Optimizing Resources Through 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 unpaved road network of 51 750 km of main and divisional roads. In addition, an 84 000-km length of minor roads is currently not included in the formal management systems. The unpaved roads typically carry between 20 and 300 vehicles per day. The expenditure on their maintenance is, however, of the same magnitude as is spent on paved roads but is fully justified where these roads serve the mining industry, major agricultural areas, and tourism. The aim of this paper is to demonstrate the value of optimizing resources and the wide-ranging benefits to the road authority and road users that are derived. First, the characteristics of the unpaved road management system and method of implementation are briefly presented. Thereafter a range of optimization aspects are considered, and the technical benefits of optimization are demonstrated. A public relations exercise has also been carried out to publicize the information on the unpaved road management system, and this important action is also discussed. Significant benefits, demonstrated in the paper, have been derived from the formal management system, and the process is recommended to all road authorities.

Historically, the provinces in South Africa have had the responsibility for providing facilities for regional and local rural mobility. As a result the Roads Department of the Cape Province manages a rural road network of 16 900 km of paved roads and 51 750 km of unpaved roads. These roads comprise the following:

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

The last two types constitute the bulk of the unpaved network. In addition an 84 000-km length of minor roads is currently not included in the formal management systems being operated by the Roads Department. The total rural road network serves an area of 656 641 km^2, which comprises nearly 58 percent of the total area of the Republic of South Africa. Unpaved roads are usually considered of lesser importance, as 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 spent on paved roads but is fully justified where these roads serve the mining industry, major agricultural areas, and tourism.

Following the successful implementation of a pavement management system for the paved road network in 1981, an unpaved road management system was implemented in August 1989. It was based on extensive research on unpaved road performance (*1*) and a formal unpaved road management system (*2*). Specific adjustments were necessary to cater to the local conditions and requirements, and the working system was presented by Visser et al. (*3*).

The aim of this paper is to demonstrate the value of optimizing resources and the wide-ranging benefits to the road authority and road users that are derived. First, the characteristics of the unpaved road management system and method of implementation are briefly presented. Then the following optimization aspects are considered, and the technical benefits of optimization are demonstrated:

- Defining road widths;
- Optimizing the regraveling program;
- Evaluating appropriate construction procedures;
- Optimizing borrow pits for regraveling, including blending if required for optimal performance;
- Reevaluating materials standards; and
- Obtaining preliminary results from the monitoring and experimental sections to evaluate and validate performance relations and to investigate new technologies.

A significant public relations exercise has also been carried out to publicize the information on the unpaved road management system, and this important action is also discussed. It will be demonstrated that the formalized collection of data in the unpaved road management system can be used to validate and improve prediction models and unpaved road actions. This is one of the important considerations highlighted by Hudson et al. (*4*) that is seldom used in actual operating systems.

IMPLEMENTATION CONSIDERATIONS

The unpaved road management system was implemented to address the managerial needs of top and middle management. Figure 1 shows the relationship and level of detail of the requirements of these levels of management. Top management is concerned with strategic issues such as the following:

1. Budget requirements for routine or special maintenance and regraveling (periodic maintenance) and the consequences of alternative budget levels in terms of network quality and future excess funding requirements and
2. Upgrading needs.

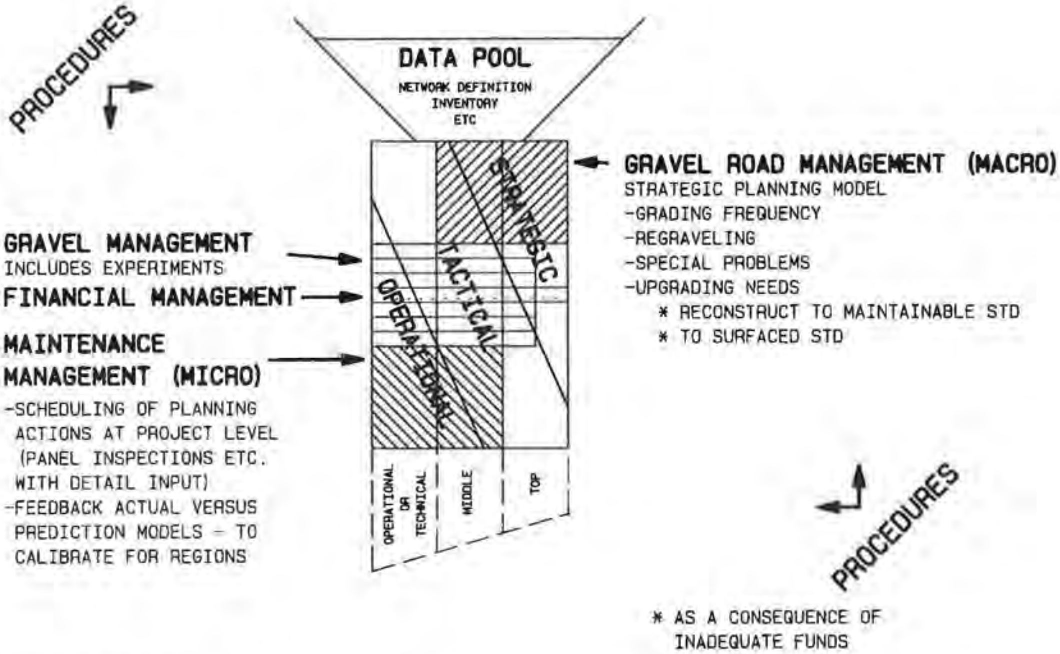

FIGURE 1 Relationship of system detail in management process.

Middle management needs to apply network information to medium-term tactical decisions. These include

1. Selection of appropriate gravel materials, with blending if required (this activity includes examining the total resources and the rate of depletion);
2. Translating the allocated budget to operational programs; and
3. Evaluating special problems or needs and identifying ways of overcoming these.

The unpaved road management system as described by Visser et al. (*3*) is specifically tailored to address these issues. To understand the applications discussed in the following sections, it is important to understand the implementation process, which will be briefly discussed next.

Implementation of the system and monitoring the 51 750-km network of unpaved roads to provide the inputs for the management system was beyond the capabilities of the operational staff of the Roads Department. Consequently the province was divided into eight regions, and a consulting engineering firm was appointed to each region to work closely with the 20 Regional Services Councils (RSCs), which carry out maintenance as an agent to the Roads Department. The consultants collected the relevant information for the management system. A further consulting group was appointed as coordinator to ensure uniformity of procedures and data processing.

OPTIMIZATION ISSUES

The management system provides a wealth of information that can be used for evaluating current practices and procedures. Hudson et al. (*4*) considered this an important application seldom used in actual operating systems that effectively optimizes resources, as will be demonstrated in the following paragraphs.

Specifying Road Widths

Traditionally gravel roads were constructed to a width of 8 m. However, when the data base information was analyzed, it was found that there was a wide distribution, as shown in Figure 2. Data were collected in the categories of 6 to 8 m, 8 to 10 m, and greater than 10 m. It was a surprise to discover the considerable number of roads that had widths in excess of 10 m. The implications are that more passes would be required during routine blading, and often the wide road is perpetuated during regraveling. This would have a significant impact on the maintenance budget.

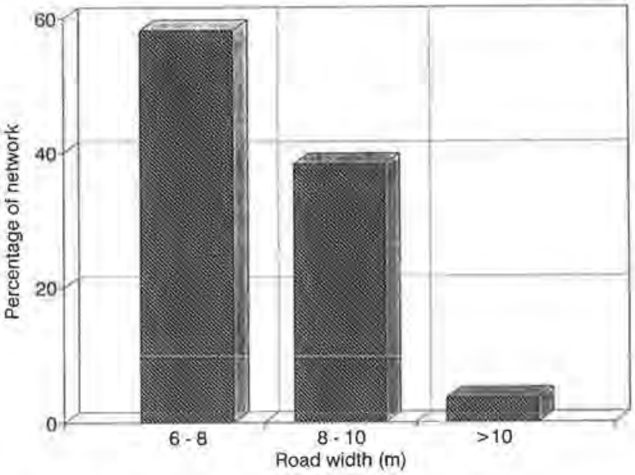

FIGURE 2 Distribution of gravel road widths.

From the operational experience, taking into account user satisfaction with the roads and blade widths to ensure retention of the shape and published literature (*5*), the following new set of gravel width specifications was developed:

1. A maximum width of 8.6 m is recommended. All through routes should have a width of at least 8.6 m. On roads complying with this requirement, curve widening of 1.0 m is applied on curves with a radius smaller than 150 m.
2. An absolute maximum width of 9.8 m is applicable in cases in which there is a combination of large numbers of trucks and other traffic, a suitable topography, and passing opportunities. The exception to this requirement is when a road is in the first phase of a project to upgrade it to paved-road standards.
3. Local experience and guidance are used in conjunction with the charts developed by Bews et al. (*5*) to define minimum widths. For example, for average daily truck traffic of less than 15, a width of 6.6 m is adequate for a design speed of 60 km/hr. The design speed should be tailored to the topographical conditions. As the gravel roads invariably provide local access, reduced design speeds in difficult terrain are encouraged.

These new specifications have helped to rationalize the area of road to be maintained, with concomitant benefits in the amount of maintenance and funding required.

Defining Regraveling Thicknesses

Traditionally a 150-mm layer of new gravel is placed during a regraveling operation. In some cases the road has to be regraveled within a few years or in other cases no regraveling is needed for more than 10 years, thereby upsetting the regraveling program. The management system permitted calculation of the gravel loss rates, and these were calculated to be representative of typical materials in each of the regions as a function of traffic. It was decided as a policy that regraveling should not take place more frequently than every 6 years. Regraveling thicknesses to comply with the policy constraints were calculated and rounded up to 100, 150, or 200 mm. Particularly considering the backlog of regraveling needs, as demonstrated by Visser et al. (*3*), this process has helped to cover as much road as possible.

Optimizing Regraveling Program

The volume of gravel lost annually should be replaced by regraveling to ensure a balance and to prevent excessive maintenance backlogs from developing. The management system is used to calculate the annual volume of gravel lost as well as to indicate the priority list of road sections that need to be regraveled. Using the regraveling volume and an average cost per cubic meter for each RSC area for regraveling, the required budget is determined. The strategic planning is thus completed, provided funds are readily available. Because of restricted funding with about a 50 percent shortfall for the gravel network, it has been possible to relate predicted weighted annual gravel loss to the required regraveling cycle, as shown in Figure 3, and apply resource fund leveling.

The next step is to carry out the tactical planning and to validate the management system information by field inspections. In addition, nonquantifiable factors such as users' complaints have to be considered, and roads that may not feature on the management system priority list may be included. After the inspection done by the District Roads Engineer, maintenance staff from the RSC, and the consulting engineer for that region, the final recommended ranked regraveling program is submitted to the Head Office for approval. In selecting the road sections for a 5-year program, the priority of adjacent sections is considered, and, if warranted, such sections are included in the same operation to minimize establishment costs. The management system has proved its value in developing a first-draft 5-year program that is then supplemented by local information rather than purely by local input, which may not necessarily capture all the issues.

When special funds from the sale of strategic oil reserves were made available for special socioeconomic projects in 1992, the Cape Province was able to obtain a special grant of R40 million ($15 million U.S.), primarily for regraveling. This was because of the gravel road network information that was available, such as a current 53-mm average gravel thickness for the network and a 13.4-mm predicted weighted gravel loss per year. Thus a fair, quantifiable claim could be staked and ultimately assessed in relation to the other contending issues.

Providing Feedback on Construction Practice

Invariably the quality of a regraveling contract is evaluated immediately after construction, and the road

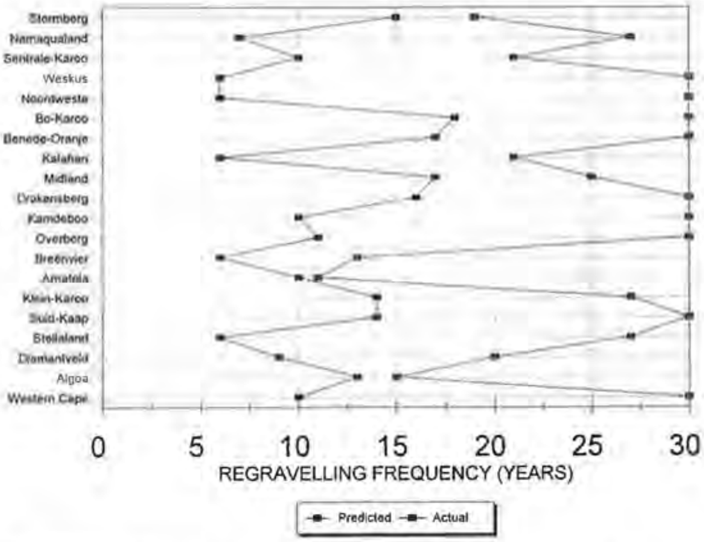

FIGURE 3 **Comparison of actual and required regraveling frequencies.**

builders seldom receive information about the performance in subsequent years. With the new management system, there is regular and consistent feedback.

When the management system was implemented, it was found that in some areas there was poor quality control of the materials that were used for regraveling, particularly of the oversize material. As a result, certain roads would be regraveled every few years, thus building up an excessive gravel layer. Today careful quality control of the gradation, particularly the maximum-size material, is maintained in accordance with the TRH20 (6) specification requirements. Where oversize material results in a poor road, reworking has proved to be a cost-effective solution if there is more than 75 mm of gravel on the road. In addition, these observations have also led to a critical reappraisal of the construction techniques.

Revising Construction Techniques

During regraveling operations, compaction is normally done with a grid roller. The theory is that the grid roller will break down the larger particles. In practice, however, the grid roller buries the larger rocks, and leaves the impression that the wearing surface is fairly fine and within specification. After about a year, these larger stones appear on the surface and inhibit blader maintenance and provide an uncomfortable ride. The management system alerted management to the extent of the problem, and the Construction Division's subdirectorate, Production Management, has instituted revised construction procedures and implemented additional training.

The revised construction standards include breaking down the oversize material while the gravel is dry and before compaction water is added. These standards were supplied to all RSCs as well as personnel involved in regraveling operations. Although these revisions have only been implemented for about 2 years, great improvements in the quality of regraveling and the performance are already noticeable.

In some areas, the oversize material cannot be broken down by grid rolling. The material is then removed, which can severely affect productivity and cost, as the oversize material could be from 20 to 60 percent of the volume brought onto the road. One option is to use a Rockbuster, a mobile hammer mill effective on materials that fracture easily such a quartzitic gravels or some mudrocks, with limited amounts of oversize material. In some areas where indurated mudrocks or shales are found, single-stage crushing is an economical option. Special equipment is then made available for specific regions, eliminating the need for every RSC to purchase it.

Optimizing Gravel Borrow Pits

Regraveling materials are normally obtained from natural gravel or weathered rock borrow pits. Only in exceptional cases is the material partially crushed. Blasting followed by crushing is not done.

A gravel management subsystem was incorporated as part of the unpaved road management system. To build up the data base, the borrow pits along the roads that were to be regraveled first were investigated. Additional sources of material were identified from landforms or vegetation and discussions with the local population. A major input requirement is the available volume of material, as in many areas gravel is scarce. Ideally borrow pits should be available every 5 km along the road and within 1 km of the road.

Borrow pits are classified into the following four categories during the preliminary investigation:

1. Good-quality gravel that has performed well and that is available in abundance;
2. Good-quality gravel that has performed well but the future availability of which cannot be determined visually;
3. Good-quality gravel that has given unsatisfactory performance on the road (blending this with material from another borrow pit is to be investigated); and
4. Poor-quality material that has performed poorly (ignore it and prospect for other sources).

From the available sources, the materials from the different borrow pits are allocated to the road. The immediate requirements as well as future needs are considered in this allocation. For example, if it is expected that a road is to be upgraded to a paved standard in 10 years, the only source of natural gravel material would not be used in the regraveling operations.

During the data collection phase, it was found that often available materials need to blend with material from other sources to obtain material that would give good performance. The mostly commonly used materials for wearing courses in the Cape Province are mudrocks and shales, calcretes, weathered dolerite, sandstone, and ferricrete. These come mainly from the Karo geological sequence. Of these, the mudrocks and shales are the most widely occurring. Depending on the state of weathering or the extent of induration, the material may be very hard, requiring blasting, or very soft. From the performance monitoring, it was found that in certain areas given blends perform well, and their use has been recommended as local practice. An advantage of mixing harder and softer materials is that the harder material will prevent significant disintegration of the softer material under traffic. The following blends were found to be satisfactory: 70 percent shale and 30 percent silty sand in the Northwestern region and 60 percent shale and 40 percent calcrete in the Midland region.

The ferricretes found in the wetter coastal regions usually have a shortage of fines and a low plasticity with resultant high gravel loss and a propensity toward the formation of corrugations. Blends of 80 percent ferricrete and 20 percent weathered sandstone or 50 percent ferricrete and 50 percent shale have been found to perform well.

In the semiarid Lower Orange region, the low-plasticity calcrete tended to ravel and pothole readily. A 50 percent calcrete and 50 percent shale mix has provided excellent performance, so much so that one of the local inhabitants recently remarked that for the first time they have a decent road.

Optimizing Material Standards

The material standards presented in TRH20 (6) were developed throughout South Africa and may not consider local or microconditions. By means of the data base, the performance of materials with the same generic classification and similar material properties may be compared.

In the semiarid Namakwaland region, two sources of gravel classified as being identical in the standard indicator test gave identical dry weather performance, but the one road has passability problems during wet weather. As the difference in performance could not be described by the normal test results, further research was carried out. The material that gave wet weather problems had a significantly higher plasticity index on the minus 0.075-mm material. Note that normally the Atterberg limits are carried out on the minus 0.425-mm material. This phenomenon is attributed to the higher clay fraction and is easily identified by the test method. Introduction of the variation of the plasticity test will now be investigated further on other roads that may exhibit wet weather passability problems.

Additional research is also being carried out into the durability of the coarser particles. Venter (7) developed a method for evaluating the durability of mudrocks. It consists of a series of five cycles of water immersion followed by oven drying; the material is then placed into one of five categories. Preliminary indications are that suitable mudrocks should lie in one of the three highest categories.

The Venter test is not appropriate for other materials that are common in the province. Instead the modified Texas ball mill test, known as the durability mill (8), is being investigated. In this test the breakdown products in terms of changes in grading and in the Atterberg limits are evaluated.

These tests are considered important in selecting borderline or marginal materials. Of particular interest is whether the material's shrinkage product (linear shrinkage times percent passing the 0.425-mm sieve) improves over time. The shrinkage product has been found to determine the raveling potential of a material (6).

SPECIAL STUDIES

The unpaved road management system has been invaluable in providing an overview of the conditions, such as traffic, materials, and topography, that exist on the network. It has therefore been possible to identify recurring combinations of these conditions so that the performance predictions can be validated. New technologies such as dust palliation also need to be investigated in representative conditions. As a consequence, different consultants have set up special monitoring and experimental sections. Preliminary results on this work are presented in this section.

Gravel Loss Monitoring Sections

Figure 4 shows preliminary results of measured and predicted gravel loss on a 50-m-long monitoring section. The gravel wearing course material in this area is a weathered kimberlite, which was not investigated when the performance models were developed. All material passed the 26.5-mm sieve, 13 percent passed the 0.075-mm sieve, and the plasticity index was 11. An average daily traffic of 202 vehicles was recorded, and the region was semiarid with a Weinert *N*-value of 9. The prediction (2) corresponds fairly well with the measured results, although the observations need to be continued so that the longer-term trends can be compared.

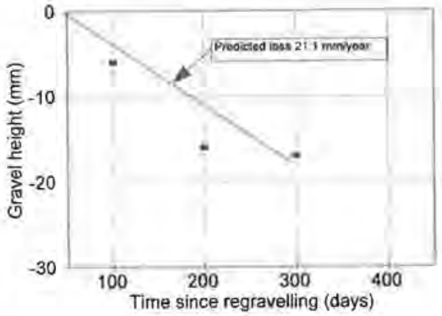

FIGURE 4 Comparison of measured and predicted gravel loss on a monitoring section.

Performance Monitoring

Selected representative regraveled roads were monitored at about 6-month intervals to quantify the deterioration. These roads were selected in the different regions to cover regional maintenance practice and local climatic and traffic influences. A total of 24 roads are under observation, and additional roads are being selected as the regraveling program proceeds. After the 24 roads were monitored for about a year, the severity of distress was less than 3 in most cases (*3*). Although the time since regraveling of about 1 year is insufficient to draw firm conclusions, the preliminary indications are encouraging because significant problems with corrugations and raveling would have appeared in this period, particularly in the drier regions of the province.

New Technologies

Sections were selected on the more heavily trafficked roads for experimentation with additives, which vendors propagate as being suitable for improving the quality of wearing course gravels. These products are invariably proprietary chemical additives that result in a binding action and thus reduce the rate of deterioration and the consequent need for frequent maintenance. In some cases there is also a reduction of dust, which is beneficial in fruit-growing areas. Some sections have been constructed throughout the province, but insufficient time has passed for meaningful statements to be made about their performance. These sections are mentioned to show how the management system is applied and to indicate the extent of further research.

DISSEMINATION OF INFORMATION AND TECHNOLOGY TRANSFER

As a part of the optimization process, the different role players had to be kept continually informed. This dissemination of information has been paramount in securing the support and interest of the participants. And although some actions may be considered trivial, they were discussed because they were an integral part of the overall process. The following actions were initiated to ensure completion of the optimization process:

1. Regular coordinating meetings among the nine consulting groups were held to make improvements to the monitoring and evaluation procedures and to familiarize them with the findings of special studies.
2. A steering committee addressed the interfacing and integration of the various management systems within the framework of a Master Systems Plan. Within the Roads Branch the function of this committee was to prevent parallel sets of similar data from being developed as well as to indentify the appropriate directorates or subdirectorates responsible for the integrity of specific data sets available to other network users.

Top management fully supported the unpaved road management process, and the strategic and tactical planning outputs were incorporated into the decision making. Much of the preparatory work was done by the Deputy Chief Engineers, and top management may not have been fully aware of all the details. For this reason special information sessions were arranged at regular intervals to familiarize top management with the details. This has had a major impact in ensuring management's commitment, support, and implementation of the optimization recommendations.

4. District Road Engineer and Road Inspector Conferences were held every 2 years. These conferences were used to inform the attendees of developments with the unpaved road management system and to solicit feedback on the developments and applicability of results.
5. The elected politicians carried the final responsibility in the national government. Information sessions were held with the members of Parliament representing the various constituencies in the Cape Province to make them aware of the situation and its associated needs. This laid the groundwork for supporting funding requests and provided an overall picture of the situation in the province.
6. The traveling public was informed and educated by regular press releases. Feedback from local administrators has confirmed that this education process has already resulted in a changed attitude among the traveling public, which is also more sympathetic toward road improvements on the unpaved network. As a result, more effective techniques, which may cause a somewhat longer disruption of traffic, can be applied without undue pressure from the traveling public.

CONCLUSIONS AND RECOMMENDATIONS

The aim of the paper was to demonstrate the wide-ranging benefits that may be derived by applying the wealth of information that is captured in the unpaved road management system. These objectives have been fulfilled, and it was shown that the results include the following:

- Optimizing road width by considering traffic and invariably reducing the area of road to be maintained;
- Deriving a cost-effective regraveling thickness;

- Applying resource-leveling to ensure a network-wide balanced regraveling program;
- Providing long-term feedback on regraveling practice, which has resulted in revised procedures and new training programs;
- Optimizing the available natural gravel wearing course materials and blending from different sources to ensure good performance;
- A review of the material characteristics to ensure good performance; and
- Special studies to validate the performance relations for local conditions and to evaluate the suitability of new technologies.

The implementation of the unpaved road management system also required a significant exercise in communication and the dissemination of information. This exercise has been important in ensuring the success of the optimization work.

Because of the valuable management information derived from them and their financial benefits to the Roads Department and to road users, the implementation of an unpaved road management system and optimization studies can be recommended to all road authorities.

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