Operational Unpaved Road Management System in the Cape Province of South Africa

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The Roads Department of the Cape Province of South Africa manages a rural road network that includes 16 900 km of paved roads and 51 750 km of unpaved roads. Unpaved roads are usually considered of lesser importance, because in the Cape Province these roads typically carry between 20 and 300 vehicles per day. The expenditure on their maintenance is, however, the same as that for paved roads. The aim of this paper is to present the characteristics of the unpaved road management system, which includes a gravel management system; to demonstrate the relationship of these systems in the planning process; and to document the experience gained with implementation of the system. The Maintenance and Design System (MDS) was used as a basis for the management system, although extensive adjustments were made to cater to local practice and requirements. It has been 3 years since the system was implemented. To date, 38 000 km of the unpaved network has been evaluated, and the information has been entered into the data base. The system has already proved its worth and is being used in compiling the annual budget and providing strategic prioritized input to facilitate the scheduling of activities at the project level. It has also helped to ensure an equitable distribution of maintenance funds among the 20 Regional Services Council (RSC) areas, through which the gravel road maintenance is executed on an agency basis. On the basis of experience in the Cape Province, the management of unpaved roads should be an integral part of the management process of any road authority.

The Roads Department of the Cape Province of South Africa manages a rural road network that consists of 16 900 km of paved roads and 51 750 km of unpaved roads. These roads include

- Trunk roads that primarily serve the larger centers,
- Main roads joining cities and smaller towns and important centers, and
- Divisional roads acting as access and link roads in the rural areas and being generally important for agriculture.

The last two types form the bulk of the unpaved network. In addition, 84 000 km of minor roads is currently not included in the formal management systems. The total rural road network serves an area of 656 641 km^2, which comprises nearly 58 percent of the area of the Republic of South Africa.

Since 1981, a pavement management system for the paved network has been in use, and the positive results from this system led to the implementation of a management system for the unpaved network. Unpaved roads are usually considered of lesser importance, because these roads in the Cape Province typically carry between 20 and 300 vehicles per day. The expenditure on their maintenance is, however, of the same magnitude as that for paved roads, but it is justified particularly where roads serve the mining industry, major agricultural producing areas, and tourism.

The aim of this paper is to present the characteristics of the unpaved road management system, which includes a gravel management system; to demonstrate the relationship of these systems in the planning process; and to document the experience gained with the implementation of the system. The unpaved road management system provides

- Routine maintenance requirements, such as blading;
- Special maintenance requirements for roads that cannot be maintained routinely, for example, reworking to remove or reduce oversize materials or reshaping;
- Regraveling requirements;
- Budget requirements and the implications of alternative budgets; and
- Optimization of the use of borrow pits for regraveling, and the implications of using scarce natural resources from the gravel management system.

The Maintenance and Design System (MDS) (*1,2*) was used as a basis for the management system, although extensive adjustments were made to cater to local practice and requirements. It has been 3 years since the system was implemented. Since the Roads Department did not have enough staff to collect the information to operate the system, eight consulting engineering firms were appointed, each to a region. To date, 38 000 km of the unpaved network has been evaluated and the information has been entered into the data base. The system has already proved its worth and is being used in compiling the annual budget and providing strategic prioritized input to facilitate the scheduling of activities at the project level. It has also helped to ensure an equitable distribution of maintenance funds among 20 Regional Services Council (RSC) areas, through which gravel road maintenance is executed on an agency basis.

The structure of the management system is presented first, and then examples of the outputs are provided. The operational aspects of implementing and operating the system are discussed. Finally the value of using the system is discussed, and recommendations for other road authorities are given.

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UNPAVED ROAD MANAGEMENT SYSTEM

Introduction

The length of the unpaved road network prohibits its being monitored by sophisticated and expensive means. Consequently, visual monitoring was adopted to evaluate the condition of the road and the need for specific actions. Ideally, such visual inspections could be done by the district road superintendents during their three-monthly visits to the roads under their jurisdiction. Setting up the system was beyond the staff capabilities of the Roads Department, and a consulting engineering group was appointed for the implementation in each of the eight regions. Another consulting group was appointed for software development and data processing.

Installing a reference system on the unpaved road network proved to be a major task. To date, about a third of the implementation cost has been expended on placing location markers in the field so that all observations could be tied to the reference system. Markers were placed at the start and end of each road section, as well as every 5 km along the section, and at boundaries of the different regions as well as at marked changes in topography. The basic building blocks for assessment purposes are the 5-km segments. Subsegments primarily involving marked changes in topography, notably in mountain passes, are also accommodated.

The unpaved road management system is essentially a network-level tool. The network is monitored to determine the global deterioration over time as well as to identify, prioritize, and determine approximate budgets for the network as a whole. The coarse network evaluation is then used as a strategic input for the detailed project-level investigations where the actual design is determined with the aid of further refined investigations and tests. Because the focus was at the network level, care was taken to collect only the information that was relevant and required at the network level.

The collected information was then processed in a computer data base to provide the outputs for top management for strategic and budgeting purposes as well as for maintenance engineers for tactical planning and execution purposes. These outputs will be discussed below.

Visual Assessment

The visual assessment is carried out by means of the evaluation form shown in Figure 1. Four different attributes of the road section are considered:

- Fixed information,
- Structural assessment,
- Functional assessment, and
- General information.

These attributes will be discussed briefly.

Fixed Information

Fixed information includes location, such as region, road number, and start and end kilometer distances. The road type typically defines the road width, and the width is used to confirm the data. Traffic counts are very costly, and three categories of traffic had to be used based on vehicles encountered on the section, knowledge of the area, and discussions with the local people. Less than 50 vehicles per day (vpd) is considered light traffic, medium is from 50 to 300 vpd, and heavy is more than 300 vpd. Terrain is designated as flat, rolling, or mountainous, according to broad guidelines. The moisture regime at the time of evaluation is important because it could accentuate or mask certain types of deterioration and is used where significant differences with previous assessments are encountered. Finally, a distinction is made between a gravel road and a nonengineered earth road, because the latter would normally receive no additional gravel. In addition, information such as the nature of agricultural activities is also collected to facilitate a strategic plan to curb the impact of dust in a prioritized manner; for example, a high earner of foreign exchange would receive a high priority for paving.

Structural Assessment

Structure The structural assessment is related to the ability of the pavement to carry the traffic loads. Although there may be arguments about the inclusion of other aspects or the exclusion of some of the evaluated factors, the process is aimed at identifying structural needs such as regraveling, ripping and recompaction,

CAPE PROVINCIAL ADMINISTRATION

ASSESSMENT (GRAVEL ROADS)

AREA :	A B C D E F G H	DATE :	
RSC :		ROUTE :	TRUNK / MAIN / DISTRICT
ROAD NO :		TRAFFIC :	LIGHT / MEDIUM / HEAVY
SECTION : FROM	km	TERRAIN :	F / R / M
: TO	km	MOISTURE :	WET / MOIST / DRY
WIDTH (m)	6 - 7.9 / 8 - 9.9 / 10 - 12	TYPE OF ROAD:	GRAVEL / EARTH

STRUCTURAL ASSESSMENT

STRUCTURE		DEGREE MINOR 1	2	3	4	SEVERE 5	EXTENT SELDOM 1	2	3	4	FREQUENT 5
POTHOLES	0										
CORRUGATIONS	0										
RUTTING	0										
LOOSE MATERIAL	0										
DUST	0										
STONINESS : FIXED	0										
: LOOSE	0										
GENERAL CONDITION		VERY GOOD		GOOD		FAIR		POOR		VERY POOR	

GRAVEL PROPERTIES					
GENERAL	FERRICRETE	CALCRETE	QUARTZITE	CHERT	DORBANK
MATERIAL TYPE	SANDSTONE	GRANITE	SHALE	DOLERITE	SAND
MAXIMUM SIZE (mm)		> 50	> 25-50	> 13-25	< 13
CLASSIFICATION		COARSE	MEDIUM	FINE	
APPROXIMATE PI		< 6	6 - 15	> 15	
GRAVEL THICKNESS (mm)					

FUNCTIONAL ASSESSMENT

RIDING QUALITY	VERY GOOD	GOOD	FAIR	POOR	VERY POOR
SKID RESISTANCE		GOOD	FAIR	POOR	
EROSION : LONGITUDINAL DIRECTION		NONE	MINOR	SEVERE	
: CROSS DIRECTION		NONE	MINOR	SEVERE	
DRAINAGE : ON THE ROAD		> 4%	2 - 4%	0 - 2%	
: SIDE OF THE ROAD		GOOD	FAIR	POOR	
: PROBLEMS	CULVERTS	SIDE DRAINS	MITRE DRAINS	TOO LOW	

GENERAL INFORMATION				NORMAL GRADING (EVERY ? WEEKS)	
	WEEKS SINCE LAST GRADED			WET SEASON	DRY SEASON
	PROBLEMS WITH: DUST	YES	NO		
	: SKID	YES	NO		

FIGURE 1 Field inspection form.

and reshaping or special blading. The way in which the visual assessment is conducted requires the use of technicians skilled in materials and unpaved roads. Assessments should preferably not be made while there is water on the road surface.

All the aspects are assessed in terms of severity and extent. Three anchor values are used to define severity, namely,

1: Visually noticeable, but still minor, usually isolated;
3: Needs attention, but not urgent; and
5: Needs urgent attention.

If the assessment is intermediate to the above anchor values, either 2 or 4 is noted. If there are no defects, a zero is noted without an extent. The extent is given on a five-point scale, as follows:

1: 0 to 5 percent,
2: 5 to 20 percent,
3: 20 to 60 percent,
4: 60 to 80 percent, and
5: 80 to 100 percent.

The occurrence is estimated, and no lengths are measured.

The condition attributes that are evaluated, according to clearly defined guidelines in the evaluation manual, are the following:

- Potholes, which are local depressions;
- Corrugations, which are regular undulations transverse to the direction of travel;
- Rutting, which defines the wheelpath and is caused by wear or compaction in the wheelpath;
- Loose material deposited adjacent to the wheelpaths or occasionally in the wheelpath after maintenance;
- Dustiness, as an indicator of safety; and
- Stoniness, which, when the stones are embedded, reflects the ability of the motor-grader to maintain the road, and when stones are loose, reflects rapid and severe ravelling.

In addition, the observer gives a general impression of the quality of the road, which is used to validate the other attributes.

Gravel Properties Detailed testing of the gravel characteristics of the complete network would have been prohibitive. Initially the most important characteristics were evaluated visually, namely, type of gravel, maximum size, type of grading, and plasticity index. As part of the gravel management program, the available sources were tested, and when one is placed on the road, the data base is updated. Fortunately, the maintenance strategy is not highly sensitive to small variations in material properties (actual versus estimated visually), and this approach gave a working solution for the initial stage of implementation. No doubt, for long-term planning of regraveling, the more accurate data will yield more reliable predicted gravel loss.

The gravel thickness was measured at least five times within a section, or every 1 km, by making a hole and measuring the thickness of the gravel. This information is used to determine regraveling needs.

Functional Assessment

The functional assessment evaluates the service that the road provides to the user. Riding quality is assessed by driving over the section, and the qualitative descriptors are linked to roughness measurements. Skid resistance on unpaved roads is difficult to measure, particularly since it is unlikely that the worst conditions are encountered at the time of measurement. Comments from the district staff or local users about skidding during the wet are used to flag potential problem materials. Erosion could make a road unserviceable, and both the erosion on the road as well as that alongside the road are assessed. Any defects would have to be corrected apart from the structural aspects of the road. Any specific problems are also highlighted.

General Information

Observations related to the general condition of the road are also noted. These include normal blading frequencies, time since last blading, and dustiness and slipperiness. This information is primarily used to judge observations that are significantly different from the general trend.

Evaluation of Special Activities

Special activities are those that are not carried out routinely but are executed in response to a deficient condition. Special activities include regraveling, ripping and recompacting, and reshaping and special grading. A flowchart showing the evaluation process is given in Figure 2. The underlying philosophy is that a higher-order action is only executed if a lower-order action would not be effective. Generally a higher order would be more expensive than a lower order. In this manner a road with a large number of rocks protruding through the surface would only be regraveled if there is insufficient gravel. Otherwise it would be ripped, the coarse stones would be removed (or if feasible, reduced to the specified maximum 37.5-mm size using gridroller or rockbuster techniques), and the road would then be recompacted.

Regraveling

The regraveling need is identified first. A regraveling score is calculated as a function of the minimum required gravel thickness to carry the loads, annual gravel loss, existing or predicted gravel thickness, and the traffic volume. The needs are prioritized by ordering the regraveling scores, and the roads are treated until the allocated budget has been expended. Five-year regraveling programs can be compiled in this manner and long-term underfunding identified at an early stage. Ideally the volume of material lost annually should be replaced to maintain a balance between wear and replacement.

Ripping, Reworking, and Recompacting

Ripping, reworking, and recompacting are triggered by the extensive presence of coarse stones that render blader maintenance ineffective. The product of severity and extent of stoniness greater than 12 triggers this need. In the event of a lack of binder, represented by less than 14 percent passing the 0.075-mm sieve, or the product of severity and extent of loose material greater than 12, additional binder has to be placed after ripping.

Reshaping

If the gravel layer is less than 75 mm, it is ineffective to try and rip the wearing course to remove the coarse stones. In such cases the wearing course is only reshaped and recompacted, because regraveling will be required within a relatively short period. The same approach would be taken if the shape of the road was poor and drainage on the road was classified as poor.

Special Blading

There are cases in which none of the foregoing actions would be triggered, but nevertheless the road is in poor condition, possibly because of neglect in maintenance. The situation often cannot be remedied by routine maintenance, and a special maintenance action is required. The road is considered in poor condition if the riding quality is poor or very poor or the product of severity and extent of potholes, rutting, or corrugations is greater than 11. In the cases of special maintenance, slippery areas in steep terrain, represented by a plasticity index greater than 15 and fine material, may be rectified by the addition of coarse material.

Evaluation of Routine Maintenance Activities

Once the network is in such condition that routine maintenance can be effectively executed, the routine maintenance needs are determined. These include the routine blading at an economic frequency, and the volume of gravel that needs to be replaced to balance the material lost.

Details of the procedure used to calculate grader maintenance were presented previously by Visser and Curtayne (*1*) and the models used by Paige-Green and Visser (*2*), and they will not be repeated. From this procedure the economically optimal allocation of motor-graders and resources for any given budget can be determined. The sum of the cost of maintenance and the road user costs is used to define economic optimality. The resources are allocated to the network such that the expenditure of an additional unit of costs would result in the same benefit on every road.

The volume of gravel lost is calculated for the gravel roads of the network using the process and models presented previously (*1,2*). Once the volume of material lost annually is known, the budget can be defined on the basis of the volume that has to be replaced to keep up to date. The roads on which the gravel would be placed are identified from the special maintenance evaluation.

Gravel Management Subsystem

Good quality road-building materials are usually relatively scarce. In a given area the better-quality materials are invariably used first, with the result that later only poorer-quality gravels are available for use as a wearing course. The situation is even worse when the gravel road has to be upgraded to the paved-road standard, and expensive processed gravels have to be purchased if the local materials are not good enough. The gravel management subsystem was implemented to handle this situation.

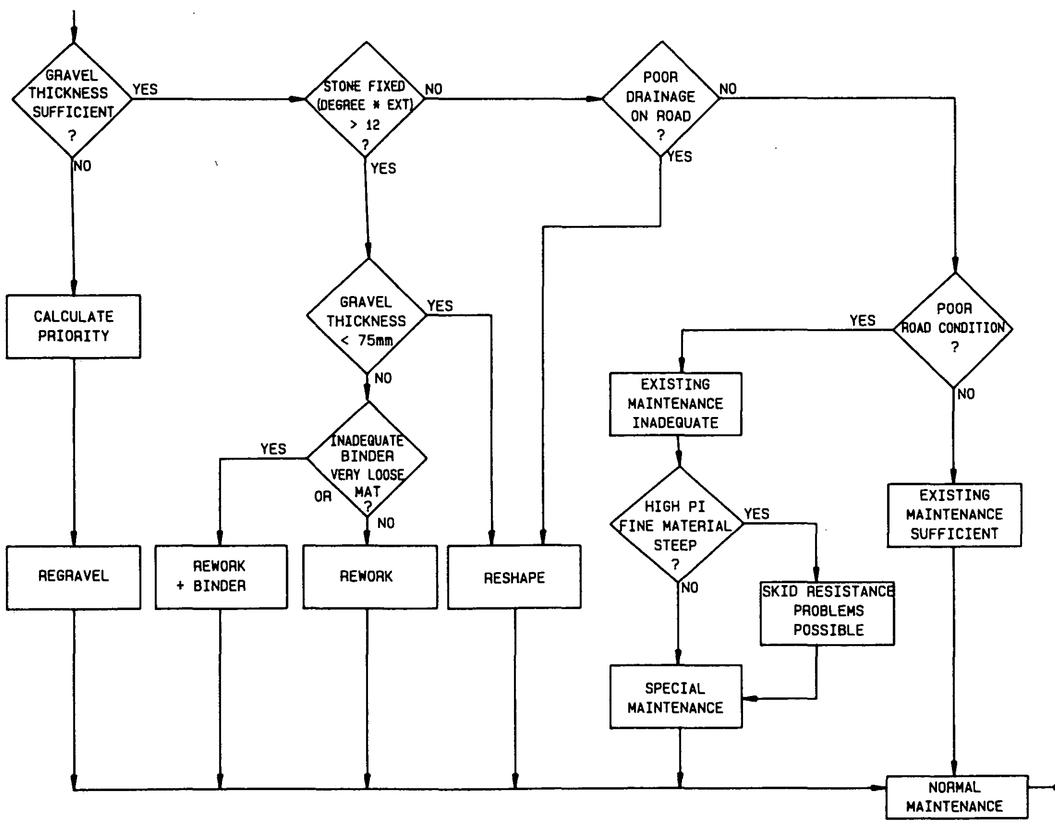

FIGURE 2 Flow chart for determining special maintenance requirements.

The gravel management subsystem contains information about the location of existing or potential gravel borrow pits and the properties and volume of the available materials. A special effort was made by the consulting engineering groups to identify all potential borrow pits within an economic haul distance of the road network. For the first time, an overall view is available as to the availability of materials. Gravel materials are also allocated to specific roads taking into account the quality of gravel, the consequent routine maintenance costs and road quality, and location of the borrow pits. This allocation process is done manually, and no formal optimization is used.

Besides the quality of the gravel, the performance of the roads on which specific materials have been used is monitored to confirm or modify the performance prediction equations. This monitoring also provides the opportunity for mixing materials from different borrow pits to obtain one that would provide the best economic performance. Consequently, planning for regraveling has been significantly enhanced.

Another major benefit of the gravel management subsystem is that, particularly in areas with limited gravel resources, the cost of bringing in processed materials can be considered. In some cases it would warrant paving the road to retain the scarce gravel resources. This would enhance long-term management of the network.

OUTPUTS GENERATED BY UNPAVED ROAD MANAGEMENT SYSTEM

Introduction

Outputs have been tailored to the specific needs of the different levels of management within the Cape Roads Department and of the Regional Services Councils (RSCs). This is particularly important because the Chief Executive Officer needs to know the financial and economic implications, whereas the maintenance engineer in a district wishes to know the sections of road where special maintenance is required and the evaluated condition that triggered this need. The different types of output that are prepared are discussed next, starting with the detailed outputs for the field staff and progressing to that required by top management.

Detailed Outputs

Detailed printouts of the input and processed information are prepared for use by the field staff. These are in typical computer printout formats and because of the large amount of data are not reproduced here. The information is also presented as a strip chart for each road, as shown in Figure 3. This is a handy format because it contains all the relevant information for the road and is normally compiled as a book for each of the 20 regions. It shows the homogeneous sections that were assessed, the traffic volumes, and the existing gravel thickness. From the analyses, a 5-year regraveling program was developed. From this overall perspective it may be decided from an operational point of view to regravel the short sections programmed for successive years in one year.

Parts of the road identified for ripping, reworking, and recompacting or reshaping are also shown, together with the assessment that triggered the need. Although some parts are due for immediate regraveling, they have also been flagged for reshaping if regraveling has to be postponed. Before the work is executed, the exact limits of each activity will be determined by a detailed field inspection at the project level, which is obviously beyond the scope of the unpaved road management system.

Management Information

Management is interested in strategic and financial implications, and the summary information has to address these requirements. One of the most easily understood formats for presenting data is graphically, and this was widely used.

Figure 4 shows the information about regraveling needs for each RSC area as well as for the complete network. Because the output is repetitive, only part of it is presented. For each RSC area the network length and annual gravel loss are shown. The regraveling needs for the next 3 years are indicated. By comparing the length of the bars for regraveling, taking into account the road length and annual loss, an immediate indication can be gained about the severity of the needs and potential backlogs.

At the end of the output, a summary is given for the complete network together with the annual gravel loss. In Figure 4 it is evident that a backlog equal to one year's regraveling has developed and that this backlog can be reduced by the recommended annual program. From inspection of the plot for the whole network, it was evident that the backlog was isolated particularly in one large RSC area. With the managerial information, this matter can be readily rectified.

A further diagram, presented in Figure 5, shows the distribution of gravel thickness as a histogram and the annual change in average gravel thickness as a trend resulting from loss and regraveling. The latter is particularly useful in determining whether the situation is being kept under control. Such plots are developed for each RSC area, for each road category, and for the network as a whole. As a further plot (not shown), the average gravel thickness for each RSC area is plotted as an arrow on a horizontal axis of gravel thickness from 0 to 150. It is possible to see at a glance where the problem areas with low average gravel thickness are located.

Special maintenance needs are also plotted as a series of bar charts for each RSC area (Figure 6). Beside the bars, numerical values are given for the length of road that requires ripping and recompacting, reshaping, or special blading. Although the needs in some areas appear large, invariably they are for large networks. In due course the special maintenance needs should decrease significantly when better control over the quality of regraveling materials is exercised, and effective routine maintenance is applied. However, the corollary is also true, namely, that routine maintenance cannot be effective if the road conditions are inappropriate.

A routine grader maintenance budget is determined from the marginal benefit/cost curve as a function of blading budget, as shown in Figure 7. For public authorities it is impossible to spend an amount on maintenance such that for an additional unit of expenditure the road user would save one unit. Analysis of public authority operations has showed that invariably one additional unit of cost is spent on maintenance for each three to five units of benefit derived by the road user. The impact of a reduction in the recommended budget can then be determined by expressing it as the additional cost incurred by the road user.

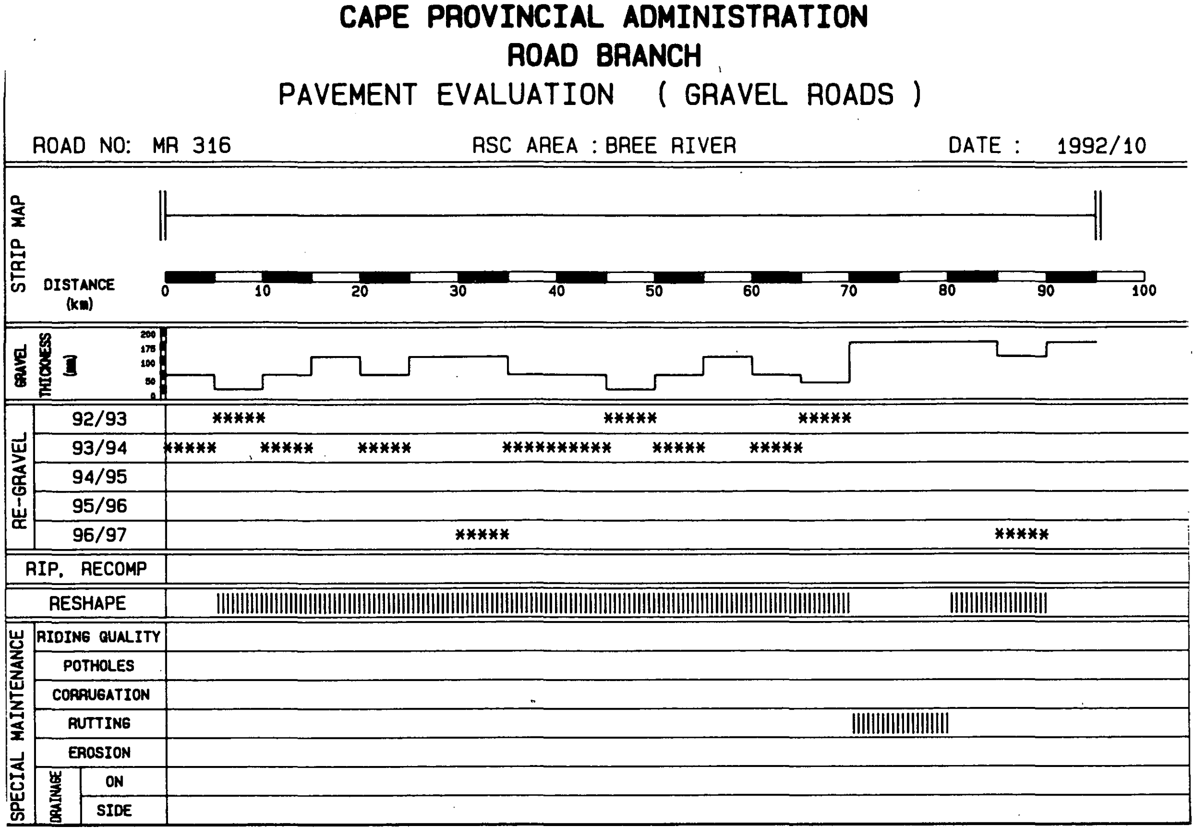

FIGURE 3 Strip chart showing condition and special maintenance needs.

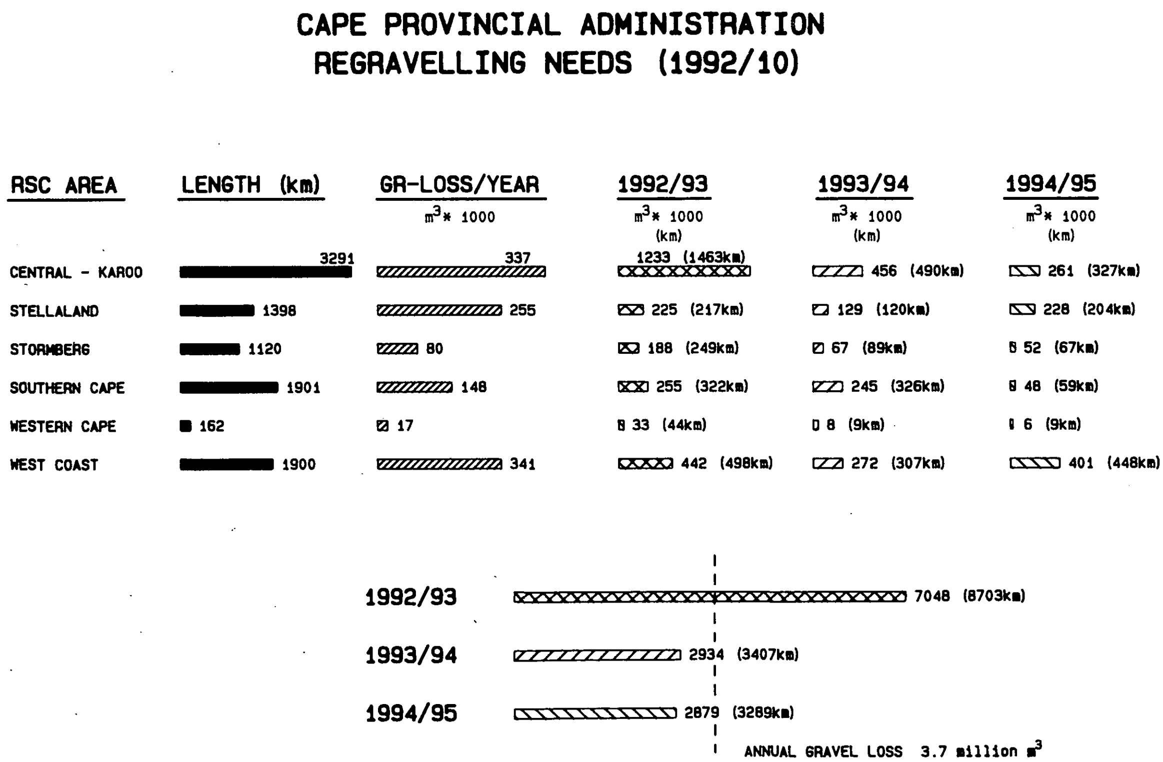

FIGURE 4 Summary chart of regraveling needs.

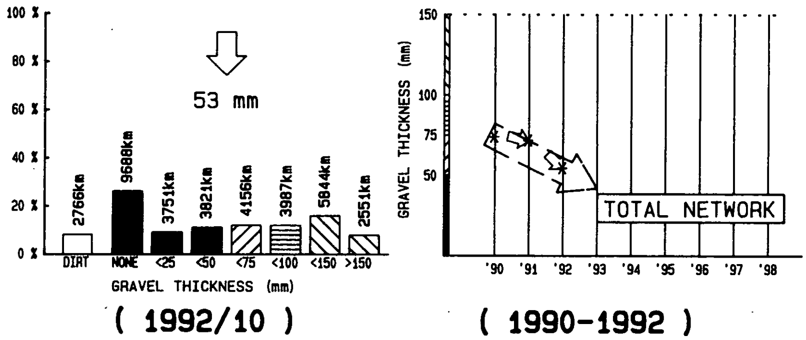

FIGURE 5 Histogram distribution of gravel thickness and changes over time.

IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

In the implementation phase of the unpaved road management system, a workload beyond the capabilities of most organizations develops. The approach adopted in this study of dividing the Cape Province into eight regions and allocating each region to a consulting engineering group has worked well. In this manner the experience of the individual groups was also harnessed to the benefit of the overall project. The coordination, data processing, and reporting constituted a further major task, and allocating this task to another consulting engineering group ensured that there was good correlation among groups. Ideally one set of assessors should be used to ensure uniformity of procedures. The magnitude of the task, however, prohibited the application of the ideal situation. The coordinating group held regular training sessions with the assessors to ensure a uniform approach to the evaluations and also to ensure that the same standard as that in previous years was being maintained.

Although at first glance the data collection phase appears prohibitively expensive and would unnerve most organizations, there are ways of overcoming the time lag for useful implementation and cost implications. It is important that the system generate useful information at an early stage. Roads that carried more than 150 vpd as well as roads previously identified as problem roads and roads scheduled for immediate regraveling were considered to be the first priority. Information relevant to these roads—that is, information that had a significant influence on managerial outputs— was collected, and the less important information was estimated from local conditions. The relevant information is road length and width and traffic volumes. Within a few months it was possible to provide a fairly good indication of the needs. As regraveling takes place the properties of the gravel wearing course are substituted for the estimated material properties, and the system is updated. In this manner valuable management information is generated at an affordable cost.

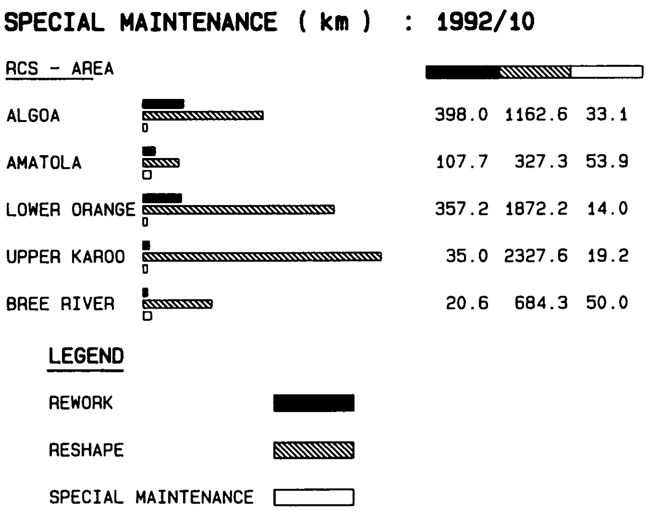

FIGURE 6 Summary chart of special maintenance needs.

Operationally there may be some additional data collection required. A system of sending as-built information to the data base manager has been instituted. In this way all regraveling information is captured. In those cases where special maintenance is executed, the team foreman sends a report to the data base manager. The routine evaluation of the network on a 3-year cycle is expected to remain the responsibility of the consulting engineering groups. This will at the same time strengthen the technical input to the RSCs, because much of the work would be carried out in close liaison with them.

The application of maintenance funds to those areas in which they are required, thus ensuring that the complete network benefits, far outweighs the cost of operating the unpaved road management system. The Cape Roads Department would recommend that all road authorities implement unpaved road management systems on the basis of the benefits of this system that have already accrued within the short period of its use.

CONCLUSIONS AND RECOMMENDATIONS

An unpaved road management system was installed in the Cape Province of South Africa. Since implementation 3 years ago, 38 000 km, or about two-thirds of the proclaimed unpaved network, has been placed on the system. The information is being used to compile the annual budget and to provide strategic prioritized input to facilitate the scheduling of activities at the project level.

One of the system outputs relates to the regraveling needs and allocation of the regraveling budget on a priority basis for a 5-year planning horizon. Special maintenance needs in terms of ripping, reworking, and recompacting; reshaping; and special blading are also identified from a visual assessment of uniform links. The special maintenance is required to bring the road to a

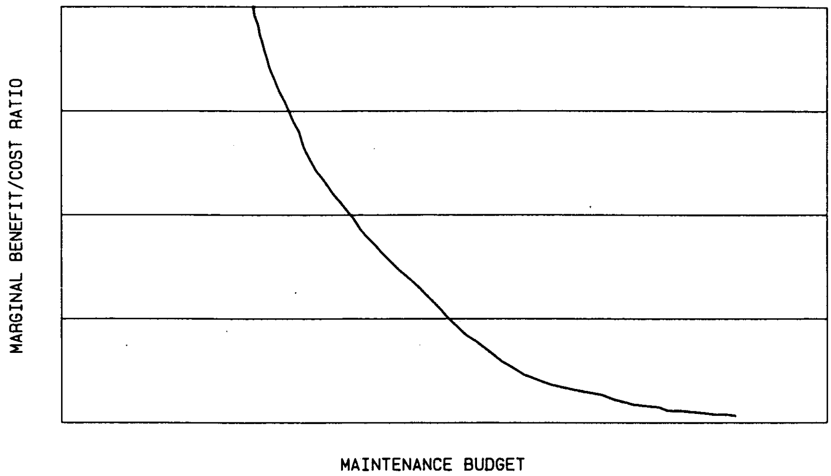

FIGURE 7 Marginal benefit cost ratio curve for determining the appropriate maintenance budget.

condition such that routine blading can be executed effectively. The routine blading budget is determined by considering the effect of maintenance on total transport cost on the network. By using the marginal benefit/cost ratio curve, the effect of changes in the recommended budget can be demonstrated in economic terms.

A gravel management subsystem is an integral part of the unpaved road management system. This is a feature that has not previously been reported as being part of an unpaved road management system. It provides powerful information for the strategic management of a road network, particularly for determining warrants for paving in areas where gravel materials are scarce.

The system has proved its worth in managing the Cape Province unpaved road network, particularly to ensure an equitable distribution of maintenance funds between 20 RCSs that execute maintenance on an agency basis. On the basis of the experience gained, the formal Unpaved road Management System should become an integral part of the road management system of any rural road authority. The process of implementation and operation adopted and presented in this paper can be recommended to other authorities.

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