trends such as average surfacing lives, relations between performance and deflection etc. This algorithm is not operational yet.

The design of rehabilitation is carried out using more detailed assessments of the pavement condition. Here the details of the history of the pavement condition contained in the PMS can be very useful for identifying the cause and mechanism of distress. (This is discussed in Appendix 5).

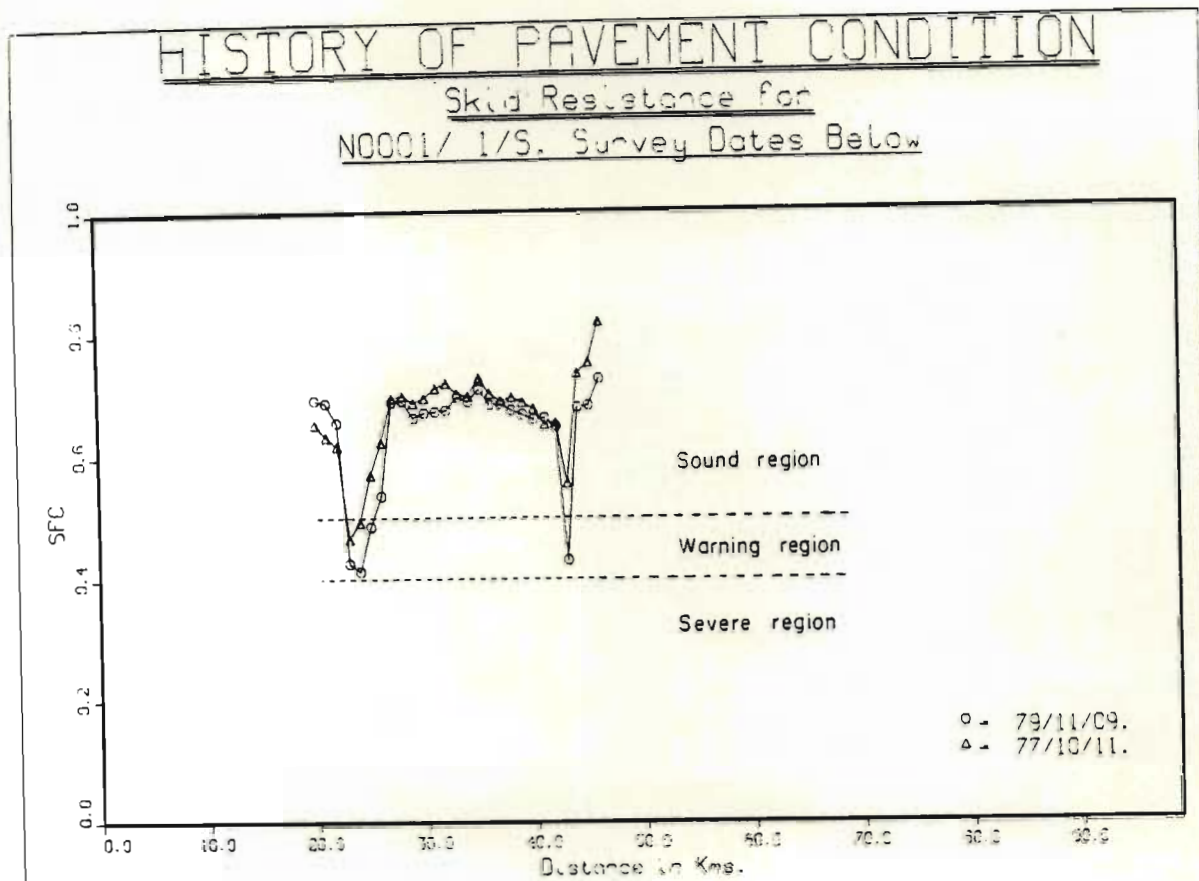


FIGURE 4.4 DISPLAY OF SUCCESSIVE SKID RESISTANCE MEASUREMENTS

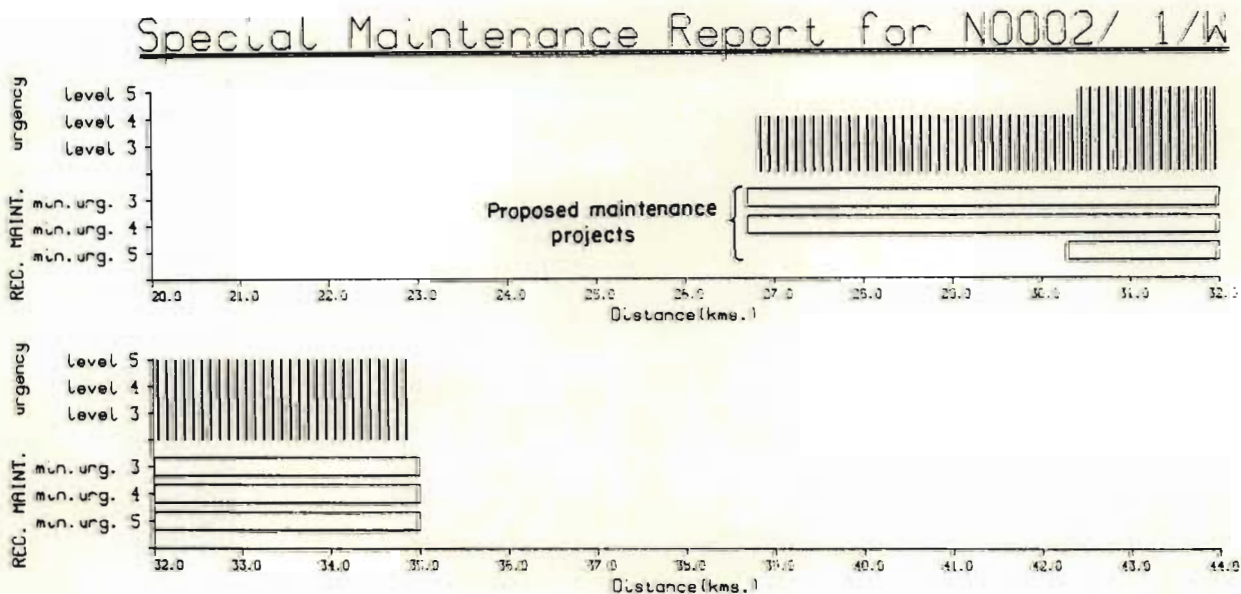


FIGURE 4.5 DISPLAY OF MAINTENANCE REQUIREMENTS

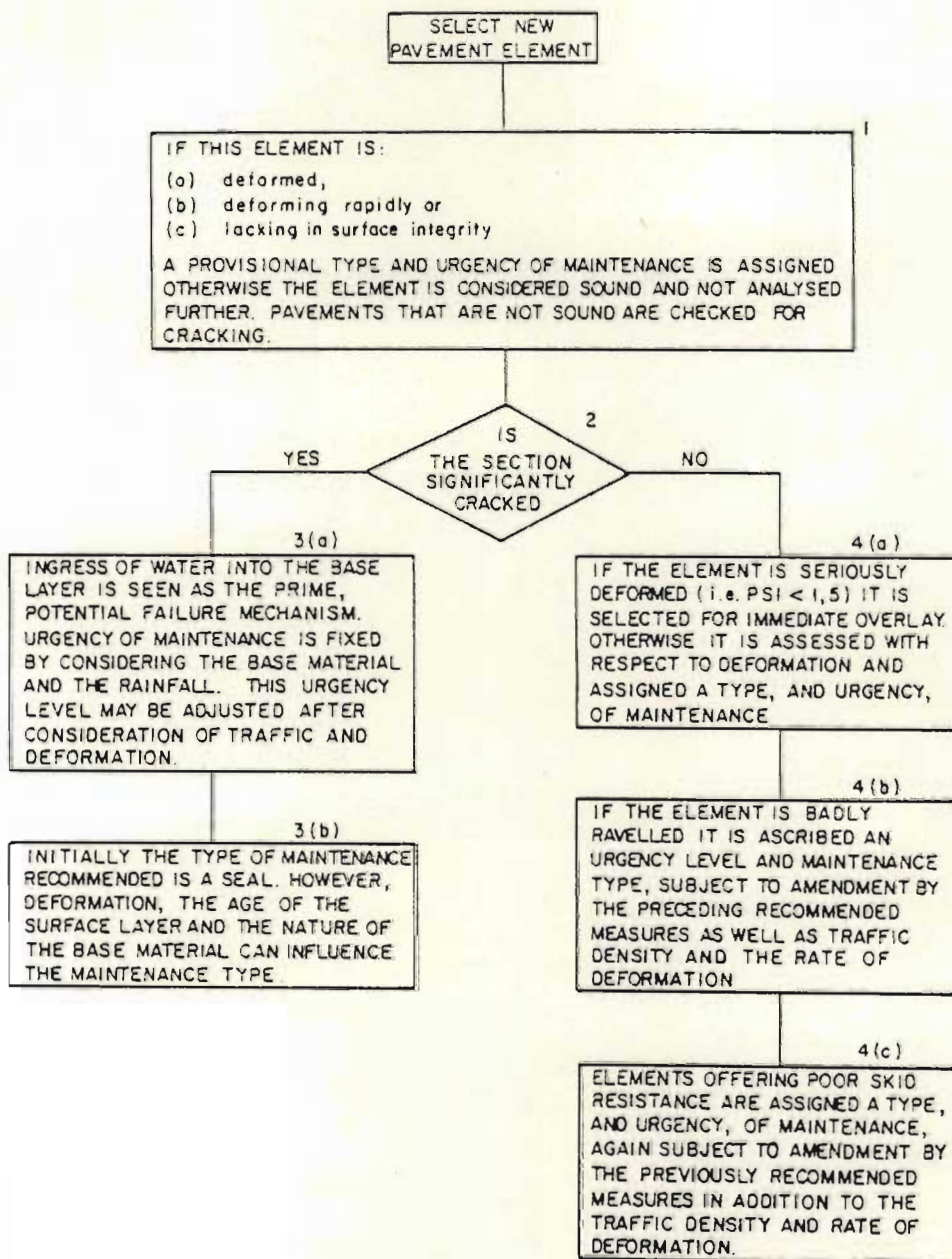


FIGURE 4.6 FLOW DIAGRAM OF ALGORITHM FOR DETERMINING MAINTENANCE REQUIREMENTS

#### Operation of the system

Control of the network is effected through five "Regions" each supervised by a Regional Engineer. Important tasks of the Regional Engineer are to control the quality of routine maintenance (carried

out by staff of the provincial authorities on behalf of the DOT) and to recommend to the Materials Engineer at Head Office what special maintenance is required. As discussed in Section 2.4, it is important to retain the interest and expertise of the field staff in pavement management operations and the system is therefore intended to function with their interaction.

Fig. 4.7 gives the proposed flow of information leading to the formulation of the rehabilitation programme. This Figure shows the Regional Engineer as taking a central role in this activity. He compares the results in the computer outputs with information obtained in the field and submits a modified list of maintenance requirements to the Materials Engineer. The important innovation

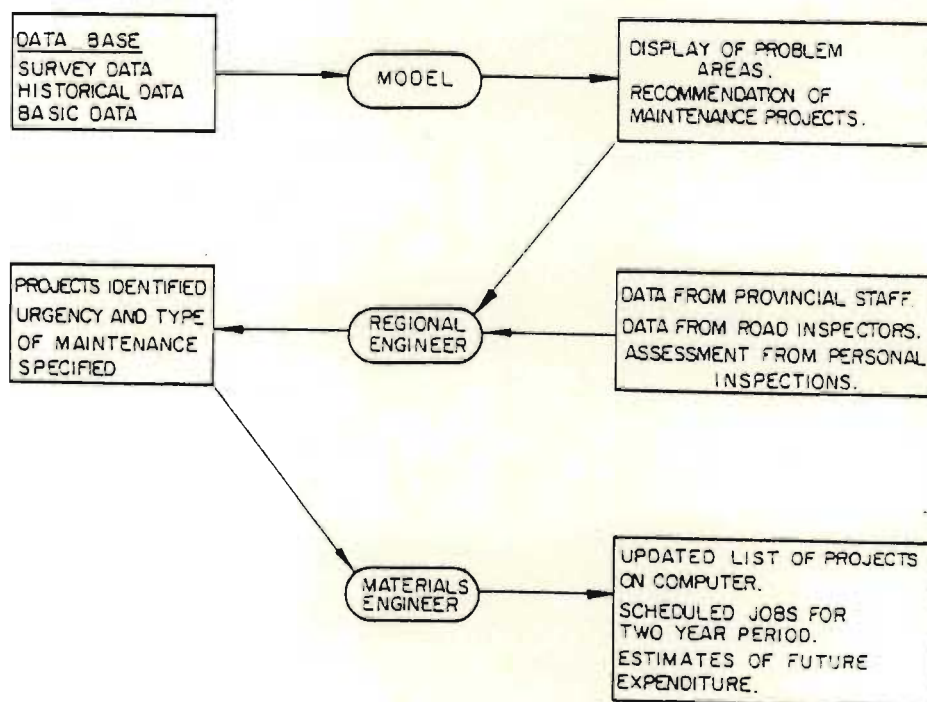


FIGURE 4.7 INFORMATION FLOW IN PAVEMENT MANAGEMENT PROCESS

is that the basis for evaluation has been formalized. If the recommendations of the Regional Engineer differ from those given by the model then:

- either he has supplementary information which he must submit as justifying a revision of requirements;
- or he disagrees with the model.

The latter case is an important feedback mechanism for adapting the system with experience.

The outputs described above were designed to facilitate this type of manual interaction.

#### Evaluation

Traffic, pavement structure and a history of pavement condition information are now all available within one data management system. Records of riding quality measurements date from 1976 and certain deflection data go back as far as 1972. This large amount of data is made easy to use by a variety of outputs. These include recommendations for special maintenance based on an agreed maintenance policy. Although the PMS still has to be tested and integrated into the operations of the DOT they are already experiencing substantial benefits from the efforts in setting up the system. These benefits include (du Plessis and Curtayne, 1982):

- (a) Pavement data is collected on a formal basis and is now readily available for daily use. In the past it has been difficult to obtain many of the data needed for routine activities;
- (b) Monitoring the condition of the network now takes place according to prescribed programme that is easy to control. Subjectivity in visual assessments has been eliminated to large degree;
- (c) Concrete evidence is now available for justifying a proposed maintenance programme;



- (d) Already the history of the behaviour of the pavements can be used to make better predictions of future maintenance requirements and can give an idea as to whether the maintenance budget is satisfactory;
- (e) The basic data needed for designing pavement rehabilitation is now easy to obtain which significantly expedites the design process.

In order for this to become a viable operating PMS it must be securely integrated into the activities of the DOT. This means the necessary authority, responsibilities, policy and controls will have to be established. Furthermore full documentation describing the nature and operation of the system is required. Attention is being given to these matters in the current phase of implementation.

#### 4.3 SYSTEM FOR THE CITY OF JOHANNESBURG

##### Road network and maintenance responsibilities

The Johannesburg City Engineer's Department (JCED) is responsible for maintaining about 2 700 km of pavement in some 4 500 streets. These are located in 956 townships and comprise 22 000 city blocks. For maintenance purposes these roads are divided into two classes:

- freeways and dual carriageways (i.e. "major roads");
- all other roads (i.e. "minor roads").

The maintenance of major roads is the responsibility of the Freeway Maintenance Team. This team undertakes regular visual inspections of their pavements and reports any major defects. These defects are usually the subject of detailed investigation.

There are about 2 500 km of minor roads which mainly consist of collector roads and residential streets. Their maintenance is the responsibility of the Maintenance Engineer. Each year the Maintenance Engineer has to prepare a list of roads for maintenance for

the following year. Since the policy is one of preventative maintenance, the vast majority of treatments being applied are slurry seals, single and double seals and thin asphalt overlays.

The funds allocated for the maintenance of road surfaces during the 1981/82 financial year was R6,4 million of which R3,5 million was devoted to resurfacing (roughly 10 per cent of the total road length).

#### History of PMS development

The standard procedure for selecting special maintenance projects in use before implementation of the PMS would take the following course:

- (a) An annual inspection of the pavements was made by the road inspector. Since it was impossible to inspect all the pavements in the network each year, a selection was made based on the road inspector's memory of probable problem areas and advice from colleagues such as the district engineers;
- (b) From the results of this inspection, a preliminary list of projects was prepared for the Maintenance Engineer;
- (c) This list was pruned and modified by the Maintenance Engineer in accordance with budget limitations and selected field investigations;
- (d) After a maintenance treatment was applied, the details were recorded on a card-index system.

The inadequacies of this procedure were well recognized in the early 1970s. The card-index system was satisfactory for answering queries such as:

"When was South Street last resurfaced?"

but was unable to cope with queries such as:

"Which streets have single seals older than six years?"

The method for identifying maintenance requirements had many drawbacks which were discussed in detail by Gordon and Curtayne (1978). In summary they are the lack of consistency in the rating of pavements, the lack of control of the choice of roads to be inspected and the lack of records of past inspections.

The first innovation was to create a computerized street inventory. Work began on this in the early 1970s in association with other sections of the JCED that were experiencing similar problems. To this inventory the records of the history of special maintenance was added from the card-index file. These data were stored on the ICL 1902 computer of the JCED as a single file. Access to the inventory was handled by a file management system, FIND 2.

The second innovation was the development of a model by which maintenance requirements could be assigned from a description of the condition of the pavement. The requirements of the model were (Gordon and Curtayne, 1978):

- (a) The model had to be suited to the policy and standards of service of the JCED;
- (b) Input to the model had to be technically compatible with the available resources and organization of the Department;
- (c) Outputs of the model should include a priority listing of maintenance work, required maintenance treatment and a schedule for future inspection.

Ideally the model should produce the best technical and most economic solutions. There was however insufficient information relating to the best maintenance treatment for a given pavement condition to create totally objective models. Furthermore, results that do not conform with current accepted practice would be resisted by the maintenance personnel. As a result it was considered that the best way of developing the model was to analyse the present procedures of the JCED and to present these as a series of formal rules. Accordingly an experiment was carried out involving

staff who normally determine special maintenance requirements in which their assessments of the maintenance requirements or need for future inspections were related to quantified descriptions of the pavement condition. An outline of the format of the experiment is given by Gordon and Curtayne (1978).

This experiment was carried out by Dr R G Gordon during the period 1976-1978 in terms of a cooperative exercise of the JCED and the NITRR. The model was subsequently formulated using the results of this experiment, supplementary information regarding skid resistance and riding quality and policy constraints of the JCED. Full details of the model and its development are given by Gordon (1978).

Although the model was available by the end of 1978, implementation of an operational PMS did not commence until the end of 1979. At that time staff changes had occurred in the crucial positions of the Maintenance Engineer and the Roads Superintendent who undertook the inspections. The loss of these staff accentuated the need for the system as it became apparent that the Department would be unable to train a new inspector and produce the following year's maintenance programme in the time available. Because of a research interest in the application of the model, the implementation was carried with the involvement of the NITRR.

The implementation centred on three main activities:

- validation and completion of inventory;
- specification of data processing;
- organization and training of staff.

Aspects of these are discussed below:

- (a) Crucial to the reliable functioning of the PMS is the integrity of the street inventory. A major undertaking was therefore validating the computerized inventory against street maps and effecting the necessary corrections and additions;

(b) Although the model had been computerized attention had to be given to:

- incorporating it into the computer environment of the JCED;
- providing input data validation procedures;
- allowing automatic access to the inventory;
- providing a program to apply the model network-wide and producing the outputs in the most suitable forms for the users;

(c) Special training was required for the preparation of the input form (i.e. the rating of pavement condition) and the use of the output forms. An inspection guide was prepared in which the various input requirements are explained with the help of photographs (Scullion, 1979). An operations manual was also produced in which the full requirements for operating the PMS are set out (Yorke-Hart, 1981).

The system was first used to assist in preparing the 1980/81 maintenance programme even though the inventory was only partially complete. Sufficient information was provided to identify approximately  $1,8 \times 10^6 \text{ m}^2$  of maintenance work to be done. The shortfall was made up from pavements identified by traditional methods and assessed using the steps laid out in the system but processed manually. By 1981 the inventory was virtually complete and the 1981/82 programme was compiled making full use of the system. Despite a few problems that persist, it is now an accepted part of their programming procedure and is no longer regarded as research and development item of the Department.

Details of the implementation phase of the PMS are given by Scullion and Curtayne (1980) and have been summarized by Curtayne and Scullion (1981). Accounts of the development of the PMS have been published at various stages. These include, apart from the ones previously mentioned, those given by Gordon and Papendorf (1979), Hesom and Curtayne (1981) and Pirie and Curtayne (1982).

Description of the system

The assessment model is the kernel of the computerized aspect of the PMS. Its use is shown diagrammatically in Fig. 4.8. Information obtained from the road inventory and annual selective assessments of pavement condition is used with the model to obtain required maintenance and reinspection recommendations. Some details of these components and the organizational process by which the system operates are given below.

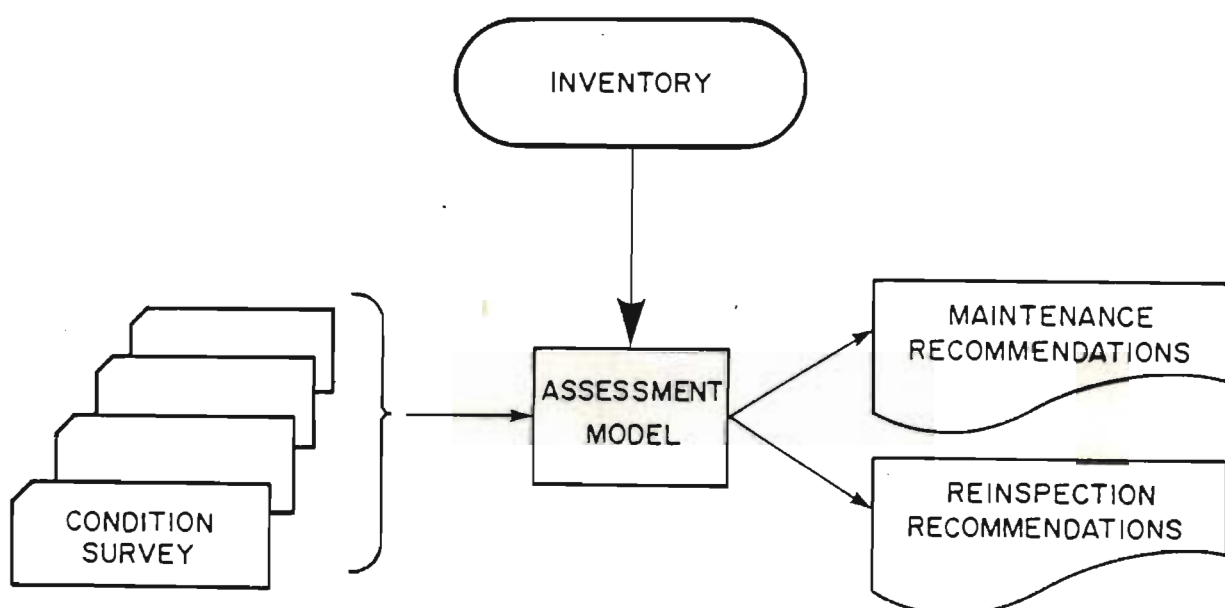


FIGURE 4.8 DIAGRAM OF COMPONENTS OF PAVEMENT MANAGEMENT SYSTEM

(a) The pavement inventory

The JCED street inventory contains information for several applications. Those data relevant to pavement management are given in Table 4.1. Note that there is very little detail about the pavement structure at this stage. Information is restricted to descriptions of surfacings and resurfacings.

TABLE 4.1 : Data items in inventory pertaining to pavement management

Data item	Details
<u>BLOCK IDENTIFICATION</u>	
- Street name	Unique 5 figure code for each
- From street name	
- To street name	
Township code	Unique 3 figure code
Block length, width	In metres
<u>SURFACING DESCRIPTION</u>	
Type of surface	Codes for each
Binder type	
Stone type	
Date of laying	Year, month, day
Laid by	Department or contract
Project No.	5 figure code
Cost	Rands
Taffic class	Class 1 ( 1 000 veh. per day) to Class 6 ( 10 000 veh. per day)

(b) Rating pavement condition

Five aspects of pavement condition are rated, i.e.:

- cracking,
- loss of stone,
- texture depth of surface,
- polishing,
- riding quality.

The method for rating each of these factors is given by Scullion (1979). In addition to the above the rater has to give a personal assessment of the maintenance requirements to be compared later with the assessment produced by the model. Every attempt was made to keep the field rating form as simple as possible.

(c) Assessment of maintenance requirements

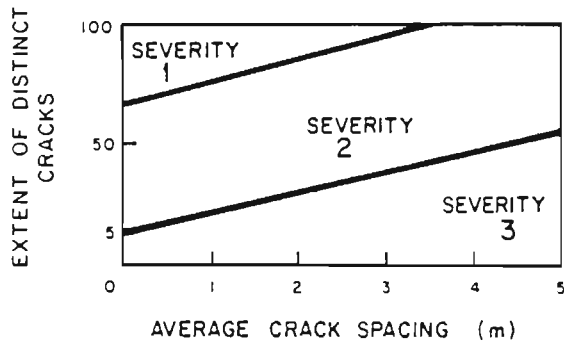
The model operates in three steps. First a severity value is given for each of the factors rated. Such values reflect the need for maintenance due to individual factors alone as defined in Table 4.2. These values are assigned by a set of simple standards, an example of which is shown in Fig. 4.9.

TABLE 4.2 : Description of severity values

Severity	Urgency of maintenance
1	Maintain this year
2	Maintain next year
3	Reassess in 2 years
4	Reassess in 4 years

The next step is to obtain priority values (integers in the range 1-10) for the pavement through a combination of the severity values of the individual factors using the decision table given in Table 4.3.





NOTE :  
Severity 4 = No distinct cracking

FIGURE 4.9 ASSIGNMENT OF SEVERITY VALUES TO CRACKING

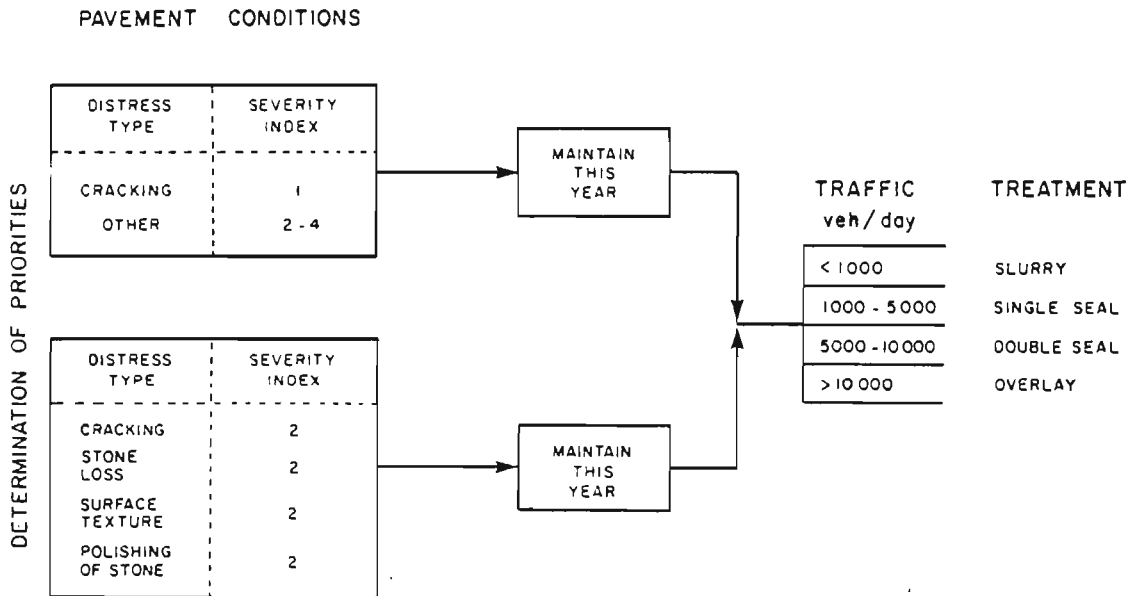


FIGURE 4.10 PORTION OF DECISION TREE FOR DETERMINING MAINTENANCE TREATMENT

TABLE 4.3 : Decision table for determining maintenance priorities

Severity indices for each aspect of condition

Cracking	Loss of stone	Loss of surface* texture depth	Polishing	Riding quality	Priority	Description of Condition
1	2 - 4	2 4	2 - 4	2 - 4	1	Cracking severity 1. Other indices 2 - 4
2	2	2	2	2	2	All aspects of condition have severity 2
2	2	2	2	3 or 4		Cracking and loss of stone severity 2
2	2	2	3 or 4	2	3	with 2 other aspects of condition having severity 2
2	2	3 or 4	2			
2	2	2	3 or 4	3 or 4		Cracking and loss of stone severity 2
2	2	3 or 4	2	3 or 3	4	with one other aspect of condition having severity 2
2	2	3 or 4	3 or 4	2		
2	2	3 or 4	3 or 4	3 or 4	5	Cracking and loss of stone severity 2 other indices 3 or 4
2	3 or 4	2	2	2		Either cracking <u>or</u> loss of stone severity 2, other aspects of condition having severity 2
3 or 4	2	2	2	2	6	
2	3 or 4	2	2	3 or 4		
2	3 or 4	2	3 or 4	2		
2	3 or 4	3 or 4	2	2		
3 or 4	2	2	2	3 or 4		
3 or 4	2	2	3 or 4	2		
3 or 4	2	3 or 4	2	2		
2	3 or 4	2	3 or 4	3 or 4		Either cracking <u>or</u> loss of stone severity 2. Either 0,1 or 2 other aspects of condition having severity 2
2	3 or 4	3 or 4	2	3 or 4	7	
2	3 or 4	3 or 4	3 or 4	2		
3 or 4	2	2	3 or 4	3 or 4		
3 or 4	2	3 or 4	2	3 or 4		
3 or 4	2	3 or 4	3 or 4	2		
2	3 or 4	3 or 4	3 or 4	3 or 4		
3 or 4	2	3 or 4	3 or 4	3 or 4		
3 or 4	3 or 4	2	2	2	8	Cracking <u>and</u> loss of stone severity 3 or 4. All other aspects of condition having severity 2
3 or 4	3 or 4	2	2	3 or 4		
3 or 4	3 or 4	2	3 or 4	2		
3 or 4	3 or 4	3 or 4	2	2	9	Cracking <u>and</u> loss of stone severity 3 or 4. One or two other aspects of condition having severity 2
3 or 4	3 or 4	2	3 or 4	3 or 4		
3 or 4	3 or 4	3 or 4	2	3 or 4		
3 or 4	3 or 4	3 or 4	3 or 4	2		
3 or 4	3 or 4	3 or 4	3 or 4	3 or 4	10	All severity indices are 3 or 4 but age of surfacing exceeds estimated maximum life of seal based on historical data

\* Note : For minor roads with traffic < 1 500 vehicles/day, the standards are relaxed as follows:  
Several Index 2 for loss of surface texture depth to be treated as Severity Index 3.

Finally the preferred type of maintenance treatment is determined on the basis of average daily traffic together with pertinent aspects of the pavement condition. This is done by means of the decision tree shown in Fig. 4.10.

Two types of output are produced:

- a list of maintenance assessments for each street in each township (as shown in Fig. 4.11);
- a summary of maintenance requirements giving total work involved for each priority and each maintenance type.

(d) Determining the inspection schedule

An important feature of this system is that roads are inspected selectively to reduce the effort of the field staff. The criteria for including a road in the inspection schedule are based on the minimum age expected from different types of surfacings before distress occurs and on the results of previous inspections.

(e) Operation of the system

An outline of the procedure by which the system operates is shown in Fig. 4.12. (A full description is given by Yorke-Hart, 1981.) The procedure is made up of the following steps:

- (i) A list of roads to be inspected is obtained from the computer output;
- (ii) Inspections are carried out according to the prescribed procedure. The results are analysed by the assessment model and a list of maintenance recommendations and priorities are obtained;
- (iii) By weighing the information given in the summary of maintenance requirements up against the available budget, the maximum priority value for which maintenance can be considered is determined;

RECOMMENDED MAINTENANCE REQUIREMENTS  
 \*\*\*\*\*

TOWNSHIP- TURFFONTAIN  
 \*\*\*\*\*

STREET- DESCRIPTION	1 2 3 4 5 6 7 8 9									AREA	COST	INSPECTOR		DIF
										sq m	RAND	TYPE	YEAR	
STREET- GARDEN STREET										5200	6240	SS	1980	
GERMAN ROA TO XAVIER ROA	SS									3200	3840	SS	1980	
XAVIER ROA TO COPONATION	SS									15700	18840	SS	1980	
COPONATION TO EASTWOLD	SS									3200	3840	SS	1980	
EASTWOLD W TO SIDE ROAD										-----	-----			
										27300	32760			
										-----	-----			
STREET- BELLAVISTA ROAD										4800	2400	SS	1980	***
TENNYSON D TO SOUTH YARD	SL									10600	5300	SS	1980	***
SOUTH RAND TO VAN HULST	SL									-----	-----			
										15400	7700			
										-----	-----			
STREET- DE VILLIERS STREET										8000	17600	VR	1983	
DONNELLY S TO LEONARD ST	VR									VF 14200	31240	VF	1983	
LEONARD ST TO CORNWALL R										-----	-----			
										22200	48840			
										-----	-----			
STREET- ALLIN STREET										4800	2400	PI	1982	**
BELLAVISTA TO SIDE ROAD	SL									-----	-----			
										4800	2400			
										-----	-----			

FIGURE 4.11

EXAMPLE OF COMPUTER OUTPUT OF ASSESSMENTS OF MAINTENANCE REQUIREMENTS FOR PMS FOR JCED

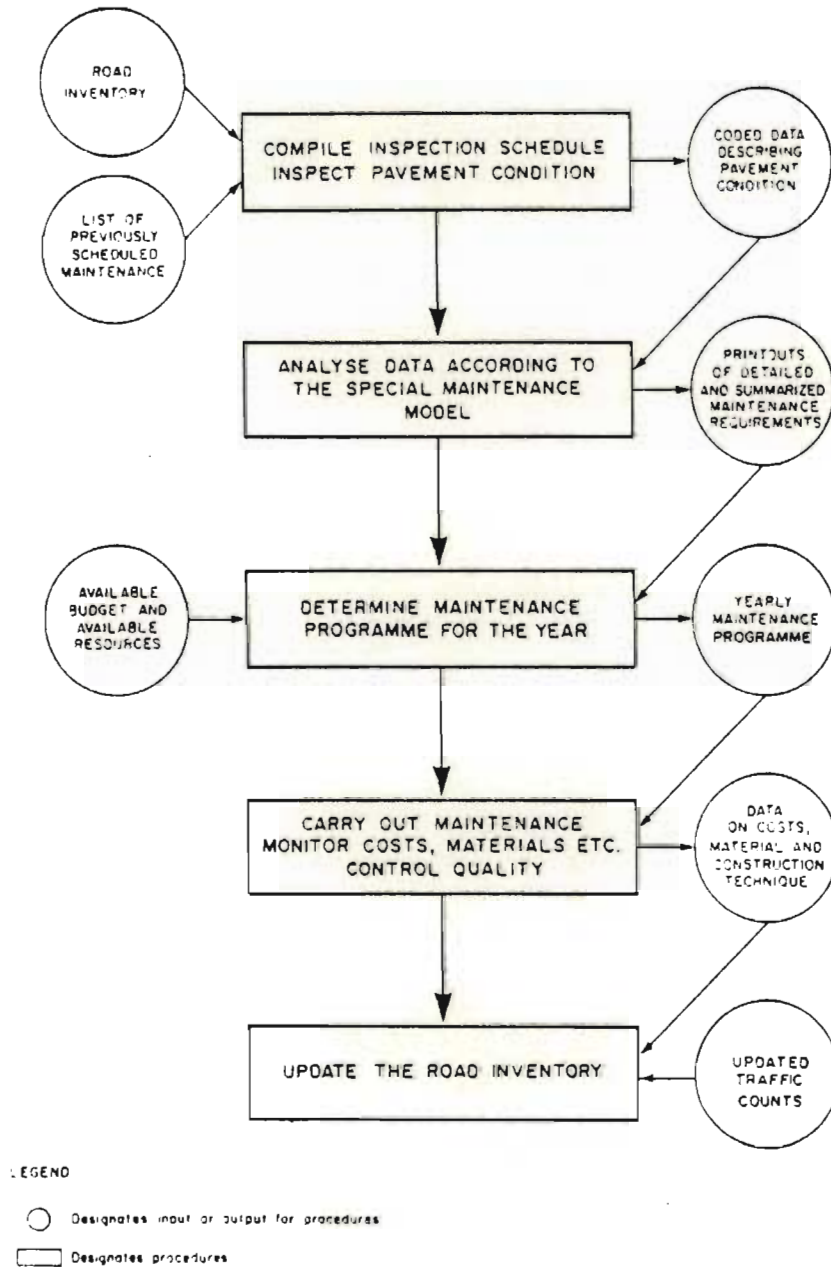


FIGURE 4.12 PROCEDURE FOR OPERATING JCED PMS

- (iv) This information is used to plan the maintenance programme after discrepancies between the model's and the inspector's assessments have been resolved.
- (v) Finally, details (e.g. cost, materials) of the maintenance work carried out during the year is used to update the inventory.

This operation is clearly aimed at ensuring that all pavements that are in need of maintenance are inspected and that the maintenance requirements are determined by formal criteria. Although this only partially satisfies the requirement of a PMS it has greatly enhanced their pavement management ability and laid the foundation for future development.

#### Evaluation

Despite several problems a satisfactory level of implementation was achieved fairly quickly. Usable results were obtained during the first year (1980) and their application was soon extended to the whole network and their reliability improved so that today the system is accepted as the official procedure for planning special maintenance. The main benefit experienced by the Maintenance Engineer of the JCED is the greatly improved control over the special maintenance planning procedure at a reduced cost (Jeoffreys, 1983). Previously two road inspectors were required to select pavements for the maintenance programme. This is now done by one inspector, part time, in a far more reliable and consistent fashion.

The problems encountered centred on the fact that the introduction of a PMS falls outside the recognized scope of the traditional duties and structure of the organization and therefore relies on the personal interest of the people involved. Specific problems were:

- (a) Staff changes. A large part of implementation concerns the motivation and the training of the staff carrying out the work.

These are required at all levels of management (i.e. senior, middle and field management.) A change of staff at any of these levels can result in a lapse of motivation from that quarter. This can severely impede the momentum of the work and jeopardize the project. In the implementation of this system, changes occurred at all three levels. However apart from temporary setbacks, continuity was maintained.

- (b) Communication. Various aspects of the implementation required communication and cooperation outside the normal organizational channel, which made them difficult to control. Although this caused problems from time to time, they were largely overcome by personal motivation (from an appreciation of the value of the work) and from encouragement by senior management.

Although goal setting and planning are important, it became clear that motivation of staff and momentum of the project were crucial to successful implementation. Motivation was promoted by:

- education at all levels regarding the nature and purpose of the work;
- participation at all levels in goal setting and work formulation;
- early results that were meaningful to the field staff.

Apart from these tactics, the success achieved has been attributed to:

- the simplicity of the system;
- the adaptation of the system to existing procedures as far as possible;
- the support of the field staff;
- the use of decision criteria acceptable to the maintenance staff.

Future development

Although this is no longer considered a research project, a number of improvements and enhancements are being planned. Some of these are discussed in the following.

- (a) Improvement in computer facilities. A major problem is that the Maintenance Division does not have direct access to the main-frame computer on which the PMS is run. This means that many delays in data communication are experienced which inhibit the smooth operation of the system. Some of the outputs are still not in their final form and are unnecessarily cumbersome to use. Serious attention is being given to overcoming these problems in the face of the difficult financial conditions now prevailing.
- (b) Updating the model. During the use of the system many differences between the results of the model and the inspector's assessments have been observed. These discrepancies will have to be investigated and the model modified where necessary.
- (c) Strategic planning. Even in its current form, the PMS can be useful in assisting the Department in their strategic planning by means of simple presentations of data in the inventory. For example, age distributions of surfacings can be obtained by dividing the total area of pavement into categories of surfacing type, surfacing age and traffic. A knowledge of the average life of each surfacing category can then be used to obtain a time distribution of future maintenance needs. This can be used to estimate total resource requirements for future years. Hypothetical examples are illustrated in Figures 4.13 and 4.14. Suitable computer programs for this application are under consideration.



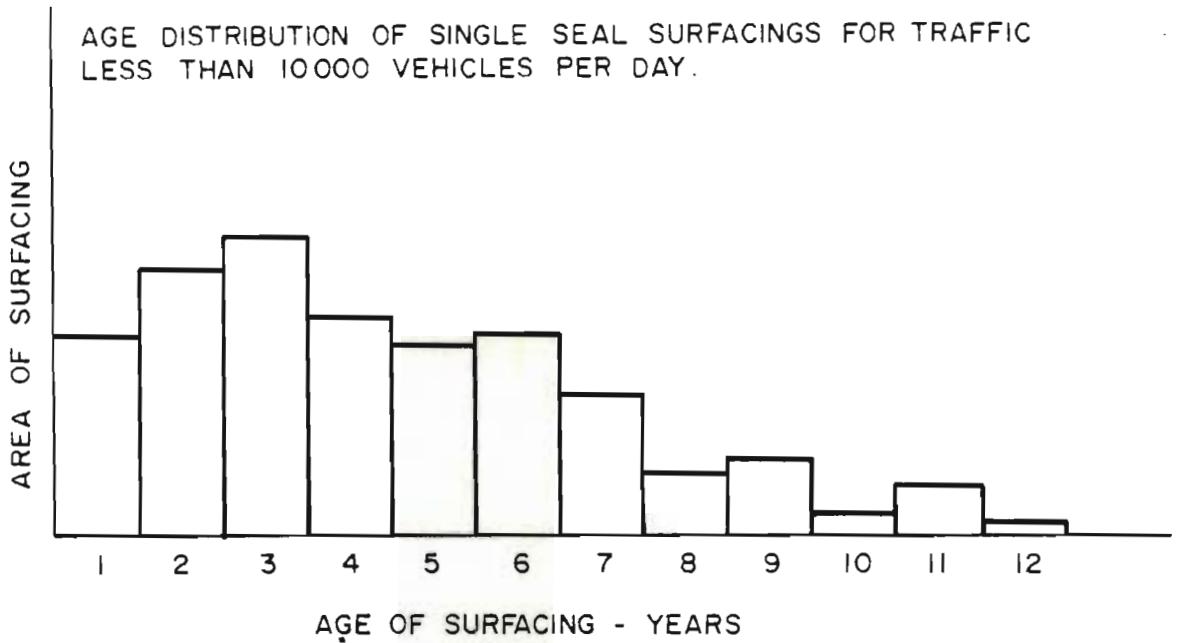


FIGURE 4.13

*HYPOTHETICAL EXAMPLE OF DISPLAY OF AGE DISTRIBUTION OF CERTAIN CLASSES OF SURFACING*

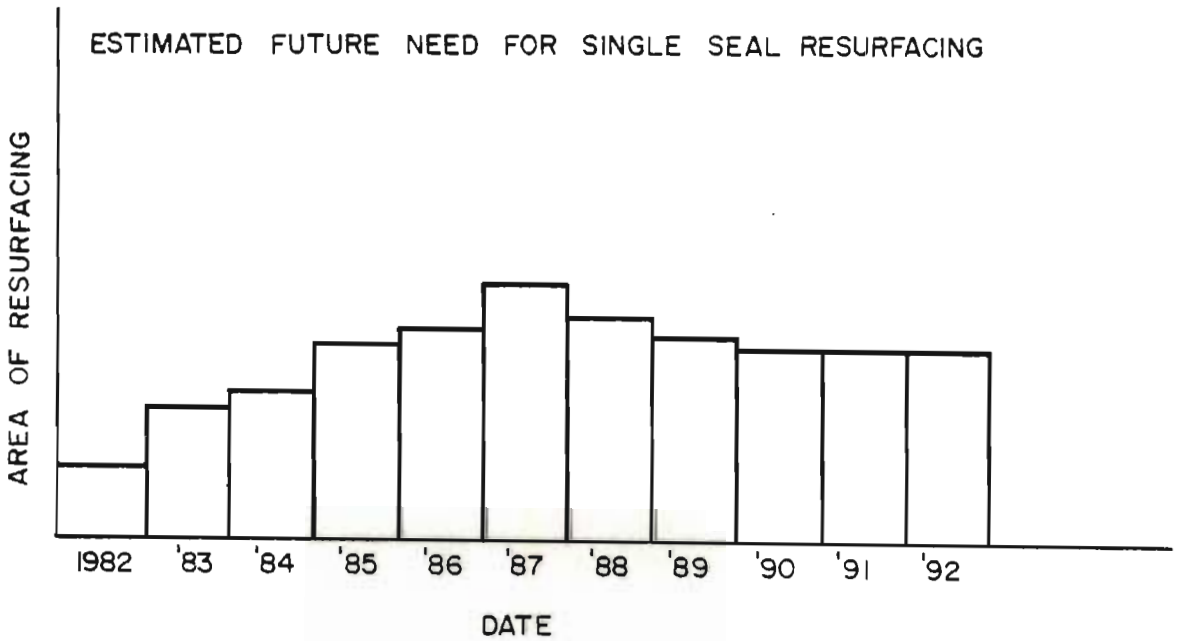


FIGURE 4.14

*HYPOTHETICAL EXAMPLE OF ESTIMATED FUTURE MAINTENANCE NEEDS.*

#### 4.4 SYSTEM FOR THE CAPE ROADS DEPARTMENT

##### Pavement network

The administration of the roads in the Cape Province differs from that in other provinces in that the improvement and maintenance of the greater proportion of the network is controlled by 36 local authorities, i.e. the Divisional Councils. The rural road classification of the Province is:

- Trunk Roads. These are the major arterial routes.
- Main Roads. These are generally farm-to-market type roads.
- Divisional Roads. These are district roads servicing an average of about 12 farms.
- Minor roads. These are generally access roads to farms.

There are about 13 000 km of Trunk Roads, almost all of which are surfaced. They are wholly owned, financed and maintained by the Department.

There are 18 000 km (14 000 km of which are gravel) of Main Road and 39 000 km (38 000 km of which are gravel) of Divisional Road. These are constructed and maintained by the Divisional Councils almost entirely with subsidies from the Department.

The maintenance of minor roads is done by the Divisional Councils and financed by local taxes.

A new subsidy scheme came into force in 1980. In the 1980/81 financial year expenditure by the Department was as follows (Province of the Cape of Good Hope, 1981):

- Routine maintenance (Trunk Roads)	R 10,4 million
- Reseals (Trunk Roads)	R 2.2 million
- Construction/reconstruction	
(Trunk Roads)	R 75,6 million
- Subsidies to Divisional Councils	
(for 1980 calender year)	R 46,0 million

Total expenditure, including administration costs, was R 151 million (Hamilton, 1982).

#### Development of the PMS

It is clear from the above that the Trunk Road system is the main concern of the Department at operational level. Management of these roads is done with the help of eight District Offices.

This network has grown from about 2 000 km in 1951 to over 13 000 km at present. The stage has now been reached where the planned network is virtually complete and the emphasis of the Department's planning activities has shifted from the selection of new roads to be constructed to identifying and prioritizing rehabilitation (or total reconstruction) needs of existing roads (Rickwood et al, 1982)

Until recently the rehabilitation programme was formulated on the basis of biennial reports of the District Roads Engineers (DREs) to Head Office. This report gave a general assessment of each road in the District and an estimate of the remaining life of the pavements. The procedure for making these assessments were not standardized and therefore were highly subjective and variable. This meant that it was difficult for Head Office to get a reasonable view of the needs of the network as a whole and to assign realistic priorities. Furthermore, data in Departmental files that could contribute to the assessments were not accessible easily enough to be useful. (Further details of this situation are given by Rickwood, 1980.)

Recognition of these problems, in 1980, gave rise to a cooperative project of the NITRR and the Department to implement a PMS. The objectives of the PMS were set out as (Rickwood, 1980):

- (a) Improvement of the procedure by which rehabilitation projects are identified and scheduled. This includes:

- making the procedure less subjective and thus encouraging some uniformity of approach among DREs and Head Office;
- improving the methods of acquisition, storage, analysis and retrieval of relevant data.

(b) Improvement of strategic planning, i.e. better estimates of future rehabilitation expenditure and better information on which to base policy evaluations and revisions.

(c) Once historic information is available, improvement of facilities for evaluating different pavement and rehabilitation designs.

From experience with the implementation of other PMSs, it was decided to limit the scope of the initial development and aim to have usable features of the system available within two years. Accordingly, (a) above was chosen as the object of the first phase of implementation and an intensive work programme was set up to fulfil the requirements within 18 months.

The development of the PMS was highly successful considering the difficulties that were encountered (such as the resignation of two key members of the implementation team). The system was providing useful information after the 18 month period and sufficient progress had been made after 24 months for the system to assist in preparing the rehabilitation programme.

#### Evaluation

The implementation of this system has demonstrated what can be achieved with proper planning, cooperation of departmental staff and support from top management. Nevertheless one should not lose sight of the fact that even a system of such modest proportions requires a substantial effort from a large number of people. However the users felt that the results amply justified the work.

The data base contains comprehensive information about the pavement structures, traffic and pavement condition, which is now readily available on standard output forms. (This in itself was considered worth the effort.) An algorithm has been prepared to identify and prioritize rehabilitation projects. Although based on fairly simple concepts, it provides a standardized method of assessing problem pavement lengths according to their current condition. (A more complex algorithm that takes into account predictions of future behaviour of pavements and budget constraints is being considered.)

The provision of of these facilities essentially completes the first phase of implementation; the next is being planned. This work is discussed more fully in Chapter 5 in which details are given of:

- the implementation considerations;
- the nature of the system;
- future planned developments.

#### 4.5 SYSTEM FOR THE TRANSVAAL ROADS DEPARTMENT

The Transvaal Roads Department is the biggest road authority in South Africa. It directly controls a network of some 49 000 km of road, 17 000 km of which are bituminized, on which it expended R 240 million for 1980/81 (Hamilton, 1982).

In 1979 the Department had defined the need for a management information system (MIS) to assist in a variety of their management activities. The NITRR carried out a feasibility study on their behalf (Curtayne et al, 1979) to set out the requirements and scope of the development of a MIS for the following functions:

- (a) Management of the road network, i.e. the identification of improvement and maintenance needs and the determination of work to satisfy these needs.

(b) Management of construction equipment, i.e. primarily the control of the maintenance and utilization of equipment and the assessment of the performance of various items with a view to making recommendations for future purchases.

The effort in setting up the system suggested from this study was more than the Department was willing to undertake at the time. They decided to postpone any development until there was more confidence about the usefulness and practicality of such systems.

Subsequently, as the needs of the Materials Division of the Department grew, they began computerizing pavement data on a structured basis, borrowing certain of the principles emanating from the above study. This initiated the development of their PMS.

The following summary of the development, current status and future prospects of their PMS was obtained from Kleyn and Van Heerden (1983).

The structure of the system has been defined as the interlinking activities of:

- monitoring the network and defining maintenance projects and their urgency;
- further analysis of pavements and design of maintenance treatment;
- programming maintenance work.

Good progress has been made in the first of these sets of activities despite difficulties of staff time and meagre computer facilities.

The paved portion of the network has been defined in terms of sections that are reasonably uniform with respect to traffic, climate and pavement type and strength. Subjective assessments of the pavement condition have been made for all of these sections by a team of materials engineers. Assessments are made on a five-

or three-point scale for various functional aspects of the pavements and on a five-point scale for the degree and extent various types of structural distress. (The assessment form is shown in Fig. 4.15.)

The maintenance requirements are determined by an algorithm that gives the expected year in which rehabilitation or resealing should be done provided that this falls within the following five years. (An example of the output is shown in Fig. 4.16.) The results of this algorithm agreed well enough with the opinions of the Regional Engineers for them to accept it as a method for screening their pavements.

Encouraged by the success of this initial phase of the development, the Department is considering a substantial expansion of data in the system. These will include:

- pavement structure details (mainly layer thicknesses and materials codes as per TRH14; National Institute for Transport and Road Research, 1980);
- traffic data obtained by accessing the data base being set up by the Planning Division;
- climatic zones classified by rainfall;
- measured values of riding quality.

There is a growing appreciation of the PMS in the Department at all levels of management. It already performs a useful function and the prospects appear good for it to expand and to become better integrated into their pavement management operations.

#### 4.6 OTHER ROAD AUTHORITIES

##### Natal Roads Department

The Natal Roads Department administers a network of 15 000 km of which 5 000 km are bituminized. Total expenditure for roads for 1980/81 was R 94 million (Hamilton, 1982).

<u>TRANSVAALSE PAAIEDEPARTEMENT</u>								VORM LM 3					
<u>TAK MATERIALE</u>													
<u>PLAVEISELWAARDERING (FASE 1)</u>													
PAD NR :		Voorbeeld			DATUM :		83-04-11						
GEDEELTE :		km 12,7 - 17,9			OPNEMER :		MJJ v H						
		P2/6 - P123/1			TERREIN :		<input type="checkbox"/> BERG <input type="checkbox"/> HEUVEL <input checked="" type="checkbox"/> <del>DO</del> <input type="checkbox"/> PLAT						
STREEK :		<input type="checkbox"/> BENONI <input type="checkbox"/> ERMELO <input type="checkbox"/> L-BURG <input type="checkbox"/> P-BURG <input type="checkbox"/> POTCH <input checked="" type="checkbox"/> <del>PRETORIA</del> <input type="checkbox"/> R-BURG <input type="checkbox"/> TUISLAND											
<b>FUNKSIONELE WAARDERING</b>													
1 ) RYGENAK		BAIE GOED	GOED	<del>REDELIK</del>	SWAK	BAIE SWAK							
2 ) GLYWEERSTAND		BAIE GOED	<del>GOED</del>	REDELIK	SWAK	BAIE SWAK							
3 ) DREINERING		VOLDOENDE		<del>HISSELVALLIG</del>		SWAK							
4a) SKOUERS		<del>REDELIK</del>		HISSELVALLIG		ONVEILIG							
b) PROBLEEM		VERSPOEL	UITGERY	TE HOOG	<del>BAAL/</del> SKUINS	TOEGEGROEI	ONSTABIEL						
<b>STRUKTURELE WAARDERING</b>													
DEKLAAG		GRAAD					OMVANG						
		GERING		ERG			SELDE		BAIE				
5a) DEKLAAGDEFEKTE		<input checked="" type="checkbox"/>											
b) DROOG/BROS													
c) KLIPVERLIES													
d) DEKLAGKRAKE													
e) DEKLAGSWIGTING													
f) BLOEI/RYK													
STRUKTUUR		GRAAD					OMVANG						
		KLEIN/GERING		GROOT/ERG			SELDE		BAIE				
6a) KRAKE (ALGEMEEN)		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2	3	4	5	1	2	3	4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
b) STABILISASIE		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>									<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
c) VERSAKKING													
d) LANGS													
e) KROKODIL													
7 ) POMPAKSIE		<input checked="" type="checkbox"/>	1	2	3	4	5	1	2	3	4	5	
8a) VERVORMING (ALGEMEEN)		<input checked="" type="checkbox"/>	1	<input checked="" type="checkbox"/>	3	4	5	1	<input checked="" type="checkbox"/>	3	4	5	
b) SPORING				<input checked="" type="checkbox"/>					<input checked="" type="checkbox"/>				
c) GOLWING/VERSACKING				<input checked="" type="checkbox"/>					<input checked="" type="checkbox"/>				
8a) SWIGTINGS/SLAGGATE/LAPWERK		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2	3	4	5	1	2	<input checked="" type="checkbox"/>	4	5	
b) VOORKOMS		STRUKTURE	BUITE RANTE	LEEGTES	<del>HELSLAGS</del>	DEUR-GRANINGS	ALGEMEEN						

FIGURE 4.15 FIELD ASSESSMENT FORM OF TRANSVAAL ROADS DEPARTMENT



TRANSVAALSE PAAIEDEPARTEMENT  
TAK MATERIALE  
AFDELING PLAVEISELMONITOR

VEL 1  
83/01/01

-----  
PADNR:

AFSTANDE	SKAKEL	PSI	DEKL	KRAK	POMP	VERV	SWIG	ERNS	SEEL	HERBOU
17,3 - 22,1	434 - 327	2,5	0	23	0	0	0	63		
30,9 - 41,0	2291 - 734	2,0*	42	22	11	23	22	443		86/87*
41,0 - 41,5	734 - 48	2,0*	42	22	11	23	22	443		86/87*
41,5 - 55,0	48 - 2043	1,5*	12	34	11	24	23	460		85/86*
55,0 - 63,4	2043 - 626	1,5*	0	0	0	23	0	194		
63,4 - 64,3	626 - 2164	3,5	11	0	0	11	0	41		
64,3 - 72,2	2164 - 1161	2,5	13	0	0	23	31	331		
72,2 - 76,6	1161 - 1897	1,5*	22	11	0	23	11	297		
76,6 - 77,2	1897 - 1905	3,0	23	0	0	0	0	99		
77,2 - 81,1	1905 - 936	2,5	22	0	11	13	11	276		
81,1 - 82,6	936 - 1952	3,0	12	0	0	0	0	95		
82,6 - 92,8	1952 - 1985	2,5	12	11	0	12	11	210		
92,8 - 98,2	1985 - P85/1	2,5	12	11	0	12	11	210		
98,2 - 100,0	P85/1 -	2,5	12	11	0	12	11	210		

-----  
PADNR:

AFSTANDE	SKAKEL	PSI	DEKL	KRAK	POMP	VERV	SWIG	ERNS	SEEL	HERBOU
0,0 - 5,8	WARMBE - 599	2,5	21	34	0	11	31	223		
5,8 - 10,5	599 - 2008	2,5	21	34	0	11	31	223		
10,5 - 13,4	2008 - GRENS	1,5*	22	21	0	33	31	440		86/87*
13,4 - 17,6	GRENS - 1394	1,5*	22	21	0	33	31	440		86/87*
17,6 - 27,2	1394 - 734	1,5*	22	21	0	33	31	440		86/87*

-----  
PADNR:

FIGURE 4.16 MAINTENANCE ASSESSMENTS FROM PMS OF TRANSVAAL  
ROADS DEPARTMENT

In the middle 1970s concern about certain of their maintenance practices lead them to initiate an investigation into ways of improving the situation. At first this work centred on setting out methods for routine maintenance tasks, training personnel to comply with them and establishing control procedures (Kain, 1978). Further efforts were subsequently made to structure these activities in a formal maintenance management framework. This development is still in progress. Later more formal ways were investigated for identifying special maintenance requirements and PMS options were investigated. However, they decided in 1981 to wait until they could assess the PMS development for the Cape Roads Department before taking further action. Towards the end of 1982 they invited the NITRR to undertake a feasibility study for a PMS development along the lines of the system of Cape Roads Department. This study was carried out in 1983 (Taute, 1983).

#### Orange Free State Roads Department

This Department administers a network of 48 000 km of which 6 000 km are bituminized. Expenditure of the Department for 1980/81 was R 72 million (Hamilton, 1982).

The Department has very poor access to pavement data and little by the way of formal pavement management procedures. They are, however, acutely aware of the need for developing more systematic procedures. They identified the following shortcomings (Yorke-Hart, 1983):

- inability to make use of information within the Department for engineering decision making for routine matters;
- lack of confidence in the programming of work in order to make optimum use of their funds;
- inability to evaluate or demonstrate the effectiveness of various maintenance strategies, or the effect of budget changes on the overall performance of the network.

They are currently investigating the feasibility of introducing a suitable PMS. They would prefer initial development to take the form of a simple system with which they can become familiar

quickly and operate with confidence since they do not have the necessary staff support to run a sophisticated computerized system.

#### Other urban authorities

A number of urban authorities have recently expressed an interest in setting up simple PMSs along the lines of the one operating in Johannesburg. Several factors appear to have contributed to this rise in interest, e.g.:

- the current financial climate in which they have to justify more objectively their need for maintenance funds than before;
- a growing need for maintenance;
- a greater awareness of PMS technology.

Implementation by some of these authorities is expected in the near future.

#### 4.7 FUTURE PROSPECTS

Although it has taken a long period of time, the development of PMSs in at least three road authorities has been fairly successful. The state of implementation in South Africa compares favourably with that of the rest of the world.

Other agencies (both rural and urban) have been encouraged by progress achieved and the evidence of the benefits that are being obtained by the authorities concerned.

Judging from the general interest shown and the positive steps being taken, it is probable that all provinces and the Department of Transport will have systems along roughly the same lines within a few years. Care must be taken to ensure that the various systems provide information that is compatible in at least general terms. Though it is instructive for various schemes to develop different ideas and procedures, it is also important to be able compare the needs of the different authorities at national level. Some cooperative study of this requirement among authorities should therefore be encouraged.

It is also possible that the maintenance of certain classes of urban roads may be partially financed by the central government some time in the future. In this event funds would be supplied on the basis of objectively defined maintenance requirements. This would further promote the interest in PMSs among urban authorities and highlight the need for general guidelines for their implementation.

## CHAPTER 5

### DETAILS OF PMS FOR CAPE TRUNK ROADS

#### 5.1 INTRODUCTION

The PMS developed for the Cape Roads Department (CRD), being the newest implementation of this study, has built upon the experience of the other systems and embodies the most recent developments. In this chapter the nature of this system is discussed in some detail, loosely following the structure of aspects set out in Table 2.3. Much of this (plus additional) information is contained in articles by Rickwood (1980), Rickwood et al (1982) and Rose et al (1983).

The success of this development can be contributed to important measures and attitudes adopted during the implementation stage. Many of these were taken to avoid problems encountered in earlier work; others were a result of circumstances prevailing in the CRD. Nevertheless problems still arose to impede progress which should be noted for future implementations. Some of the factors considered during implementation and their results are discussed later in the chapter.

Even though much unfinished business remains before even the first phase of development is totally complete, attention is being given to the structure of refinements and enhancements to the system. This is currently regarded as a research activity. An overview of the proposed approach is given at the end of the chapter.

#### 5.2 DATA INCLUDED IN THE SYSTEM

The various type of data included in the PMS are categorized in Table 5.1. Subsidiary comments follow:

TABLE 5.1 : Data on PMS

Data types	Remarks
Definition of network	List of all routes, and their sections, plus section start and end points and distances of salient features relative to the start.
Traffic	AADT (in equivalent vehicle units <sup>x</sup> and number of heavy vehicles), number of equivalent 80 kN axles.
Pavement structure	For each layer, thickness and material classification as per TRH 14 <sup>xx</sup> . For surfacings also the year opened to traffic is recorded.
Riding quality	As measured by the NITRR's roadmeter. (See Appendix 1).
Deflection	As measured by the Lacroix Deflectograph.
Rut depth	As measured by high speed measuring devices <sup>+</sup>
Cracking, bleeding and ravelling	As assessed by a formalized visual inspection procedure
Maintenance costs	The cost of routine and special pavement maintenance on each section
Climatic region	The climatic environment of every section as given in Department's materials manual 4.

<sup>x</sup>One heavy vehicle = 3 equivalent vehicle units (evu).

<sup>xx</sup>See National Institute for Transport and Road Research (1980).

<sup>+</sup>Development of high speed equipment is being investigated - currently measured with Lacroix Deflectograph (see Appendix 1) in special cases.

#### Network definition

There are 13 000 km of road divided into 79 routes containing a total of 208 sections. Section lengths vary between 2 km and

199 km. The area covers eight Districts. Any datum on the network is referenced by giving the route, section and distance from start of section. In this way, for example, District boundaries and intersections with other roads are given.

Carriageways are distinguished by + and - sign where a + sign indicates those with directions of increasing section distances or the only carriageway. In addition each route section has been assigned a survey direction for riding quality and other mechanical measurements.

### Traffic

Length of pavements between road intersections (or between an intersection and the start or end of a section) are defined as links. Traffic statistics are supplied for every link by a separate data base run by the Statistics Section of the Department.

The number of equivalent 80 kN axles is calculated for each link by multiplying the number of heavy vehicles by the "standard axle factor" assigned to the link, i.e.:

$$E80 = eH$$

where E80 = number of equivalent 80 kN axles

e = standard axle factor

H = number of heavy vehicles

These factors are assigned according to traffic composition of the route section or measurements of axle loads.

### Pavement structure

Pavement structure details for about 70 per cent of the network have been obtained from laboratory materials control sheets and correspondence files. Resurfacing details were obtained from files kept by the Roads Inspector.

Mechanical surveillance

Riding quality is recorded at 0,5 km intervals on a scale of 0-5. Measurements are taken every two or three years depending on the previous results. Deflection measurements are only taken in cases of special interest on an ad hoc basis. The use of lasers in a high-speed rut depth measuring device is being investigated as this is expected to provide a sensitive measure of pavement deformation. However for the moment rut depth is measured with the instrument used with the Lacroix Deflectograph (discussed in Appendix 1) when deflection measurements are required. For both rut depth and deflection the 95th percentile value over 100 m is recorded.

Visual assessments

Visual assessments of cracking ravelling and bleeding are made over a sample 50 m length of pavement every 5 km. In an attempt to make the assessments as simple as possible, each of the above are rated in terms of a "severity value", which in broad terms are defined as:

- Severity 0 = Virtually no distress evident and no requirement for maintenance or even reassessment the following year.
- Severity 1 = Not yet a requirement for maintenance but notable distress that should be reassessed the following year.
- Severity 2 = Distress signifying excessive surface porosity, reduction in structural capacity or poor skid resistance such that maintenance would probably be required within the following budget year, depending on other factors such as traffic and climate.
- Severity 3 = A condition indicating that maintenance is an urgent requirement and probably overdue.

A panel of officials from the Department inspected a number of roads in order to identify conditions of cracking, ravelling and bleeding that they would consider to comply with the above defini-



tions. The results, shown in Fig. 5.1, are specified in their "PMS Visual Assessment Manual". These assessments are made by District staff according a schedule supplied by the PMS based on the age of the surfacing, loss of riding quality and the results of the previous inspection.

#### Maintenance costs

Each month three categories of pavement related maintenance expenditure are supplied by the Districts for each route section (in Rand/km), i.e.:

- normal routine maintenance (crack sealing, shoulder maintenance, patching, filling depressions etc.);
- special routine maintenance (improvement of drainage, reconstruction or overlay of small lengths of pavement);
- resealing.

Currently the normal routine maintenance expenditures are collated and recorded on the PMS data base annually as a total for each route section. Recording of the other categories will follow. It is also desirable that annual maintenance costs be recorded over shorter lengths, say one km, when it is practically feasible to do so.

#### Climate

Three climatic regions have been defined for the Cape province, i.e. dry, moderate and wet. Regional factors of 0,3; 0,5 and 0,75 have been assigned to these regions respectively in accordance with TRH4 (National Institute for Transport and Road Research, 1980). This system has been adopted for classifying the environment of each section in the network.

Severity	Type of cracking	Primarily non traffic ass. cracking	
		Primarily traffic associated cracking	Shrinkage cracking
1	Crack width less than 1 mm and over more than 5 percent of the length	Discernable pattern of transverse cracks width less than 1 mm	Crack width less than 1 mm and over more than 5% of the length
2	Crack width greater than 1 mm and over 5-50% of length. Minimal pumping	Sealable cracks width $\pm$ 3 mm spacing more than 1 m OR sealed cracks	Crack width 1-3 mm and over more than 5% of the length
3	Crack width greater than 1 mm and over more than 50% of the length OR significant pumping, spalling, patching	Sealable cracks width $\pm$ 3 mm spacing less than 1 m. Further disintegration = traffic 3	Crack width greater than 3 mm over more than 5% of the length

TABLE 1: CRACKING

Definitions of severity indices for cracking.

Severity 1	Severity 2	Severity 3
Less than 10% length of wheeltrack binder flush with aggregate	10-50% length of wheeltrack binder flush with aggregate	More than 50% length of wheeltrack binder flush with aggregate

TABLE 2: BLEEDING

Definitions of severity for bleeding.

Severity	Surfacing			
	Single seal	Double seal	Slurry seal	Asphalt
1	Less than 20% stone lost	Less than 30% stone lost in upper layer 0% stone lost in bottom layer	Less than 10% slurry lost	Less than 20% of area fine stone lost from surface, and 0% large stone lost
2	20 - 50% stone lost	30 - 70% stone lost in upper layer, and less than 10% stone lost in bottom layer	10 - 30% slurry lost	20 - 50% of area has fine stone lost from surface and less than 20% of area has large stone lost from surface
3	More than 50% stone lost	More than 70% stone lost in upper layer, and more than 10% stone lost in bottom layer	More than 30% slurry lost	More than 50% of area has fine stone lost from surface, and more than 20% of area has large stone lost from surface

TABLE 3: RAVELLING

Definition of severity levels for ravelling of various surfacings. All descriptions apply to the worst 10 m<sup>2</sup> area within a 50 m length of pavement.

NOTE: Severity = 0 must be recorded where applicable.

FIGURE 5.1 DEFINITION OF SEVERITY VALUES FOR VARIOUS TYPES OF DISTRESS

### 5.3 PMS DATA PROCESSING CONFIGURATION

#### Computer environment

The Department possesses its own HP 1000 Model 45 computer system. The standard system has been modified and now has a 256 k byte high performance memory and a 50 M byte master disc drive. The system has also been extended by the following additions:

- a nine-track tape unit,
- two printers,
- a 600 cards/minute card reader,
- two terminals, one of which has graphics capabilities,
- the data base management system software Image/1000,
- a CALCOMP 748 flatbed plotter.

The computer is under the control of the Computer Services sub-division of the Department and is currently operated by three engineers and three technicians.

The accessibility, user support, and range of facilities offered by this computer environment were considered to outweigh the advantages offered by more powerful main-frame computers supporting sophisticated data base management systems (DBMSs). This far the only significant limitation in the hardware or the use of Image/1000 experienced with the PMS has been the disc storage capacity. However, this will be alleviated when their new 120 M byte disc arrives.

#### Data processing

The data processing routine of the PMS is shown schematically in Fig. 5.2.

The data base is updated regularly from a number of sources. Mechanical surveillance measurements are taken by the NITRR on request of the Materials Engineer. They are supplied on magnetic tape in a format compatible with the PMS data base. Traffic counts

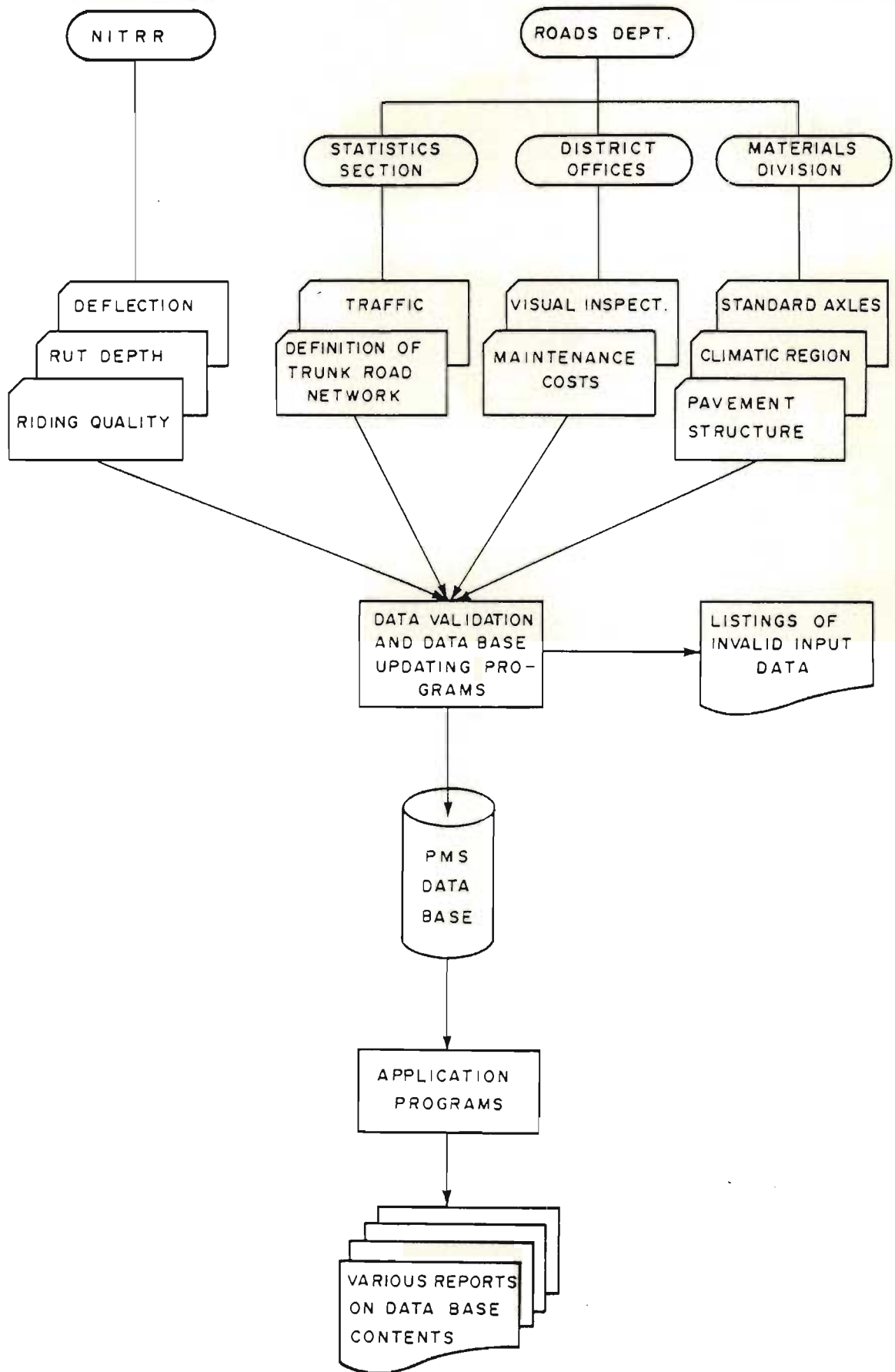


FIGURE 5.2

*SCHEMATIC OF PMS DATA PROCESSING ROUTINE*

are updated annually from the data base operated by the Statistics Section. Visual assessments and maintenance costs are supplied by District staff. Pavement structure details are updated to take account of resealing or rehabilitation.

Various procedures are used to ensure that the required data are provided, e.g.:

- computer programs are used to check the completeness of the data base;
- other programs determine schedules for measuring riding quality and visual assessments, which are sent on to the responsible parties;
- "annual data return" forms are sent to the Districts (with a list of the route sections under their control) on which they give details of any improvements made to pavements during the year and any changes to the network definition.

All incoming data are checked by validation programs. Such data are usually batched and updating will only commence once the entire batch is free of errors to avoid confusion arising from partial updates. After updating a copy of the data base is archived on magnetic tape. The infrequent batch-type updates of the PMS lend themselves to these simple yet robust methods of protecting the security and integrity of the data base and obviate the need for the sophisticated DBMS techniques (e.g. audit trails) required by more dynamic systems.

The query language of Image/1000 allows information to be extracted from the data base fairly easily on an ad hoc basis. Furthermore, a suite of application programs operating on the data base provide a variety of standard reports on request. Details of these outputs are given in Sections 5.4 and 5.5.

#### System design

The data base is divided into two parts. The first one (the "live data base") contains all the most recent information about any particular length of pavement. The other (the "historic data

base") contains current as well as historic information. The reason for this split is that most of the queries are expected to concern current information and can be dealt with more efficiently using the live data base. The historic data base is used when changes with time need to be evaluated.

The data on the live data base is stored in order of distance from the start of route sections. This also allows the most common reports to be produced as fast as possible.

Considerations such as these reduce the effect of the limited power of the DBMS and are suited to the nature and use of the PMS.

The development of the data base was done by consultants in accordance with specifications given by Rickwood et al (1981). Full details of the design, the format of the input files, the structure of the validation and update programs and the validation requirements are given by Worthington-Smith & Associates (1981). Specifications for the application programs were given by Rickwood et al (1981) but they have been modified substantially during development.

#### 5.4 DATA OUTPUTS

Three types of data output are provided by the application programs, i.e.:

- listings of subsets of the raw data in convenient formats;
- graphical and summarized representations of the data for easy assimilation in various pavement management functions;
- results of analyses of the data to assist in determining maintenance requirements.

Examples of the first two types of output are given in this section; the third type is discussed in the next section.

Listings of raw data

The characteristics of the network can be presented in a variety of ways. One instance is given in Fig. 5.3 where the route sections within a particular District are listed with the start and end distances of the section (or that part of the section falling within the District boundaries).

Details of the pavement structure (e.g. layer thicknesses, material classifications, surfacing and resurfacing types and ages) can be tabulated for specified route sections. A typical example is shown in Fig. 5.4.

CPA PAVEMENT MANAGEMENT SYSTEM  
LIST OF DISTRICTS ON THE D-8

ROUTE-SECTION	START DISTANCE	END DISTANCE	DISTRICT CODE	DISTRICT
TR 2/ 1+	0.00	42.79	1	W. CAPE
TR 2/ 2+	0.00	67.84	1	W. CAPE
TR 2/ 3+	0.00	48.78	1	W. CAPE
TR 2/ 4+	0.00	57.05	1	W. CAPE
TR 2/ 5+	0.00	24.57	1	W. CAPE
TR 9/ 1+	0.00	18.70	1	W. CAPE
TR 9/ 2+	0.00	58.09	1	W. CAPE
TR 9/ 3+	0.00	74.59	1	W. CAPE
TR 9/ 4+	0.00	81.74	1	W. CAPE
TR 9/ 5+	0.00	69.50	1	W. CAPE
TR 11/ 1+	0.00	52.45	1	W. CAPE
TR 11/ 2+	0.00	34.01	1	W. CAPE
TR 11/ 3+	0.00	31.16	1	W. CAPE
TR 11/ 4+	0.00	38.26	1	W. CAPE
	0.00			

FIGURE 5.3 LISTING OF ROUTE SECTIONS IN A DISTRICT

Results of condition surveys can be tabulated in the same fashion. Fig. 5.5 gives an example of riding quality measurements.

Similarly the traffic statistics for the links (length of road between intersections) in a given route section can be listed as shown in Fig. 5.6.

Graphical and other summarized data

The results of instrumented measurements of pavement condition can also be given graphically. Fig. 5.7 gives an example of a plot of riding quality measurements over a particular route section. The dotted lines on the graph represent two critical reference values.

\*\*\*\*\*  
 33 3+ FROM: OUDTSHOORN MUN MR 75 TO: DE RUST JCT MR 4  
 \*\*\*\*\*

FPAYST

RSD	START DISTANCE	END DISTANCE	TYPE	LAYER THICKNESS(MM)	MAT CLASS	YEAR OPEN	LOOSE CODE
TR 33 3+	0.00	1.11	10	999	ND	1935	0
			20	999	ND	1935	0
TR 33 3+	1.11	2.80	10	999	ST2	1958	0
			20	100	G4	1958	0
			30	75	G5	1958	0
			40				

FIGURE 5.4 LISTING OF PAVEMENT STRUCTURE DATA

\*\*\*\*\*  
 26 1+ FROM: SPRINGBOK JCT MUN MR 6 TO: POPADDER JCT MR 15  
 \*\*\*\*\*

\*RIDIN

RSD	SURVEY DATE (YYMM)	REC START DISTANCE	PSI VALUES																
			PSI (1)	PSI (2)	PSI (3)	PSI (4)	PSI (5)	PSI (6)	PSI (7)	PSI (8)	PSI (9)	PSI (10)							
TR 26 1+	8211	0 KMS	2.4	2.5	2.7	2.6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	
TR 26 1+	8211	5 KMS	2.8	2.9	3.0	2.4	2.5	2.8	3.0	3.0	3.0	2.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0
TR 26 1+	8211	10 KMS	2.7	2.7	2.9	2.8	2.9	3.0	3.0	3.0	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0
TR 26 1+	8211	15 KMS	2.7	2.9	2.8	2.8	2.8	3.0	3.0	3.0	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

FIGURE 5.5 LISTING OF RIDING QUALITY MEASUREMENTS



The lower line is the terminal level (i.e. the lowest tolerable level) of riding quality. This value,  $p_t$ , depends on the traffic carried by the pavement as follows:

$$\begin{aligned}
 p_t &= 1,5 \quad \text{for} \quad \text{evu/day} < 1\,000 \\
 p_t &= 2,0 \quad \text{for} \quad 1\,000 < \text{evu/day} < 6\,000 \\
 p_t &= 2,5 \quad \text{for} \quad 6\,000 < \text{evu/day}
 \end{aligned}$$

CPA PAVEMENT MANAGEMENT SYSTEM  
LIST OF TRAFFIC DATA ON THE DATABASE

PAGE 13

ROUTE-SECTION	FROM	TO	*****LINK DETAILS*****				*****COUNT DETAILS*****				
			LINK REF #	EQV FACTOR	CARR TRAVEL	YEAR	ADOT	#HYYS	#ES05	%0.1	%0.5
	23.50	25.93	10280140	1.00		1981	0.0000			00.0	00.0
	25.93	27.13	10280145	1.00		1981	3732.0	263	263	00.0	00.0
	27.13	31.03	10280150	1.00		1981	3937.0	267	267	00.0	00.0
TR 28/ 2-	0.00	9.21	10280205	0.60		1981	733.00	57	34	00.0	00.0
	9.21	22.93	10280210	0.60		1981	995.00	85	51	00.0	00.0
	22.93	23.93	10280215	0.60		1981	1052.0	112	67	00.0	00.0
	23.93	28.00	10280220	0.60		1981	759.00	85	51	00.0	00.0
	28.00	44.18	10280225	0.60		1981	709.00	83	49	00.0	00.0
TR 29/ 1+	0.00	3.01	10290105	1.00		1981	2957.0	273	273	00.0	00.0
	3.01	14.39	10290110	1.00		1981	387.00	94	94	00.0	00.0
	14.39	25.32	10290115	1.00		1981	575.00	65	65	00.0	00.0
	25.32	29.51	10290120	1.00		1981	607.00	65	65	00.0	00.0
	29.51	30.54	10290125	1.00		1981	562.00	63	63	00.0	00.0
	30.54	41.18	10290130	1.00		1981	566.00	56	56	00.0	00.0
	41.18	46.45	10290135	1.00		1981	591.00	45	46	00.0	00.0
	46.45	53.12	10290140	1.00		1981	454.00	40	40	00.0	00.0
	53.12	56.36	10290145	1.00		1981	528.00	50	50	00.0	00.0
	56.36	70.99	10290150	1.00		1981	675.00	56	56	00.0	00.0
	70.99	73.95	10290155	1.00		1981	107.00	27	27	00.0	00.0

FIGURE 5.6 LISTING OF TRAFFIC DATA

Any values falling below these limits are considered "severe" and by definition constitute a maintenance requirement. The upper line is the so-called "warning" limit,  $p_w$ , and is given by:

$$p_w = p_t + 0,7$$

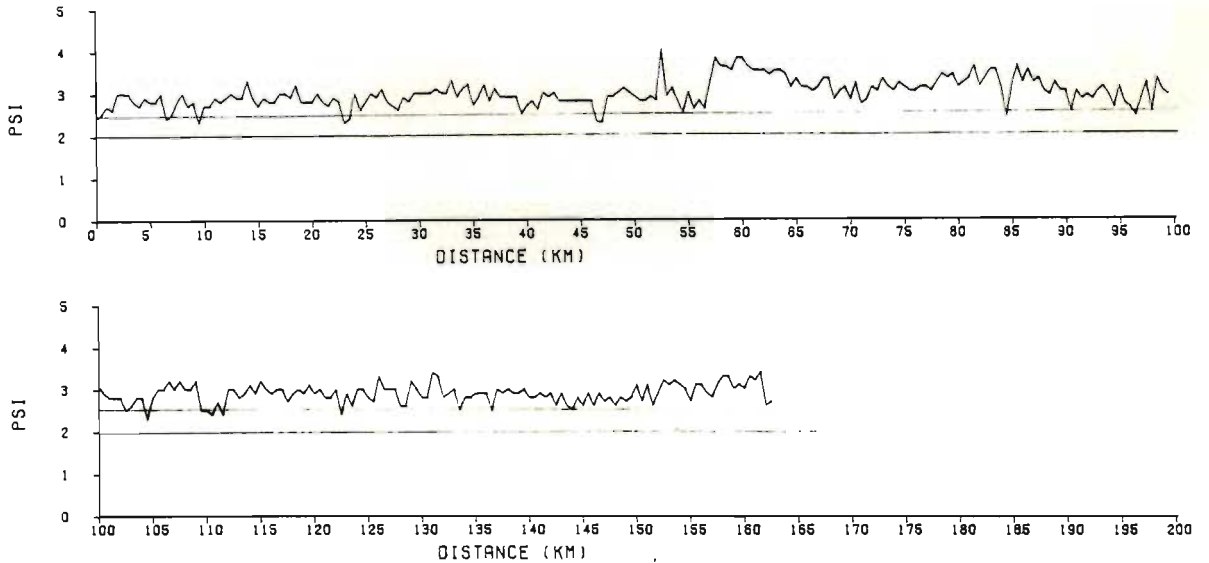
Values of riding quality falling below these limits indicate an impending maintenance requirement.

This representation makes provision for displaying successive survey results so that changes in condition can be readily observed. (As is used for the Department of Transport - see Fig. 4.4.) However at this stage only one set of measurements has been taken.

REPORT DATE: 13/4/83

CAPE ROADS DEPT - PMS  
RIDING QUALITY

SHEET 1



TR 26/ 1+ FROM :SPRINGBOK JCT MUN MR 6 TO :POFADDER JCT MR 19

LENGTH : 163.22

TR026-01/0.00 - 165.00

FIGURE 5.7 EXAMPLE OF A PLOT OF RIDING QUALITY VALUES

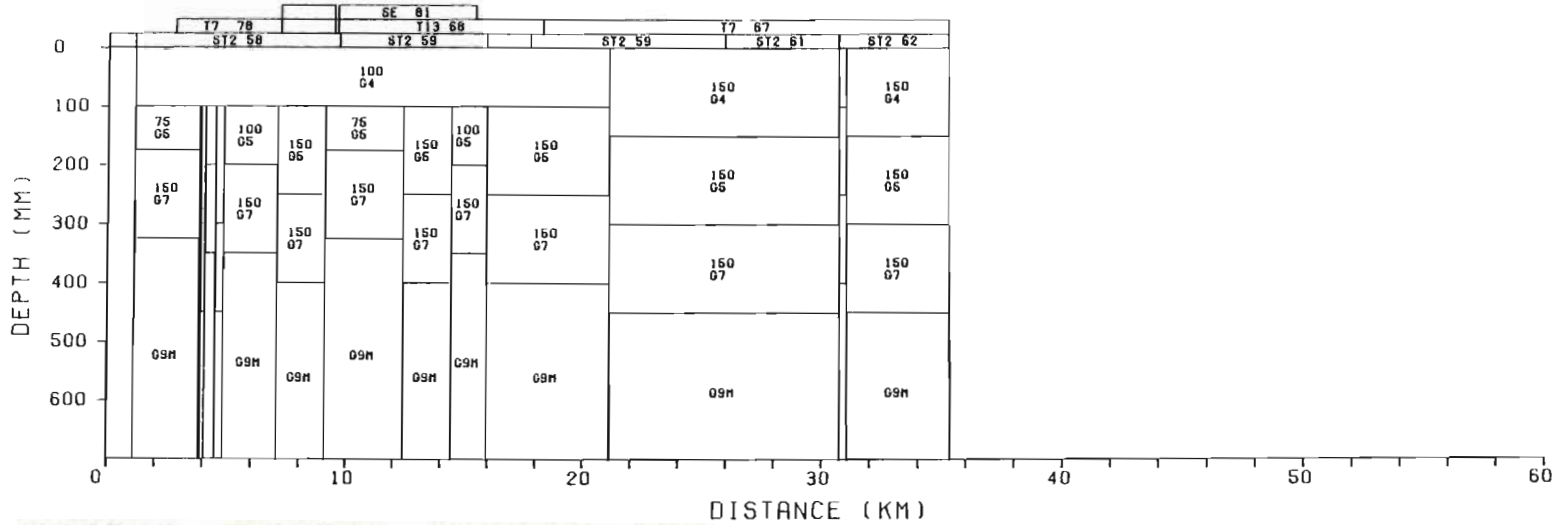
Fig. 5.8 gives an example of a graphical display of the pavement structure. The material code and the thickness of each layer are shown as are the type and age of each surfacing and resurfacing. Where uniform pavement lengths are too short for these data to be shown on the diagram, they are listed below.

Also similar to the representation used for national roads is the summarized display of current pavement condition shown in Fig. 5.9. Here sound, warning and severe conditions are represented by dots, short lines and long lines respectively for riding quality (roughness), rut depth, deflection and visual assessments according to defined critical values. For easy reference, links and their traffic statistics are included in the Figure and the section is divided into lengths of similar pavement structure.

REPORT DATE : 13/4/83

SHEET 1

CAPE ROADS DEPT - PMS  
PAVEMENT STRUCTURE AND REHABILITATION HISTORY



FROM: 0.00 TO: 1.11	FROM: 3.84 TO: 3.91	FROM: 3.91 TO: 4.08	FROM: 4.08 TO: 4.52	FROM: 4.52 TO: 4.86	FROM: 30.77 TO: 31.09
CLASS THICK YEAR	CLASS THICK YEAR	CLASS THICK YEAR	CLASS THICK YEAR	CLASS THICK YEAR	CLASS THICK YEAR
NO 36	04 100 58 05 100 58 07 150 58 09M 58	04 100 58 05 200 58 07 150 58 09M 58	04 100 58 05 100 58 07 150 58 09M 58	04 100 58 05 200 58 07 150 58 09M 58	04 100 62 05 150 62 07 150 52 09M 62

PAVEMENT

SURFACING

FROM :	0.00	7.20	7.20	9.50	15.96	15.96
TO :	1.11	9.50	9.60	9.65	17.01	17.81
NUMBER :	10	9	8	9	10	9
CLASS :	NO	T19	SE	SE	ST2	T13
AGE :		71	01	01	60	68
THICK :						

TR 33/ 3+

FROM : OUDTSHOORN MUN MR 75

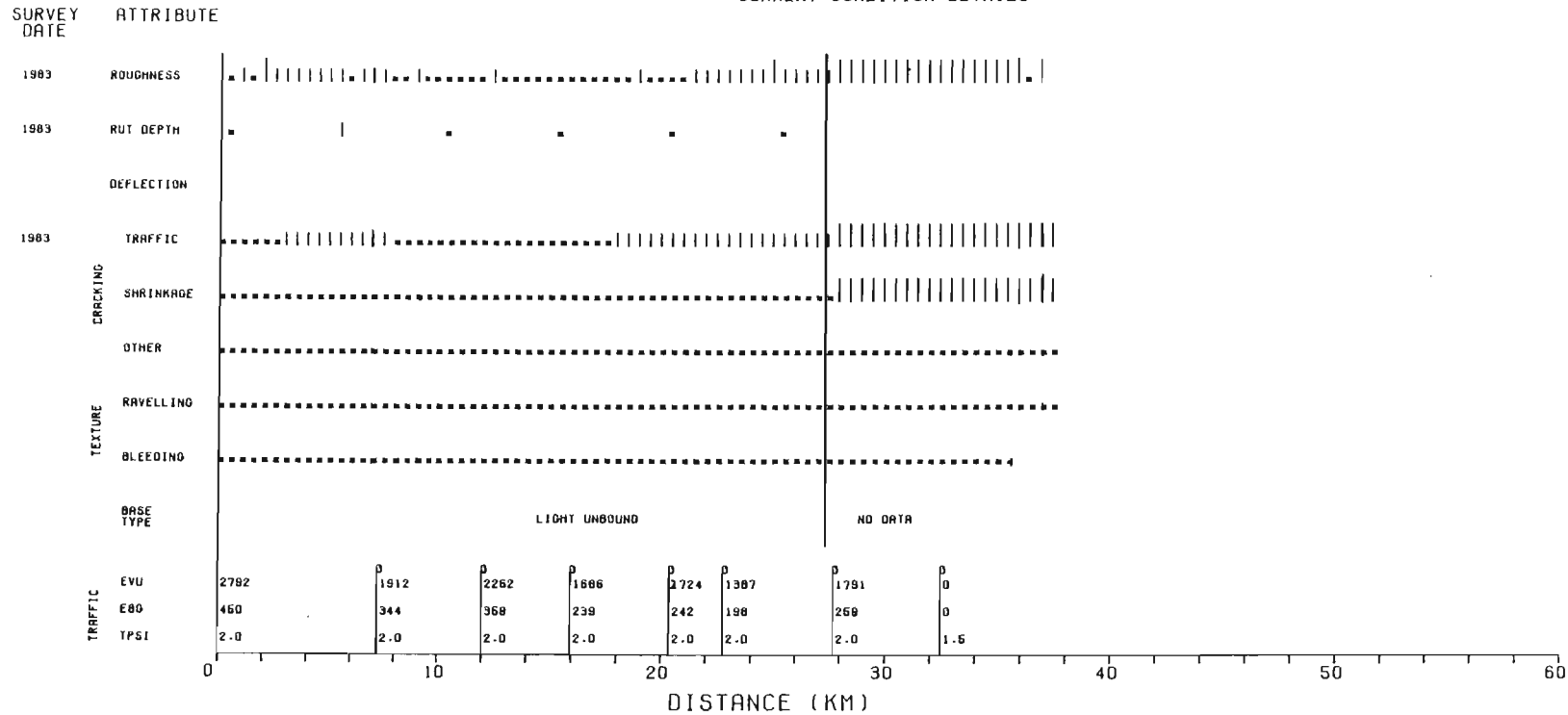
TO : DE RUST JCT MR 4

LENGTH : 35.36

TRO33.03/0.00 - 35.36

(SHEET 1 OF 1)

CAPE ROADS DEPT - PMS  
CURRENT CONDITION DETAILS



SYMBOL	ROUGHNESS	RUTTING	L.U OR M.U DEF < 1MM	DEFLECTION FOR PAVEMENT TYPE N.U OR B.T DEF < 0.7MM	C.T OR C DEF < 0.3MM	CRACKING TEXTURE SEVERITY CLASS 0 OR CLASS 1
■	PSI ≥ TP61+0.7	RUT < 10MM				
	TP61 < PSI < TP61+0.7	10MM ≤ RUT < 16MM	1MM ≤ DEF ≤ 1.4MM	0.7MM ≤ DEF ≤ 1.0MM	0.3MM ≤ DEF ≤ 0.6MM	CLASS 2
	PSI ≤ TP61	RUT ≥ 16MM	1.4MM < DEF	1.0MM < DEF	0.6MM < DEF	CLASS 3

TR 22/ 1+

FROM :GOUDA JCT TR 23

TO :CERES JCT MUN MR 2

LENGTH : 37.09

TRO22.01/0.00 - 60.00  
(SHEET 1 OF 1)

FIGURE 5.9 SUMMARY DISPLAY OF PAVEMENT CONDITION

Note that because of the short lengths of uniform pavement structure commonly found (see for example Fig. 5.6) a broader classification of pavement type is more practical for demarcating lengths of similar structure, i.e.:

(a) Bound pavements

- cement treated
- bitumen treated
- concrete

(b) Unbound pavements

- light
- medium
- heavy

The algorithm by which the unbound pavements are classified is given in Fig. 5.10.

As discussed in the next Section, the main considerations for deciding on rehabilitation are the riding quality of the pavement and the amount of annual routine maintenance being administered. With this in mind, a report form was prepared in which these statistics are summarized for every route section. (A portion of such a report is shown in Fig. 5.11.) An asterisk is placed alongside every section for which either the average maintenance costs exceed R1 000/km/yr or there is 20 km of pavement with riding quality in the severe range.

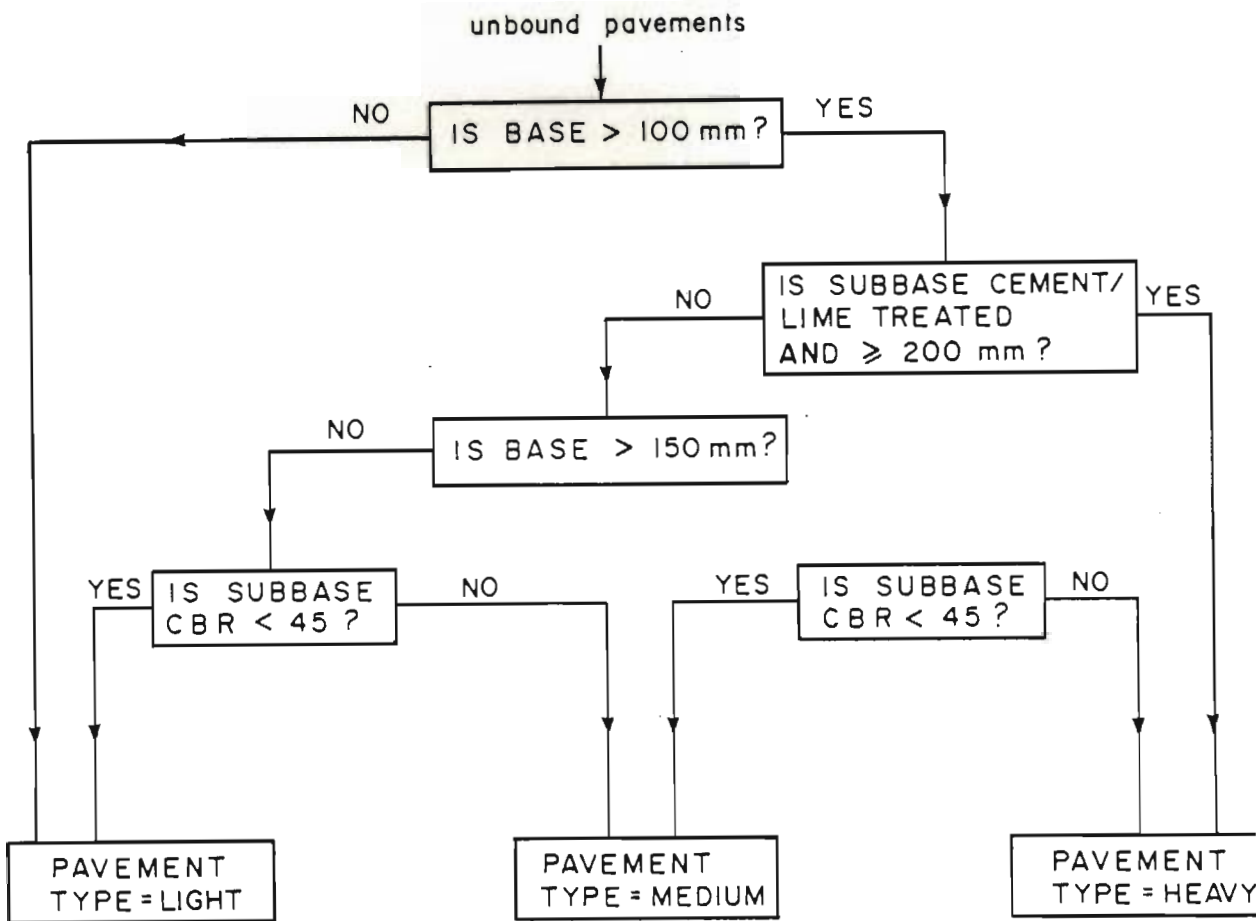


FIGURE 5.10 ALGORITHM FOR CLASSIFYING UNBOUND PAVEMENT TYPES

The various forms of output discussed this far can be used in the following sequence:

- Route sections possibly requiring attention can be identified from the condition statistics report (Fig. 5.11);
- The summarized display of condition (Fig. 5.9) can then be obtained to assess the nature and extent of the problem;
- Appropriate representations of raw data can then be obtained to study the problem further.

This procedure will enable the engineer to familiarize himself very quickly with the condition of the network without recourse to optimization or other analytical routines. As such the data base already provides data for practical decisions to a far greater degree of accessibility than was the case prior to the PMS development.

REPORT DATE : 25/11/83

C.P.A PAVEMENT MANAGEMENT SYSTEM

CONDITION STATISTICS  
=====

DISTRICT : OUDTSHOORN

ROUTE-SECT-DIR.	RSD. LEN KM	M.COST R/KM	** KM-LENGTH CLASSED SEVERE **				** KM-LENGTH CLASSED WARNING **			
			R.QUAL	V.ASS	RUT	DEF	R.QUAL	V.ASS	RUT	DEF
* 1 1 +	24.51	1541	0	0	25	22	0	5	0	0
1 2 +	85.02	673	0	0	85	85	0	10	0	0
1 3 +	59.79	782	0	15	60	43	0	20	0	0
* 2 8 +	44.90	1140	0	0	45	45	0	0	0	0
9 5 +	199.18	434	0	0	0	0	0	0	0	0
* 31 4 +	76.08	1028	0	0	76	76	0	15	0	0
31 5 +	48.18	865	0	0	48	48	0	10	0	0
31 6 +	47.80	574	0	0	0	0	0	0	0	0
* 33 1 +	15.75	1507	0	0	0	0	0	5	0	0
33 2 +	76.60	842	0	0	77	52	0	0	0	0
* 33 3 +	35.36	1258	0	0	0	0	0	0	0	0
* 33 4 +	28.44	1812	0	0	0	0	0	0	0	0
33 5 +	110.04	439	0	15	0	0	0	35	0	0
34 1 +	43.90	740	0	0	0	0	0	0	0	0
35 1 +	148.80	311	0	0	0	0	0	0	0	0
* 44 1 +	78.83	1403	0	0	79	79	0	5	0	0
* 44 2 +	42.90	2670	0	5	43	43	0	5	0	0
58 1 +	111.03	293	0	0	111	28	0	10	0	0
59 1 +	70.65	0	0	0	0	0	0	0	0	0
75 1 +	33.96	917	0	0	0	0	0	0	0	0
* 75 2 +	28.53	1141	0	0	0	0	0	20	0	0
83 1 +	68.60	823	0	0	0	0	0	0	0	0
83 2 +	23.80	0	0	0	0	0	0	0	0	0

RQ:RIDING QUALITY    VA:VISUAL ASSESSMENT    RU:RUT    DE:DEFLECTION    MC:MAINTENANCE COST

- \* : (1) SEVERE RID.QUAL TOTAL LENGTH >= 10 KM.
- (2) SEVERE RID.QUAL TOTAL LENGTH > 50% OF ROUTE SECTION LENGTH,WHEN THE LATTER IS < 10 KM
- (3) MAINTENANCE COST EXCEEDS 1000 R/KM.

FIGURE 5.11 CONDITION STATISTICS REPORT

A further useful graphical display has the form of a road map highlighting lengths of road of interest. This can be given for the whole network or for individual Districts. Fig. 5.12 gives an example for the Western Cape District in which selected lengths are highlighted by thick lines. This type of display can be used to show the locations of surfacings exceeding a given age, links with traffic falling in a specified range, sections requiring measurements of a particular type and many other properties of interest.

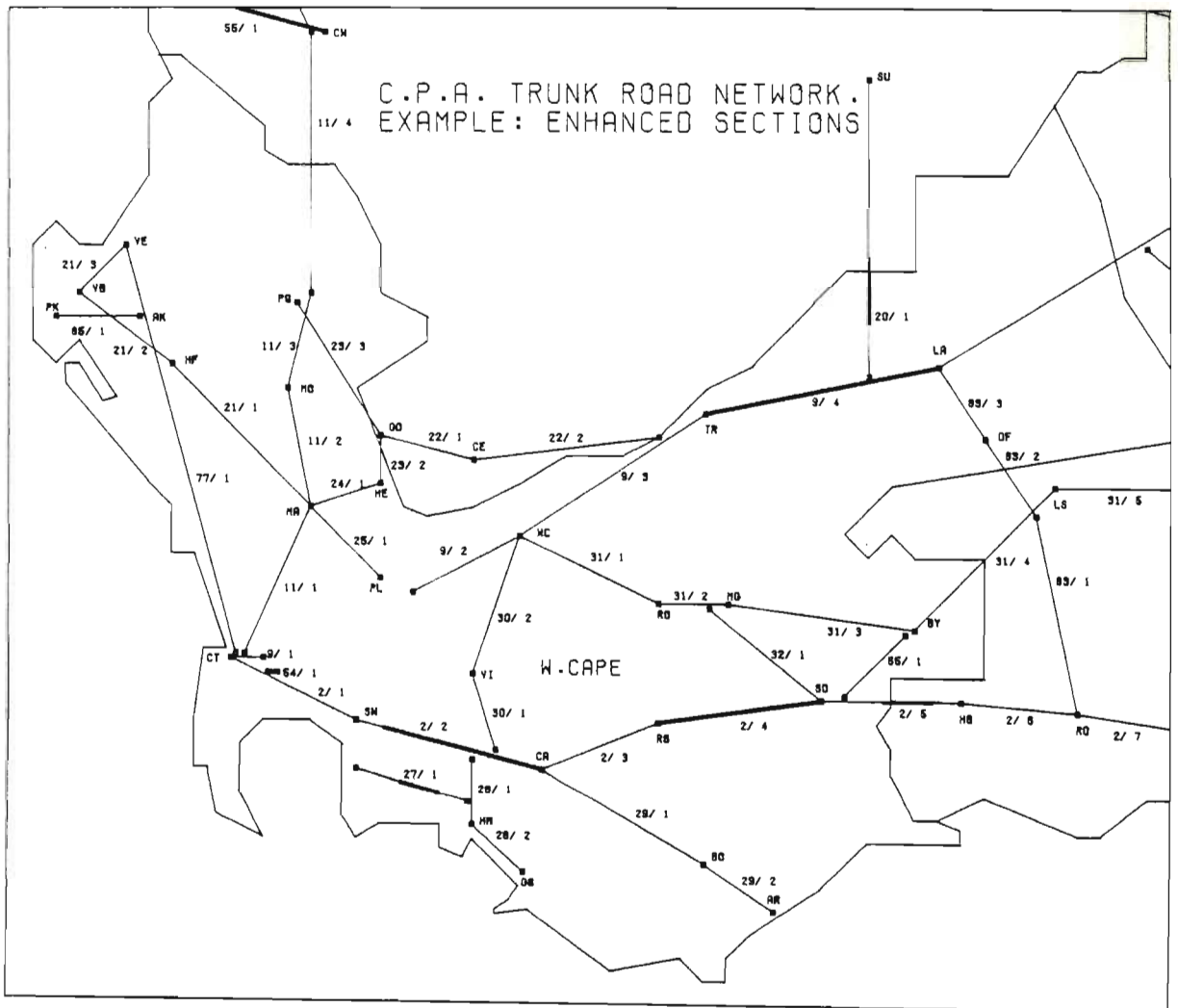


FIGURE 5.12 ROAD MAP DISPLAYING SECTIONS OF INTEREST



5.5 PRELIMINARY ALGORITHM FOR DETERMINING MAINTENANCE REQUIREMENTSPurpose and nature of algorithm

In addition to providing the necessary data for describing the pavement condition, a formal procedure is required which can determine maintenance projects from the data and assign them urgency or priority values. This introduces two problems:

- (a) The first is the need for a set of rules to assign a type and a priority of maintenance to a pavement of given uniform condition;
- (b) The second is to formulate a further set of rules by which uniform pavement elements can be joined to form projects of reasonable length. This is a particularly taxing problem because of the variable way in which distress is usually found along the length of a supposedly uniform pavement. Although it is often easy to demarcate project lengths subjectively by considering the pattern of distress and changes in traffic and pavement structure, it has proved very difficult to formulate this by a suitable algorithm.

The rules for assigning maintenance requirements were set in accordance with the attitude and procedure adopted by the Department. These imposed the following restrictions:

- (a) Special maintenance projects are identified and programmed by a procedure that is independent of that for rehabilitation and therefore the algorithm need not take account of resealing requirements;
- (b) The urgency of rehabilitation should be assigned on economic grounds by considering road user costs, routine maintenance costs and the cost of rehabilitation;
- (c) The minimum length of a rehabilitation project should be 20 km.

An outline of the algorithm that was eventually chosen (described by Curtayne, 1982) is given below.

The net value of rehabilitation is defined as:

$$V = U + M - R$$

where V = net value of rehabilitation per km per year

U = savings in road user cost per km per year

M = savings in maintenance costs - taken as  
routine maintenance costs of previous year

R = annual capital recovery cost of average type  
of rehabilitation

The value of U is related to riding quality and traffic according to:

$$U = (30 - 18,3p + 2,67p^2)T \quad \text{for } p < 2,7$$

$$= 0 \quad \text{for } p > 2,7$$

where p = current riding quality in units of PSI

T = traffic volume in evu.

The value of U/T as a function of p is shown in Fig. 5.13. This relationship is based on work by Visser (1981), modified to suit local cost conditions and to allow no improvements to road user costs above a riding quality of 2,7. This representation of road user costs predates but is based on the same general considerations as the more formal analysis given in Appendix 2.

First a net value  $v_i$  is calculated for every 0,5 km element i of pavement of a given route section. Next the section is segmented into 5 km units and an average net value  $q_j$  determined for every unit j.

The four consecutive units (representing 20 km of road) in the section having the highest average of their net values is then found and form the basis of the first project. Adjoining units are added to this project provided their net values are within specified limits of the average value of the original four units.

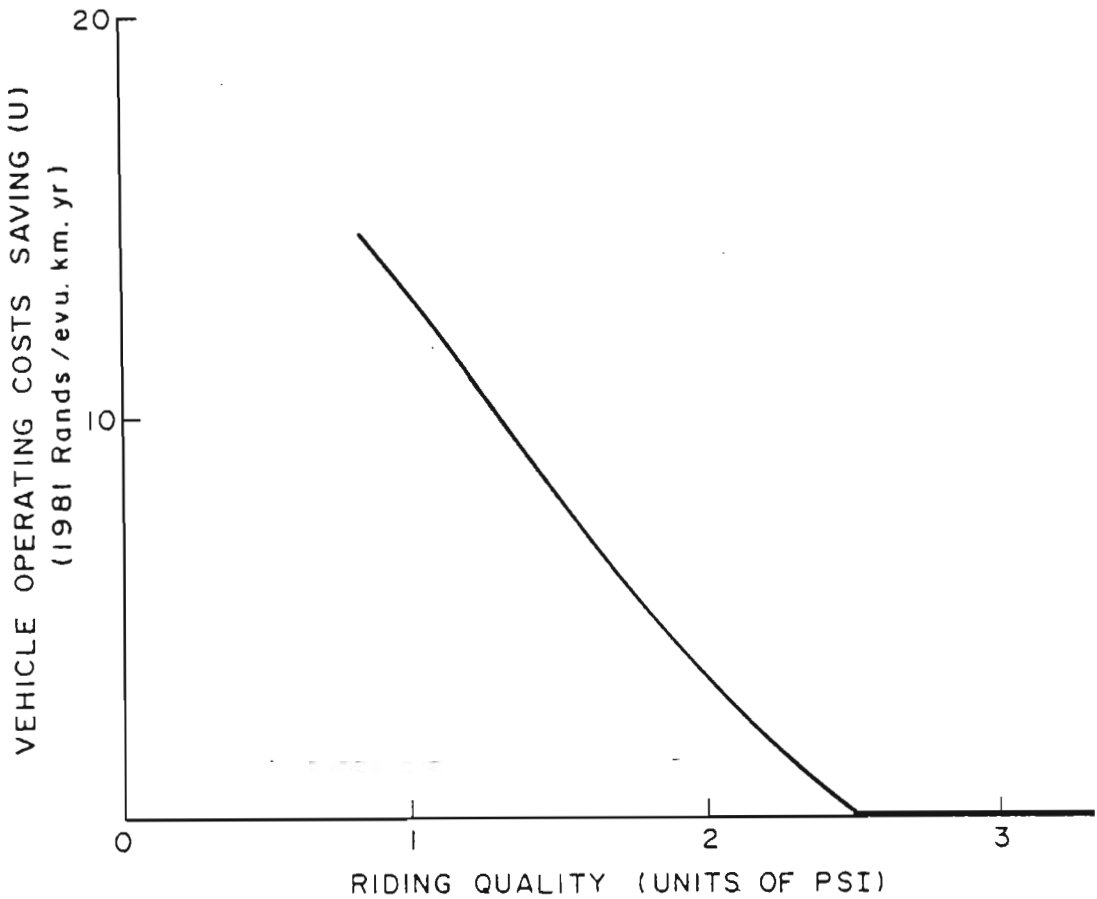


FIGURE 5.13 FUNCTION OF SAVINGS IN VEHICLE OPERATING COSTS AGAINST RIDING QUALITY USED IN ALGORITHM

The units making up the project are eliminated from further consideration and the process then repeated to determine the next most profitable project. This is continued until there are no more lengths of road of 20 km or more between projects. The intermediate units are then joined to neighbouring projects having average net values closest to their own.

At this stage every element of the road is allocated to a project and every project  $k$  is assigned a value  $V_k$  equal to the average of the net values of the elements it consists of. The higher the value  $V_k$  the higher the priority of the project. If  $V_k$  is negative the project is not economic.

An example of a graphical display of these results is illustrated in Fig. 5.14. Here economic projects are shown by horizontal bars (in which the project value is given) along the distance scale. The values of the individual elements are indicated by the vertical lines where their height  $p$  is determined according to:

$$\begin{aligned}
 & 0 \text{ for } v_i < 0 \\
 & 1 \text{ for } 0 < v_i < 2\,000 \\
 p = & 2 \text{ for } 2\,000 < v_i < 5\,000 \\
 & 3 \text{ for } 5\,000 < v_i
 \end{aligned}$$

This presentation can be used to judge the manner in which the algorithm grouped elements to form projects.

The analysis is performed for every route section and the results listed in the following outputs:

(a) A list of all projects is given in order of their priority in which the value, the type and the location of the projects are specified. (See Fig 5.15(a).)

(b) A list of economic projects is given for every route section. (See Fig. 5.15(b).)

#### Utilization of results

The intended use of the results of the algorithm follows the same general lines as the procedure described in Fig. 2.9. The various District Engineers are each presented with evaluations and supporting data pertaining to route sections falling in their areas. They are asked to verify or modify the demarcation of rehabilitation projects and their urgencies and to bring to the attention of Head Office any further considerations that may be important to the rehabilitation programme.

CAPE ROADS DEPARTMENT  
1983 01 11

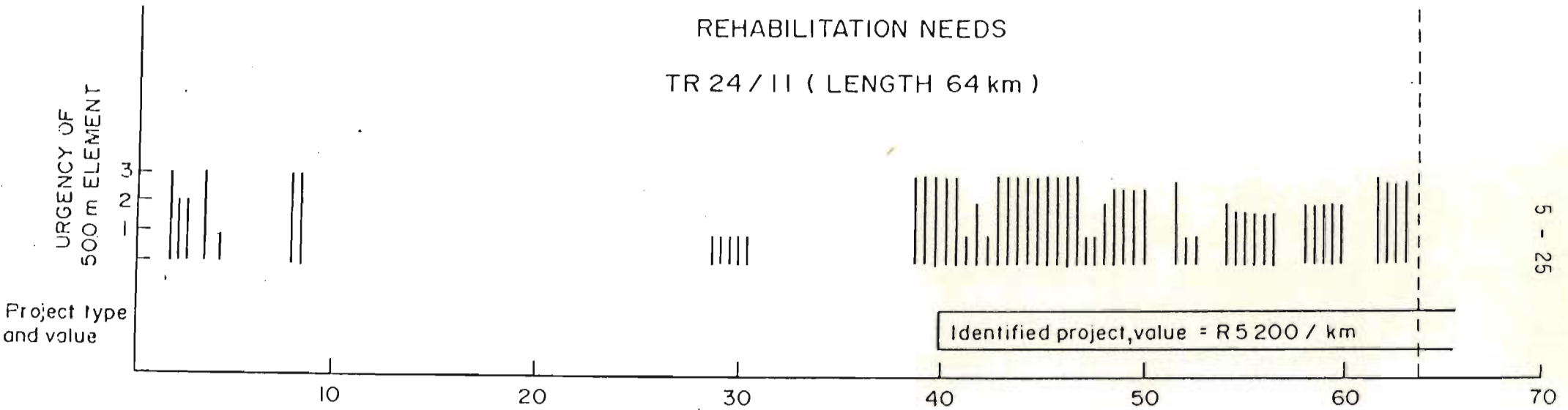


FIGURE 5.14

*DISPLAY OF REHABILITATION REQUIREMENTS FOR A ROUTE SECTION*

CAPE PROVINCIAL ADMINISTRATION			POTENTIAL REHABILITATION PROJECTS			
VALUE R/KM	TYPE	ROUTE-SECTION	FROM KM	TO KM	ANNUAL CAPITAL RECOVERY COST (R/KM)	
1	8354.	IDENTIFIED	TR 2+	0.00	35.00	2000.
2	6140.	IDENTIFIED	TR 2+	35.00	55.00	2000.
3	4558.	IDENTIFIED	TR 212+	22.00	42.00	2000.
4	4407.	IDENTIFIED	TR 210+	0.50	20.50	2000.
5	3722.	IDENTIFIED	TR 21+	35.00	57.00	2000.
6	3155.	IDENTIFIED	TR 221+	15.00	37.00	2000.
7	3018.	IDENTIFIED	TR 223+	0.00	20.00	2000.
8	2986.	IDENTIFIED	TR 226+	0.00	29.44	2000.
9	2823.	IDENTIFIED	TR 229+	0.00	26.50	2000.
10	2441.	IDENTIFIED	TR 211+	21.50	37.96	2000.
11	2318.	IDENTIFIED	TR 21+	0.00	24.50	2000.
12	2152.	IDENTIFIED	TR 211+	35.00	52.45	2000.
13	2062.	IDENTIFIED	TR 216+	100.00	119.50	2000.
14	1971.	IDENTIFIED	TR 212+	2.00	22.00	2000.
15	1805.	IDENTIFIED	TR 221+	0.00	15.00	2000.
16	1804.	IDENTIFIED	TR 21+	15.00	35.00	2000.
17	1666.	IDENTIFIED	TR 211+	1.50	21.50	2000.
18	1538.	IDENTIFIED	TR 223+	30.00	43.50	2000.
19	1351.	IDENTIFIED	TR 221+	0.00	20.00	2000.
20	1333.	IDENTIFIED	TR 225+	18.00	50.00	2000.
21	1157.	IDENTIFIED	TR 226+	0.00	29.44	2000.

(a) Projects in order of priority

CAPE PROVINCIAL ADMINISTRATION			ECONOMIC REHABILITATION PROJECTS		
ROUTE SECTION	SECTION LENGTH	PROJECT LENGTH	PROJECT VALUE	LENGTH OF ECONOMIC ELEMENTS NOT IN PROJECTS	
TR 1 1+	24.51	24.50	2318.	0.	
TR 1 6+	106.00	20.00	10.	3.	
TR 2 5+	56.66	32.00	1333.	0.	
TR 2 6+	29.44	29.44	2986.	0.	
TR 2 9+	26.83	26.50	2823.	0.	
TR 210+	61.28	20.00	4407.	0.	
		40.00	360.		
TR 211+	37.96	20.00	1666.	0.	
		16.46	2441.		
TR 212+	66.22	20.00	1971.	0.	
		20.00	4558.		
		24.00	145.		
TR 216+	119.69	40.00	286.	9.	
		19.50	2062.		
TR 4 1+	82.19	15.00	29.	0.	
		20.00	1804.		

(b) Projects in each route section

FIGURE 5.15 EXAMPLES OF OUTPUT FROM ALGORITHM DEFINING REHABILITATION REQUIREMENTS

This involvement of the District staff assists them by providing them with:

- data for evaluation that would not normally be available to them;
- a clearer perspective of needs in their area;
- feedback to check on the accuracy and thoroughness of visual assessments done by their inspectors.

Head Office is assisted by:

- a mechanism for overcoming current limitations of the algorithm,
- the incorporation of the experience of field staff of local conditions,
- feedback of the algorithm,
- being able to argue the final distribution on projects among Districts on the grounds of decisions they had been involved in.

Projects ratified or redefined by the District staff are given the status of "candidate projects" and added to the project file of scheduled, planned and candidate projects. The value (or priority) of candidate projects are reassessed in terms of the model and ranked accordingly. The results are used to revise the 5-year programme and to determine which projects should be scheduled for the next financial period. This information is then used to update the status of projects on the project file.

#### Operational status

The model in its current form makes no prediction of the future behaviour of the pavements. Although this is recognized as a disadvantage (see Section 5.8), it does not detract from the improvement introduced by the facility for systematically comparing the current condition of pavements.

It has the further advantage that it is based on simple principles so that the results are easy to interpret. By applying the model to the network the users will familiarize themselves with its limitations and be in a better position to appreciate more complex models. Therefore the stage development of an optimizing (or prioritizing) model will allow the users to "grow" with the model and ultimately treat the resultant "black box" with less suspicion.

Nevertheless, the parameters of the model in its current form are still tentative and will doubtlessly have to be adjusted considerably to give acceptable results. Only when this has been achieved can it be formally incorporated into planning process.

On the other hand the pavement management data processing operations are becoming well established. The data base administrator has been appointed and his functions, requirements and authority are being set out in an operational manual that is expected soon to become accepted as departmental policy.

## 5.6 IMPLEMENTATION CONSIDERATIONS

### Initial Considerations

From the experience of earlier implementations, it was clear that the momentum of development and the motivation of both the implementation team and the ultimate users of the system were the most important factors governing their success. These in turn were found to rely on the commitment of top management, the support of field staff and early realization of usable products of the system. These constraints imply that the initial goals should be well defined but modest and that the first use of the system should be adapted to current policy and operations of the Department and should be compatible with resources already allocated to Department functions.

The first stage of implementation therefore took the form of a "preliminary study" to:



- ascertain the policy, operational procedures and resources of the Department;
- define implementation goals;
- recommend a choice of hardware and software;
- propose an implementation approach;
- estimate resource requirements for implementation.

A report on this study (Rickwood, 1980) was submitted to top management early in 1981. They agreed to undertake the development and make R100 000 available for external costs. A meeting was held with representatives of the Districts to outline the objectives of the proposed PMS and to indicate their involvement. This early engagement of all parties proved to be very important in overcoming later implementation problems.

#### Implementation strategy

The goals set for the PMS are given in Section 4.4. For the initial phase of implementation it was decided to concentrate on the first of these and produce a system to significantly improve procedures for programming pavement rehabilitation within two years. Although meeting this objective was considered all important, the system had to be designed in a way that would accommodate the other goals in later developments envisaged in an overall 5-year plan.

An important consideration in the implementation of a PMS is whether to purchase a suitable software package or to develop a custom-designed software for the precise needs of the authority. The former would obviously save greatly on development costs and would have the further advantage that the vendor would normally be responsible for system maintenance and enhancement. However this option is greatly limited by the number of suitable packages available. At the time of the preliminary study there was only one known package, namely CHART (Wingate and Peters, 1975) distributed by the Highway Engineering Computer Branch, Department of Transport, U.K., and as this was not acceptable to the Department they decided to develop their own using computer consultants (Rickwood et al, 1982). In retrospect this was not a serious disadvantage as

it appeared that the relative cost of software development was small compared with the total cost of implementing and operating a PMS. In fact, a package should only be considered if it very closely meets the needs of the authority, otherwise the cost savings will be offset by the immediate and long term effects of having to adapt the PMS operations to the requirements of the package.

As stated above it was decided to use the HP 1000 of the Department rather than the main-frame (UNIVAC) computer of the Cape Provincial Administration. The design of the system therefore had to make allowances for the limitations of this computer.

The implementation of a PMS involves many people and numerous, diverse tasks and therefore demands serious attention to project management. In this regard two key personnel were identified, i.e.:

- (a) The project manager. His duties in designing the system, specifying data collection procedures and supervising the activities of project team members warranted a full-time commitment for the first year of implementation but could subsequently be managed on a part-time basis;
- (b) The project administrator. His function was to interpret Department policy, elicit support from other Sections of the Department and take overall responsibility for the system. This role was fulfilled by the Materials Engineer.

The work was controlled jointly by the Department and the NITRR using a formal project planning techniques such as critical path analysis. They not only served as an essential discipline for the project team but were also effectively used to demonstrate the urgency of cooperation of other Sections.

Report on certain activities

The most critical part of the operation turned out to be the definition of the road network. Although it had been departmental policy to have a manual road log of the features along each of the route sections, it was found that these logs were very incomplete. This meant that the locations of intersections and other important features for many of the roads had to be measured anew by the District staff. Because of their limited resources this took many months to complete and, since the network definition is a prerequisite for the storage of any other data on the data base, caused a delay in the initial use of the system. The difficulties involved in defining the network and the time required should now be recognized as primary considerations in planning the development of any new system.

Pavement materials data were obtained from laboratory records in the form of micro-film of completion plans, project files and, for the older pavements, correspondence files. Two members of the laboratory staff collated the data and assigned material codes to the pavement layers. The accuracy of the data was controlled by spot checks by an engineer and the use of validation computer programs. Data for about 70 per cent of the network were obtained and coded over a period of six months. Although this constituted a considerable effort, the greatly improved accessibility of pavement data - even the knowledge of where data do not exist - is considered sufficient to have justified the amount of work.

The development of the PMS prompted the Statistics Section to set up their own traffic data base. This is expected to expedite the planned improvements to the sampling and interpretation of traffic counts. The Statistics Section will in future be responsible for processing the raw traffic counts and providing the PMS with single values of evu, per cent heavy vehicles and growth factors for each route section every year. Any change in the way the values are obtained in the future will be transparent to the PMS.

The computer programming was almost entirely done by one programmer over the two year period. The total cost of this work including the documentation was R70 000. Because of the attention paid to specifying the computer requirements at the outset of the project, at no time was the computer programming responsible for delaying the work programme.

### Results

The first usable results from the PMS were being obtained within 20 months of the initiation of the project. These were mainly in the form of listings and graphical displays of riding quality and pavement structure data. The palpable benefits this provided encouraged the Departmental staff to play an increasingly active role in ensuring the successful fulfilment of the system's objectives.

After an implementation period of just over two years, a stage has been reached where the data processing system as illustrated in Fig. 5.2 is functional. The usefulness of the application programs within the framework described above (i.e. after Fig 2.9) is being tested by using the system to assist with the biennial compilation of the rehabilitation and reconstruction schedule. The next step is to make any modifications indicated by this assessment, complete the system documentation and then formally incorporate the system into the planning process as Department policy. Ultimately no scheduling should be allowed to proceed without involving the PMS - this will secure its relevance and integrity.

In summary, the success of this first phase of implementation can be attributed to:

- the support of top management;
- the commitment of the project administrator to produce tangible benefits within two years;
- the full-time involvement of a project manager during the initial stages of the work;
- the motivation of the project team;
- appropriate planning and project management.

The results achieved by this system have been appreciated by the other provincial authorities and they are all interested in implementing systems along similar lines. Since they each have a similar computer configuration they should derive considerable benefit from the experience and developments emanating from this work.

#### 5.7 FUTURE DEVELOPMENTS

Two further types of development are being considered. The first is to broaden the scope of the PMS to include the 4 000 km of surfaced main roads. Although these roads are currently managed by the Divisional Councils, their rehabilitation is subsidized in full by the CPA and such work should compete for funds on the same grounds as Trunk Roads. The same procedures should therefore be used to evaluate their maintenance needs but special provision will be necessary to operate the system in collaboration with the Divisional Councils.

The second type of development is the improvement of the rehabilitation assessment (tactical planning) model and the investigation of strategic planning models. An important requirement in the formulation of these models is that the consequences of applying them to a road network can be tested against what is subjectively (or politically) acceptable to the Department (e.g. levels of service on certain roads resulting from a given policy may be correct by economic criteria but be unacceptable from a political point of view). This would normally take many years to observe in practice. However, a useful interim technique is to develop models to simulate the behaviour of a subset of the network under different maintenance policies. The results of simulation models can be used as a first step in assessing the suitability of proposed planning models. Attention is now being given to the structure of these models. Since they all incorporate (tacitly or explicitly) some prediction of pavement behaviour, the first consideration is the nature of the prediction models to be used. An overview of the approach currently being taken for developing these models for the CRD is given below.

Pavement behaviour prediction models

There are essentially four ways of predicting pavement behaviour, i.e. by using:

- formulations of subjective assessments of experienced engineers (see for example Smith, 1974);
- theoretical models based on fundamental principles (see e.g. Kenis, 1977);
- extrapolation of past behaviour of the pavements (see e.g. LeClerc and Nelson, 1982);
- empirical relations obtained from road experiments (see e.g. Hudson and McCullough, 1973).

There are advantages and disadvantages in each of these methods. Subjective opinions are an important source of information where little or no objective information is available. However their use should be seen as an interim measure until systematic empirical relations can be established. Theoretical models have the appeal of introducing a physical interpretation of the behaviour into the analysis, but in their present form require more detailed information than is possible to provide at the network level. Extrapolation makes use of the knowledge of the past behaviour of pavements but by itself does not provide a sound basis for predicting the future. Though empirically verified relations are desired, none has been established that appears to apply to the CRD situation. The well known results of the AASHO (Highway Research Board, 1962), Alconbury Hill (Lister, 1972) and Kenya (Hodges et al, 1975) road experiments relate to climate or pavement conditions that are atypical of the majority of roads in this network. The most promising data set for obtaining suitable relations is the one arising from the Brazil road experiment (GEIPOT, 1976). However these results are still being analysed.

Ideally the pros and cons of these methods severally could be counter-balanced in a joint prediction technique. Briefly this would entail:

- a model based on empirical data but with a structure compatible with behaviour trends expected from accepted theoretical principles;
- a formulation of the model to base predictions on the current condition (and, preferably, the rate of deterioration) of the pavement rather than on the initial condition;
- the ability to adjust the model or enlarge its scope by introducing subjective considerations of factors not adequately accounted for by the model for local conditions.

Although this ideal is difficult to achieve, these considerations will be borne in mind when constructing the model. As a starting point, it is proposed to make use of some preliminary analysis of the Brazil road experiment made by Paterson (1983a). He derived a number of empirical relations relating the onset and progression of various types of distress to pavement structure and traffic parameters.

These comprise four basic types of equation. The first two give the expected time interval for a change in the severity of cracking and ravelling respectively, the third relates the the extent of patching to the time after commencement of ravelling or cracking and the fourth gives the change in roughness with traffic. These sets of equations have the following forms:

$$\begin{aligned}
 E(t_{i+1} - t_i) &= W(\beta_k, x_k) \quad i = 0, 1, 2 \\
 E(t_r - t_0) &= W(\beta_r, x_r) \\
 A_r &= h_k(t-t_r, t-t_2, H, T, S) \quad \dots \dots (5.1) \\
 \Delta q &= \frac{a_0 q^a \quad T^a \quad C^a}{S^4} + \sum \Delta d_m b_m
 \end{aligned}$$

where:  $E(\Delta t)$  = expected value of the time interval  $\Delta t$ ,

$t_0$  = time surfacing was constructed

$t_i$  = time at at which crack condition  $c_i$  is reached,

$c_1$  = crack initiation,

$c_i$ ,  $i=2,3$  = progressively serious crack conditions,

$t_r$  = time at which onset of ravelling occurs,

$A_r$  = area of surface patched or potholed,

$\Delta q$  = change in roughness of surface in units of QI (i.e. a measure of deformation that is inversely related to riding quality, see Appendix 1)

and where  $W(\beta, x)$  has the form:

$$W(\beta, x) = \beta^{(1-\beta)/\beta} \Gamma(1/\beta) e^{-x}$$

where  $\Gamma$  = the gamma function.

The other parameters on the right hand side of the equations are defined in Table 5.2.

The first two sets of equations were obtained using the method of "failure time" analysis suggested by Chesher (1982). For this purpose  $\Delta t$  is assumed to have a Weibull distribution. The most likely values for the coefficients  $\beta_k$  and  $\gamma_{jk}$  (see Table 5.2) are obtained from the experimental data by a numerical procedure.

The structure ( $h_k$ ) of the third set of equations is still being studied. Coefficients for the fourth set of equations were obtained using a combination of linear and non-linear regression (Paterson, 1983a).

By way of illustrating the form of the models, an example derived for one of the first set of equations, i.e. for the expected time from construction to the initiation of cracking in a pavement with an asphalt surfacing, is:

$$E(t_1 - t_0) = 1,3 \exp(2,8 - 0,61h + 0,058h^2 + 0,28s - 0,24v)$$

where:  $h$  = surfacing thickness

$s$  = structural number

$v$  = no. of heavy vehicles per year



TABLE 5.2 : Definition of parameters in Equations 5.1

Parameter	Definition
$\beta_k$	Shape of Weibull distribution of $\Delta t$ for structure type k.
$x_k = \exp(\sum X_j \gamma_{jk})$	Scale parameter of the Weibull distribution of $\Delta t$ for structure type k.
$X_1 = 1$	Dummy parameter.
$X_2 = H$	Symbolic for parameter(s) describing surfacing properties (e.g. H = surfacing thickness).
$X_3 = S$	Symbolic for parameter(s) describing structural strength (e.g. S = structural number).
$X_4 = T$	Symbolic for parameter(s) describing traffic (e.g. T = number of equivalent 80 kN axles per year).
$\gamma_{jk}$	Coefficient for parameter $X_j$ determined for structure type k.
$h_k$	Function for structure type k giving the area of patching or potholing with respect to the periods since the initiation of ravelling and of potholing.
C	Area of cracking of surfacing.
$a_\ell, \ell=0,1,2,3,4$	Coefficients determined by regression.
$\Delta d_{m m}$	Increase in pavement roughness caused by change in distress of surfacing.
$\Delta d_m, m=1,2,\dots$	Changes in surface distress, e.g. patching, cracking, ravelling.
$b_m, m=1,2,\dots$	Coefficients determined by regression.

An example derived for the last equation for granular pavements with a double surface treatment (assuming all potholes patched and no rutting) is:

$$\Delta q = 4,9 \frac{g^{1,1} n}{S} + 0,1c + 0,06r$$

where: n = no. of equivalent axles  
s = structural no.  
c = change in extent of large cracks  
r = increase in extent of patching.

These sets of equations provide a suitable and sufficient basis for predicting the behaviour of pavements for the proposed planning models. They have the advantage that their incremental structure allows predictions to be made in the form of estimations of changes in condition from the last measured values. Moreover, the data required for these equations are generally available on the PMS in a suitable form (e.g. the discrete classification of distress conforms to the way distress is recorded on the system). This situation has the further advantage that the information in the system can be used in future to re-evaluate the prediction models (by applying the same statistical analysis techniques) as more data becomes available through operating the PMS.

Unfortunately a full set of equations is not yet available, even for the conditions in Brazil. This is, in the first place, because the available data is still being analysed to provide equations that have uniform structures, are theoretically acceptable and agree sufficiently well with the data. In the second place, the deterioration of these roads has not progressed far enough for establishing equations that predict the more severe conditions. Furthermore, these equations apply only to original surfacings; modified forms are probably required for reseals and other forms of maintenance. Although a number of sections were provided to study the behaviour of pavements after various maintenance treatments, the scope and duration of this study has been too limited to produce alternative relations (Visser, 1983). Finally, it is not yet clear to what extent behaviour observed in Brazil applies to pavements of the CRD, although a limited study on South African roads (Visser and Paterson, 1983) suggests that there may be good agreement.

On reflection on the comments above and on the fact that the study of pavements in Brazil involved 116 surfaced pavement sections and cost \$5 million, it is evident that continual analysis and adaption

on a network scale by means of a PMS will be necessary before a suitable set of empirical relations for local conditions can be established.

The suggested approach is then to model the prediction of pavement behaviour in the form of Equations 5.1, estimating the values not yet available by obtaining subjective opinions of maintenance engineers. These equations will be reviewed when further analysis of the Brazil data becomes available and by analysing the data on the PMS. Special provision should also be made in the PMS to facilitate the periodic re-evaluation of the equations on the basis of the behaviour of pavements in the Trunk Road network and the observed effects of alternative maintenance treatments.

#### Tactical planning model

The proposed improved procedure for determining the priorities of rehabilitation projects still follows the basic principles set out in Section 5.5 and incorporates the following assumptions:

- Only those projects on the project file are considered, i.e. other pavement lengths in the network that are sound now but that may distress during the analysis period are not considered;
- These projects are considered as entities, i.e. priorities cannot be assigned to parts of a project;
- Resealing will take place when the surfacing reaches a critical condition and routine maintenance is carried out as required;
- Once a pavement has been rehabilitated there will be no further significant road user costs related to the pavement condition for the rest of the analysis period;
- The total salvage value of the rehabilitation done during the analysis period will not be greatly affected by the order in which the work is carried out and is therefore not considered.

The object of the analysis is to minimize the total costs:

$$\phi = \sum d_j (u_{ij} + m_{ij} + Y_{ij} D_i)$$

where:  $d_j$  = discount factor for year j

$u_{ij}$  = user costs for pavement length associated with project i in year j

$m_{ij}$  = ordinary maintenance costs for pavement length associated with project i in year j,

$Y_{ij}$  = proportion of project i constructed in year j

$D_i$  = cost of project i

such that the expenditure on rehabilitation does not exceed the available budget in any year, i.e.:

$$\sum Y_{ij} D_i < b_j$$

where:  $b_j$  = rehabilitation budget for year j.

(Other constraints are required to allow for the fact that once a project has started it will be completed not later than within the following year.)

Road user costs are provisionally related to the riding quality of the road as before, i.e. according to:

$$u_{ij} = (30 - 18,3p + 2,67p^2)TL \quad p < 2,7$$

$$= 0 \quad p > 2,7$$

where: p = average riding quality in units of PSI  
 T = traffic in evu  
 L = length of project

The relation between p and q (used in Equation 5) is:

$$p = \exp \left[ \frac{(92,63 - q)}{56,39} \right] \quad (\text{see Appendix 2})$$

Later a relation for road user costs involving both vehicle operating costs and a premium for comfort such as given by Equation A2.5 in Appendix 2 may be considered.

The maintenance costs  $m_{ij}$  are related to the condition of the pavement (associated with project  $i$ ) in year  $j$  in the following way: If the condition is critical with respect to the need for resealing, then  $m_{ij}$  is equal to the cost of the seal; if not,  $m_{ij}$  is equal to the cost of routine maintenance which will depend on the pavement condition (i.e. the severity of cracking and ravelling); i.e.:

$$\begin{aligned} m_{ij} &= sL \quad \text{for } \vec{c} \in S_c \\ &= f(\vec{c}) \quad \text{for } \vec{c} \in S_c^{-1} \end{aligned}$$

where:  $s$  = cost of seal per unit length

$\vec{c}$  = condition vector (giving the severity of cracking and ravelling,  $c_i$  and  $A_r$  in Equation 5.1)

$S_c$  = set of critical surfacing conditions  
(e.g. Severity 3 conditions defined in Section 5.2)

$f(\vec{c})$  = function giving routine maintenance costs for given surfacing condition.

The above has the form of a dynamic programming problem that can be solved if values for  $q$  and  $\vec{c}$  can be predicted (e.g. by using a model in the form of Equations 5.1 and current condition values from the data base). This representation was provided as a framework for the investigation of a suitable tactical planning algorithm currently in progress.

#### Strategic planning model

The object of a strategic planning model is to determine the long term consequences of a particular maintenance policy. In this case it is not necessary to know which projects will be carried out in a given year but merely what proportion of pavements in a given state in a given year will change to other states the next year as a result of a particular maintenance policy. In this way the overall condition of the network as a function of time can be determined. Alternatively, the maintenance policy (e.g. budget) required to produce a state of equilibrium with respect to annual maintenance

costs and a specified network condition can be determined. The latter is the approach adopted by the Arizona Transportation Department (Kulkarni, 1982).

The prediction of the proportion of pavements changing from one state to another requires a stochastic model. For this purpose the Weibull distributions on which Equations 5.1 are based can be used. The method would involve classifying the pavements in the network into lengths with similar pavement type, climate, traffic etc. and predicting what proportion of the total length in each category will be in a particular state in a given year.

Although this type of analysis is recognized as important to the road authority, both internally, for determining their maintenance policy, and externally, for motivating additional funding, little more attention than this has been given to the problem to date.

#### Simulation model

A simulation model has been developed previously to evaluate some of the application programs of the PMS for national roads (Curtayne, 1977). This model had the form of a few simple stochastic relations based on the subjective opinions of a number of research engineers. Although this model proved to be instructive in demonstrating the consequences of maintenance policies in relation to the way pavements were believed to behave, it was abandoned in favour of more pressing implementation needs.

A revision of this model is being considered in which the subjective relations will be replaced with stochastic representations of Equations 5.1 to make it consistent with the planning models. In this case two stochastic variables are of interest; the first to simulate the random nature of the average behaviour of a uniformly constructed length of pavement, the other to give the variability of the condition within such lengths. The latter feature presents a more realistic picture of the future condition of the pavement and will be useful for instance in illustrating the problems of defining rehabilitation project lengths.

Resume

The algorithms developed this far are considered to have introduced a substantial improvement in the data availability and evaluation procedures. Their simple structure should mean that their principles and limitations will be easily understood.

The first requirement for the future advancement of the PMS is therefore to involve the proposed users in applying these programs so that they may familiarize themselves with the outputs and suggest improvements, and that the overall role of the system in the rehabilitation process can be evaluated.

The next requirement is to extend the scope of the system to the surfaced main roads so that the maintenance needs of all major roads in the province can be judged on the same basis.

The improvements to the planning models discussed above are therefore currently regarded as research for future development. Although much additional work is required to derive a satisfactory formulation of the prediction equations, the approximations suggested will provide a useful basis on which to develop and test the planning models. Involving the equations in this way will also demonstrate their shortcomings and indicate where further research effort may best be directed.

The simulation model is expected to have a central role in this work by providing a means for inspecting the consequences of abstruse algorithms to assess whether acceptable results are being obtained. It also has the wider research value of providing an integrated formulation of the various aspects of the way pavements are believed to behave, which can be tested and built upon.

## CHAPTER 6

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 INTRODUCTION

A maintenance control system is a set of procedures that are used to assist a road authority in the planning functions of pavement management that deal with the maintenance of existing pavements. As such it is considered to be a subsystem of a more comprehensive pavement management system. In this thesis emphasis has been given to tactical and strategic planning considerations rather than the design of maintenance treatments and their application to a rural road network has been demonstrated. However, continual attention has been given to the relationship between these and broader pavement management issues. Various findings from this study are summarized below and recommendations are given for their further development and application.

#### 6.2 GENERAL SITUATION REGARDING PMS IMPLEMENTATION

During the past decade and a half there has been an ever increasing awareness of the importance of PMSs locally and overseas, especially among the developed countries. The growing importance of PMSs can be attributed to a number of factors, i.e.:

- (a) The basic networks of pavements in developed countries are virtually complete and for large proportions of many of these networks the pavements have been in service for a number of years and for such countries the emphasis has shifted from construction to maintenance;
- (b) Most road authorities throughout the world are experiencing more stringent financial conditions than in earlier years, establishing a need to plan and operate more efficiently;
- (c) A number of technical developments during this period have greatly advanced the ability to obtain and use information for



planning maintenance at the network level. These include data collection methods, computer systems for storing and processing the data and evaluation procedures for translating the data into an account of maintenance requirements.

Although most of the countries reviewed were taking steps to record the condition of their pavements in a systematic way, only a few could be considered to have operational pavement management systems for determining maintenance requirements. In particular, there were only a small number of road authorities who were using optimizing procedures for determining maintenance programmes and policies. Considering the capabilities of available technology and the fact that the need for PMSs is virtually common cause, the relatively low level of implementation internationally can be considered surprising. This points the practical difficulties of installing and operating PMSs as viable entities in road authorities.

Although the implementation of PMSs in South Africa is still at a low level, several major road authorities have made substantial progress in developing at least simple maintenance control systems. In general the situation in South Africa compares favourably with that in other parts of the world. However, there is a need for the other road authorities to develop systems to determine maintenance needs on a comparable basis so that road maintenance needs can be assessed at the national level.

### 6.3 CONSIDERATIONS FOR PMS DEVELOPMENT

A systems approach to pavement management involves pavement engineering, operational research, management science and aspects of socio-political science. The considerations for applying these disciplines are determined by analysing pavement management requirements in systems engineering terms from three different levels:

- (a) The technical level. Here the PMS is considered to be a feedback system to control the condition of the pavements by applying suitable maintenance on the basis of information

obtained about the condition of the pavements. The first problem at the technical level is to determine the optimum application of maintenance; that which is expected to maximize the value of service provided by the pavements to the road user under the prevailing resource and policy constraints. The second problem is to determine the effect of different budget and policy conditions on the service that can be offered. These problems are too complex to provide an overall solution in closed form. They are broken down into subproblems concerning the different types of maintenance activities. The results are co-ordinated to determine the best allocation of resources among them. However, because of deficiencies in predicting pavement behaviour, uncertainty about appropriate decision criteria and external demands, rigorous optimizing solutions cannot even be provided for the subproblems. The PMS should therefore be designed to adapt to changing conditions, policies and state of knowledge and should be able to interact with subjective opinions. The **results** should also be of a form that can be co-ordinated with other road management activities.

- (b) The operational level. Here the use and control of communication of information among the various entities making up the total PMS are examined. In the first place attention must be given to the collection and storage of formal data such as to ensure their validity, security, timeliness and ease of use and to be compatible with the resources of the organization. Secondly operational **requirements** should take account of **human** conditions. Here the decision making process should be **structured** to involve field staff in a way that recognises the **value** of informal information and the importance of meaningful participation to their job satisfaction. Thirdly the nature of and responsibility for communication should be formalised and documented as official policy. At this stage attention to operational aspects appears to be a greater immediate problem than the accuracy of algorithms that determine maintenance requirements.

- (c) The organization level. Road authorities are in competition for funds with other public organizations. The funding re-

ceived reflects a compromise between services obtained from roads and other social services. Road authorities should strive to provide quantitative estimates of the consequences of alternative levels of funding in order to assist the financing authority to arrive at rational decisions according to perceived public preferences.

Apart from the design aspects, a number of criteria have been identified for the successful implementation of a PMS, viz.:

- commitment from top management at the outset (for providing suitable funds and for securing the co-operation from the various sectors in the organization);
- involvement of field staff in design aspects;
- use of project management principles (implementation should not be tackled in a part-time, piecemeal fashion);
- use of short time-horizons for obtaining first tangible benefits;
- sustainment of motivation and momentum of project through difficulties (e.g. staff resignations);
- use of operational procedures and decision criteria, initially, in close conformity with existing practice and subsequent system developments to accommodate recognised deficiencies.

#### 6.4 APPLICATION OF DEVELOPMENT CONSIDERATIONS

The first phase of implementing a PMS for a 13 000 km rural road network has been completed. This phase has centered on providing a system for identifying and ranking possible rehabilitation projects. The chief feature of the system is considered to be the provision of pavement data in a variety of forms that are convenient to use in a distributed decision making process. Before this development many of these data were either unavailable or prohibitively difficult to obtain. A simple algorithm based on valid economic principles is used to rank potential rehabilitation projects. Although recent comparisons have demonstrated a fair agreement between urgent projects identified by the model and by field staff, the fact that the model does not take predictions of the future behaviour of pavements is thought to be a serious deficiency.

The implementation was carried out taking due cognizance of the criteria listed in the previous section which had been identified from experience with the implementation of earlier systems. The success achieved has underlined the validity of these criteria and has provided a sound basis for the implementation of similar systems in other road authorities.

Although the system is still far from ideal even in terms of the scope of the first phase objectives, it has the facility of answering basic questions such as:

- what is the condition of pavements in the network?
- what is the magnitude of the maintenance problem?
- is the situation improving or deteriorating?

Although these questions are simple in scope, they are fundamental to good pavement management, yet without this type of PMS it is very difficult or provide factual answers.

#### 6.5 THEORETICAL CONSIDERATIONS FOR FUTURE APPLICATION

Existing algorithms have poor optimizing facilities or unsuitable models for predicting pavement behaviour for South African conditions (or both). The preliminary analysis carried out by the World Bank on the behaviour of pavements in the Brazil study appears to provide a framework for a suitable prediction model for the CRD PMS. It has a form that allows extrapolation from records of current pavement condition and that can be readily updated when pavement behaviour trends are established for the CRD roads through use of the PMS. The results of the model can be used in an optimization algorithm that conforms to the decision criteria of the CRD.

The definition and measurement of road user costs are central to the evaluation of the serviceability of pavements. The relations of vehicle operating costs and of comfort to riding quality have been shown to have the same form, however, their relative weights will have to be determined according to public preferences and the level of service that can be achieved and sustained will depend on

how much the public are willing to pay. Some interaction is therefore required between the public and the decision makers. This is best achieved through a declared policy of minimum levels of service for particular classes of road. Optimizing algorithms for tactical or strategic planning would then use such minimum levels as constraints.

Theoretical frameworks for these ideas have been postulated. The detailed development and application will be the subject of the next phase of research.

#### 6.6 RECOMMENDATIONS

The principles of PMS development and implementation as set out in this study have been shown to be practical and of considerable value to a rural road authority even in the initial stages. Other rural road authorities who have yet to initiate a PMS are therefore recommended to adopt the same principles even if specific requirements differ. In doing so they should make use of the experience and techniques that have resulted from this work. The following should be noted in particular:

- (a) Table 2.3 provides a useful summary of considerations that should be taken into account in the development of a fully operational system and can be used as a check-list to identify aspects needing further attention.
- (b) The various steps for overcoming implementation problems as discussed in chapter 5 (and summarized above) should be followed.
- (c) All South African rural road authorities have compatible computer systems and so much of the software that has been developed can be transferred to them directly.

A mechanism for coordinating the developments of individual PMSs should be established to encourage the various road authorities to provide comparable evaluations of maintenance needs.

The main objective of creating a framework for providing a communicating information for pavement management decisions for the Cape Trunk Roads has been accomplished. However, there is now a basis for exploring more advanced tactical and strategic planning models. Although the approach discussed above is recommended for improving the PMS for the Cape Roads Department (CRD), care must be taken not to make this development too abstract. A model to simulate the behaviour of the pavements in the network should be set up by which the effects of different maintenance policies arising from alternative planning models can be observed and compared subjectively as well as quantitatively.

Experience gained from using the CRD PMS will be continually used to modify and upgrade the system. However, certain immediate research at the technical level is recommended to supplement the development of the improved planning models. Two important areas of such research are given in the following:

- (a) The results of the optimization model will be very sensitive to the ascribed relation between road user costs and pavement condition, especially at high traffic volumes. It is therefore important to obtain relations that are realistic for South African conditions as soon as possible, particularly the relation of comfort and vehicle operating costs to riding quality (e.g. as discussed in Appendix 2).
- (b) Another area urgently requiring empirical data is the formulation of prediction models of pavement behaviour. Although only recently established, the CRD PMS can already assist in providing some information to check and improve the relation suggested in Chapter 5 (Equation 5.1). Examples of such information are:
  - frequency of resealing;
  - relation between routine maintenance costs and pavement condition;
  - change in riding quality since construction under different conditions.

Finally, PMSs have also been shown to be important for urban authorities. However, the development costs may be prohibitive for smaller municipalities. Consideration should be given to setting up a general simple system, with the concomitant documentation and implementation guide, that can be readily adopted by such authorities.

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## APPENDIX 1

### THE DESCRIPTION OF PAVEMENT CONDITION

#### A1.1 INTRODUCTION

The ability to describe the condition of pavements objectively is the corner-stone of PMS. Considerable attention was given in the early 1970s to defining the various properties of interest and their relationship to one another as part of this study. Although a number of recommendations had been put forward in the literature (e.g. Highway Research Board, 1957, 1968a and 1970), there was no universal agreement on the terms used or on the manner in which the various properties were to be measured - this was especially true in South Africa (Curtayne and Walker, 1972 and 1974a). In particular there was still a great deal of confusion regarding the difference between the aims of functional and structural (then called mechanistic) descriptions of pavement condition as set out, for example, by Haas and Hudson (1971).

In 1974 an approach for use in South Africa was suggested by Curtayne and Walker (1974a). After the general acceptance of this point of view by the major road authorities, a comprehensive set of terms was recommended as a standard nomenclature for describing pavement condition (Curtayne and Walker, 1974). This was later accepted, after minor modifications, as No. 6 of the series "Technical Recommendations for Highways" (TRH6) by the Highway Materials Committee of the Committee for State Road Authorities on a trial basis (National Institute For Transport and Road Research, 1980).

In TRH6 the various features of the pavement that contribute to its serviceability are discussed. (These are given in Table A1.1 along with various possible methods of assessing them.) In addition, a number of "structural indicators" are identified that can be used to assess the "structural capacity" of the pavement, i.e. its ability to withstand the effects of traffic and environmental forces. (These indicators are listed in Table A1.2.)

TABLE A1.1 : Road features related to pavement serviceability

Features	Factors contributing to serviceability	Method of assessment
Riding quality	(a) Longitudinal surface roughness (deformation)	(i) Subjective assessment (ii) Measurement of riding quality with roadmeters (e.g. PCA roadmeter)
	(b) Rutting in wheelpaths	Straight-edge measurements Rut depth gauges
	(c) Potholes	Inspection
	(d) Uneven patching	Inspection, (also included in (i) and (ii) above)
Skid resistance	(a) Surface texture depth	SCRIM, pendulum apparatus sand patch test
	(b) Harshness of surface	
	(c) Water film thickness	Related to surface drainage
Surface drainage	(a) Transverse and longitudinal grades	Levelling, inspection during rain
	(b) Efficiency of drainage	Inspection
	(c) Deformation of surface profile	Inspection, straight-edge measurements

For the purpose of a PMS at the network level, descriptions of pavement condition must necessarily be confined to those factors that can be rated rapidly and cheaply. These are those factors that are measured by high-speed mechanized surveillance equipment and visual assessments of distress. Other forms of assessment, such as laboratory testing of materials, are only made for more detailed evaluation at the project level.

In the following sections of this appendix an overview is given of the factors considered and the apparatus available for rating pavement condition for PMSs in South Africa. Because of its central role in the philosophy and practice of PMSs, special attention is given to the work done on the definition and measurement of riding quality. (The interpretation of riding quality measurements is discussed in Appendix 2.)

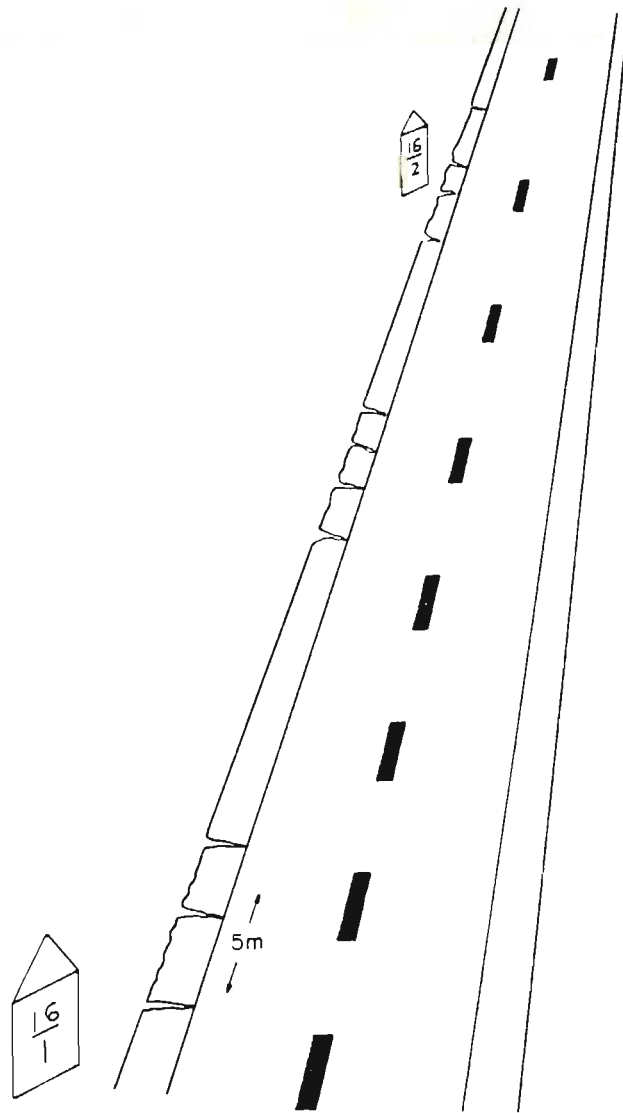
TABLE A1.2 : Indicators of structural condition

Type	Examples
Structural reaction	Deflection, radius of curvature, elastic moduli in association with layer thicknesses
Material properties	Stability, fatigue, plasticity index, CBR
Structural integrity	Porosity, cracking of stabilized layers
Drainage	Crossfall, culvert capacity, efficiency of subsurface drainage
Distress	Deformation, cracking, disintegration of surfacing, smoothing of surface texture
Structural response	Accelerated behaviour (e.g. with Heavy Vehicle Simulator), assessment of past behaviour

#### A1.2 VISUAL ASSESSMENT OF DISTRESS

A codified description of distress is complicated by the large variety of ways in which it is manifested. In order to deal with this variety, a number of attributes are defined in TRH6 by which the condition can be classified unambiguously. (An illustration of the use of these attributes is given in Fig. A1.1 from which their meaning can be inferred.) Full details are given in TRH6 for classifying the magnitude or category of each of the attributes.

The intention of TRH6 was to provide a comprehensive vocabulary by which to describe the state of distress to the detail desired. In the development of a PMS the required detail must be specified to suit the use of the data and the available resources for field rating. Usually coarser categories would be presented (e.g. as in Fig. 5.1) but defined within the framework and terminology of TRH6. Often these categories are defined in terms of a number of attributes and identified by a severity index indicating the seriousness of the distress (e.g. as in Fig. 5.1). Ad hoc guides are required for specifying the rating procedure for each PMS application (see for example Scullion, 1979).



LOCATION : ROAD R29 -1, 16,1 km to 16,2 km  
MODE : CRACKS  
TYPE : TRANSVERSE CRACKS  
DEGREE : DEGREE 5 (5mm CRACK WIDTH )  
EXTENT : LENGTH 40 %  
SPACING : 5 m  
POSITION : SHOULDER

FIGURE A1.1  
*ILLUSTRATION OF ATTRIBUTES OF DISTRESS  
FOR A PAVEMENT WITH TRANSVERSE CRACKS*



### A1.3 SURVEILLANCE EQUIPMENT

A number of instruments have been developed and/or commissioned by the NITRR for the rapid monitoring of road condition. Some of these, i.e. those for measuring riding quality, have been developed within this study; others have been developed by colleagues but form part of the services available to PMSs.

#### Instruments for measuring riding quality

A modified version of the PCA roadmeter suggested by Brokaw (1967) was completed in 1976 and since then has been operated as a service to road authorities nation-wide. The modifications comprised:

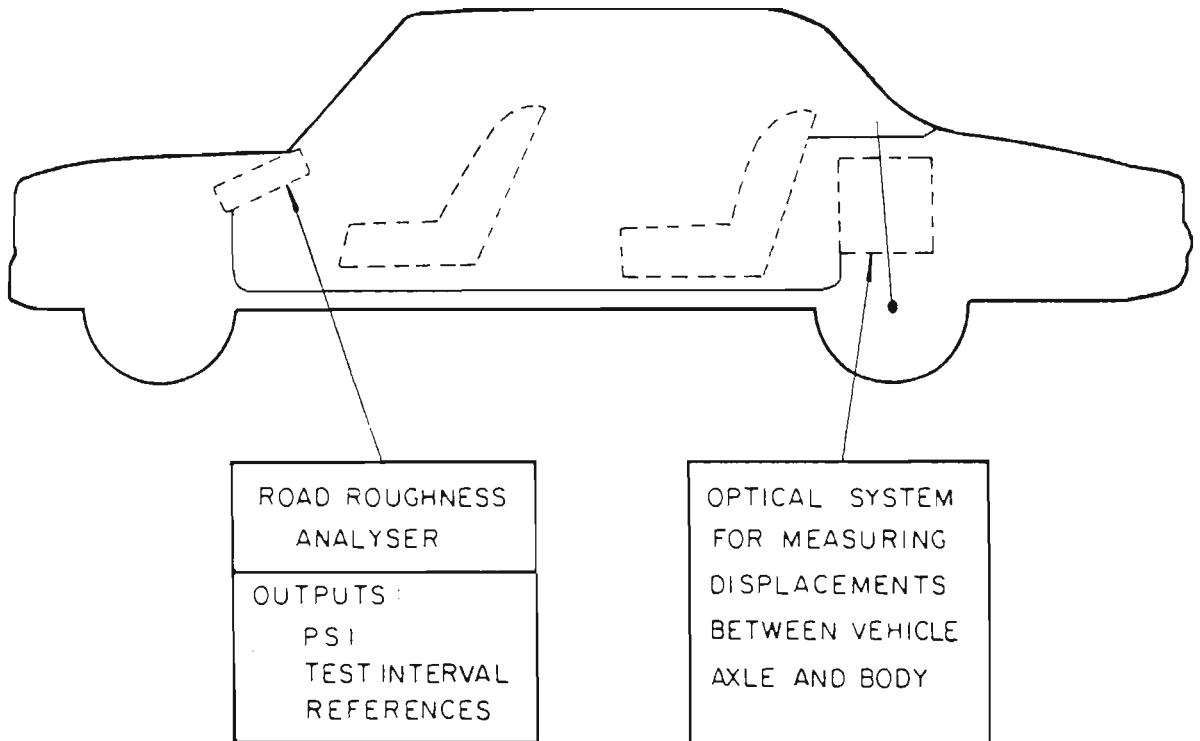
- a rigid shaft with optical sensors to measure the relative displacement of the back axle with respect to the body of the car,
- a dynamic, automatic zeroing device that adjusts for changes in the load carried in the vehicle and changes in the gradient of the road,
- an electronic processor that converts displacement values directly into values of riding quality (on a PSI scale of 0-5) at selected intervals according to adjustable calibration constants,
- provision of output in the form of a digital display of last measurement, printed tape of all values and (in the most recent development) recording onto magnetic tape.

A photograph and a schematic diagram of the instrument is shown in Fig. A1.2.

The choice of this response-type measuring system stemmed from prior experience with the standard version of the PCA roadmeter (Curtayne and Walker, 1972). However recent work by Gillespie et al (1980) has indicated that the linear response equipment is more suitable than the quadratic response used in the PCA roadmeter. Therefore the new roadmeter currently under development (the NITRR



(a) View of interior



(b) Schematic presentation

FIGURE A1.2 THE MODIFIED PCA ROADMETER

Roadmeter) provides for both modes of response. Displacements between the rear axle and the body of the vehicle are measured with a rotational transducer. All further processing (e.g. automatic zeroing) is done by means of micro-processors, which provide great flexibility in specifying options such as the mode of testing, speed correction etc.

A simpler instrument, the Linear Displacement Integrator (LDI) was developed (van der Merwe and Grant, 1980) along the lines of the NAASRA roughness meter (Kaesehagen et al, 1972) except in that optical sensors and electronic accumulators and displays were used. This is a less convenient but much cheaper instrument than those mentioned above. A number have been supplied to road authorities and consultants to decentralize the measurement of riding quality in South Africa but care is being taken to ensure uniform calibration among instruments (Visser and Curtayne, 1982) so that results from different agencies can be compared.

Other, more sophisticated, equipment (i.e. high-speed profilographs) have been considered but found to be currently not worth the expense for routine measurement. The modified PCA road meter has proved to be a simple, easily operated device that has given good repeatability over a considerable number of years (as can be seen in the example given in Fig. A1.3). Changes in riding quality are determined accurately enough for practical purposes. Even if more detailed information of the road profile were available, it is doubtful whether at this stage it would provide more meaningful statistics.

#### Measurement of skid resistance

The Sideways-force Coefficient Routine Investigation Machine (SCRIM), developed by the Transport and Road Research Laboratories (Millard and Lister, 1971) was commissioned by the NITRR with minor modifications to the mechanical and electrical system to improve accuracy and reliability. It has been operated as a NITRR service since 1973 (Visser, 1974).

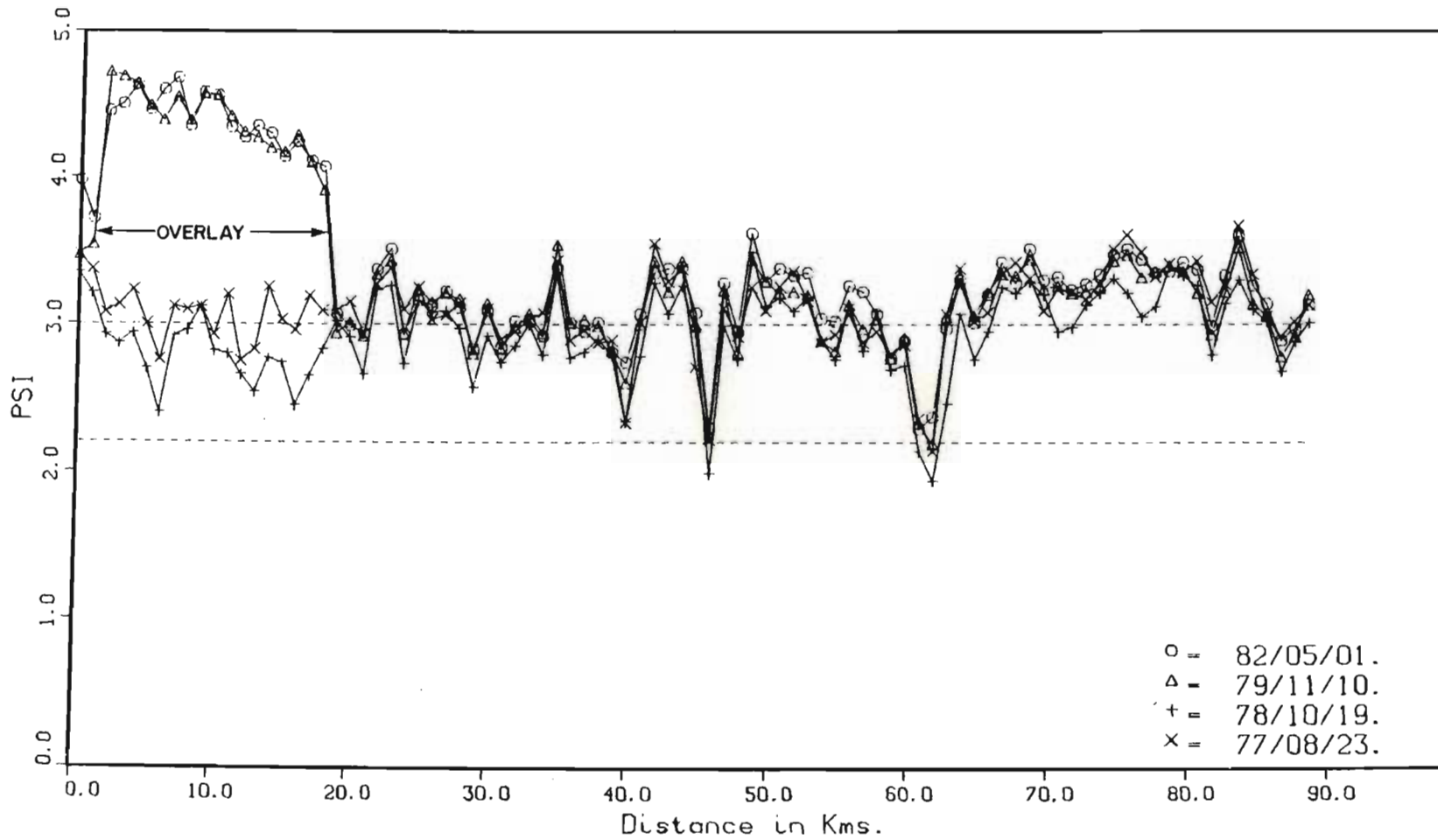


FIGURE A1.3 COMPARISON OF RIDING QUALITY MEASUREMENTS OVER 5 YEARS OVER A 90km LENGTH OF ROAD

Measurement of deflection and rut depth

The Lacroix deflectograph, developed by the LCPC (Autret, 1972) was commissioned by the NITRR with very little modification (Grant, 1974). It has been used since 1972 for research and as a NITRR service.

Rut depths are currently measured by a specially developed gauge towed behind the deflectograph (illustrated in Fig. A1.4). It consists of a number of wheels mounted on a single axle. An additional wheel in the centre is free to move in relation to the this axle and remains in contact with the surface. The displacement relative to the axle approximates the measurement under a 2 m straight-edge.



FIGURE A1.4 RUT DEPTH METER TOWED BEHIND LACROIX DEFLECTOGRAPH

The measurement of rut depth is currently limited to the low speed of operation of the deflectograph (3 km/h). The use of non-contact sensors are being investigated with a view to measuring rut depth in conjunction with riding quality, i.e. at 80 km/h.

#### The photologger

A Techwest photologger has been used by the NITRR since 1982. In addition to providing a forward-view photograph of the road every 20 m, it also records the altitude, gradient, crossfall, horizontal curvature and riding quality of the road at 20 m intervals. Although it is now being used in independent road needs investigations, it can, in future, be used to broaden the scope of PMSs to include more general road management applications.

#### Al.4 DEFINITION AND CALIBRATION OF RIDING QUALITY MEASUREMENTS

A subjective rating experiment was carried out in 1971 in order to define a reference set of riding quality values using 44 road sections in the vicinity of Pretoria (Curtayne and Walker, 1972). Ratings were made by 23 persons following a procedure very similar to that used in the AASHO Road Test (Highway Research Board, 1962). The raters marked their impressions of riding quality on the category scale shown in Fig. Al.5 and the average of the individual ratings was termed the present serviceability rating (PSR).

Reservations had been expressed by Hutchinson (1963) as to the reliability of such results, especially in the face of the well known systematic errors of psychophysical ratings (i.e. the errors of the "halo" effect, "central tendency" and "leniency"). However, it was found (Curtayne and Walker, 1972) that with 23 raters these errors had little effect on the averages and that results of high reliability were obtained.



FIGURE A1.5 CATEGORY SCALE FOR RATING RIDING QUALITY

These sections were subsequently used to test and calibrate instruments to measure riding quality. However with time many of the sections deteriorated and some were rehabilitated and so the road sections became unsuitable as a reference set. A new rating experiment was performed in 1977 (Gordon, 1978) and the resultant PSR values on the 31 road sections have subsequently been used as the national standard.

The situation has once again been reached where the number of usable sections is diminishing and the rating of a new set of sections will soon be required. However, further subjective experiments are undesirable because of their expense and practical difficulties and, more especially, because the results of one experiment cannot necessarily be considered to be representative of another (as people's opinions may change with time). An absolute physical measure of the road surface profile that can be related to PSR values is required so that reference sections can be regenerated for calibrating routine measuring instruments when required.

The importance of an absolute, physical method of recalibrating sections arises from the fact that the response-type instruments used for measuring riding quality in South Africa (and, widely, overseas) also deteriorate with time. They must themselves be continually recalibrated and cannot therefore be used to monitor changes in the reference pavements.

Gillespie et al (1980) give a detailed critique of a number of possible methods for establishing such a calibration procedure. They recommend the use of the simulated response of a standard response-type instrument on the measured pavement surface profile. The standard instrument has the form of a single wheel roughtometer (representing a "quarter-car") with specified parameters determining its equations of motion. The response is calculated by computer and the result termed the quarter-car simulation (QCS). QCS values can then be correlated with PSR values to complete the calibration procedure. (Note that deformations in the road surface affecting the riding quality is termed "roughness" and that the higher the QCS value the rougher the road and the lower the PSR.)

The disadvantage of this method is the cost of equipment for measuring the road profile in the necessary detail. Although non-contact sensors are being considered for this purpose as a research activity of the NITRR, two surrogate procedures have been considered as an interim measure:

- (a) The first follows a method described by Queiroz (1981) in which a relation between a simple statistic of rod-and-level measurements and QCS values is obtained. The estimated QCS values obtained using this relation are termed quarter-car index (QI) values. Visser (1982) has obtained good correlations between QI values and the response of the various roadmeters used by the NITRR. Similarly, in a recent international experiment to establish a standard calibration method good results were obtained with this method (Sayers et al, 1982). The disadvantage of this method is that it is slow and labour intensive and thereby expensive. However since it is only used to recalibrate a reference set of roads every few years, this is not a prohibitive factor.
- (b) An alternate (or supplementary) method being investigated is to correlate PSR values with slope variance measurements using the CHLOE profilometer (described by Carey et al, 1962). Curtayne and Walker (1972) demonstrated the possibility of this using simulated slope variance results (calculated from measured



profiles). As the slope variance is a feature of the road profile and should not be related to the suspension characteristics of the profilograph it should be a time stable reference system. Gillespie et al (1980) have however pointed out that the frequency range affecting this measure of slope variance extends far higher than that determining the response of vehicles. This may mean that unrepresentative values and poor correlations with PSR values would be obtained. A CHLOE profilometer has subsequently been built at the NITRR (modifying only the electronics) and is currently being used to test these hypotheses. Although it is a slow and difficult instrument to operate on an open road it is considerably faster and cheaper than rod-and-level measurements.

#### A1.5 SUMMARY

A firm basis for monitoring the condition of pavements for PMSs has been developed.

A standard nomenclature for describing distress has been accepted for use in South Africa and a number of rating procedures for visual assessments are being tried out by various road authorities. The cost of these assessments vary according to the detail and intensity of measurement required by the different PMSs but is in the order of R5 - R10 per kilometre.

Several reliable surveillance instruments are operated by the NITRR as a service to road authorities. Data are supplied in a form suitable as direct input into existing PMSs. Special attention has had to be given to providing a permanent reference scale that can be compared with scales developed by other agencies. The 1983 charges for the surveillance equipment is given in Table A1.3.

Overall, judging from the summary given by Transportation Research Board (1981), the availability availability and use of pavement condition monitoring methods compares favourably with practice in the USA.

TABLE A1.3 : NITRR 1983 charges for  
measurement with  
surveillance equipment

Instrument	Cost R/km
Modified PCA roadmeter	6
SCRIM	37
Lacroix deflectograph	189
Techwest photologger	6

## APPENDIX 2

### INTERPRETATION OF RIDING QUALITY MEASUREMENTS

#### A2.1 INTRODUCTION

Poor riding quality (or high roughness) of a pavement surface affects the road user in four ways, i.e.:

- it reduces his speed of travel,
- it reduces his safety,
- it reduces his comfort,
- it increases his vehicle operating costs (VOC).

For a given speed the effect on safety, comfort and VOC can be considered as independent (i.e. comfort is not an aspect of safety or VOC). On the other hand, for a given levels of riding quality, the level of safety, comfort and VOC all depend on the speed of travel. In principle, the loss in value of time for the road user can be offset against the improvement in the other factors at lower speeds. This relationship has, however, not been given much attention. (However, Slavik, 1983, describes a method by which the value that road users place on their time can be related to the cost of fuel by observations of their behaviour).

The roughness of a pavement affects the safety of the road user by reducing the traction of tyres on the pavement surface when braking or cornering (Leger, 1970; Wambold et al, 1973). The relation between safety and riding quality is, however, very complex and would be greatly dependent on factors such as the geometry of the road and the traffic density. Consequently this effect is very difficult to quantify.

Comfort is a psychophysical experience of roughness and, as such can only be measured subjectively. Two approaches are commonly taken:

- (a) The first can be considered to be a fundamental approach in that it begins with the study of the effect of vibrations on the human body. This is then related to the vibrations of the vehicle resulting from the roughness of the road (as determined by spectral density techniques from measurements of the pavement surface profile, e.g. Leger 1970, or by direct measurement inside the vehicle). This approach has not been successful up to now, essentially because the substantial amount of study regarding the response of human beings to vibrations has failed to provide consistent and practically useful results (Osborne, 1976). However, even if this had been achieved there would still be the major obstacle of obtaining an aggregate measure of comfort for a given length of road because of the different vibrations experienced in the various vehicle types at different speeds.
- (b) The other approach is to obtain the subjective response of road users directly by asking them to rate their assessment of the riding quality of the road whilst driving in a vehicle with which they are familiar (as discussed in Appendix 1). Each rater provides an "individual present serviceability rating" (IPSR) for a given length of road on a scale 0-5 (see Fig. A1.5). The average of the IPSR values of a number of raters is the "present serviceability rating" (PSR) of the road. The PSR of a road is then considered to represent the aggregate assessment of riding quality of users with respect to their normal experience. A problem with this approach is that the PSR is not necessarily a measure of comfort alone but could include subjective impressions of safety and VOC.

Vehicle operating costs comprise all the costs of owning and using a vehicle. Marginal costs arising from poor riding quality are due to increased vehicle maintenance and fuel costs. A number of experiments and surveys of operations have been undertaken to provide relations between VOC and roughness for various types of vehicles (e.g. Hide et al, 1975, Harrison and Chesher, 1983).

Even when considering only the effects of comfort and VOC, the interpretation of the meaning and significance of riding quality is complex.

In the first place the relative and absolute significance of PSR values (of comfort) are not clear. For example it is not clear by how much a PSR of 3 is better than a PSR of 2, nor to what extent a PSR of 2,5 is satisfactory or undesirable.

Secondly, comfort and VOC are two dimensions of riding quality that are not necessarily related in the same way to the road profile. For example some wave lengths may be more important for comfort and others for VOC. This may mean that for two roads A and B, A could be better than B with respect to comfort but inferior with respect to VOC. Moreover, even if this is not the case, if there is not a linear relationship between VOC and comfort, comparing averages of riding quality values will produce different results depending on whether PSR or VOC values are used.

The above questions centre on the relative properties of the PSR and VOC scales. In this appendix an overview of some work done in determining the properties of the PSR scale and of relating this to VOC and the QI scale of roughness (defined in Appendix 1) is given.

## A2.2 PROPERTIES OF THE PSR SCALE OF RIDING QUALITY

Hutchinson (1963) expressed caution against the indiscriminate use of the individual present serviceability rating (IPSR) scale derived from the "category" scaling method used in the AASHO Road Test (and by many agencies subsequently) - see Fig. A1.5. Stevens (1959) had shown that the validity of various mathematical (and thus statistical) operations depend on the properties of the scale concerned. The various scale types, the empirical operations required to erect the scales and examples of valid statistics are summarised in Table A2.1. In the absence of certain properties, therefore, obtaining the average, integral or ratio of scale values would give meaningless results. These operations are often of interest for deriving a number of riding quality statistics, e.g.

- average riding quality over a length of road
- average riding quality over a period of time (a measure of pavement performance)
- the relative significance of one level of riding quality with respect to another.

TABLE A2.1 : Scales of measurement and valid statistical measures  
(after Stevens, 1959)

Scale	Basic empirical operations	Valid statistical measures	
		Location	Dispersion
Nominal	Determination of equality	Mode	Information
Ordinal	Determination of greater or less	Median	Percentiles
Interval	Determination of the equality of intervals or differences	Arithmetic mean	Standard deviation
Ratio	Determination of the equality of ratios	Geometric mean Harmonic mean	Per cent variation

Note that properties listed are cumulative, i.e. those listed lower in the Table include properties given above.

It is thus pertinent to establish the properties of the IPSR scale and the validity of these operations.

Holbrook (1969) investigated the application of several subjective rating techniques for riding quality and the properties of their resultant scales but the properties of the IPSR scale were not explicitly stated. Rickwood and Curtayne (1983) describe two small scale experiments carried out in 1976 to study the nature of the IPSR scale. The first centred on opinions of a number of people having considerable experience with the measurement of riding quality. Hypothetical situations were presented to them (e.g. as in Fig. A2.1) in which they had to assign a value of riding quality to one route that would be equivalent to another route divided into two lengths with different stated levels of riding quality. The second experiment used the "constant sum" approach by Guilford (1954). In this method a number of roads were physically rated in pairs and points allocated to the discomfort experienced on each of the pair in such a way that the total equalled 100. The results of the two experiments were combined to produce the relation between the IPSR scale P and discomfort on a ratio scale D. This relation is shown in Fig. A2.2 and can be approximated by:

CHOOSE A PSR VALUE FOR ROUTE A THAT WILL MAKE IT EQUIVALENT IN RIDING QUALITY TO ROUTE B

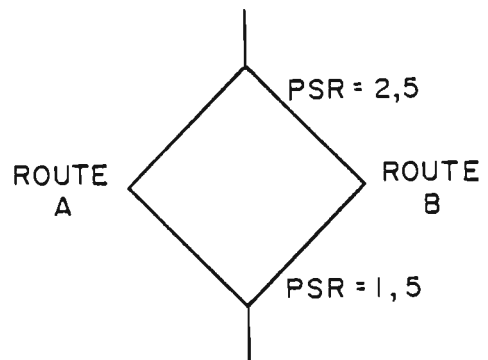


FIGURE A2.1

EXAMPLE OF QUESTIONS USED TO OBTAIN TRUE MEAN OF PAIRS OF PSR VALUES

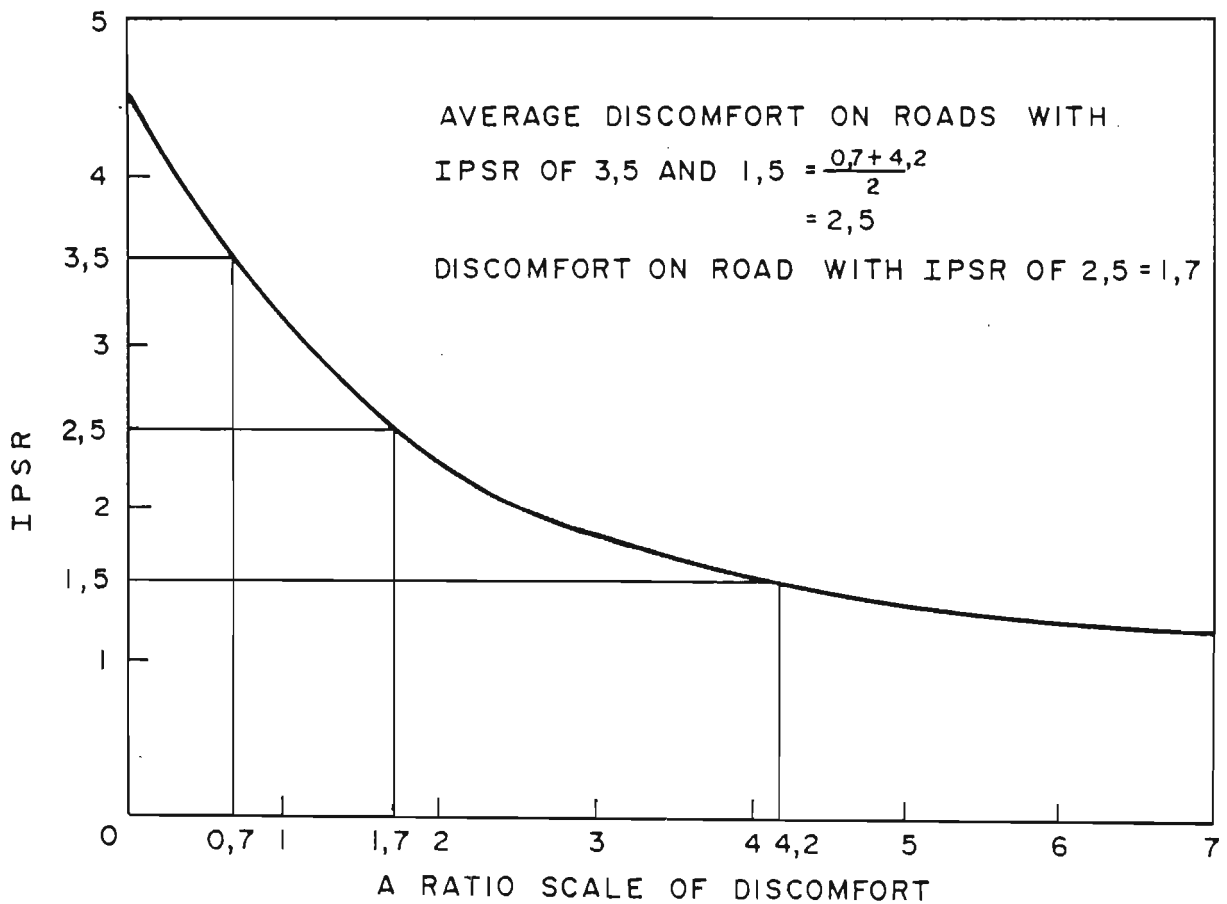


FIGURE A2.2

RELATION BETWEEN THE IPSR SCALE FOR RIDING QUALITY AND A RATIO SCALE FOR DISCOMFORT

$$p = 4,5 \exp(d^{-0,67}) \quad \dots \dots \dots (A2.1)$$

where  $p \in P$  and  $d \in D$

Although the scope of the experiment was considered to be too limited to place much reliance on the accuracy of this relation, it was established sufficiently well to allow a number of conclusions, i.e.:

- (a) The shape of Relation A2.1 is decidedly non-linear indicating that the IPSR scale has ordinal rather than interval or ratio properties.
- (b) The average of IPSR values over a fairly uniform length of road, varying say from 2 to 3, would be meaningful as over this range the relation can be assumed linear for practical purposes.
- (c) However, by referring to Fig. A2.1 it can be seen that the average discomfort over two lengths of road with IPSR values of 3,5 and 1,5 respectively is nearly 50 per cent higher than the discomfort on a road with an IPSR of 2,5 (i.e. the average of 3,5 or 1,5).
- (d) If a scale with only ordinal properties is used (e.g. the IPSR scale) the performance of two roads (say A and B) can only be compared if IPSR of A is greater than that of B for every value of time (as shown in Fig. A2.3). When the performance curves intersect as in Fig. A2.4 no meaningful conclusion can be made. However, if the IPSR values are transformed into ratio values of discomfort the performance curves can be integrated and the results interpreted as average discomfort over the time period and ranked accordingly.



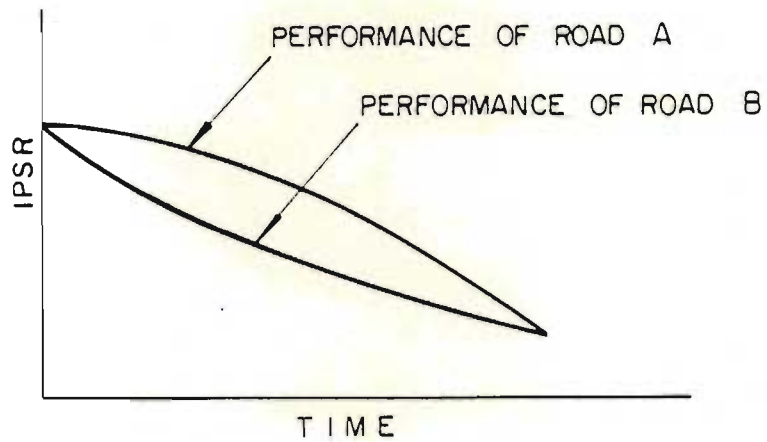


FIGURE A2.3

*COMPARISON OF THE PERFORMANCE OF TWO ROADS FOR WHICH THE PERFORMANCE CURVES DO NOT INTERSECT.*

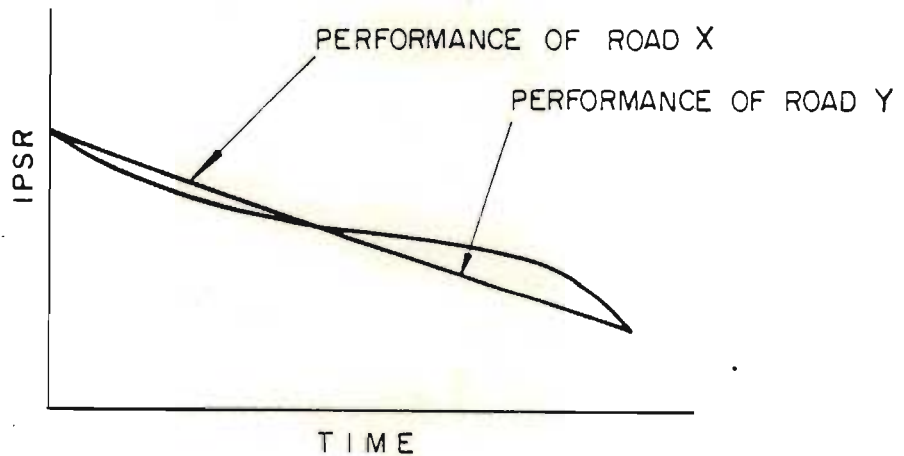


FIGURE A2.4

*COMPARISON OF THE PERFORMANCE OF TWO ROADS FOR WHICH THE PERFORMANCE CURVES DO INTERSECT.*

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This limited study indicated the need for caution when carrying out various mathematical operations on IPSR values. Certain evaluations do not cause problems but for others misleading results can be obtained. Although Relation A2.1 provides ratio values of discomfort that can be used to overcome the limitations of the IPSR scale considerable further work is required to establish its accuracy.

Note that Visser (1982) found a correlation between roughness and PSR of the form:

$$q = 92,63 - 56,39 \ln(p) \quad \dots \dots \dots \dots (A2.2)$$

where q = roughness on QI scale

From Relations A2.1 and A2.2, the relation between discomfort and roughness is:

$$d = (q - 8)^{1,5} \quad \dots \dots \dots \dots \dots \dots (A2.3)$$

### A2.3 EFFECT OF RIDING QUALITY ON ROAD USER COSTS

Tentative relations showing the effort of riding quality on vehicle operating costs for a heavy (2 axles) and a passenger car are shown in Fig. A2.5 with riding quality expressed as road roughness on the QI scale. These relations were derived by Visser (1983) from results obtained from the Brazil Study (Chesher et al, 1980, Harrison and Swait, 1980) and adapted to South African conditions by Visser (1983) from cost data given by Schutte (1981) and Pienaar (1983).

These cases represent total vehicle operating costs and are considered to be valid over the range of 40 - 100 units of QI. To measure the proportion of the VOC resulting from the roughness of the pavement over the full range is difficult because of the small differences of VOC obtained at very low values of roughness. The following model was therefore used to described these curves:

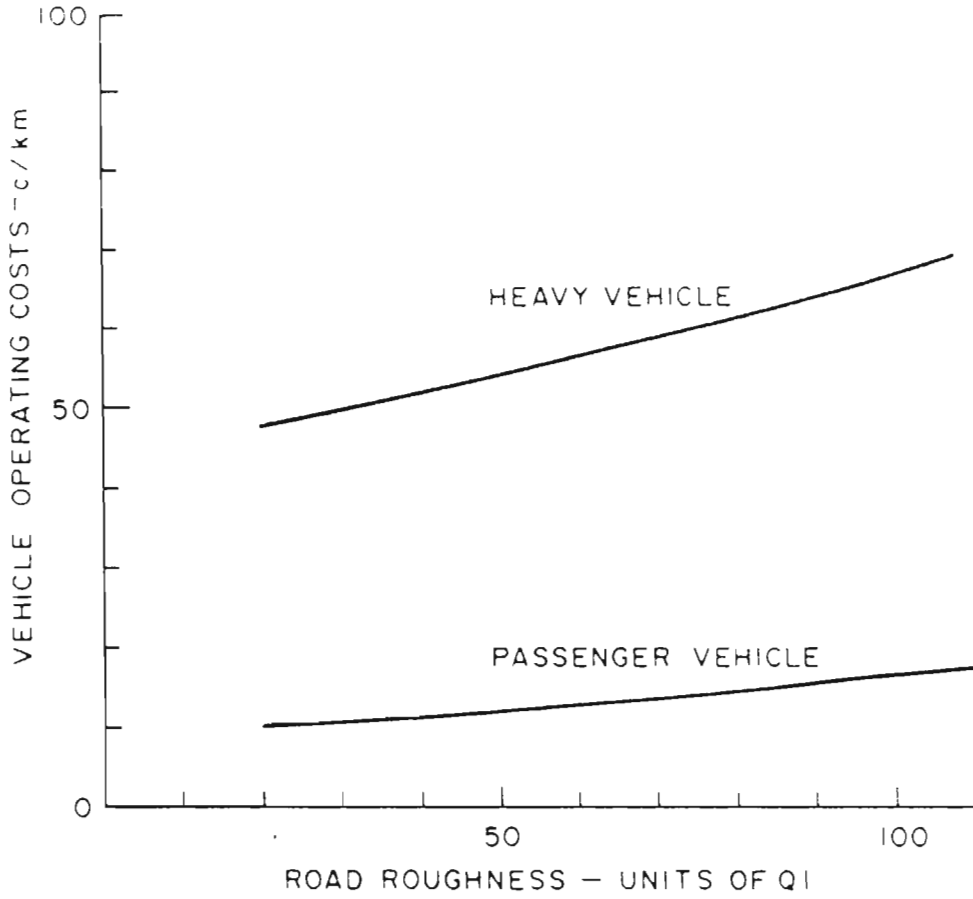
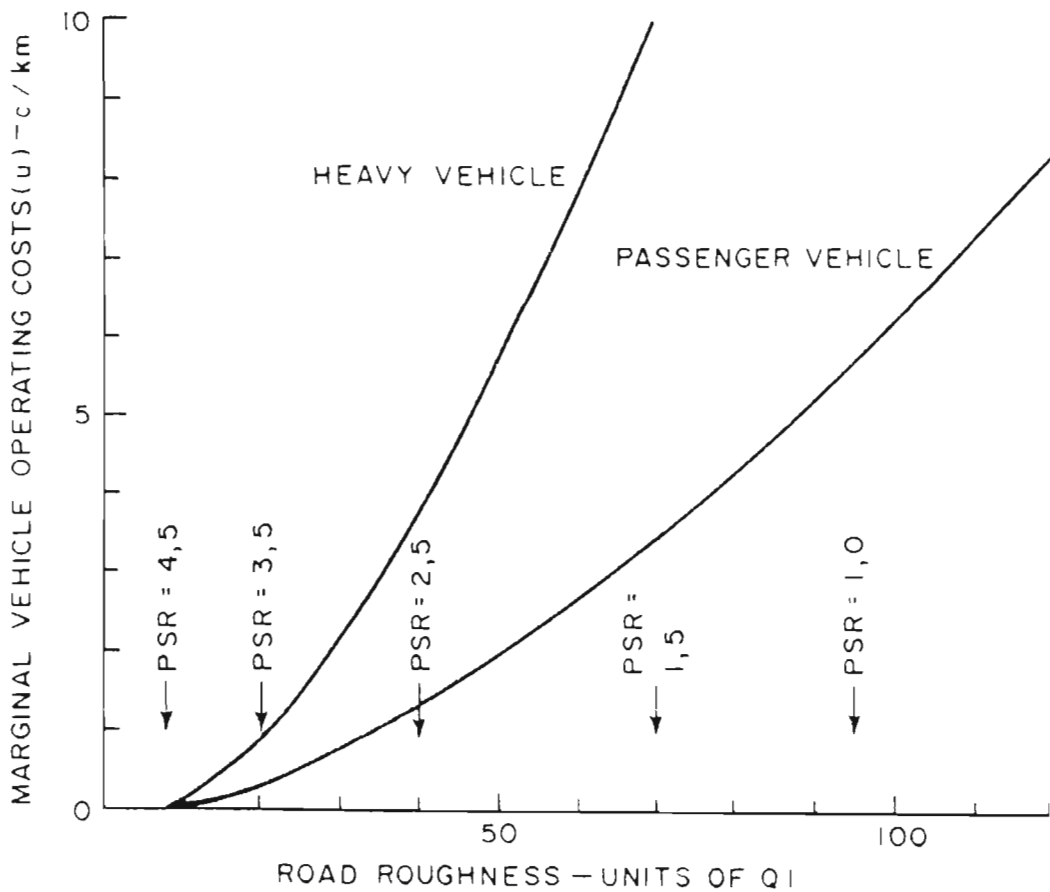


FIGURE A2.5

*TOTAL VEHICLE OPERATING COSTS AS A FUNCTION OF ROAD ROUGHNESS*



$$U = V - \eta = a(q-b)^c \text{ for } q > b \dots \dots \dots (A2.4)$$

$$= 0 \quad \text{for } q < b$$

where U = marginal VOC due to road roughness

V = total VOC

$\eta$  = VOC for  $0 < q > b$

q = roughness in QI

a,b,c = constants depending on the type of vehicle.

Assuming  $b = 8,0$  and  $c = 1,5$  in accordance with Relation A2.3 values for  $\eta$  and a were calculated for the heavy and light vehicles and are given in Table A2.2. The resultant curves for U are illustrated in Fig. 2.6 and the goodness of fit of the model to the curves in Fig. A2.5 can be judged from Table A2.3.

TABLE A2.2 : Coefficients obtained for Relation A2.4

	$\eta$	a
Light vehicles	10,03	0,00698
Heavy vehicles	48,43	0,0209

TABLE A2.3 : Comparison of experimental and model values of VOC

Roughness QI	Total VOC - c/km			
	Light vehicles exp.	Light vehicles model	Heavy vehicles exp.	Heavy vehicles model
20	10,0	10,3	48,0	49,3
40	11,3	11,3	52,2	52,2
60	12,7	12,7	56,6	56,3
80	14,3	14,3	61,2	61,2
100	16,1	16,2	66,3	66,9

The total annual marginal VOC,  $K_v$ , for roads with roughness  $q$  is thus given by:

$$K_v = (0,0209h + 0,00698l) (q-8)^{1,5}$$

where  $h$  = number of heavy vehicles per year

$l$  = number of light vehicles per year

or

$$K_v = 0,007 e_v (q - 8)^{1,5}$$

where  $e_v$  = annual number of equivalent (light)

vehicles, where one heavy vehicle can be

taken to be equivalent to three light

vehicles.

Relation A2.3 was obtained for passenger vehicles. On the assumption that travellers in heavy vehicles will suffer three times the discomfort experienced in light vehicles, the total cost of discomfort per annum  $k_d$  will be:

$$k_d = w_d e_v (q - 8)^{1,5}$$

where  $w_d$  = cost per equivalent vehicle per km per unit discomfort.

The combined road user cost is then:

$$\begin{aligned} k_T &= k_d + k_v \\ &= (w_d + 0,007) e_v (q - 8)^{1,5} \quad \dots \quad \dots \quad \dots (A2.5) \end{aligned}$$

In this form the discomfort and operating costs are simply added to give a combined coefficient for total road user cost. The value of  $w_d$  must be established on the basis of what the society collectively is willing to pay for comfort and added as a "premium" to VOC. This relation is a useful result from a number of points of view:

- (a) The relation transforms values of roughness (or riding quality) to a ratio scale of cost for which the mathematical operations of averaging, integration etc. are valid.

- (b) An important consequence is that if a given route of varying riding quality is preferred to another in terms of VOC it will also be preferred for reasons of comfort.
  
- (c) Relation A2.3 was derived from subjective response to road roughness and apart from being an indication of discomfort the rating could also include a measure of the rater's perception of the effect of the roughness on safety and VOC. However, provided the total costs are represented as in Relation A2.5 these confounding effects are unimportant and it remains only to establish the premium to be added to VOC to account for discomfort.

Note that Relation A2.5 is based on very few data and a number of assumptions. The goodness of fit of Relation A2.4 to the empirical data was found to be fairly robust with respect to changes in the values of the parameters  $b$  and  $c$  and thus their true values have not necessarily been found to be the same as the equivalent values in Relation A2.3 (in themselves of doubtful accuracy). On the other hand the relation does not contradict any known empirical findings and its simple and convenient form would be useful to retain even if it is only approximately correct. In any event it is important that further work be carried out to improve the accuracy of the above relations.

## APPENDIX 3

### NOTES ON THE ROLE OF ROAD USER COSTS IN PAVEMENT MANAGEMENT EVALUATIONS

#### A3.1 INTRODUCTION

Design and project priority evaluations in pavement management must take into account both immediate and future costs to the road authority (i.e. maintenance costs) and to the road user. Two approaches for dealing with road user costs are possible:

- (a) The direct (or total cost) method is to determine a strategy that will minimize the sum of maintenance and road user costs (suitably discounted to allow for time effects) over the analysis period. This requires a well defined relationship between serviceability and road user costs as well as a means of predicting serviceability as a continuous function of time.
- (b) Alternatively, road user costs can be accounted for implicitly by considering only those rehabilitation strategies that will ensure that the serviceability of all pavements will be kept above a specified minimum (terminal) value (depending on the functional class of the road). The problem is then to determine the most cost effective strategy satisfying this criterion.

The underlying assumption of the second case is that no additional value is given to levels of serviceability above the terminal level. There would therefore be no distinction made between the two performance curves shown in Figure A3.1. It is assumed further that if the serviceability were to drop below the terminal value the increased road user costs would exceed any savings derived from delaying the rehabilitation. Therefore any strategy that allows this to occur would be less economical than the optimum.

Consequently, the direct method has the more immediate appeal as it appears to account for all the costs actually incurred.

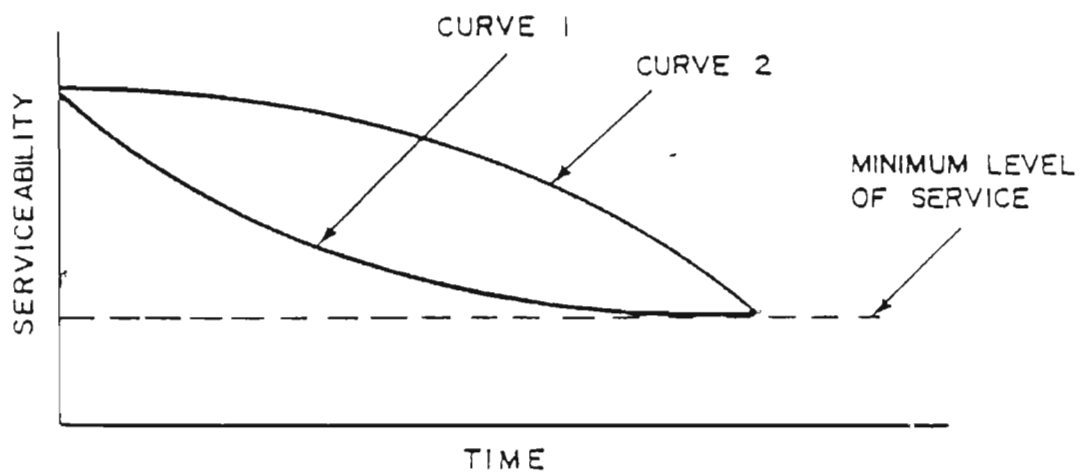


FIGURE A3.1

*TWO PERFORMANCE CURVES (CURVE 1 AND CURVE 2) THAT ARE EQUIVALENT UNDER "MINIMUM LEVEL OF SERVICE" CRITERION*



However there are a number of practical and theoretical reasons for which the indirect (or cost effective) method of analysis may be preferred:

- (a) It is the simpler method. Once terminal levels have been set for the various road categories only the maintenance costs of eligible maintenance strategies need be considered. For any one strategy there are only a few maintenance treatments and their costs are easy to obtain. Determining whether a strategy is eligible (i.e. whether it maintains the serviceability above the terminal value) is not easy but the problem is more limited than determining the shape of the performance curve.
- (b) It avoids problems created by uncertainty of the relationship between serviceability and road user costs. Small differences, for example, in the choice of intercept and slope of the function of marginal vehicle operating costs with riding quality (Figure A2.6) can have a great effect on evaluations for high traffic values, especially at higher levels of riding quality. This effect can be difficult to relate back to the assumptions regarding road user costs as these are embodied in the total cost result and therefore it is difficult to determine whether the cost of maintenance is in keeping with the public's willingness to pay for the service provided. Fixed minimum levels of service on the other hand are easy to relate to and the effect of raising or lowering them can be examined subjectively or in terms of a sensitivity analysis of road user costs.
- (c) The uncertainties regarding the prediction of the shape of the performance curve (and the associated road user costs) result in there being little benefit in trying to distinguish between curves such as those shown in Figure A3.1.
- (d) It is more in line with the way (public or commercial) service are generally provided; a certain quality is specified and an attempt is made to provide this as cheaply as possible. A consequence of this is that certain facilities with a low

level of use may have a higher standard than may be justified by simple cost considerations. They would in fact be subsidized by heavily utilized facilities having a lower standard when costed per unit useage.

The above arguments indicated the respective advantages of two methods of dealing with road user costs and the complexity of the problem even when confined to vehicle operating costs and their relation to riding quality. In practice though one has to deal with a number of serviceability features and has to consider road user costs that are not directly quantifiable. Ideally, an analytical approach would:

- incorporate all aspects of road user costs in a unified framework,
- consider both total costs and minimum levels of service and their relationship,
- establish a negotiable basis for determining the willingness of the community to pay for given levels of service,
- provide a feedback mechanism between the public and the road authority by which the community can use assessments of the effect of past decisions to indicate a better balance between expenditure and benefits.

In the following section the components of road user cost are discussed and in the final section a framework for dealing with them in pavement management evaluations is suggested. Although only presented in general terms it is believed to be amenable to a formulation that will meet the above requirements.

### A3.2 COMPONENTS OF ROAD USER COSTS

Four components of road user costs are:

- vehicle operating costs (VOC),
- discomfort (i.e. complement of comfort),
- time (i.e. complement of speed),
- risk of accident (i.e. complement of safety).

Driver behaviour can trade speed for the other components. However, roads are usually designed geometrically to accommodate traffic at specific speeds. Therefore the three independent pavement related components to consider are:

- VOC
  - discomfort
  - risk of accident
- } at an appropriate operating speed

As noted in Appendix 1, these costs must be derived from the value of the various pavement features, (i.e. riding quality, skid resistance, surface drainage) as illustrated in Figure A3.2. In principle, the following relations apply:

$$y_i = f_i(\vec{x})$$

$$z = g(\vec{y})$$

where  $\vec{x}$  = vector of pavement feature values  
 ( $x_1$  = riding quality, etc.)  
 $\vec{y}$  = vector of road user cost components  
 ( $y_1$  = VOC, etc.)  
 $z$  = total road user costs.

A possible structure for  $g$  is:

$$z = \sum_1 \omega_1 y_i$$

where  $\omega_1$  are the weighting factors for the road user costs components.

Although the form of the functions  $f_i$  may be established empirically (albeit with difficulty - see Appendix 2) the relative weights  $\omega_1$  must reflect the wishes of the community at the time. Comfort and safety cannot be bought as such and therefore their value (or the cost of discomfort and risk of accident) cannot be determined commercially, VOC on the other hand can be expressed in commercial terms but savings of these costs cannot necessarily be offset directly against maintenance costs producing them. Firstly

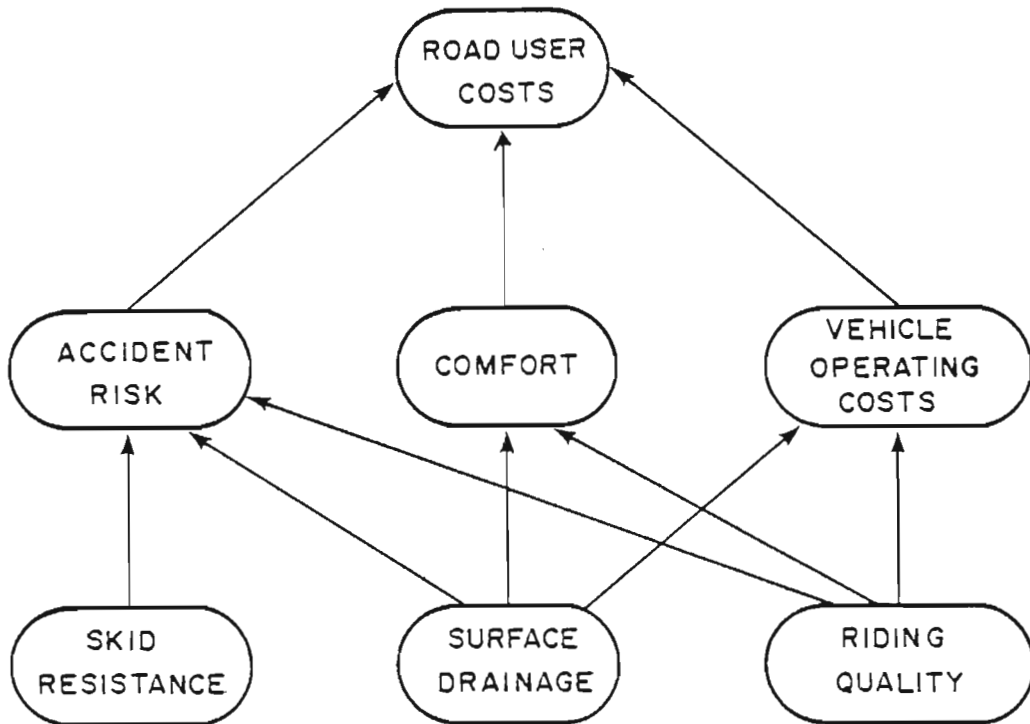


FIGURE A3.2

*RELATION BETWEEN COMPONENTS OF ROAD USER COSTS  
AND ASSOCIATED PAVEMENT FEATURES*

different people may be paying for the maintenance than are benefitting from the savings. Secondly the money spent on maintenance could possibly be spent more effectively elsewhere. The relative and absolute value of the above criteria must be established by assessing how much the public is willing to pay for avoiding them via the political process. The problem lies in achieving this.

### A3.3 SUGGESTED PROCEDURE FOR DEALING WITH ROAD USER COSTS IN A PMS

The following approach is based on an interactive goal programming technique for multi-criteria decisions described by Weistroffer (1983):

Step 1: Set minimum desired levels of service  $\gamma_i$  of each of the features  $x_i$  (according to the class of road) that are known to be achievable within the current budget constraints.

Step 2: Assume approximate values for the functions  $f_i$  and the weights  $\omega_i$  and determine a maintenance policy to optimize

$$z = \sum \omega_i g_i$$

such that  $x_i > \gamma_i$  for all  $i$

and  $b < B$

where  $b$  = cost of the maintenance policy

and  $B$  = currently envisaged budget.

Step 3: If the solution for  $z$  implies values for  $x_i$  significantly above  $\gamma_i$  it means that the target minimum levels of service are lower than can be achieved with the current budget. One or more of the limits can then be raised according to which will provide the greatest benefit and a new solution obtained. This step is repeated until the road authority is satisfied that a reasonable balance is obtained between minimum levels of service, the optimum policy and the budget.

Step 4: This policy is put into operation for a period of time, ensuring that the specified minimum levels of service are maintained. If the public are unhappy about certain aspects of this policy (e.g. riding quality of a class of road too low) this would come to the attention of politicians who control road finance. The road authority should then be in a position to suggest a new trade-off between minimum levels of service or an increased budget to raise the level of the aspect of service causing discontent. The financing authority will have to decide on the course of action to be followed.

Step 5: Whatever the decision, this should result in a new policy to which the public can react and the whole process becomes a goal seeking operation that is adaptable to changing economic and technological circumstances. This is illustrated in Figure A3.3. (see also Fig. 2.12).

Although the details of this method must still be developed, the optimization problem can, in theory, be solved by mathematical programming. However, the importance of this formulation is thought to lie in the principles developed to accommodate the various complexities of road user costs considerations.

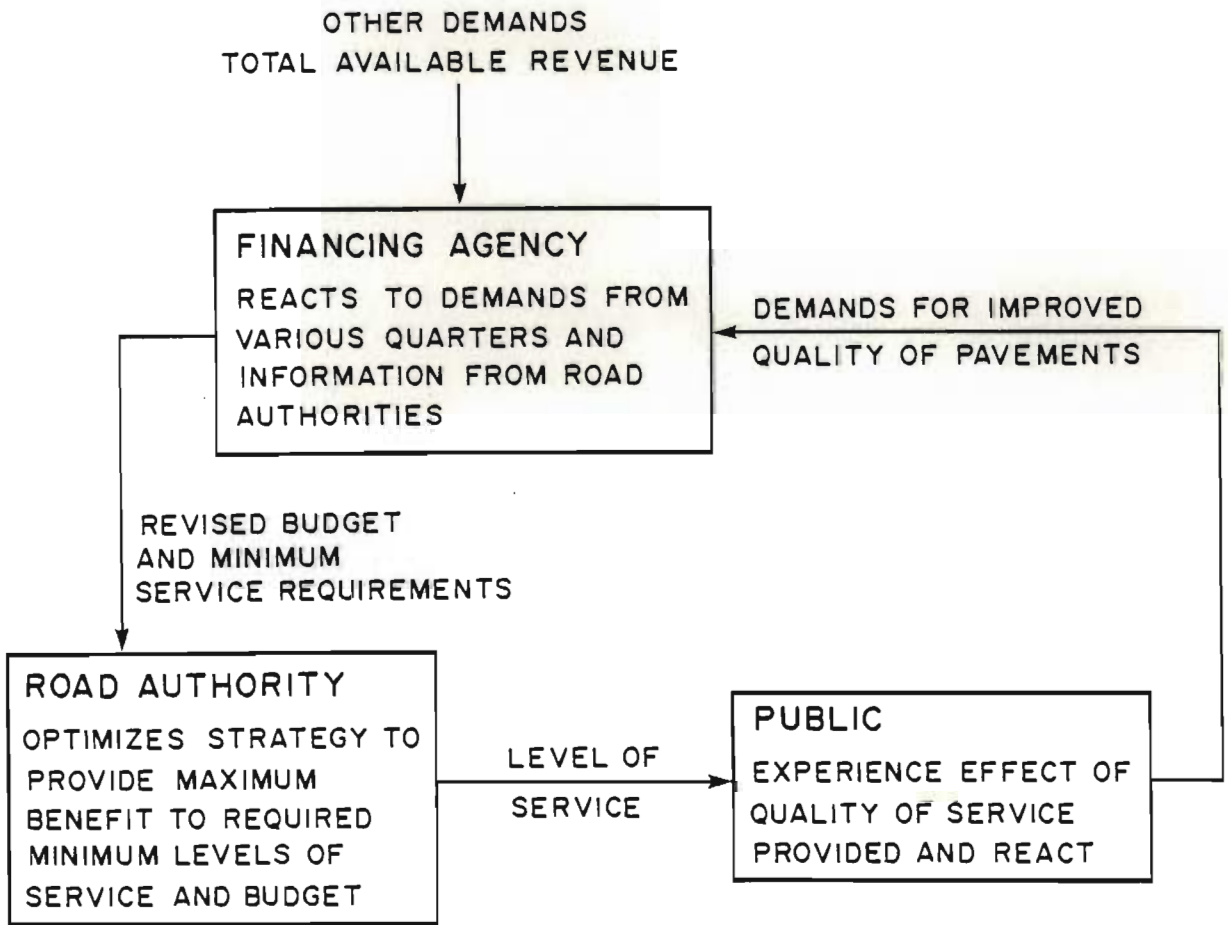


FIGURE A3.3

*ITERATIVE PROCEDURE BY WHICH THE CORRECT BALANCE BETWEEN EXPENDITURE AND LEVEL OF SERVICE IS OBTAINED*

## APPENDIX 4

### BRIEF REVIEW OF VARIOUS PAVEMENT MANAGEMENT SYSTEMS

A number of PMSs have been developed overseas and several of these are being routinely used by road authorities. These systems have different objectives and are based on a variety of evaluation procedures using diverse decision criteria. In addition these systems have different approaches towards the prediction of the behaviour of pavements and incorporating this into the analysis. In certain cases, i.e. where standards are specified when certain maintenance should be done, the prediction of undesirable consequences of forbearing such maintenance is implied. In other cases explicit predictions of pavement behaviour using either empirical or subjective models are incorporated into the evaluation procedure.

Table A4.1 gives a summary of the characteristics of various PMSs developed overseas. This is not an exhaustive list but it covers the main types of systems found in the literature and provides a useful summary of the approaches used.

Note that seven of these systems are concerned with strategic or tactical planning and of these only four make use of some form of optimization, i.e.:

- RAMS developed for the Texas Department of Transportation (DOT);
- The system developed for the Arizona DOT;
- The system developed for Washington State DOT;
- The system developed by Karan and Haas (1976).

None of these four systems makes use of empirical models for predicting the behaviour of the pavements. Only two of these, those for Arizona and Washington State, are currently integrated into the operations of the road authority.



TABLE A4.1 : Summary of various proposed or existing PMSs

Name - Agency (Reference)	Application	Pavement prediction method	Optimization/ evaluation procedure	Decision criteria
CALMS - University of California (Smith and Monismith, 1976)	Design of rehabilita- tion	Subjective probabilities for state changes (to be improved by experiment using Bayes principle)	Infinite linear programming	Minimize total cost (pavement plus specified proportion of user costs)
CALTRANS - California Dept. of Transport (Bartell, 1978)	Tactical planning of maintenance	-	Dominant strategy - for maintenance type Decision table - for priority	Critical limits of dis- tress selection in order of priority
CHART - UK Ministry of Transport (Wingate and Peters, 1975)	Tactical planning of maintenance	-	Dominant strategy - for maintenance type	Critical limits of dis- tress
HDM - World Bank (Harral et al, 1979)	Design of new pave- ment	Empirical models derived from Kenya and AASHO road experiments	Inspection of results of selected strategies	Minimum total costs (user plus pavement)
NIMPAC - NAASRA (NAASRA, 1981)	Essentially strategic	User supplied rate of deterioration coefficients	Simulation	Selection of condition standards appropriate to budget
OPAC - Ontario Dept. of Transport (Jung et al, 1975; Kher and Phang, 1975)	Design of new pave- ments	Estimated subgrade de- flection related to loss of riding quality from AASHO Road Test results (environmental effects predicted using results of Brampton road experi- ment)	Spectrum of designs and overlays	Minimum design life, minimum level of riding quality minimize total costs (pavement plus user)
PDMAP - NCHRP (Finn et al, 1977)	Design of new pave- ments	Mechanistic prediction of cracking and deforma- tion calibrated against results of AASHO Road Test	Inspection of selected alternatives	Cheapest design with limits to cracking and deformation over design life
PDMS - US Forestry Service (Luhr et al, 1982)	Design of new pavements and rehabilitation	Semi mechanistic: re- gression equations relating strains to AASHO Road Test results	Inspection of selected alternatives	Overlay at terminal PSI, choose strategy with lowest present worth of costs (inclusion of user costs optional)
RAMS - Texas Dept. of Transport (Lytton et al, 1982)	Tactical planning	Probabilities of state changes input to program, presumably subjective	Integer linear pro- gramming	Maximize maintenance effectiveness, i.e. avoidance of distress
SAMP - NCHRP (Haas and Hudson, 1978)	Design of new pavements	Empirical regression equation involving structural number (based on results of AASHO Road Test)	Generation of spec- trum of design and overlay alternatives	Overlay at terminal PSI, choose strategy with minimum pavement plus user delay costs
VESYS - FHWA (Kenis, 1977)	Design of new pavements	Mechanistic	Inspection of pre- dicted behaviour of of selected optims	Reliability of not exceeding specified dis- tress in design period
- Arizona Dept. of Transport (Kulkarni et al, 1982)	Strategic planning	Subjective probabilities for state changes	Linear programming (to minimize long term costs producing steady state of ave- rage condition)	Maximum length of un- acceptable condition, minimum length of accept- able condition (in terms of cracking and riding quality)
- US Army Corps of Engineers (Shahin, 1982)	Design of maintenance treatment	Empirical regression for overall condition, extra- polation for distress	Class of initial op- tions based on deduct point rating	Choose strategy with lowest present worth of costs that maintains pavement above minimum overall condition

Table A4.1 (continued)

Name - Agency (Reference)	Application	Pavement prediction method	Optimization/ evaluation procedure	Decision criteria
- Washington State Dept. of Transport (Le Clerc and Nelson, 1982)	Tactical planning	Extrapolation	Project optimization by analysis of given list of possible strategies, schedule to fit budget accord- ing to net benefit	"Should rehabilitate" and "must rehabilitate" trigger limits; dis- counted total costs
- (Karan and Haas, 1976)	Tactical planning	Subjective probabilities for state changes	Linear programming	Terminal value of index representing sum of riding quality and ap- pearance, minimum total costs (user plus pave- ment)

## APPENDIX 5

### NOTES ON THE DESIGN OF PAVEMENT REHABILITATION

#### A5.1 INTRODUCTION

This study has concentrated on the strategic and tactical planning functions of pavement management. However, once a rehabilitation project has been identified, the next task is to determine the most economical design within the prevailing constraints (which will include availability of materials, plant and expertise). The design of rehabilitation has the advantage over new pavement design in that many of the design variables that would have to be estimated for the latter case can be measured on the existing pavement to be rehabilitated. A judicious evaluation of the existing pavement can determine the cause and mechanism of distress and the strengths and weaknesses of the pavement and can indicate the most suitable type of rehabilitation.

Many detailed rehabilitation design procedures have been suggested. These range from the earlier procedures using simple measurements of deflections of the existing pavement (see e.g. Asphalt Institute, 1969) to the use of mechanistic theory in conjunction with more elaborate deflection measurements (see for example Koole, 1979). Monismith and Finn (1977) have summarized the general approach to the latter type of analysis.

The first objective of a rehabilitation design procedure to choose an economical design that will withstand the traffic and environments forces for a reasonable length of time. However to be complete the analysis should also take into account the effect of alternative designs on road user costs and future maintenance. Pavement management systems at the project level are procedures that assist the designer in taking all of these considerations into account collectively when choosing among rehabilitation alternatives. A number of proposed systems that achieve this to a greater or lesser extent are listed in Appendix 4.

The difficulty in formulating a standard design procedure is that there are numerous tests that could, in principle, be used to determine the condition of the existing pavement. However, such tests are expensive and should be limited to those that contribute significantly to the type of evaluation appropriate to the situation. According to the nature of the distress, the past behaviour of the pavement, the pavement structure, etc., for some cases the simple use of deflection measurements may be sufficient, for others some form of mechanistic analysis may be required and in certain instances special testing of the material properties may be necessary.

The choice of testing is therefore part of the evaluation procedure and requires a sound understanding of pavement behaviour and an appreciation of the cost of testing and the degree to which various tests can contribute to resolving uncertainties about the effect of alternative rehabilitation treatments. Moreover the evaluation has to take account of many factors that cannot readily be incorporated into evaluation models. These include conditions seen to be relevant but not explicably included the model, local experience of pavement behaviour and political considerations. Ideally rehabilitation design procedures should allow such subjective input as a formal part of the evaluation.

#### A5.2 SUGGESTED ANALYSIS FRAMEWORK

Grant and Curtayne (1982) discuss an iterative procedure using Bayesian analysis (see e.g. Benjamin and Cornell, 1970) as a general evaluation framework. An outline of the main principles of this method is given in the following:

##### (a) Bayesian analysis

The procedure is illustrated in Figure A5.1 where the possible effects of a thin overlay on a hypothetical pavement are evaluated. First the possible outcomes and their associated probabilities after 5 years are indicated. Subsequent treatments in the event of each of these outcomes is considered and their outcomes at the end of the 10 year period are indicated.

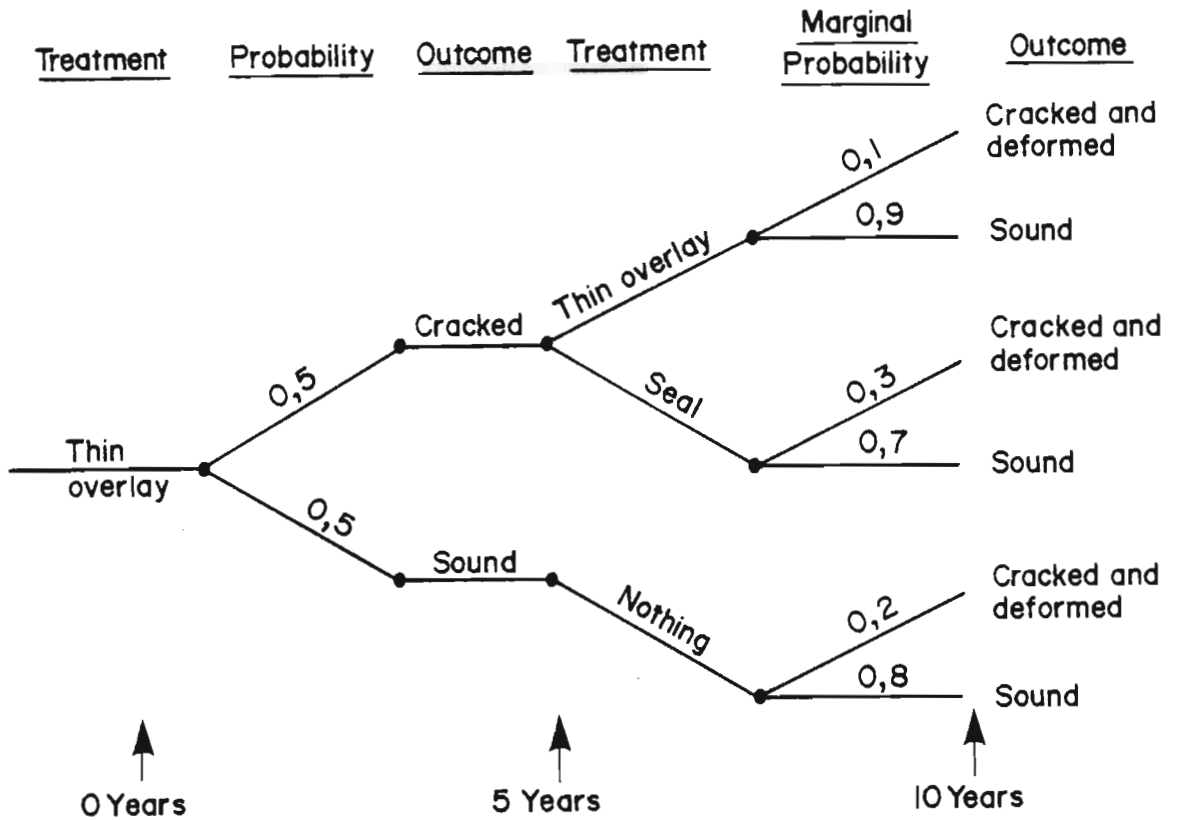


FIGURE A5.1 ILLUSTRATION OF BAYESIAN DECISION TREE

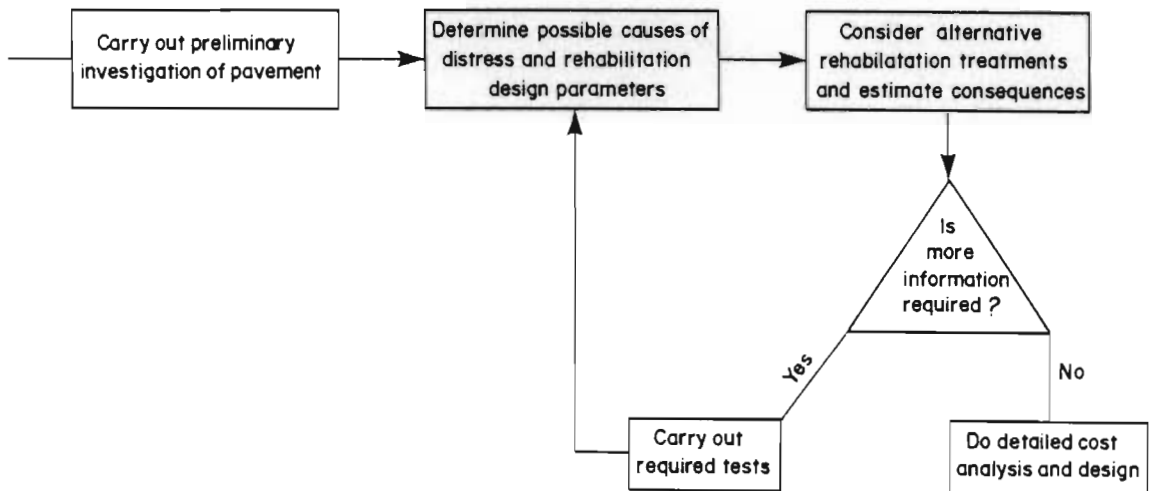


FIGURE A5.2 ANALYSIS PROCEDURE FOR REHABILITATION DESIGN

By assigning costs to each of the final outcomes the best follow up action after 5 years can be determined and then the expected present worth of the original treatment is calculated.

This procedure allows uncertainties of subjective assessments and numerical models (be they empirical, mechanistic or hybrid models) to be handled together in a formal manner. The assigned probabilities reflect the degree of knowledge about the possible outcomes given the information available at the time. The diagram can then be used to indicate where additional information may improve the analysis. Further measurements can be taken accordingly and the analysis repeated.

(b) The analysis procedure

The iterative nature of the analysis is shown in Figure A5.2. After a preliminary investigation into the cause of the pavement deterioration and its remaining structural capacity possible maintenance strategies are considered. If more information is likely to benefit the analysis, further measurements are taken and the analysis repeated until a maintenance strategy can be selected with appropriate confidence. At this stage the initial treatment of the selected strategy is evaluated in greater detail in which, for example, the benefits of recycling can be determined.

Further details of this approach are given by Servas and Curtayne (1982) and the economic considerations are discussed by Curtayne and Servas (1983). These principles are being incorporated into TRH12 (National Institute for Transport and Road Research, 1983).

A5.3 RELATION TO PMS DATA BASE

A standard procedure for carrying out a preliminary assessment of the pavement requiring rehabilitation has been incorporated in TRH12 (Servas and Curtayne, 1982).

The results are set out graphically for ease of interpretation and example of which is given in Figure A5.1 from a study by Yorke-Hart and Jordaan (1982). This representation is similar to the summary of pavement condition output of certain PMSs (see for example Figure 5.9).

Data bases of PMS can provide much of the information required for preliminary investigations, e.g. details of the pavement structure, traffic and past behaviour of the pavement. Specially prepared outputs from the PMS can therefore provide an important link between the network and project levels of pavement management systems.

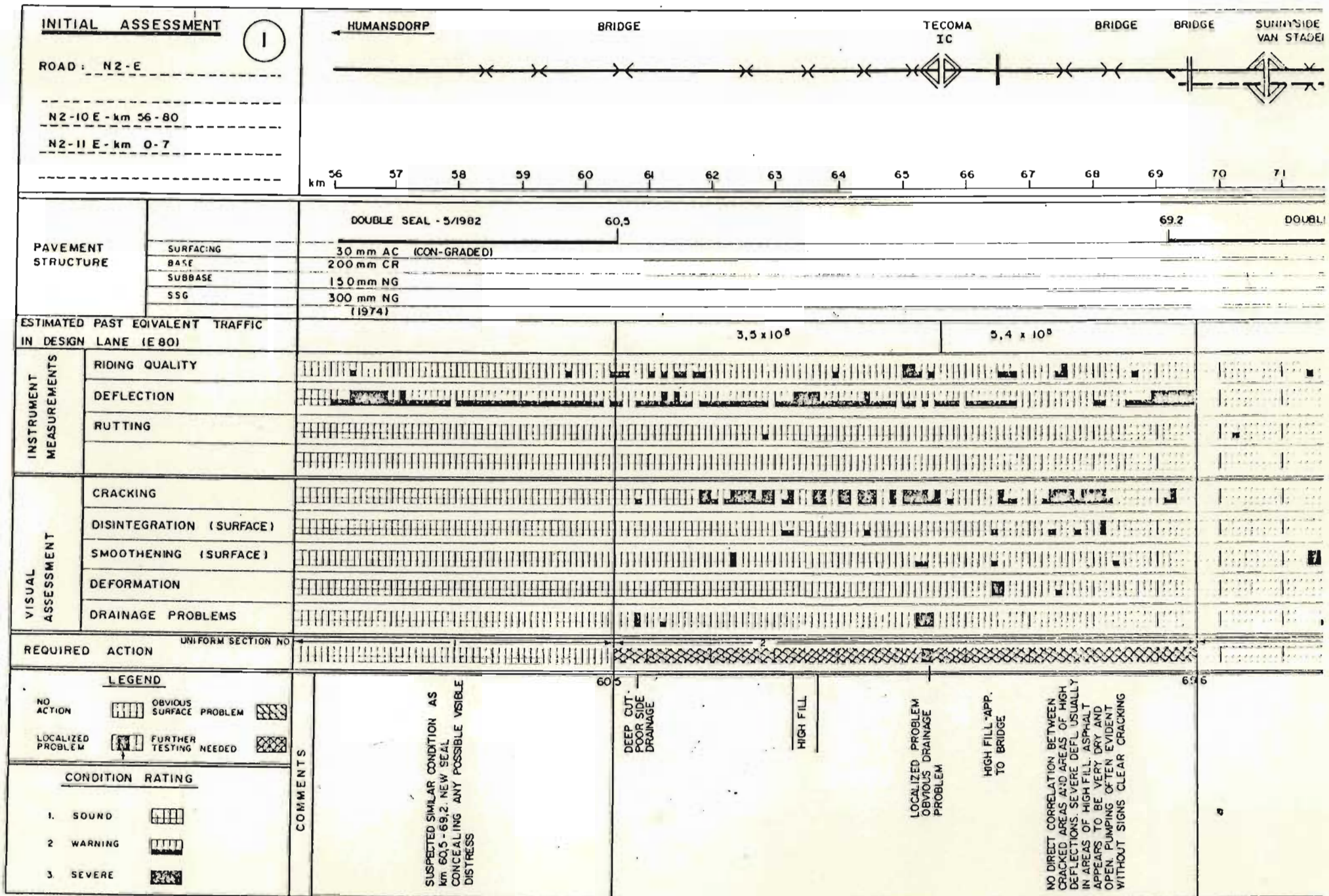


FIGURE A5.3 EXAMPLE OF INITIAL ASSESSMENT SUMMARY SHEET



## POSTSCRIPT

### INTRODUCTION

Because of the large number of people and organizations involved in the implementation of the pavement management systems discussed in this thesis, further clarification is offered here regarding what I consider to have been the major steps in my contribution to this work. In this vein the important decisions and contributions by other persons or organizations are stated.

### BACKGROUND

In the early nineteen seventies I was involved in studying methods for describing pavement condition and for measuring riding quality. The object was directed towards relating the behaviour of pavements to their elastic properties in order to evaluate various rehabilitation design methods. Most important in this work was to test various instruments for measuring riding quality and to carry out an experiment to provide a scale of riding quality for use in South Africa. This experience led me to suggest the scope for monitoring the condition of pavements for controlling their maintenance at the network level. A formulation of this idea is illustrated in Figure P1 and was submitted as the original proposal for this thesis in 1972. Although the work did not develop exactly as foreseen it followed roughly the same lines as is indicated in the following.

### METHODS FOR DESCRIBING PAVEMENT CONDITION

An unambiguous nomenclature for describing pavements to any degree of detail is prerequisite for the development of all pavement management schemes. At the start of the project there was considerable lack of clarity about such terms among local engineers and I considered the classifications suggested overseas to be incomplete or inappropriate. My first task was thus the classification of the factors determining the serviceability of pavements and those pertaining to its structural condition. Included in the latter was a full categorization of the

various distress manifestations which was defined by examining the opinions of engineers experienced in evaluating pavement surfacings and structures. (See Appendix 1.) These results were accepted in the form of a guide for South African use by the Highway Materials Committee of the Committee of South African Road Authorities as TRH6.

Because the processing of data from the first road meters was slow and tedious, I decided to develop and commission a high speed instrument based on the PCA roadmeter that provided an output directly in terms of the standard riding quality scale. (See Appendix 1.) This instrument has been widely used in South Africa for the past 12 years.

This work together with concurrent work by colleagues in commissioning instruments for the routine measurement of skid resistance and deflection provided the basis for pavement management systems development.

#### DESIGN OF A PAVEMENT MANAGEMENT SYSTEM

On examining the design requirements of a pavement management system it became clear that they depended very much on the resources, network, policy and operations of the authority concerned. To be meaningful a system would have to be designed around a real situation. I therefore approached the Department of Transport with a proposal to implement a pavement management system which they accepted along with other proposals for a more comprehensive management information system. I was granted the task of designing the pavement management subsystem which included the input requirements, output specifications and development of associated algorithms. (See Section 4.2.)

The output formats were designed around the objective of providing information with varying degrees of detail according to the needs of the different levels of management. Here extensive use was made of graphical techniques to present large quantities of data in an easily assimilable form. The method of presentation also served the very important function of allowing the engineers to interact meaningfully with the assessment of maintenance requirements.

The algorithm generating maintenance requirements had the form a set of rules arranged as a decision tree relating the pavement condition to the type and urgency of maintenance needed. An assessment of the future performance of the pavements is implicit in deriving these maintenance requirements. These rules were based on personal discussions with acknowledged experts in various fields of pavement engineering. This procedure is a formalization of the traditional approach of arriving at maintenance decisions and the individual rules can be easily negotiated with officials of the authority to ensure that they are compatible with their preferences. Although not ideal in the sense of economic optimization the procedure has the important advantage of generating confidence in and acceptance of the system, of relating the logic with field assessments and of being readily adaptable to changing attitudes.

The method of deriving the decision rules for this system was rather informal. I subsequently proposed a more formal procedure for relating pavement condition to the opinions of a panel of engineers. This was done in response to a request by the Johannesburg City Engineer's Department for a set of rules for their conditions. This proposal was followed up in an experiment by Dr R G Gordon whose results were finally incorporated under my guidance in their pavement management system. (See Section 4.3.)

The next step in the development of these algorithms was in the implementation of a pavement management system for the Cape Provincial Administration. Here the design of the system was a blend of the philosophy and the procedures that I had developed for the Department of Transport and features specified by the CPA to accommodate their own approach to pavement management. In particular they proposed the economic criterion for ranking the priority of rehabilitation projects. (See Chapter 5.)

An important feature of the maintenance needs algorithm is the problem of joining individual segments of pavement with varying defined maintenance needs into projects of a practical length. I developed such procedures for both the DOT and the CPA systems. (See especially Section 5.5.)

These developments in the basic design of pavement management systems to a large extent cover the original proposed work set out in Figure P1. However during the implementation of these systems it became apparent that cognisance of the operational requirements of the system are as important to its success as technical considerations.

#### OPERATIONAL ASPECTS OF PAVEMENT MANAGEMENT SYSTEMS

For various reasons the DOT abandoned the development of their management information system in 1980, but allowed me to continue with the development of the pavement management subsystem until it was operational. This entailed both management of the programming and setting up the data capture systems. This was achieved in 1982 and resulted in the DOT deciding to reinstate the system.

The development and implementation of the CPA system was a collaborative effort between the NITRR and the CPA under my coordination and with my assistant, Mr D R Rickwood, acting as full-time project leader during the initial phase of this work. Similarly the incorporation of the models developed by Dr R G Gordon into an operational system was carried out under my guidance for the Johannesburg City Engineer's Department.

Each of the above activities was beset by numerous problems from which I was able to identify various considerations necessary for creating a viable operational system. These include organizational, technical, managerial and human factors. A description and classification of these considerations are given in Chapter 2 and listed in Table 2.3. Recognition of these factors greatly assisted the development of the CPA system and has become the basis for subsequent implementation in other road authorities. Practical examples of operational aspects are discussed in Chapters 4 and 5.

#### FURTHER DEVELOPMENTS

Although the original goals of this project have been surpassed in that operational systems have been established and other road authorities

have been encouraged to adopt similar developments, there is considerable scope for refinement of existing algorithms and for introducing additional features. Certain ideas I have developed in this regard have been presented in this thesis :

- (a) The economic model of the CPA is limited in that it is based on the current condition of pavements only. No account is taken of the probable change in condition if rehabilitation should be delayed, i.e. no explicit prediction of future performance is made. I have thus proposed in Chapter 5 a refinement of the model using prediction equations of pavement behaviour originating from the Brazil study and scheduling rehabilitation projects by maximizing benefits within specified budget constraints.
- (b) Serviceability has traditionally been associated with riding comfort. Recently, however, more attention has been paid to vehicle operating costs to define response of road users. I examine the question for providing a combined scale for these factors in Appendix 2 and the question of providing a mechanism for setting standards for riding quality, skid resistance etc. according to public preferences in Appendix 3.
- (c) Although pavement management at the project level has a distinctly different approach from that at the network level, data collected at the network level provides an important initial input into project analysis. I have suggested a typical format for transferring such data in Appendix 5. This is in accordance with the Highway Material Committee guide on project level evaluation (TRH12) which I assisted in formulating.
- (d) There is a need to develop strategic planning algorithms. I have suggested procedures ranging from simple aggregate predictions for the JCED system (Section 4.3) to simulation methods that could be based on a simulation model I developed previously.

## CONCLUSIONS

Overall I have succeeded in developing and implementing a system that greatly improves the ability of a rural road authority to control the maintenance of their pavements at the network level. This has included the provision of techniques for monitoring and recording the condition of the network (especially the measurement and interpretation of riding quality), outputs that highlight and classify lengths of pavement requiring maintenance, and procedures for incorporating these results into the decision making process of drawing up a maintenance programme. The objective framework for pavement management provided by this system has introduced recognised improvements vis-a-vis traditional subjective and informal methods, to the extent that the other rural authorities are considering similar innovations.

Implementation work demonstrated the importance of operational aspects in addition to technical considerations to the success of pavement management systems. The classification of these provides an important basis for new implementations to proceed. Not the least of these aspects is the recognition that formal methods must interact with the established informal system for practical and economic reasons. The emphasis has therefore been to facilitate this process rather than to attempt to provide optimal numerical solutions.

Nevertheless I have suggested enhancements to the system whereby identified projects can be ranked according to economic criteria by a process which involves recently provided empirical models of pavement behaviour and vehicle operating costs and which assumes a budget constraint. Judicial use of this technique can demonstrate the sensitivity of the maintenance programme to these factors and so broaden the rationale for its defence.

The net result of this work is, therefore, that procedures have been made available for a rural road authority to readily implement a system by which they can objectively monitor and control the maintenance needs of his network and argue for the necessary finance on economic grounds.

PROPOSED WORK PROGRAM FOR THE ESTABLISHMENT OF A SYSTEM  
TO MANAGE THE MAINTENANCE OF A ROAD NETWORK  
ON A SOUND ECONOMIC BASIS

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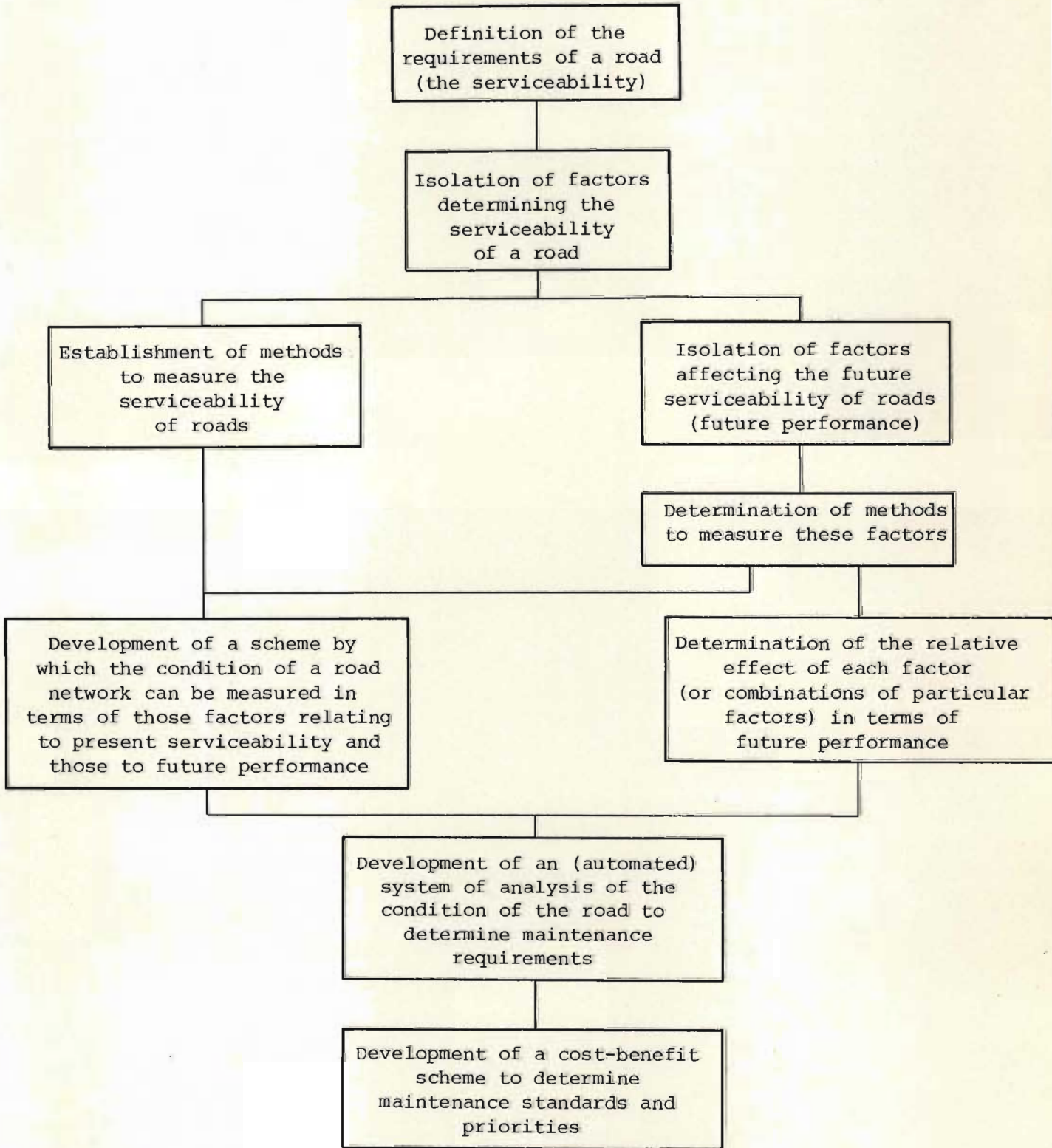


FIGURE P1 ORIGINAL THESIS PROPOSAL