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TITLE: A study of the economics of a gravel road upgrading in Botswana

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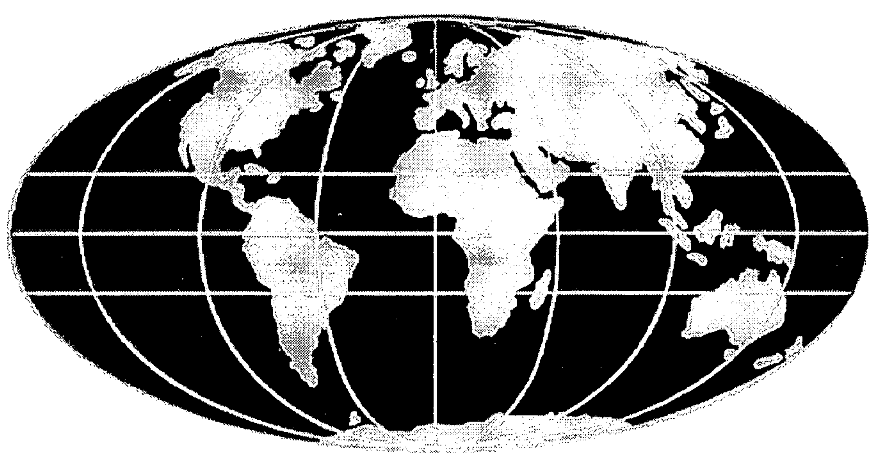

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A STUDY OF THE ECONOMICS OF A GRAVEL ROAD UPGRADING IN BOTSWANA

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SYNOPSIS

This paper describes a study of the feasibility of upgrading a major gravel road 304km long in Botswana to bitumen standard. The study, which involved the use of the TRRL road investment model (RTIM2), compared the costs of upgrading immediately and upgrading at a later date. Surveys of material resources adjacent to the route showed that the local calcrete gravels were being rapidly exhausted by their continued use in maintaining the road and that, in comparison with other more conventional materials, they exhibited much higher rates of wear even at the low traffic levels existing on the road. This meant that an increasingly large proportion of the national maintenance budget was being required to keep the existing road from deteriorating to an unacceptable condition. Because of this, in the economic analysis, neither, a 'do nothing' option nor a conventional net present value approach were appropriate. Instead, an incremental cost analysis was performed making use of a 'do minimum' case.

The study showed that, on the basis of construction and maintenance costs alone, a net capital cost saving could be made on choosing the option to upgrade immediately and that this was the best of the options examined. The study illustrated that RTIM2 can be modified for local conditions provided that a strong base of data which relates road deterioration, material types and traffic exists locally. It also showed that the collection of detailed engineering data specific to a route is important in designing and planning gravel road upgrading and concludes that similar studies could be usefully done on other routes and would improve economic decision making.

1 INTRODUCTION

The Transport and Road Research Laboratory (TRRL) of the United Kingdom and the Ministry of Works and Communications, Botswana, have collaborated in a joint road research project since 1978. A major part of the research programme has involved the location, properties and performance of roadmaking materials in Botswana with special emphasis on the use of calcretes, a calcareous gravelly material, which is the main source of locally available material for road construction in the western and central regions of the country. Full scale road trials have been constructed to develop specifications appropriate for the use of calcretes; other work has included studies of rates of deterioration and effectiveness of maintenance treatments for gravel roads. The results of this research together with data obtained from traffic studies and vehicle operating costs have provided an increasing amount of information which can be used for planning and designing new road projects in Botswana.

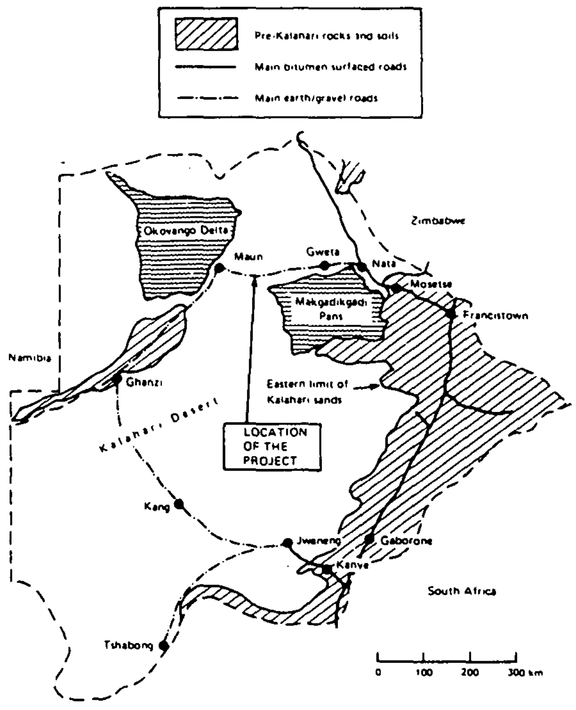

FIGURE 1: Map of Botswana showing the location of the project

In September 1983, the Roads Department of the Ministry of Works and Communications (MOWC) sought the cooperation of TRRL in a study of the 304km long Maun to Nata road. The road is an important link connecting the northwest and the eastern part of the country (Fig.1). With increasing development of the national economy, it was evident that in the future the existing gravel road would require upgrading to bituminous standard. An

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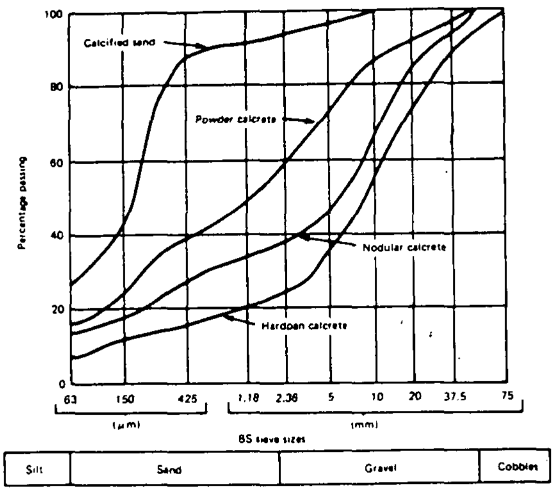

FIGURE 2: Four particle-size distribution curves to illustrate the range of grading found in calcretes

PLATE 1: Powder calcrete in pit

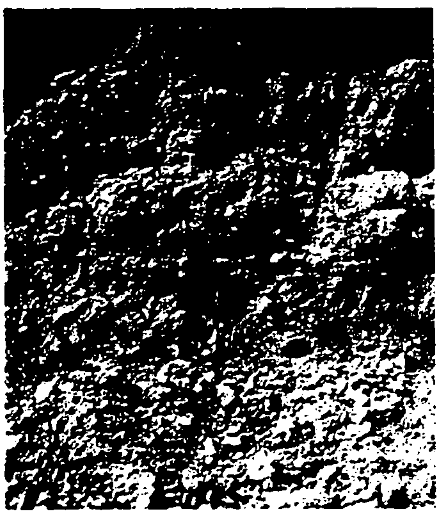

PLATE 2: Nodular calcrete

important factor in improving the road standard was the availability of materials for construction. Surveys showed that the material resources were being depleted by their continued use in maintaining the gravel road and that this was likely to have a considerable influence on future construction costs.

A further consideration was that the research undertaken by TRRL had indicated that the calcrete gravel used to surface the existing Maun-Nata road exhibited much higher rates of wear than gravels available to surface roads in other countries. This high rate of wear is in part due to the engineering properties of the calcrete roads in the semi-arid and arid climates in which they occur. This was particularly important for two reasons. Firstly, very high rates of gravel loss meant that re-gravelling was needed very frequently and this placed great strain on the already depleted sources of suitably available material. Secondly, the rate of increase of surface deformation of the gravel was very high, leading to high average roughness values and, consequently, high levels of vehicle operating costs. It was anticipated that both of these facts would have a significant impact on the results of the study.

The main objectives of the study were, therefore, to look at the feasibility of upgrading the Maun-Nata road immediately and to compare the rate of return of this with deferring the upgrading for five years.

As a direct result of the recommendations from the study, detailed design of the project is now being undertaken and construction is expected to commence in 1987/88.

2 CALCRETES AS ROADMAKING MATERIALS

Calcrete is a naturally occurring calcareous material composed of host sand grains and calcium or magnesium carbonate. It occurs within the Kalahari sand areas of Botswana and forms beneath the sand surface. The material has characteristics which vary from uniformly-graded calcified sands and powdery soils to well-graded, hard gravels and rock layers. Deposits of calcrete occur throughout most of the central and western areas of Botswana and are often associated with such landscape features as pan formations, inter-dune hollows, depressions and former drainage lines. They may also occur as cappings to near-surface rocks, often those providing the source of the calcium carbonate. The quality of the material, varies greatly as does the frequency of occurrence of the better types.

In Botswana, a classification of common calcrete types has been adopted based on the South African groupings (1) which are distinct both physically and in their engineering properties. These are calcified (or calcareous) sand, powder calcrete, hardpan calcrete (including 'boulder calcrete') and nodular calcrete. They differ by the proportion of sand to carbonate content and the degree of induration which determine their hardness and, to some extent, their grading. Hardness and grading are two of the most important engineering properties of the material. A certain amount of fine material, including water soluble salts and clay materials, may also be present in some calcretes. Typical gradings of the four main types of calcrete are shown in Fig. 2. The predominant types which occur adjacent to the Maun-Nata road and which have been used as gravel wearing courses on that road are powder calcretes and nodular calcretes. These are described below.

Powder calcrete (Plate 1) contains a high proportion of calcium carbonate (greater than thirty per cent) with the host soil grains proportionately less visible. The in-situ material may have acquired a laminar, blocky or massive structure, and can normally be excavated with a pickaxe, although it can be very tough and difficult to remove. With restricted handling, the material may retain its original proportions of the various fractions but, due to its essentially soft nature, being composed largely of a fragmented mass, it is easily broken down in handling. When used as a gravel wearing course, it can be compacted to a high density and can contain sufficient plastic binder to maintain a coherent surface under traffic. Because of the soft nature of the particles, the surface layer is subject to high wear rates. It is also susceptible to weakening in wet conditions, due to its lack of gravel sized particles and, if compacted dry, it can deteriorate to form a loose powdery layer of material on which traction is difficult.

Nodular calcrete (Plate 2) is a natural calcrete gravel composed of a high proportion (greater than fifty per cent by weight) of rounded gravel-sized nodules of calcium or magnesium carbonate and quartz, in a matrix of power calcrete or calcified sand. The material is typified by a generally 'well-graded' particle-size distribution and a hard aggregate fraction, although the hardness of the nodules varies greatly. Nodular calcretes are often considered the most useful calcrete for pavement layer construction, by virtue of their relatively good grading and mechanical interlock. They do, however, often contain a large proportion of oversize particles which, when exposed on a road surface, give a rough ride. As a result, maintenance of the surface by reshaping is made difficult and, as an alternative, a loose layer of sand is placed at frequent intervals to improve riding quality. Reduction of the oversize particles to a specified maximum size improves the material.

3 STAGES OF THE STUDY

In designing the study, it was recognised that, since the project was not assigned preferential development status, its economic justification would depend largely on the collection of data of direct relevance to the route. In particular, it had been recognised for some time that a disproportionately large amount of recurrent maintenance funds were being allocated to the road. This was mostly attributed to the poor performance of the calcretes available in the region, which were used as the gravel wearing course. It was also felt that the structural capacity and alignment of the existing road should be utilised as much as possible in a future upgrading. The study therefore, involved the following stages:

a) Assessment of traffic. This involved the examination of past records and the conduct of classified traffic counts and axle load surveys.

b) Inventory of the geometry and drainage of the existing road. This was undertaken to check that minimum standards were being satisfied since it was hoped to utilise the existing alignment to minimise costs.

c) Location and evaluation of construction materials. This involved the location and testing of materials to be reserved for a future upgrading and the establishment of an inventory of resources for gravel road maintenance. Roadstone deposits were also identified.

d) Investigation of the strength of the existing road and the properties of the gravel wearing course. This would enable design subgrade CBR values to be calculated and the existing wearing course to be assessed as a future sub-base.

e) Assessment of road maintenance, its costs, capacity and effect. This considered the availability of resources and the response of the calcrete wearing course to road maintenance inputs. The result of studies of unpaved calcrete roads in Botswana provided appropriate road deterioration relationships.

f) Choice and design of alternative pavements. This took into account the various structures suitable for the design traffic, the availability of materials and the cost of the alternatives.

g) Collection of vehicle operating cost data.

h) Derivation of unit costs for road construction items and the calculation of construction costs based on b), c), d) and f).

i) Analysis of alternative maintenance and construction policies using the TRRL road investment model.

The various stages are described in the paper.

4 THE TRRL ROAD INVESTMENT MODEL

Economic analysis of the Maun-Nata project was carried out using the TRRL road investment model for developing countries (RTIM2). The model is designed as an aid to decision making in the roads sector in developing countries and can be used to determine road construction and maintenance costs, and to evaluate the benefits of vehicle operating cost and time savings. It may be used to appraise road construction, maintenance and upgrading projects. The effect on vehicle operating cost of the changing condition of the road surface is taken into account in the determination of costs and benefits. The detailed relationships used in the model are given in TRRL Laboratory Report 1057 (2). Operation of the model is shown in Fig. 3 and starts by the user specifying the analysis period and defining the road alignment. Construction details are then input and the cost of construction determined. Alternatively, the construction cost may be specified directly. For each year that the road is open to traffic, road deterioration, road user costs and road maintenance costs are predicted. Road deterioration is calculated as a function of the construction specification, the maintenance policy, the rainfall and the traffic. Road geometry and road surface condition are used to predict the vehicles' speeds and fuel consumption. Costs of fuel, oil, tyres, vehicle maintenance, depreciation, etc, are then determined to give the total vehicle operating costs for the year. An option is available to calculate time costs and these are based on unit values of time which must be input to the model. Road maintenance requirements are found from the condition of the road surface in conjunction with the maintenance policy specified by the user, and these are used to calculate the maintenance cost. The model then continues with its year-by-year analysis. The process continues for the selected analysis period and, at the end, the total construction costs, road maintenance costs and road user costs will be known. These costs can then be discounted at different discount rates. The model is normally run first for a 'do nothing' or 'do minimum' case. A series of project options may then be run and, as each is completed, its results are compared with those of the 'do nothing' case to determine benefits.

The original road deterioration relationships used in the RTIM2 model were derived from research carried out by TRRL in Kenya and these were modified to reflect the different materials and environmental conditions in Botswana. Relationships obtained from the research on calcrete roads in the TRRL-MOWC research project were used. In particular, revised relationships for the progression of both roughness and gravel loss were provided to ensure that the behaviour of the calcrete gravel was modelled in an appropriate way. The resulting deterioration parameters obtained were directly applicable to the maintenance and economic planning methodology used in the RTIM2 program.

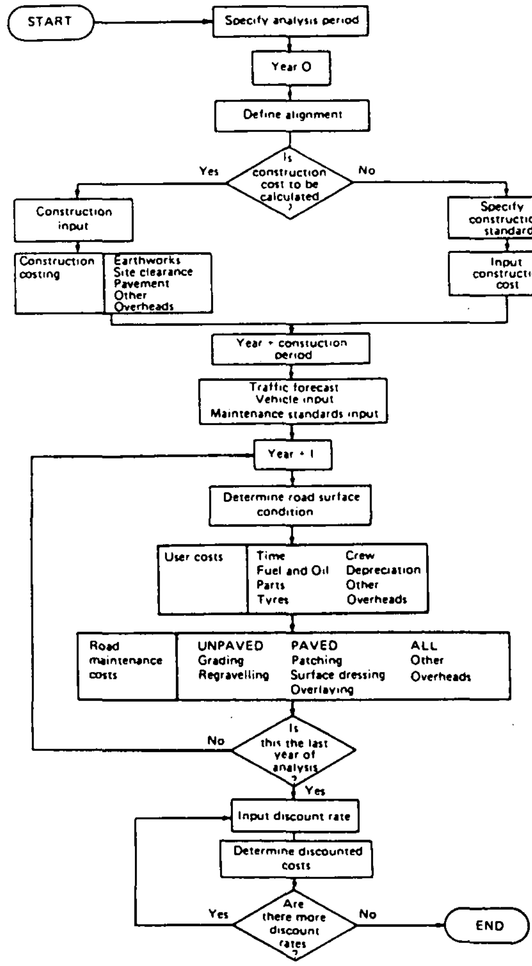

FIGURE 3: Detailed flow-diagram of TRRL Road Investment Model (RTIM2)

4.1 Gravel loss

Gravel loss relationships were obtained by analysing data from monitoring four test sections which were constructed on the Maun-Nata road.

The equations were of a similar form to the gravel loss relationships in RTIM2. The annual gravel loss (G) is given as:

$$G = F(4.2+0.092T_A+3.5R_f^2+1.88Vc)\left[\frac{T_A^2}{T_A^2+50}\right]$$

Where T_A = total annual traffic in both directions, measured in thousands of vehicles

R_f = rainfall in metres

Vc = average percentage road gradient

For calcretes, two separate 'F' values were determined:

nodular calcrete: F = 4.5

powder calcrete: F = 6.8

Typical 'F' values for lateritic or quartzitic gravels found in other countries are between 1.0 and 1.5 (3) indicating that the rate of loss of calcretes was between four and six times as great as typical road building gravels used in other countries.

4.2 Roughness

Relationships for road roughness were developed from an examination of the four sections on the Maun to Nata road and data from other specially constructed test sections near Gweta (See Fig. 1).

The experience gained in the study of the deterioration of riding quality of calcrete gravel roads indicated that conditions worsened with age, ie the rate of deterioration of riding quality increased with age, and the condition of the road immediately after maintenance was poorer with age.

The trend of the equations was different from the original RTIM2 equations which tend to be a positive power curve of the form, $y = a^x$, where $x > 1$. The calcrete equations were linear, although at very high roughness levels, they may eventually become asymptotic. The equations developed specific to calcretes are shown below.

Nodular calcrete

- Age ≤ 1 year $R = 5.0 + 0.703T$
- Age > 2 years $R = 5.6 + 1.625T$
- Age > 4 years $R = 5.6 + 2.410T$

Powder calcrete

- Age ≤ 1 year $R = 4.8 + 0.632T$
- Age > 2 years $R = 5.7 + 1.076T$

where Age = number of years since last regravelling

R = roughness, equivalent towed fifth wheel value, expressed in m/km

T = cumulative vehicle passes in both directions between gradings in thousands of vehicles

A comparison of the roughness relations developed in Botswana and the original RTIM2 relationships is shown in Figure 4.

5 TRAFFIC

5.1 Traffic counts on existing road

Traffic counts were obtained for the period 1980-1983. Classified counts were usually carried out over a twelve hour day time period for seven days once a year. Table 1 shows that the level of traffic varied over the length of the road between Maun and Nata. As traffic volume is a major factor affecting road user costs, road deterioration and pavement design, the route was divided into the following four sections:

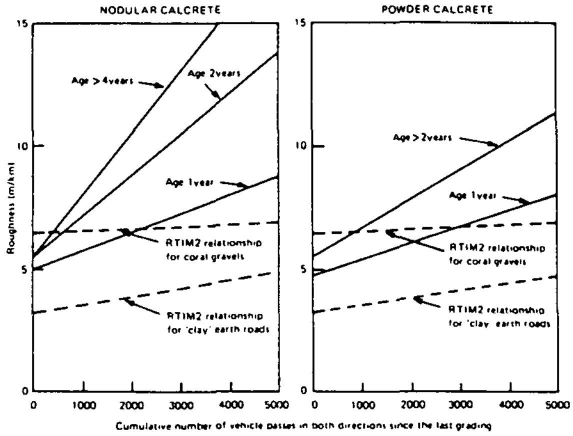

FIGURE 4: Road roughness relationships for nodular and powder calcretes

Section 1	Maun to Samedupi	km2.3-17
Section 2	Samedupi to Makalamabedi	km17-56
Section 3	Makalamabedi to Gweta	km56-203
Section 4	Gweta to Nata	km203-303

A further reason for dividing the road into sections was because the distribution of materials suitable for upgrading and regravelling also varied along the route.

Maun was chosen as the starting point for upgrading because traffic levels were highest in Section 1 (see Table 1), and this part of the road was in a more deteriorated condition. Higher benefits, released more quickly, would be achieved in this way.

Road section	Survey point	Year of Survey			
		1980	1981	1982	1983
1	Samedupi	--	--	92	142
2	Samedupi	--	--	87	126
	Makalamabedi	--	--	--	126
3	Makalamabedi	--	--	--	60
	Xhaneo	--	43	--	61
	Gweta	--	--	51	77
4	Gweta	--	--	61	80
	Zoroga	--	44	56	--
	Nata	42	54	46	57

TABLE 1 : SUMMARY OF TRAFFIC COUNTS (VPD)

The classified counts also provided information on the numbers of vehicles in each of the following classes:

- Type 1 Passenger cars
- Type 2 Pick-ups, eg Land Rovers, etc
- Type 3 Light goods (1.5 - 4.99 tonnes)
- Type 4 Light trucks (5 - 9.99 tonnes)
- Type 5 Medium trucks (10 - 19.99 tonnes)

Type 6 Heavy trucks (more than 20 tonnes)

Type 7 Buses

The assumed first year trafficking for each vehicle type and corresponding road section required in the analysis is shown in Table 2. The first year was taken as 1983 for section 1 and 1984 for sections 2, 3 and 4.

Road section	VEHICLE TYPE							Total
	T1	T2	T3	T4	T5	T6	T7	
1	9	18	64	33	6	10	2	142
2	9	17	58	29	6	11	2	132
3	7	14	25	17	3	4	3	73
4	7	14	24	17	3	3	3	73

TABLE 2 : NUMBERS OF VEHICLES BY TYPE IN YEAR 1 (VPD)

5.2 Axle loading on existing road

A seven day, twenty four hours a day, axle load and origin and destination survey was undertaken on the Francistown to Nata road near the village of Mosetse using the guidelines in TRRL Road Note 40 (4).

The results of the survey indicated that vehicles travelling on the Maun to Nata road are exceptionally loaded. The average equivalency factors attributed to each vehicle type are shown in Table 3.

Traffic category	E80 per vehicle
Light truck (5-9.99 tonnes)	1.5
Medium truck (10-19.99 tonnes)	9.0
Heavy truck (>20 tonnes)	9.6
Buses	1.4

Note: E80 = one equivalent 80 KN axle or one equivalent 8.2 tonne axle (esa)

TABLE 3 : NUMBER OF EQUIVALENT 80 KN AXLES PER VEHICLE BY TRAFFIC CATEGORY

These axle load survey results indicate that, on average, each vehicle on this route with an unladen weight greater than 5 tonnes contributes approximately 4 esa. Using the recommendations in the Botswana Road Design Manual (5), an average value of 0.5 esa per vehicle would be calculated and this emphasises the need to obtain axle loading data relevant to a particular route.

5.3 Timing of the upgrading

The study considered both an immediate upgrading option and a deferral for five years. It was assumed for the "upgrade-now" option that completion of Section 1 could be achieved in 1983, and that for Sections 2, 3 and 4 upgrading would take place over a period of three years being completed in 1984, 1985 and 1986 respectively. For the deferred option, commencement and completion would be five years later.

5.4 Traffic projections

Projected traffic has been estimated by applying growth rates based on those recommended in the National Transport Plan (6), as shown in Table 4.

NATIONAL TRANSPORT PLAN
20% increase on bitumenisation
First 5 years at 8% per annum
North and West thereafter at 5% per annum (ie Maun-Nata)
South thereafter at 8% per annum

TABLE 4 : RECOMMENDED GROWTH RATES FOR RURAL ROADS

A growth rate of 5 per cent per annum was applied to all vehicle types on the road prior to paving. Immediately an individual link was paved, it was assumed that the growth of vehicle types 2, 3 and 4 would increase to 8 per cent. Once the complete road was paved, there would be an immediate once and for all growth of 20 per cent. After final completion, growth of all vehicles would continue at the rates forecast in the National Transport Plan. The resulting projected traffic levels are shown in Table 5.

Road section	Upgrade Now			Defer Upgrading		
	1984	1986	2003	1984	1991	2003
1	153	198	522	149	251	519
2	132	171	451	132	219	453
3	73	92	243	73	119	246
4	73	92	243	73	119	246

TABLE 5 : PROJECTED FLOWS FOR 20 YEAR ANALYSIS PERIOD (VPD)

On the basis of the results of the classified traffic counts, the axle load surveys and the anticipated growth rates, the projected axle loadings in Table 6 were calculated.

6 GEOMETRIC DESIGN AND DRAINAGE

For the purposes of the appraisal, a standard design was selected from the Botswana Road Design Manual that was appropriate for the projected levels of traffic that the road would carry. The chosen design has a bituminous carriageway six metres wide, with 1.5 metre shoulders and a design speed of 100 km/h. To accommodate this, the existing road formation would have to be widened and minor cuttings would have to be introduced in some places.

Road section(s)	Cumulative 80 KN axles			
	Upgrade now		Defer upgrading	
	After 10 years	After 20 years	After 10 years	After 20 years
1 and 2	0.5×10^6	1.7×10^6	0.3×10^6	1.4×10^6
3 and 4	0.2×10^6	0.7×10^6	0.15×10^6	0.6×10^6

TABLE 6 : PROJECTED AXLE LOADING

An inventory of the existing alignment was undertaken by assessing the sight distances and measuring possible sections of road with deficient vertical alignment. The results of the inventory confirmed that only minor alterations would be necessary to improve alignment and the cost of this work was assumed to be negligible. The horizontal alignment of the existing road includes long straights which exceed the maximum length recommended in the Botswana Road Design Manual. However, this deviation from standard was accepted in order to achieve the objective of a low cost upgrading.

Most of the route traverse flat areas of Kalahari-type sand which is generally free-draining, so catchment-area design was not considered in this study. However, as a precaution against flooding during high intensity storms, a minimum side drain depth of 0.6 metres was recommended. A sum to cover the provision of balancing culverts was included in the construction cost, but no major structures were required.

7 MATERIALS RESOURCES AND UTLISATION

7.1 Pavement material resources

A pavement materials study was undertaken of the 304 km route in a 15 km wide corridor using modern remote sensing techniques and the normal method of field reconnaissance and probing (7). Material types and quantities were identified in terms of their potential for use as untreated natural gravel bases, cement-stabilised bases, lime-modified bases and gravel wearing courses. Techniques which involve the lime or cement stabilisation of an existing gravel wearing course, considered suitable in some countries (8), were excluded due to risk of carbonation attack and disintegration of the unsurfaced calcrete layer (9)(10). In hot dry climates, such as those in Botswana, effective stabilisation requires the curing and sealing of the stabilised layer to enable the reaction to occur and to maintain the durability of the cementitious components.

On this basis material quantities were estimated from the results of field studies and a detailed laboratory test programme. The properties determined in the laboratory included the California bearing ratio (CBR), aggregate hardness, grading and plasticity of the material.

The assessment of materials suitable for use in gravel wearing courses was based on an interim guide for the selection of calcretes (11) produced as part of the TRRL-MOWC research project. This recommends suitable gravel wearing courses on the basis of estimated gravel wear rates in relation to an original classification by Netterburg (1). The soils properties of the calcrete wearing course materials are shown in Table 7. Only classes 1 and 2 were deemed acceptable for use. In the assessment of materials resources, those materials with a CBR>60% were considered to be suitable as potential stabilised bases provided they also possessed a grading modulus of >1.5 since it was not possible to carry out much stabilisation testing. The term grading modulus is defined as:

GM = Sum of the material retained on the 2mm, 0.425mm and 0.075mm sieves divided by 100.

The value varies between 0 and 3.

For Botswana calcretes, a value of 1.5 would contain approximately 50 per cent, or less, material passing the 0.425mm sieve, ie it would possess a granular texture.

The limited amount of testing that was performed, by determining the initial consumption of lime (12) of the calcretes, indicated that a relatively low amount of stabiliser would be required.

Potential untreated natural gravel base and sub-base materials were selected on the basis of standard laboratory test properties (see requirements in Tables 8 and 9).

7.2 Materials requirements and utilisation

The conclusion from the available information on resources indicated that a depletion of total reserves in the area km 0 to km 180 would occur if a further regravelling of the existing road was undertaken before work on upgrading started. The calculations were based on the assumption that reserves for the upgrading should be allocated and conserved, and that only net resources were of potential use for regravelling purposes. It was also assumed that the minimum regravelling layer thickness would be 150mm.

From an assessment of net resources, with deposits reserved for upgrading, gravel supplies for a second regravelling of the area from Maun to km 180 would have to be hauled from km 180. The net effect of any regravelling over this length of the road would exhaust supplies for the future and a dramatic regravelling cost increase would be expected. From current regravelling costs of Pula 10 000 per km, it was anticipated that these would increase to P20 000 and P80 000 per km for a first and second regravelling cycle, respectively. The road section between km 203 and Nata has large reserves of materials, although this should not preclude conservation.

Test Property	High Proportion of Heavy Vehicles		Low Proportion of Heavy Vehicles	
	Class 1	Class 2	Class 3	Class 4
Percentage passing 425μm sieve	15-45	45-55	55-65	65-75
Liquid Limit	25-65	20-45	20-40	18-30
Plasticity Index	8-23	5-22	8-13	5-13
Linear Shrinkage (LS)	3-9	2-8	3-5	2-5
LS x % - 425 μm	100-380	100-420	100-330	100-330
Aggregate Finger Value (AFV)*	> 65	> 60	ns	ns
Aggregate Pliers Value (APV)*	> 25	> 20	ns	ns
10% Fines Aggregate Crushing Value	> 30	> 30	ns	ns
Minimum soaked CBR at field density (%)	60	60	60	60
Estimated gravel loss per year per 50 vpd (mm)	22	22	33	33

* Netterberg 1971 (Ref 1)

TABLE 7 : REQUIREMENTS FOR CALCRETE GRAVEL WEARING COURSES

Pavement layer in completed pavement	Field compaction (% Mod AASHTO)	Design 1	Design 2	Source of material
Base	98%	150 mm C3 cement-stabilised	150 mm G4 natural gravel or lime-modified	Imported
Subbase	95%	150 mm G5 natural gravel	150 mm G5 natural gravel	Imported or existing
Upper subgrade	93%	-	-	Existing wearing course
Subgrade	-	-	-	Existing calcrete/sand roadbed

TABLE 8 : ALTERNATIVE PAVEMENT STRUCTURES

PROPERTY	MATERIAL TYPE					
	C3	G4	G5	G7	G9	G10
Is there a specified grading	--	yes	-	--	--	--
Minimum grading modulus	1.5	2.05	1.5	0.75	ns	ns
Maximum plasticity index	ns*	6	10	3GM+10	ns	ns
Maximum linear shrinkage	ns	3	5	ns	ns	ns
Maximum liquid limit	ns	25	30	ns	ns	ns
Maximum nominal size	ns	53mm	63mm	2/3D**	ns	ns
Minimum 10% FACT	ns	50kN	ns	ns	ns	ns
Minimum 4 day soak CBR at field density	ns	80	45	15	7	3
Maximum swell at 100% Mod AASHO	ns	0.2%	0.5%	1.5%	2.0%	2.0%
UCS at 7 days (MPa)	1.2-2	ns	ns	ns	ns	ns

Notes: * ns - test not specified
**D: Depth of compacted layer (mm)

TABLE 9 : MATERIAL STANDARDS FOR PAVEMENT MATERIALS

No conventional hard rock deposits are known to exist in the area that could be used for surface dressing aggregate. The nearest deposits are in the Pandamatenga area, 200 km north of Nata, or from Mosetse eastwards towards Francistown. The north of Botswana currently does not have a crushing plant and aggregates are usually imported from Zimbabwe.

Research is however in progress in which the harder varieties of calcretes and silcrete deposits, which occur in pan areas and along river courses, are being examined for use as surfacing aggregates (10). Road experiments constructed as part of this research have been monitored for a period of four years and they have shown that the best calcrete/silcrete aggregates can satisfy the strict criteria (eg 10% FACT>210kN) set for surface dressings and meet performance requirements. The softer varieties, eg those with 10% FACT values of around 100kN, perform less well, but can be suitable for use in lightly-trafficked roads. A particular problem associated with the practical exploitation of these deposits, however, is the variable nature of the profiles, both laterally and vertically as a result of their mode of formation. This often gives rise to a honeycomb structure and the occurrence of hard and soft layers. Drilling studies and test crushing have been performed to determine the use of potential sources in the construction of the road.

8 PAVEMENT DESIGN

8.1 Design choice

A minimum construction of adding a new 150mm base to the existing gravel road was adopted to ensure that the minimum base standards compatible with the anticipated traffic loading would be met and in order to satisfy minimum cross-section requirements (see earlier in 6). Two basic designs were considered for detailed analysis. Design 1 comprised a cement stabilised base and a granular sub-base, and Design 2 comprised a granular base and a granular sub-base. The details of the two designs and the appropriate material standards are shown in Tables 8 and 9, respectively. The cement stabilised base was expected to possess the properties of a lightly-stabilised granular material requiring a low quantity of cement (2-4%). Although this type of design has not previously been used in Botswana, similar pavements have performed satisfactorily in other parts of Southern Africa (13). Both designs were therefore considered to provide acceptable structural capacity, and hence the choice of design was based on minimum construction cost and the availability of base materials.

No road strengthening measures were considered necessary during the design period, although it would be important that any cracking due to shrinkage of the stabilised-base and surface deterioration were attended to promptly by the application of a surface dressing at appropriate intervals.

8.2 Subgrade

An assessment of the bearing capacity of the existing subgrade was made by conducting dynamic cone penetrometers tests (14) at 1 km intervals along the entire road. The DCP values were converted to approximate CBR values using the relation developed by van Vuuren (14). As an estimate of the soaked subgrade strength a value of 50% of the existing in-situ value was taken as the design strength of that layer. For design purposes, a minimum subgrade support CBR of 15 per cent was adopted for the entire length of the road.

The results of the DCP tests indicated that about 25 km of the proposed road length should be completely reconstructed, or, if possible, super-compacted, to achieve the required subgrade support values.

8.3 Sub-base

Over parts of the length of the road, the existing gravel surfacing could be used as a sub-base for the new pavement. However, over most of the length, a new sub-base would have to be provided either to elevate the road or for the structural reasons noted above. In all cases the sub-base should conform to the standards of a G5 material as listed in Table 9.

In the assessment of the existing gravel surface as a future sub-base, consideration was given to the potential migration of water soluble salts which may damage a future seal. This problem is extensively reported from Southern Africa (15) and calcrete materials often possess high salt contents (1). Soluble salt determinations using a wet paste conductivity method (16) were carried out on samples taken from the road at 1 km intervals. Only nine out of 300 samples failed to satisfy the soluble salt requirements of a maximum of 0.5% for sub-bases. At the locations of these samples, extra sub-base material would need to be imported. Provided that the salt in the calcrete derives from the original material deposit, then the salt levels measured will not constitute a problem. If, however, it derives from groundwater, particularly in pan areas, then it may be necessary to consider the need to place a moisture barrier in the pavement to control the upward migration of the salt.

8.4 Base

Two types of base were considered suitable to withstand the predicted traffic loading over the analysis period. Design 1 consists of a 150 mm C3 cement stabilised base (6.5 m wide) and Design 2 consists of a 150 mm G4 natural gravel base (6.0 m wide) as shown in Tables 8 and 9. In both cases, the natural base materials should be extended through the shoulders to facilitate drainage of the base.

For Design 2, it was assumed that untreated natural gravels, some of which might require lime modification, were available along the entire length of the road. However, from the pavement materials survey conducted between Maun and km 105 east of Maun, it was possible that some materials identified might be below the required standard. If this proved to be the case, or if the standards for a natural gravel base could not be satisfied from existing borrow pits or by the mechanical stabilisation of calcrete with crushed silcrete obtained from local deposits, then a cement stabilised base should be constructed. The properties of materail to be stabilised should approximate to the particle size distribution and aggregate hardness of a G5 material.

8.5 Surfacing

The recommended surfacing was a double spray and chip treatment consisting of a 19 mm first stone layer and a 10 or 13 mm second layer. The surface dressing design was proposed to give a guide to actual requirements and for cost estimates and was based on Southern African practice (5). An alternative "low-cost" design consisting of a double treatment using a conventional single surface treatment of 13 or 19 mm chips in the first layer, followed by graded crushed fines or river sand in the second layer, was proposed based on the results of research in Botswana (10). The economics of this would depend on the products produced by a particular crusher. Where a stronger base was guaranteed, eg cement stabilised or low plasticity graded gravel, the alternative surfacing could be used.

9 ROAD MAINTENANCE

In order to carry out a cost-benefit analysis using the RTIM2 program, it was necessary to predict what road maintenance would be carried out over the economic analysis period of the project for both the existing road and for the upgrading alternatives.

9.1 Existing gravel road

The critical maintenance activities that would be carried out on the existing road were grading and regravelling, although fixed costs were included to cover the costs of routine maintenance and overheads.

Because of the difficulty that the Roads Department would have in increasing the original grading frequency of eight gradings per year, it was assumed that this frequency would be maintained throughout the project life, where appropriate. When maintaining at a constant level, the average condition of the road will deteriorate over time because of the increase in traffic flow. The average roughness of the existing Maun-Nata road was 9.0-10.0 m/km. A significant deterioration in riding quality and consequential increase in vehicle operating costs could therefore be expected by adopting a policy of constant grading frequency. This is illustrated in Table 10, which shows projected roughness levels between gradings related to the different road sections. In a study of this kind, the roughness levels are of great importance since, from an engineering point of view, a road is likely to be impassable when it reaches a roughness of about 15 m/km.

Road section	Year	Estimated average roughness between gradings m/km	No of vehicle passes between gradings
1	1984	9.5	6 798
		14.2	7 138
	1988	15.5	8 263
2	1984	9.0	6 022
		13.6	6 640
	1989	15.0	7 686
3	1984	7.5	3 331
	1990	11.0	4 463
4	1984	9.5	3 331
	1990	11.0	4 463

TABLE 10 : CHANGE IN ROUGHNESS BY DEFERRING UPGRADING

The need for regravelling was determined by calculating the gravel loss for each year and deducting this from the average residual gravel on the roadway. An estimation of gravel loss and residual gravel thickness for each road section were made using the computer program and the dates when regravelling would occur determined from the residual gravel thickness. This was based on a minimum gravel thickness of 175 mm, which is the recommended minimum thickness given in the Kenya Road Design Manual (17) for a subgrade CBR of 15, to avoid excessive compressive strains and prevent punching into the underlying soil. One important feature of the data was that gravel loss would be reduced after the first regravelling on sections 1, 2 and 3 when more durable but costly nodular calcrete was used. A second point was that the residual gravel thickness prior to upgrading section 3 was expected to be considerably lower than when measured in the design survey and an extra 150 mm layer might need to be added to elevate the road formation in the year of upgrading.

9.2 Bitumen road

The most expensive item of maintenance for the upgraded road was surface dressing which, from evidence elsewhere in Botswana, it was assumed would take place every seven years. Fixed costs were also included to cover the costs of routine maintenance and overheads. As the road deteriorated, there might also be a need for patching which the program would predict and a unit cost for this was included in the input.

10 COST ESTIMATES

The RTIM2 economic analysis program works using quantities and non-dimensional ratios and it is necessary to apply unit prices to basic commodities in order to obtain the values of costs and benefits.

The costs of upgrading, maintenance and vehicle operation were initially obtained as financial costs. The conversion to economic costs was carried out using the factors obtained from the National Transport Plan which are listed below.

Construction costs	= Financial costs x 0.81
Bitumen road maintenance	= Financial costs x 0.89
Gravel road maintenance	= Financial costs x 0.92
Vehicle operating costs	= Financial costs x 0.97

Time costs were excluded from the analysis.

Unit prices for construction were based on information from recent major road construction contracts and regravelling contracts. In the latter case, this meant that local contractors' prices were used. Cost data relating to routine and recurrent road maintenance were determined from maintenance cost returns (1982/83) from the Botswana Road Department. Vehicle input data for the study were obtained from surveys undertaken for the National Transport Plan (6) and by TRRL.

11 ECONOMIC ANALYSIS

11.1 Do nothing case

Preliminary runs were carried out within the RTIM2 program to evaluate the 'do nothing' case where normal traffic grew at a constant rate of 5 per cent throughout the economic analysis period of 20 years. In these cases, on the four sections of road, the rates of gravel loss predicted for the road in the future would increase so rapidly that, within the timescale being considered, the road would need regravelling at least once every year.

Such a situation was unrealistic both from the point of view of the practicality of such work being carried out by the Roads Department, or because of the costs involved which would account for a significant proportion of the national annual road maintenance budget. It was unlikely that such a policy and a direction of funds would be acceptable to the Roads Department in the future. If the road was not regravelled, traffic would quickly puncture through to the subgrade of Kalahari sand and traction would become difficult.

Such driving conditions would be a considerable constraint to traffic and would be inhibiting to the economic development of the whole area of north west Botswana. This again was considered unacceptable.

The 'do nothing' case was therefore considered to be infeasible and it was decided to investigate instead a 'do minimum' case. It quickly became clear that any option that did not involve paving the road in the relatively short term gave rise to major problems because of the depletion of the limited gravel resources caused by the frequency of regravelling.

As a result of this, it was decided instead to carry out an evaluation of the alternatives of paving the road immediately or deferring the paving by five years. The costs and benefits were evaluated using incremental analysis.

11.2 Incremental analysis

Even deferring paving by only five years from the start of the economic analysis period gave rise to high costs of maintenance before the paving took place. To illustrate this point periodic maintenance costs for the period leading up to the date of deferred upgrading are given in Table 11 for deferred upgrading.

YEAR	Cost (Pula)	Activity
1984	322 300	regravel
1985	2 111 179	regravel
1986	3 222 914	regravel
1987	1 416 394	regravel
1988	3 284 725	regravel
1989	1 256 096	regravel
1990	(5 731 236)	(regravel)
Total Cost	11 613 608	

TABLE 11 : COSTS OF PERIODIC MAINTENANCE FOR DEFERRED UPGRADING 1984 - 1990 (Pula*)

* 1 Botswana Pula was equal to 0.90 US $ in 1984

The calculated periodic road maintenance costs for the gravel road over this period which would be financed from the recurrent budget is conservatively estimated at P11.6 million. Other additional costs could also be added if, for example, the road level had to be raised, because of gravel losses, to avoid flooding during period of intensive rainfall. In addition to the estimated cost of P11.6 million for periodic maintenance, it has also been estimated that routine and recurrent maintenance activities would cost a further P1.8 million over seven years. The recurrent road maintenance budget for Botswana is approximately P8 million per year. On an average yearly basis, the maintenance costs of maintaining the Maun to Nata road, in what would be a gradually deteriorating condition, would account for approximately 25 per cent of the existing total recurrent budget. This amount of funds is not likely to be directed towards maintaining the road. A similar situation also existed with other, though less important routes and therefore the findings of this study were considered to be important to future gravel road policy.

The incremental analysis has considered the benefits of upgrading the road immediately compared with deferring the upgrading for five years. These benefits have been calculated for each vehicle type using the method shown conceptually in Figure 5. Benefits to traffic consist of savings in vehicle operating costs for normal traffic, generated traffic benefits as a result of deferred upgrading and additional generated traffic benefits as a result of upgrading immediately.

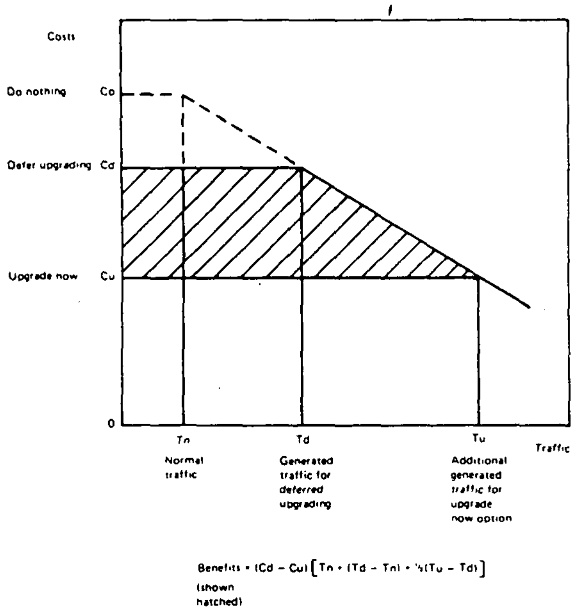

FIGURE 5: Method of calculating incremental benefits

The maintenance policy for the paved roads after upgrading has been chosen such that the road condition in the final year of analysis is the same for both the 'upgrade now' and 'defer upgrading' option. Thus, the residual values of the two options are the same and can be ignored for the purpose of incremental analysis.

Cost streams for upgrading, maintenance, vehicle operating costs for normal traffic and vehicle operating costs for generated traffic were obtained by the RTIM2 program which discounted them at the test discount rate of 6 per cent and also at 10 per cent. Using these figures, the capital costs and benefits shown in Tables 12 and 13 were obtained. These show that for the project as a whole, the immediate upgrading option gives a net capital cost saving. When account is taken of vehicle operating costs, the incremental net present value of upgrading in 1983 compared with deferring upgrading for five years is P12 million considering normal traffic only, rising to P23 million when generated traffic is taken into account. At a ten per cent discount rate, these values fall to P8 million and P 16 million, respectively. The unusually high contribution of generated traffic to benefits should be noted. This has been partly caused by the incremental nature of the analysis, but also because of the high values of predicted generated traffic which have been based on information in the Botswana National Transport Plan.

An estimate can be made of the incremental benefit of upgrading now over deferring upgrading by carrying out a linear extrapolation of net present values and discount rates to give an 'incremental rate of return'. This gives a range of between 18 and 19 per cent, irrespective of whether generated traffic is included or not. Upgrading the road to bituminous standard immediately is clearly the better of the two options investigated in this analysis.

12 SUMMARY AND CONCLUSIONS

A study has been undertaken of the upgrading to bitumen standard of the Maun-Nata road in Botswana. Costs were determined of upgrading, maintenance and vehicle operating costs using the TRRL road investment model (RTIM2) modified for conditions in Botswana. The study had several interesting features and results.

(i) The study illustrated how road investment models such as RTIM2 can be modified for local conditions, where there is a strong research base of data on such items as the relationship between road deterioration, material type and traffic. In this case, both the road roughness and gravel loss equations were modified based on the results of data collected as part of the joint TRRL-MOWC road research project.

(ii) The study showed that, in this particular case, it was infeasible to consider a 'do nothing' case because of the resulting high rates of road deterioration and gravel loss. These would lead to regravelling requirements and the depletion of material resources that were unacceptable within the context of Botswana.

(iii) Because, the 'do minimum' case of upgrading in five years would still give rise to generated traffic, the conventional net present value and internal rate of return methods of cost-benefit analysis could not be used and an incremental analysis approach had to be used instead.

(iv) The study showed that, if upgrading was deferred for the five years, the resultant depletion of materials resources would still mean that an increase from approximately 10 per cent to 25 per cent of the national road maintenance budget might need to be allocated to the Maun-Nata road to prevent it deteriorating to an earth road. The analysis of construction and maintenance costs alone, without considering the benefits of vehicle operating costs, showed a net capital cost saving, at the test discount rate of 6 per

Section	Capital cost Saving	Benefits to Normal Traffic	Benefits from Generated Traffic
1. Maun - Samedupi	1 018 064	794 846	874 698
2. Samedupi - Makalamabedi	2 172 155	2 230 597	2 196 889
3. Makalamabedi - Gweta	-1 219 372	3 707 828	4 392 499
4. Gweta - Nata	- 300 499	3 802 856	3 707 184
TOTAL	1 670 348	10 536 127	11 171 270
Incremental NPV for normal traffic only = 12 206 475			
Incremental NPV including generated traffic = 23 377 745			

TABLE 12 : BENEFITS AT 6 PERCENT DISCOUNT RATE OF UPGRADING NOW COMPARED WITH DEFERRED UPGRADING (Pula)

Section	Capital cost Saving	Benefits to Normal Traffic	Benefits from Generated Traffic
1. Maun - Samedupi	741 387	795 181	557 264
2. Samedupi - Makalamabedi	1 437 762	2 005 072	1 397 709
3. Makalamabedi - Gweta	-2 139 276	3 100 711	3 442 334
4. Gweta - Nata	- 822 208	3 175 476	2 366 546
TOTAL	- 782 335	9 076 440	7 763 853
Incremental NPV for normal traffic only = 8 294 105			
Incremental NPV including generated traffic = 16 057 958			

TABLE 13 : BENEFITS AT 10 PERCENT DISCOUNT RATE OF UPGRADING NOW COMPARED WITH DEFERRING UPGRADING (Pula)

cent, for the immediate upgrading option.

(v) In this particular case, upgrading from gravel to a bitumen surface was worthwhile at a traffic level of less than 100 vehicles per day.

The study has shown clearly, therefore, that upgrading the road to bituminous standard immediately is the better of the two options that were investigated. At a 6 per cent discount rate, the project had an incremental NPV of P12 million and, with the inclusion of generated traffic, this rose to P23 million. The project gave an incremental rate of return of between 18 and 19 per cent, irrespective of whether generated traffic was included or not.

(vi) Finally, the study has illustrated the need to collect and collate data specific both to the route and the locally available materials. In this instance it was particularly important to assess materials resources, produce appropriate deterioration relationships for the gravel road and conduct traffic loading studies. In the future it is expected that similar studies will be performed on other gravel roads in Botswana which will lead to an improvement in economic decision-making.

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14 REFERENCES

(1) NETTERBEG, F (1971). Calcrete in road construction. NITRR Bulletin 10. Pretoria: National Institute for Transport and Road Research.

(2) PARSLEY, L L and ROBINSON, R (1982). The TRRL road investment model for developing Countries (RTIM2). TRRL Laboratory Report 1057. Crowthorne: Transport and Road Research Laboratory.

(3) JONES, T E (1984). The Kenya maintenance study of unpaved roads: research on deterioration. TRRL Laboratory Report 1111. Crowthorne: Transport and Road Research Laboratory.

(4) TRANSPORT AND ROAD RESEARCH LABORATORY (1978). A guide to the measurement of axle loads in developing countreis using a portable weighbridge. TRRL Road Note 40. London: HM Stationery Office.

(6) MINISTRY OF WORKS AND COMMUNICATIONS.

(1983). The national transport plan. Gaborone: MOWC.

(7) LAWRANCE, C J and TOOLE, T (1984). The location, selection and use of calcretes for bituminous road construction in Botswana. TRRL Laboratory Report 1122. Crowthorne: Transport and Road Research Laboratory.

(8) DUNLOP, R J (1979). Some aspects of pavement design and performance for low volume roads in New Zealand. Low-Volume Roads. Second International Conference. Transportation Research Record 898. Washington DC: Transportation Research Board, National Academy of Sciences, 24-29.

(9) PAIGE-GREEN, P (1984). A laboratory investigation into the influence of carbonation on the strength of lime-stabilised materials. In: BOYCE, J R et al (EDs). Soil Mechanics and Foundation Engineering. Proc. of 8th Reg. Conf. for Africa, Harare, 1984, Vol 1. Rotterdam: A A Balkema, 403-406.

(10) LIONJANGA, A V, T TOOLE and P A K GREENING (1987). The use of calcrete in paved roads in Botswana. Paper to 8th Reg. Conf. for Africa, Lagos. Soil Mechanics and Foundation Engineering.

(11) TOOLE, T (1982). An interim guide to the selection of calcretes as gravel wearing courses. TRRL/MOWC Joint Road Research Project Report. Gaborone, Botswana.

(12) KLAUS, K A and P A LOUDON (1971). The influence of the initial consumption of lime on the stabilisation of South African road materials. In: Soil Mechanics and Foundation Engineering. Proc. of 5th Reg. Conf. for Africa, Launda, 1971, Vol 1.

(13) MITCHELL, R L (1982). Flexible pavement design in Zimbabwe. Proc. Instn Civ Engrs, 72, (Part 1), 333-354.

(14) VAN VUUREN, D J (1979). Rapid determination of CBR with the portable dynamic cone penetrometer. The Rhodesian Engineer, 105.

(15) NETTERBERG, F (1979). Salt damage to roads - an interim guide to its diagnosis, prevention and repair. Journal Instn. Mun. Engrs in South Africa, 4 (9), 13-17.

(16) NATIONAL INSTITUTE FOR TRANSPORT AND ROAD RESEARCH (1979). Standard methods for testing road construction materials. NITRR TMH1. Pretoria.

(17) MINISTRY OF TRANSPORT AND COMMUNICATIONS (1981). Kenya road design manual. Nairobi, Kenya.