Management of Tertiary Road Networks in Rural Areas of South Africa

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Tertiary roads provide mobility in the local context. Since traffic volumes on these roads are low, relatively simple and low cost management techniques are required for maintaining and upgrading the network. This paper presents a methodology for providing optimal tertiary road networks. The paper addresses a management framework for tertiary roads. Techniques to optimize the layout of the network utilizing transportation demand modeling and benefit-cost analysis are then presented. Techniques for estimating traffic volumes are addressed. A method based on the visual evaluation of factors related to road characteristics and the road condition yielded good results, but the trip-generation approach was found to be unsuitable for use by itself. A methodology to identify regraveling and betterment projects on unpaved roads based on the visual evaluation of unpaved road defects is discussed. Project evaluation and prioritization methodology based on economic analysis procedures is developed. Both roads and low-level river crossings are addressed. It is concluded that the techniques developed contribute to the methods available for managing tertiary roads, and it is recommended that the techniques be applied in practice.

Internationally, roads are usually classified according to their function. This system distinguishes between principal arterials and minor arterials (primary roads), major and minor collectors (secondary roads), and local roads (tertiary networks) (*1*). According to this method, the function of roads in the network varies from providing high mobility and low accessibility (higher-order roads) to providing low mobility and high accessibility (lower-order roads).

In South Africa, a similar approach has been adopted. In this country, tertiary roads constitute about 83 percent of the road network of 359,000 km and are generally unpaved. These roads typically carry less than 200 vehicles per day.

Problem Statement

Tertiary roads form a significant portion of most rural road networks. Although the traffic on these roads is generally low, they are an essential part of the network. They play as important a role as any other road as far as accessibility to and the mobility of local communities are concerned.

Road management systems have been established successfully in rural areas. These systems are, however, aimed to a large extent at the primary and secondary road networks, mainly because of the extent of the needs on these networks and their higher traffic volumes.

Because of the relatively low traffic volumes on tertiary roads and the lower costs of maintenance and upgrading projects (expressed per kilometer of road length), road monitoring techniques and project identification and prioritization methodologies developed for higher-order roads are too expensive for tertiary roads. A need therefore exists for relatively simple alternatives to expensive traffic-counting programs and pavement and other management systems that are used for the higher-order roads and also for easy-to-use project evaluation and prioritization methods.

Objectives

The goal of this paper is to present a methodology for providing optimal tertiary road networks (*2*). The methodology consists of the following:

- Techniques to optimize the layout of tertiary road networks,
- Techniques to estimate traffic volumes,
- Methodology to identify maintenance and upgrading projects on tertiary roads, and
- Project evaluation and prioritization methodology.

The paper addresses a management framework suitable for tertiary roads. The methodologies are then developed, and finally conclusions are given.

Management Framework

The management process for the tertiary road network in rural areas is shown schematically in Figure 1. This framework will be used to discuss the important features of the road management system.

Network Evaluation

The properties of the network, which typically consist of such factors as the definition of road links, link lengths and widths, pavement types, drainage infrastructure, road signs, and other road furniture, need to be assessed.

One of the most important management needs at this level is to determine the optimum road network layout.

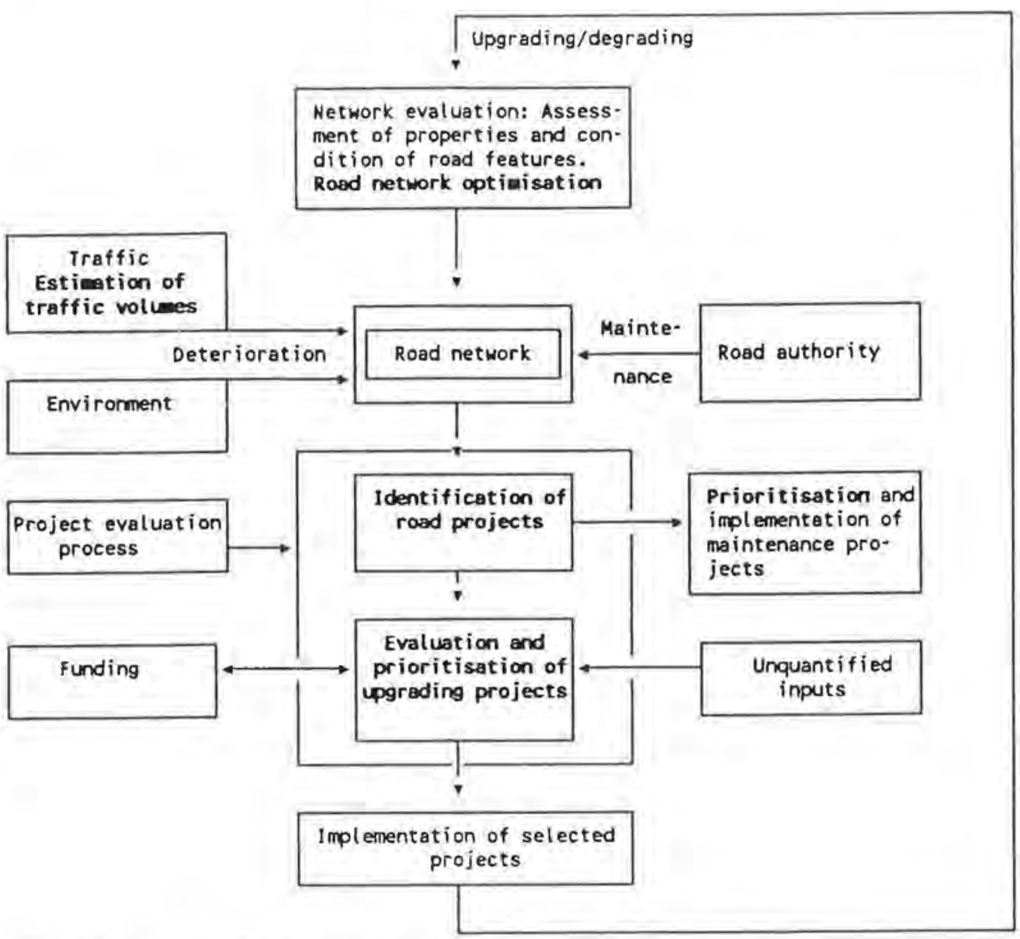

FIGURE 1 Framework for management of tertiary roads in rural areas (2).

The network layout dramatically influences traffic flow patterns, which are a key determinant in identifying and setting priorities for projects. As more funds are spent on the network and the land uses adjacent to roads develop, it becomes more difficult to effect changes in the layout of the network. Often in the case of tertiary roads, little has been spent for road infrastructure in the past, and land development along the road is generally at a low intensity, so applying road network layout optimization effectively to these networks is possible.

Road Network Infrastructure

Central to the management process is the road network, consisting of roads and other infrastructure. On the one hand, the network is deteriorating because of traffic and the environment (climatic conditions, etc). On the other hand, maintenance and upgrading of the network applied by the road authority lead to an improvement of the network.

The quantification of traffic volumes is important for evaluating the extent of deterioration because it influences the maintenance and upgrading actions required from the road authority.

Identification of Projects

Maintenance and upgrading projects need to be identified at the network level at low cost and with simple methods. Routine maintenance is taking place on a continuous basis and is therefore excluded from the project identification methodology. The most important maintenance activity to be identified is regraveling, and betterment is the more important upgrading activity. Network-level prioritization of projects for implementation purposes should be addressed at the same time.

Evaluation and Prioritization of Projects

Once potential upgrading projects have been identified at the network level, these projects have to be evaluated to determine the appropriate action required. The justification of the action must also be evaluated. Priorities need to be determined because sufficient funds to execute all worthwhile projects are seldom available. The available funding plays a key role in setting priorities and the decision on allocation of funds is also influenced by the extent of upgrading needs. Certain unquantified inputs also need to be taken into consideration in the prioritization process. These factors may be difficult to measure or cannot be quantified, for example, the developmental impact of a project or the strategic role in a military application.

Implementation of Selected Projects

After evaluating and setting priorities for projects, the selected projects are implemented, after which the road network information must be updated. Although projects normally consist of upgrading infrastructure, they could also include degrading existing facilities. An example is the closing of a redundant road link in the network.

Optimization of Road Network

Road network optimization should not be done in isolation but should take cognizance of the broad development objective of the area. This objective, generally, strives to support the strengths and overcome the weaknesses of the area in terms of developmental status, mobility, and economic well-being.

The methodology proposed is not a rigorous mathematical optimization. It is a methodology that uses economic assessment at a network level to determine a solution.

Models

It is recommended that a transportation demand model be prepared and calibrated for the existing road network. Traffic is modeled as a function of suitable socioeconomic parameters such as population distribution, location of employment opportunities, and the location and nature of other trip generators. Roads may be classified in terms of factors influencing construction, maintenance, and such road user costs as road type and topography.

In light of the low-cost methodology required for tertiary roads, transportation modeling may not be considered appropriate. Sketch planning models such as QPLAN, a modified version of QRSII (3), are therefore recommended. These models are particularly suitable for the purpose, mainly because they require few data inputs and are therefore cheaper to operate.

Road maintenance models suitable for application at the network level must be adopted to determine the cost to the road authority of maintaining the road network. Maintenance models are often expressed as a fixed cost per road type plus a variable cost dependent on traffic volume and traffic loading.

Road user cost models, or data tables, describe the owning and operating costs of road users. These costs generally consist of vehicle operating costs and may also include the time cost for vehicle occupants and collision costs. Road user costs also include the cost of transporting such goods as agricultural produce or mining products.

Parameters To Be Optimized

Optimization of a road network can be done only in terms of certain predefined parameters. Examples of such parameters are

- Minimum road length to support all land uses,
- Minimum road maintenance cost for a given level of service,
- Minimum road upgrading cost (of a capital nature),
- Minimum total cost to the road authority, and
- Minimum total cost (consisting of road upgrading, maintenance, and road user costs).

Simultaneous optimization of all the parameters is not possible. Furthermore, the definition of minimum acceptable levels of service also needs to be taken into account in the optimization of road networks. Examples are the provision of access to all land users, all-weather accessibility, or minimum riding quality levels.

Abandonment of Road Links

A benefit-cost analysis has proven effective in evaluating the economics of reducing the size of the road network. The value of a road link, or a group of links, in the road network is as follows:

$$B/C_j = \frac{(R_j - R_{j-1})}{(M_{j-1} - M_j) + (U_{j-1} - U_j)} \quad (1)$$

where

B/C_j = abandonment benefit-cost ratio of jth road link or set of road links,
R_{j-1} = total annual road user cost before jth link or set of links is abandoned,
R_j = total annual road user cost after jth link or set of links is abandoned,
M_{j-1} = total annual road maintenance cost before jth link or set of links is abandoned,
M_j = total annual road maintenance cost after jth link or set of links is abandoned,
U_{j-1} = total annualized road upgrading cost before jth link or set of links is abandoned, and
U_j = total annualized road upgrading cost after jth link or set of links is abandoned.

The benefits accruing to the road user are estimated in two steps. First, the network model is used to estimate traffic flows. Second, the extent of road user travel is determined in order to calculate the benefits to the road user. The estimate of the benefit to the road user of keeping a road or group of roads in the system is calculated as follows (*4*):

- The transportation model is used to route the trips through the study area road system to obtain the total distance traveled and the cost of this travel;
- The computerized road network is altered by removing a link or a set of links, for example, a link with low traffic or one of two parallel roads;
- The model is run again to reroute trips through the altered road network to obtain the total distance traveled and the cost of travel on the adjusted network; and
- The change in the travel costs between the two solutions is the estimated benefit of considering the link or set of links for abandonment.

In certain cases, a road link is essential to the road network, for example, when it is the only access road serving a particular community. In such a case, abandoning the road should not be considered unless the responsibility of the road is transferred to the land user.

New Links

Often links that could contribute to improving the optimization function are missing from the network. As a first step in considering new links, constraints should be identified, for example, mountainous areas, large rivers, densely populated areas, or geological problem areas. The total cost and annualized cost of providing the new link must then be determined, taking into account the residual value of the link after the analysis period. As before, the network must be remodeled, and maintenance and road user costs must be recalculated after each link or group of links has been added to the network.

Upgrading Roads

Once the road network has been established, roads to be upgraded to a higher standard—for example, a gravel to a paved road or an earth road to a gravel road—must be identified. This identification is initially made by using network-level evaluation criteria rather than by doing a project-level evaluation. Traffic flows in the model must be adjusted to the upgraded situation by rerunning the model in order to accommodate the influence of attracted traffic. It is then possible to determine total benefits and costs for the calculation of the optimization parameter.

Estimation of Traffic Volumes

For the development of low-cost techniques to estimate traffic volumes on tertiary roads, two approaches were investigated—predictions from the road condition and trip generation models. The methodology followed in each case is described in the ensuing paragraphs.

Traffic Estimation from Road Condition Models

People with experience on unpaved roads can make fairly accurate estimates of the traffic volumes carried by these roads. The research was aimed at identifying and quantifying the factors taken into account, often subconsciously, when making such estimates.

The factors that might be influenced by the traffic volume on a particular road were identified and then visually evaluated for a number of roads with known traffic volumes. Examples of these factors are road width, number of wheelpaths, road surface condition, and vegetation growth on the road surface. The evaluation was done in terms of a five point scale. General guidelines describing the factors to be evaluated were prepared (2).

Data were collected on 86 road links in the territories of Gazankulu, Lebowa, and Venda, situated in the Transvaal province of South Africa. Only links with an average daily traffic (ADT) value less than 200 vehicles were considered because above this limit conventional traffic counting is justified.

Using the factors evaluated as the independent variables and the known traffic volume as the dependent variable, multiple linear regression analyses were done to identify the significant independent variables and determine the weights of these variables. It was anticipated that the model developed in this way could be used to estimate traffic volumes as a function of the variables which are visually evaluated.

The model was assumed to be

$$ADT_{pr} = b_0 + \sum_{i=1}^{n} b_i * V_i \qquad (2)$$

where

- ADT_{pr} = predicted ADT,
- b_0 = calibration constant,
- b_i = weight of variable i, and
- V_i = variable i.

The following general model was developed:

$$ADT_{pr} = 14.2 - 46.2R_1 - 31.8R_2 - 21.4R_3 + 10.8W + 12.8V \qquad (3)$$

re

- R = road type:
  - $R_1 = 1$, $R_2 = 0$, $R_3 = 0$ for an earth track (unbladed),
  - $R_1 = 0$, $R_2 = 1$, $R_3 = 0$ for an earth road (bladed or shaped)
  - $R_1 = 0$, $R_2 = 0$, $R_3 = 1$ for a gravel road (low standard),
  - $R_1 = 0$, $R_2 = 0$, $R_3 = 0$ for an engineered gravel road (high standard);
- W = traveled width (m) (W between 2.0 and 9.0 m);
- V = vegetation growth:
  - $V = 1$ for lush growth,
  - $V = 2$ for moderate growth,
  - $V = 3$ for some growth,
  - $V = 4$ for thin growth,
  - $V = 5$ for no vegetation.

The 95 percent level of confidence was applied to identify significant variables. With the above model, the coefficient of determination (R^2) was found to be 0.41 and the standard error of the estimate was 35.5.

It was to be expected that traffic volumes would correlate with the road type since roads are generally provided in response to the extent of usage. Traffic volumes correlate well with the traveled width because, in the areas under consideration, many tertiary roads have never been formally constructed and therefore tend to follow the ground surface. The more traffic a particular road carries, the wider the traffic tends to spread, partly because the oncoming traffic needs to pass conveniently and partly because vehicles try to avoid poor surfacing conditions such as corrugations and potholes in the wheel tracks. It is significant that vegetation growth decreases with increasing traffic volumes.

Trip Generation Models

The trip-making characteristics of the land uses and populations served by the tertiary road network may be used as a basis to estimate traffic volumes. A prerequisite for this approach is that the size of the trip generators be known or that it can be easily determined. If not, a traffic count must be conducted.

A trip generation approach can be applied successfully only in cases where the specific link is used only by the trip generator(s) under consideration. When through traffic uses a link, it becomes virtually impossible to generalize its effect on the traffic volume. Such through routes then fall outside the tertiary road definition and should be reclassified.

The model developed for rural settlements was based on data collected for 57 road links and is summarized as follows:

$$ADT_{pt} = 0.01frp \quad (4)$$

where

ADT_{pt} = predicted ADT;
f = percentage of traffic generated that uses link (100 percent in case of single link);
r = trip generation rate:
r = 0.02 per person for low trip-generating cases,
r = 0.10 per person for average trip-generating cases,
r = 0.20 per person for high trip-generating cases; and
p = size of population served by link.

It was found that the trip generation rates of the data points collected were distributed over a wide range. Although one can use these models to determine typical traffic volumes expected from the mentioned land uses, the level of accuracy is not high enough to be used on its own for road management purposes. It could, however, be of value if used in conjunction with other methods of estimating traffic volumes.

Remark

It must be emphasized that the above models are specifically applicable to the areas investigated. Before the models can be applied to other geographic areas, they should be recalibrated to establish the relative weights of the variables.

Identification of Unpaved Road Projects

Maintenance Activities

Maintenance activities applicable to unpaved roads can be divided into three categories: routine maintenance, regraveling, and betterment. Betterment consists of either rehabilitating a road that has deteriorated seriously or upgrading a road that originated as a track. The methodology developed is aimed at identifying and prioritizing regraveling and betterment projects.

Visual Evaluation

A number of aspects related to unpaved road performance are evaluated. These aspects refer to defects occurring on unpaved roads, the condition of certain elements of the roadway, or indicators of road performance (Table 1).

The visual evaluation of the aspects is conducted on homogeneous road sections, referred to as links. Both the degree and the extent of each aspect are evaluated in terms of a five-point scale. Degree 1 indicates a defect that is minor or difficult to discern and does not require maintenance. In the case of Degree 5 the defect is of extreme consequence, unacceptable, and requires immediate maintenance. A value of 1 for the extent denotes isolated occurrence; that is, less than 5 percent of the road is affected. A value of 5 denotes extensive occurrence; that is, more than 60 percent of the road is affected.

An experiment consisting of the visual evaluation of 66 road links was conducted to collect the data required for the calibration of the algorithms proposed in the following section. A subjective evaluation of the regraveling and betterment maintenance indices that the algorithms were expected to produce was also made.

Identification of Maintenance Projects

The information collected was used to develop a regraveling maintenance index (an indication of the regraveling need) and a betterment maintenance index (an indication of the betterment need) for each road link. These maintenance indices are independent of the traffic volume. The maintenance indices are based on the following approach.

An urgency index (UI) is defined for each aspect as follows:

$$\text{UI} = \text{degree} \cdot \text{extent} \quad (5)$$

An interim regraveling maintenance index (RMI_I) and the betterment maintenance index (BMI) are calculated as the weighted sum of the urgency indices, as follows:

$$RMI_\text{I} = K_r + \sum_{i=1}^{n} (\text{UI}_i \cdot \text{weight}_{ri}) \quad (6)$$

$$BMI = K_b + \sum_{i=1}^{n} (\text{UI}_i \cdot \text{weight}_{bi}) \quad (7)$$

where n aspects are taken into account and K_r, K_b, weight_{ri}, and weight_{bi} are regression constants.

The maintenance indices have minimum and maximum values of 1.0 and 5.0, respectively.

Regression Analysis

The weights of the aspects evaluated were determined by considering them as regression coefficients. A regres-

TABLE 1 Weights of Urgency Indices

		Maintenance Index			
		Regraveling	(Interim)	Betterment	
Variable *i*	Aspect Evaluated	Regression Coefficient	Standard Error	Regression Coefficient	Standard Error
Surface					
1	Loose material	—	—	—	—
2	Dustiness	—	—	—	—
3	Stoniness	—	—	—	—
4	Gravel loss	0.0856	0.0080	0.0448	0.0088
5	Corrugations	—	—	—	—
6	Potholes	—	—	—	—
7	Wet weather trafficability	—	—	—	—
Formation					
8	Miter drains	—	—	—	—
9	Side drains/fill heights	0.0375	0.0092	0.0707	0.0121
10	Protection of drainage structures	—	—	0.0254	0.0101
11	Rock outcrops	—	—	—	—
Functional aspects					
12	Riding quality	—	—	—	—
13	Skid resistance	0.0573	0.0146	—	—
14	Surface drainage	—	—	0.0409	0.0104
15	Edge safety	—	—	—	—
K_r, K_b		0.536	0.207	0.519	0.147
Correlation coefficient		0.929		0.915	
Standard error of regression		0.393		0.449	

NOTE: Number of data points = 66.

sion analysis was done by using the subjective evaluation of the values of the RMI_I and BMI as dependent variables in Equations 6 and 7. The 95 percent level of confidence was applied to identify significant variables. Table 1 shows the aspects that were significant in the prediction of the RMI_I and the BMI, the weights determined for these aspects, and the standard errors.

From a socioeconomic point of view, wet weather trafficability of roads is highly valued in developing areas because commuters traveling to work to earn their income use these roads on a daily basis. Therefore, the following additional condition in the determination of the RMI is included:

$$RMI = \max(RMI_I; \text{degree of wet weather trafficability}) \quad (8)$$

The methodology was tested in Lebowa by a panel of maintenance personnel. The results of the evaluation confirmed that the method is practical and workable and that the values of the maintenance indices produced agree with the values expected.

Prioritization

Although the values determined for the maintenance indices form the basis of the prioritization of regraveling and betterment projects, the influence of traffic also needs to be taken into consideration. The reasons are twofold:

- The urgency of regraveling is a direct function of the expected rate of gravel loss, which Visser (5) showed to be related to traffic volume, and
- The economic benefits that accrue from the improvement of a road are proportional to the number of vehicles deriving benefits from the improvement.

Priority indices are therefore based on the maintenance indices adjusted for traffic volumes. The following exponential function was used to determine the regraveling priority index (RPI) and the betterment priority index (BPI):

$$P = 1 + (M - 1) \cdot [1 - \exp(\Sigma f_i \cdot Q_i)] \quad (9)$$

where

P = priority index (1 to 5), i.e., RPI or BPI;
M = maintenance index (1 to 5), i.e., RMI or BMI;
Q_i = ADT for vehicle type i, and
f_i = vehicle type factor.

The main reason for using this function is that it only influences the maintenance index significantly if the traffic volume is relatively low (in which case the maintenance index is reduced). In the case of higher traffic volumes, the priority index is almost equal to the maintenance index. An approach whereby the whole road network is maintained at an acceptable level (provided that the traffic volumes exceed the threshold value) is therefore supported by the model. Furthermore, the function is smooth, which helps to address the problem of conflicting priorities often encountered at discontinuities.

The vehicle type factors used to compute the priority index are based on typical vehicle operating and occupant time costs for each vehicle type. Typical values used are 0.02 for an automobile, 0.06 for a medium truck and 0.10 for a bus.

Evaluation of Projects

Project evaluation is the process whereby a public agency or private enterprise determines whether a project meets the country's economic and social objectives and whether it meets these objectives efficiently (6). This section is specifically aimed at the development of economic project evaluation methodology for tertiary roads. A distinction was made between road construction and river crossing projects.

Roads

A number of road cross-section standards considered to be appropriate for the tertiary road network were used as a basis for the development of models for the evaluation of tertiary road projects and are shown on Figure 2 (7).

The following cases where analyzed:

- Upgrading of cross section 5 to cross section 4,
- Upgrading of cross section 5 to cross section 3,
- Upgrading of cross section 3 to cross section 1, and
- Upgrading of cross section 4 to cross section 2.

Economic Analysis

The CB-Roads program suite (Version 4.1) (*8*), developed for the cost-benefit analysis of rural road projects by the Department of Transport, was used for the economic analysis. A number of variables considered to be the more significant ones with regard to the economic justification of road upgrading projects were selected and analyzed. The approach was to determine the maximum construction cost at which a particular project is justified (assuming a discount rate of 15 percent). The user of the methodology then determines the actual construction cost and compares it with the maximum cost justified. If the actual cost exceeds the maximum justified, the project is not warranted; otherwise it is.

The following relationships were investigated:

- Maximum construction cost justified versus the ADT,
- Maximum construction cost justified versus the percentage reduction in length of the road, and
- Maximum construction cost justified versus the expected traffic growth rate.

In the first two cases, the relationships are linear, but the relationship is hyperbolic for the third case. This information was taken into account in the development of the model.

The maximum upgrading cost per kilometer of the new road justified is given by the following equation:

$$C_{max} = \frac{a + f \cdot b \cdot Q + c \cdot L + f \cdot d \cdot Q \cdot L}{1 - L} \quad (10)$$

where

C_{max} = maximum upgrading cost per kilometer of proposed road justified, expressed in 1992 Rand value (must be adjusted for other Rand values) [note that 1 Rand (1992) equals $0.33 US],
a,b,c,d = constants [provided by Pienaar (2, Table 5.2)],
f = traffic growth factor,
Q = ADT, and
L = relative reduction in length, e.g., $L = 0.1$ in the case of a 10 percent reduction in length.

Normally all benefits are taken into account, that is, vehicle operating cost (VOC) benefits, road maintenance benefits, accident cost benefits, and time cost benefits of vehicle occupants. In some cases, however, it may be more appropriate to take only VOC and road maintenance benefits into account since these are considered the direct benefits. The model allows for such

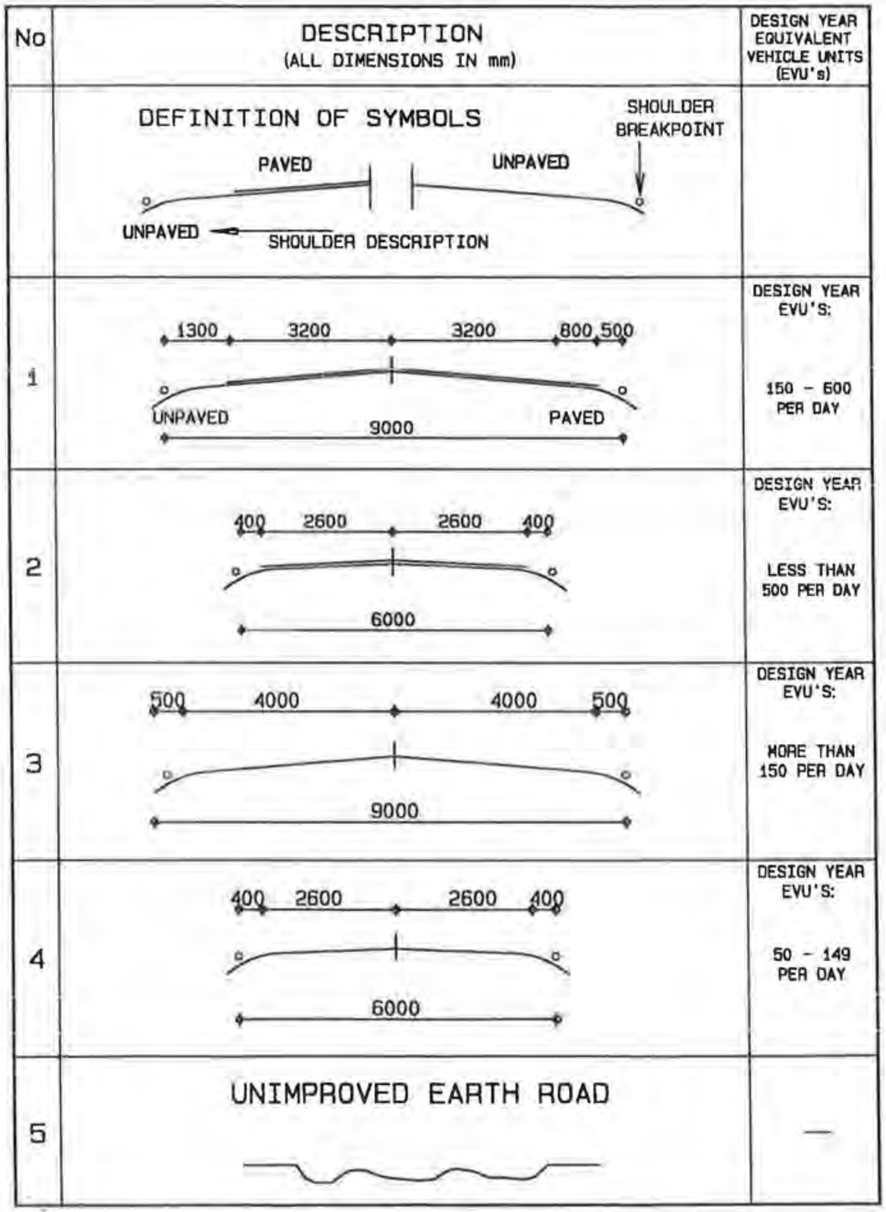

FIGURE 2 Pavement cross-section standards (7).

an approach. For general use, the model can also be presented as a set of graphs, an example of which is shown in Figure 3 (2).

Prioritization

Prioritization of projects is done in terms of the actual benefit-cost ratio of projects. First, the actual construction cost (C_u) of the project must be determined. The maximum allowable construction cost (C_{max}) is then calculated, using the model (Equation 10). C_{max} is the construction cost, where the B/C ratio equals 1 and is therefore equal to the benefits of the project discounted to the present value. If C_u is less than C_{max}, the project is viable. The actual benefit-cost ratio for the project, defined as the priority index (P), is determined as follows:

$$P = B/C = C_{max}/C_u \tag{11}$$

Projects can then be arranged in order of priority for implementation purposes.

River Crossings

A distinction is made between low-level structures, consisting of causeways and low-level bridges, and high-

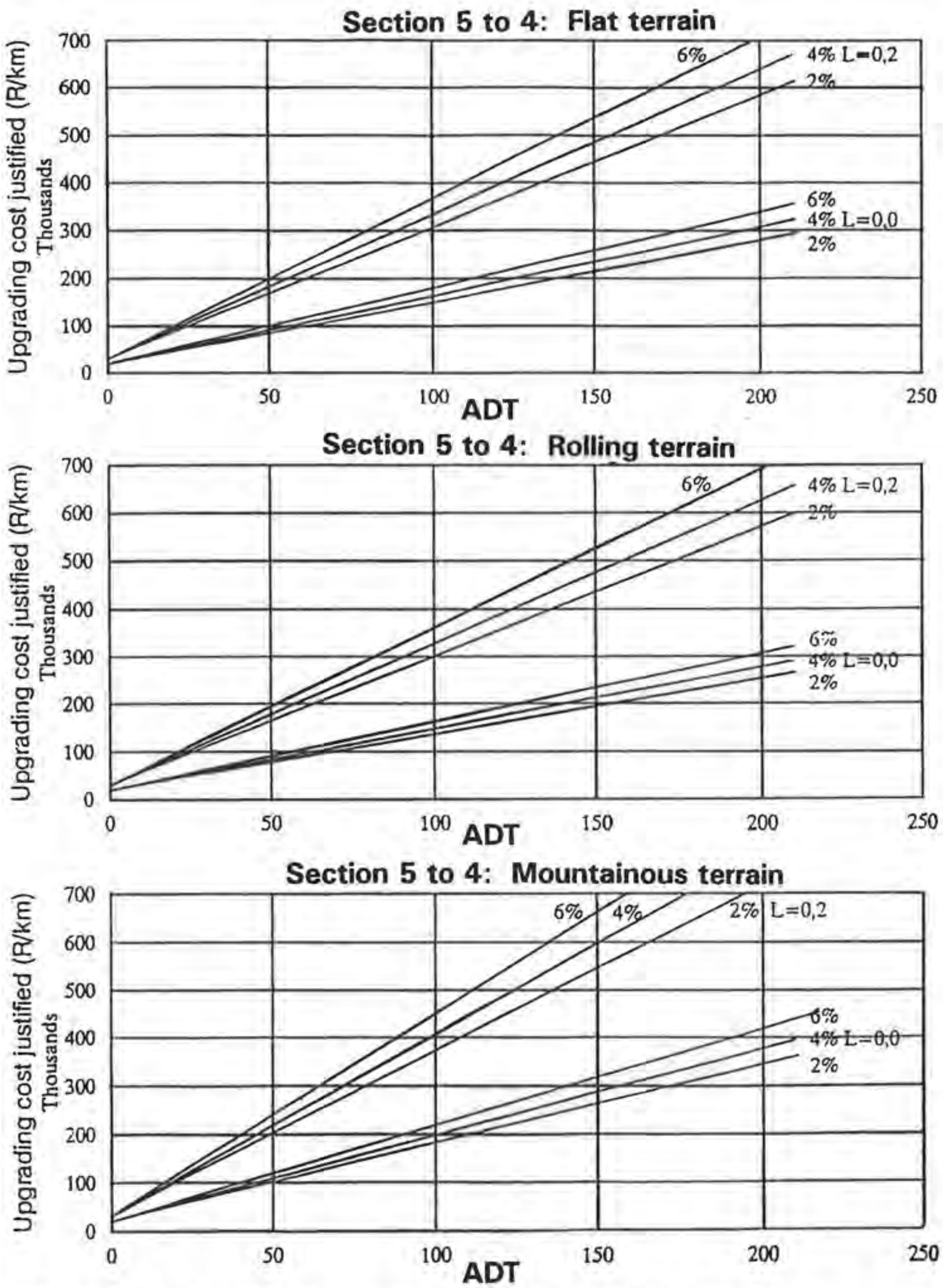

FIGURE 3 Cost justified for upgrading cross section 5 to cross section 4.

level bridges. High-level bridges will generally not be considered on the tertiary road network. Exceptions are when a low-level crossing is not possible because of geometric constraints or strategic considerations with regard to permanent accessibility or when a high-level bridge is economically warranted and the decision is that it is indeed required.

As far as the upgrading options are concerned, sometimes no river crossing structure exists, especially in the dry and remote parts of the country. Vehicles then drive on the river bed. In these cases, a decision must be made about whether a low-level structure is adequate or a high-level bridge is required.

Often a low-level structure does exist, but upgrading of the structure is considered because of geometric requirements or to improve the level of service with regard to the time period when the structure is submerged.

For the evaluation of low-level river crossings, it is necessary to know how often certain floods will occur and how long the structure can be expected to be submerged. This knowledge is necessary in order to evaluate the impact on road users, who must either use alternative routes in the case of inundation or wait for the structure to become passable again. Without this information, an economic analysis of the investment decision to provide a low-level structure (LLS) is not possible.

This section addresses the development of three models to describe the flooding of LLSs and the economic evaluation of river crossings.

Methodology

Historic river flow data for a number of catchment areas with a variety of characteristics were used as a basis for the development of the above models. The study area was the northern part of the Transvaal, which consists of three drainage regions, known as Regions A, B, and X. A total of 41 data sets was used for the study. As far as was possible, the data collected covered the time period August 1, 1972, to July 31, 1991.

Certain fractions of the 1-in-2-year flood were chosen to determine a number of flow values per data set, for example 0.25; 0.5 and 1.0 times the 1-in-2-year flood. For each of these flow values, flow data were analyzed to determine

- The total time period per year that the flow value was exceeded,
- The number of times per year that the flow value was exceeded, and
- The average duration of excess flow.

Figure 4 shows the data and the model developed for the number of times per year that certain flow values were exceeded. (For example, the flow value corresponding to 0.25 times the 1-in-2-year flood was on average exceeded 1.25 times per year.)

The design flow for a particular structure is determined as follows:

$$Q_{design} = f_i \cdot Q_2 \qquad (12)$$

where

Q_{design} = design flow,
f_i = factor described below, and
Q_2 = flood with a 1-in-2-year return period.

Three levels of design were defined on the basis of the models (Table 2). In the determination of the design level, the designer must take into account the local circumstances, the road user expectations, and the relative construction cost associated with each design level.

The structure should be designed in such a way that the available capacity over and under the structure is

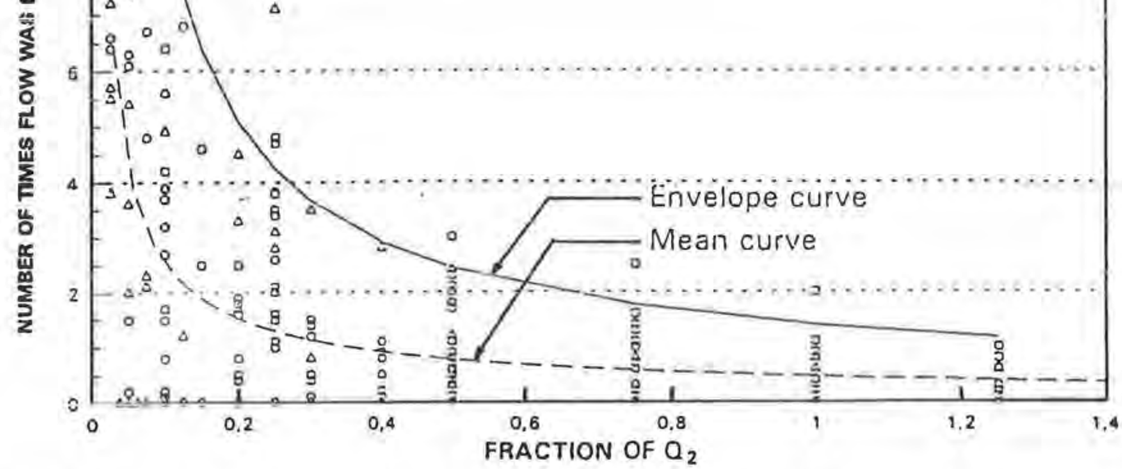

FIGURE 4 Number of times certain flows were exceeded (note: Q_2 is the 1-in-2-year flood) (2).

TABLE 2 Levels of Design for LLSs

Design Level		Average No. of Times Exceeded/Year/ Gauging Station			Average Duration/ Flood (hr)/ Gauging Station		
i	f_i	Min	Max	Avg	Min	Max	Avg
1	0.25	0	4.2	1.3	0	30	9.0
2	0.50	0	2.4	0.8	0	13	5.5
3	1.00	0	1.4	0.5	0	6	3.4

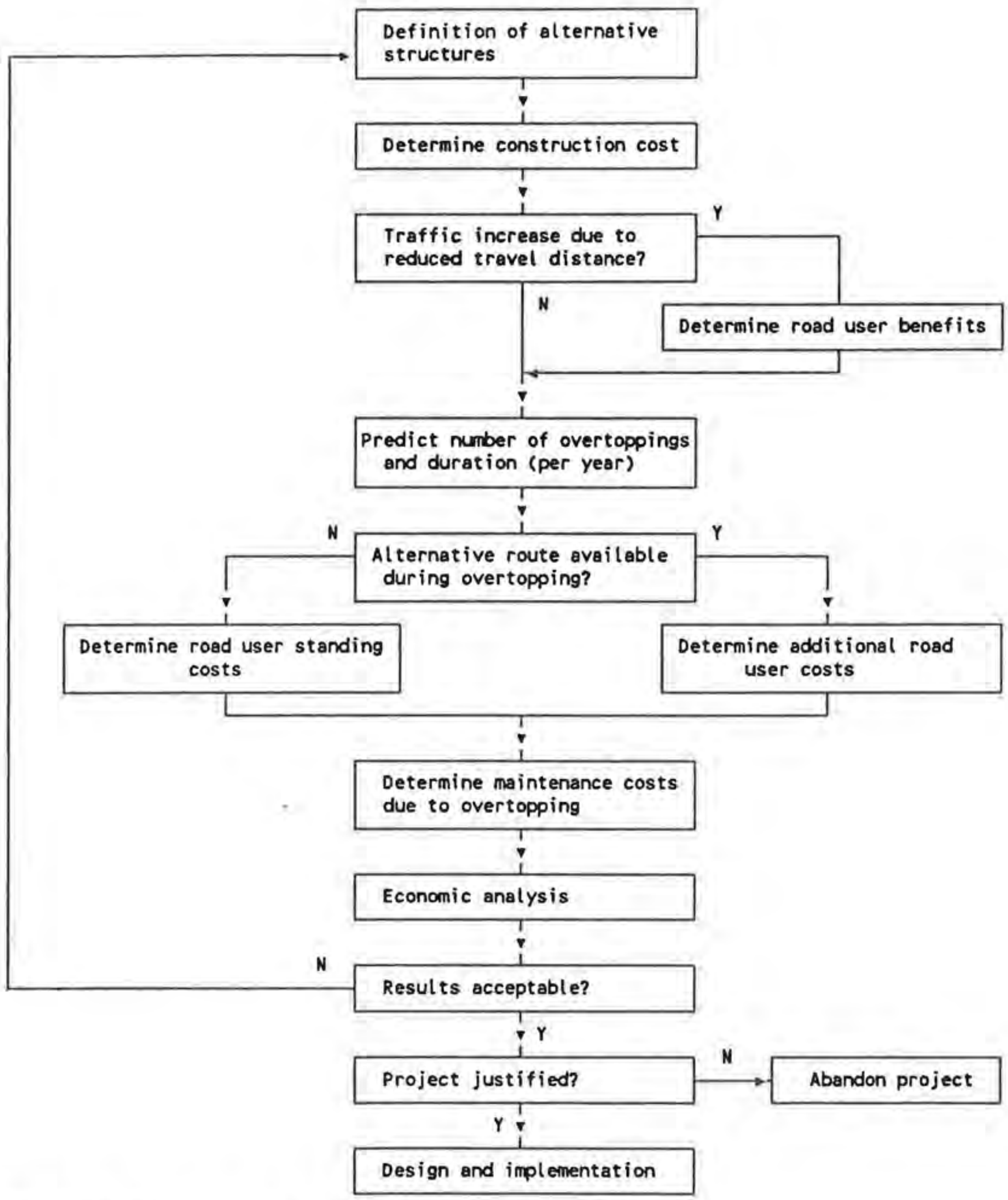

FIGURE 5 Economic analysis of LLSs (*2*).

greater than the design flow, that is,

$$Q_o + Q_u \geq Q_{design} \tag{13}$$

where Q_o is the flow over the structure within the acceptable flow depth and Q_u is the flow passing underneath the structure.

It was accepted that a vehicle should not pass over an LLS that is being overtopped if the depth of flow exceeds the underbody ground clearance height of the vehicle. The flow velocity, however, also needs to be taken into account. The following design values are recommended:

- Supercritical flow: maximum depth, 100 mm;
- Subcritical flow: maximum depth, 150 mm.

Economic Evaluation Process

The economic evaluation process proposed for LLSs is shown schematically in Figure 5. The project is considered for implementation when the maximum cost at which the project is justified (C_{max}) exceeds the actual cost estimate (C_a). The ratio C_{max}/C_a can be used for prioritization.

In order to simplify the economic procedure, the following two models were developed to assist the user who may not have computerized programs available.

1. No alternative route available when the route is impassable during floods:

$$C_{max} = a + b \cdot Q \tag{14}$$

where

C_{max} = maximum construction cost justified,
Q = ADT, and
a,b = constants provided by Pienaar (2, Table 5.10).

2. Alternative route available when the structure is impassable during floods:

$$C_{max} = a + c \cdot Q \cdot L \tag{15}$$

where L is the additional length of the alternative route in kilometers and a and c are constants provided by Pienaar (2, Table 5.10). The models are shown graphically in Figure 6.

CONCLUSIONS

The goal of this paper was to present a methodology for providing optimal tertiary road networks. A framework, which was used as the basis for the paper, was defined for the management process on the tertiary road network.

It has been shown that a method of road network optimization is possible, although it cannot be considered a truly mathematical optimization function. The method presented uses economic assessment at a network level and yields satisfactory results from a benefit-cost point of view. A considerable amount of engineering knowledge and judgment is, however, still required.

The feasibility of estimating traffic volumes as a function of certain road characteristics was investigated. It was found that traffic volumes can be estimated and correlate reasonably well with some of these characteristics. The accuracy of the estimates is considered to be adequate for road management purposes. Although one can use trip generation models to determine typical traffic volumes, the level of accuracy is not high enough to be used on its own for road management purposes. It is, however, of value if used in conjunction with other methods of estimating traffic volumes.

A methodology to identify regraveling and betterment projects, based on the visual evaluation of a num-

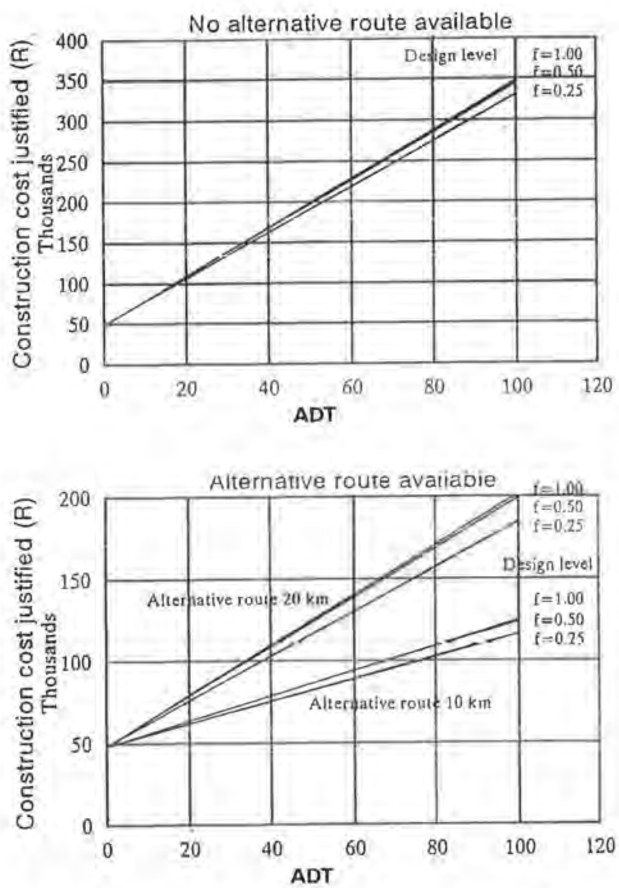

FIGURE 6 Maximum construction cost justified for LLSs (2).

ber of aspects related to the performance of unpaved roads, was developed. Algorithms were developed using linear regression techniques. The prioritization of projects is done by taking traffic volumes into account because traffic volumes provide an indication of the number of road users that will benefit from a particular maintenance action.

A simple and easy-to-use mechanism to determine whether upgrading a particular road is warranted was developed. This mechanism is based on the economic analysis of typical projects in order to evaluate the role of a number of variables.

Historic river flow data for a number of catchment areas with a variety of characteristics were used to model the flooding of low-level river crossings. Based on these models, project evaluation methodology for low-level river crossings was prepared.

These guidelines are practical, and implementation has been demonstrated (2). The application of these guidelines is therefore recommended.

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