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EFFECT OF SIMPLE ROAD IMPROVEMENT MEASURES ON VEHICLE OPERATING COSTS IN THE EASTERN CARIBBEAN

H Hide, Transport and Road Research Laboratory, UK
D Keith, British Development Division in the Caribbean, Barbados

The paper describes the effect on vehicle operating costs of a simple labour-intensive method of rehabilitating and maintaining badly deteriorated bitumen surfaced roads in the Eastern Caribbean. The techniques developed for the rehabilitation and maintenance of the roads are described, and the equipment, materials and manpower required are listed. The rehabilitation and maintenance system is a simple one restricted to providing adequate drainage, filling the potholes in the road and providing a minimum seal over the whole road surface. The reduction in vehicle operating costs resulting from the improvement in the riding quality of the road surface is shown to be sufficient to recover the rehabilitation costs in a very short time even at flows as low as 100 vehicles per day. The majority of the roads included in this scheme are of low strength, have low geometric standards and have traffic flows ranging from 50 to 1500 vehicles per day. All the roads have been trafficked for at least one year since being rehabilitated and some for two years. During this time little or no damage to the surface has taken place.

Introduction

This report describes the cost-effectiveness of a simple labour-intensive method of rehabilitating and maintaining badly deteriorated bituminous road surfaces.

The method used to improve the road surfaces was developed in the Eastern Caribbean island of St Vincent by one of the authors whilst Regional Public Works Advisor to the British Development Division in the Caribbean. Data on vehicle operating costs were obtained from an investigation into vehicle operating costs being undertaken by TRRL in the Eastern Caribbean and from an earlier study(1). The cost-effectiveness of the operation is calculated by comparing the cost of the improvements with the savings in vehicle operating costs resulting from the improved riding quality of the road surfaces.

All the roads included in the analysis are of low strength having a modified structural number of less than 3,(2) and have high horizontal and vertical curvature (at least 300 degrees/km and up to 100m/km respectively). They carry between 50 and 1500 vehicles per day and have all been trafficked for between one and two years since rehabilitation.

As the improvements were carried out to the road surface only there was no change in road geometry but the riding quality of the road surface was improved. Riding quality has been measured using a vehicle mounted bump integrator unit. The roughness values obtained were then converted to the corresponding towed 5th wheel bump integrator value(1). The road surface roughness as measured by this method reduced from 7000mm/km before the improvements to an average of 4000mm/km on completion of the restoration of the road surfaces. Details of these roughness measurements for a representative sample of the roads are given in Table 1, and their locations are shown on the map in Figure 1.

All costs are quoted net of tax in Eastern Caribbean dollars (EC$2.7 = US$1: EC$ 5.2 = £1 sterling).

The situation prior to the Rehabilitation Programme

St Vincent has 320 kilometres (200 miles) of bituminous surfaced roads and, with the exception of 24 kilometres (15 miles) which have been reconstructed over the last 10 years, they had received little if any surface maintenance since they were first bituminised in the period 1950-1968. This neglect had resulted in serious deterioration of the running surface characterised by extensive potholing and crazing, as shown in Figure 2. If a 'pothole' is defined as having a minimum diameter of 150mm (6") and a minimum depth of 25mm (1"), then by 1976 incidences of one pothole per linear metre of road were commonplace, and in many cases the whole width of the road surface had been broken up, forcing traffic to drive on the boulder base. The method of construction adopted when the roads were originally bituminised was basically grouted macadam. A loose layer of 25mm (1") stones was laid over a boulder base, blinded with 13mm (½") stones and then penetrated with bitumen and finished off with a layer of 6mm (¼") to dust. Whilst this method of construction provides a reasonably waterproof finish initially, it has the disadvantage that once water gains access through the finished surface it easily penetrates the porous 25mm (1") layer down to the base, lifting off large areas of surfacing.

Between 1968 and 1976 the St Vincent Government, using grants from the UK Ministry of Overseas Development, reconstructed 8 kilometres (5 miles) of the Leeward (West Coast) Highway and 16 kilometres (10 miles) of the Windward (East Coast) Highway. In addition in 1978 the reconstruction of a further 19 kilometres (12 miles) of the Windward Highway was started using funds provided by the European Development Fund. However with reconstruction costs of the order of $300,000 per kilometre ($½ million per mile) it was clear that because of limitations on funds the remainder of the road network could not be reconstructed in this way.

The amount available for maintenance of bitumen roads in the Recurrent Annual Budget is only $800,000 or $2500 per kilometre ($4000 per mile) approximately and the Roads Maintenance Department found that these funds were sufficient only to repair the worst of the potholes with premixed bituminous macadam. It was not possible to undertake a maintenance and surface dressing programme sufficient to arrest the decline of the road surface condition. To alleviate this situation the UK Ministry of Overseas Development in 1975 approved a grant to establish a Pilot Road Maintenance Unit on St Vincent to train local staff in maintenance procedures and to develop a cheap, labour-intensive method of rehabilitating the road system in order that its continued maintenance could be financed within the recurrent budget allocation.

The Rehabilitation and Maintenance Programme

The rehabilitation and maintenance of a typical broken bituminous road surface comprises the following activities:

1. Clean and improve side and cross drainage.
2. Repair the potholes, bringing the road profile as nearly as possible to its original shape.
3. Surface dress or otherwise waterproof the repaired surface.
4. Maintain the road so repaired by:-
   (a) Keeping the drains clean.
   (b) Repairing minor potholes as they appear and before they become major ones.

Drainage

Since the side drains and road culverts had become blocked and overgrown and numerous landslides had not been cleared, the initial cleaning of the side drains was carried out using a grader, a front end loader, and dump trucks. The cost of this operation ranged from $1250 to $2500 per kilometre ($2000 to $4000 per mile). Thereafter it has been possible to maintain the drains in good order at a cost of $950 per kilometre ($1500 per mile) per year.

Repairing Potholes

The normal method of repairing potholes is to trim off the sides, prime with MCO grade bitumen and fill with a premixed bituminous macadam. This was the method most extensively used in St Vincent. In order to make maximum use of labour the premix was mixed by hand and this was found to be more effective and cheaper than machine mixing. The cost of hand mixed material is about $93 per cu. metre ($70 per cu. yard) as compared with $113 per cu. metre ($85 per cu. yard) for material made by a Spotmix machine and $142 per cu. metre ($107 per cu. yard) for material bought commercially. It was found that 10 to 50 cu. metres of premix were required per kilometre (20 to 100 cu. yards per mile) depending on the state of the road and its width. The cost of providing and laying this material ranged from $1240 to $6200 per kilometre ($2000 to $10,000 per mile).

In order to reduce the costs of patching still further a method of grout patching was evolved (Figure 3). This consisted of brushing clean the area to be repaired, priming with an RC 2 grade bitumen, filling the hole with a suitably graded stone (the grading being dependent on the size of the hole), grouting with RC 2 bitumen and blinding with sand. Although rather crude, this method was quick and produced a watertight patch. It was also less extravagant on materials since the hole was not squared off and was therefore of smaller volume than when filled with premix.

Surface Dressing

It was soon found that roads repaired as described above quickly deteriorated again, especially during the rainy season. Water soon penetrates to the road base through crazing in the bitumen surface, through small potholes which have not been repaired, and through patches. For example the 8 kilometre (5 mile) long Vigi Highway required the expenditure of the following sums for repairing potholes over a twenty month period:-

Date	Cost of repairing 8 kilometres
Nov.75	$10,000
Mar.76	$25,000
Oct.76	$23,000
April/June 77*	$18,000

*immediately prior to surface dressing

Clearly the repair of potholes alone was insufficient to arrest the deterioration and it was necessary to waterproof the road surface by some inexpensive means. Accordingly a programme of surface sealing was started in November 1976. After experimenting with various forms of surface dressing, including spray and chippings and slurry sealing, it was found that the most effective method was labour-intensive sandsealing. This had the following advantages:

1. It could be readily adapted to labour-intensive methods.
2. It used an easily obtainable and cheap surfacing material.
3. It provided a dense, waterproof finish.
4. It caused the minimum disruption to traffic.

The method of sandsealing employed is as follows:

1. RC 2 bitumen is poured on the road surface at a rate of approximately 0.27 litres/sq. metre (0.2 gals/sq. yard).

2. It is then spread with rubber squeejees.
3. The bitumen is then covered with a layer of sand 25 to 30mm thick.
4. The sand is then lightly rolled.

These steps are shown in Figures 4, 5 and 6 and a completed road in Figure 7. At normal daytime temperatures in St Vincent (over 70°F) the RC 2 does not need heating and can therefore be poured straight from the drums.

The cost for a kilometre of 3.7 metre (12 ft) wide road is:

RC 2 Bitumen	6000 litres	@$0.42 per litre	$2500
Sand	100 cu-metres	@$7.50 per cu-metre	$ 750
Roller	6 days	@$35 per day	$ 210
Labour	177 man days	@$7 per day	$1240
Small tools etc			$ 300
		Total	$5000

or approximately $1.35 per sq. metre ($1.10 per sq.yd).

Regular Maintenance

Side Drainage. As mentioned above the recurrent maintenance cost for keeping clear side drains and culverts is approximately $950 per kilometre per year, which equates to one man per 1.6 kilometre (1 mile) per year plus a few hundred dollars extra for emergencies. In some instances the method adopted for this maintenance is to give one labourer the responsibility for keeping clear one kilometre of road, but usually casual gangs are employed to clear specific lengths. In either case the importance of keeping the side drains clear to stop water from getting into the road base cannot be over-emphasised.

Surface Maintenance. The object of the rehabilitation and surface dressing programme is to bring down the costs of regular surface maintenance to manageable proportions and in this the programme has succeeded. The first stretch of 8 kilometres (5 miles) to be sandsealed on the Leeward Highway has not required patching since it was sealed in the period November 1976 to May 1977. The more heavily trafficked Vigi Highway was sandsealed in early 1977 and to date (May 1978) has only required minor pothole patching on one occasion at a total cost of $360.

A mobile patching gange of 8 men has been formed equipped with minor tools such as hand rammers and a flat-bed truck for transport. This gang patrols the sealed roads in a 3-month cycle, patching with premix or grouting any small failures as they occur.

The cost of this gang per day is as follows:

Materials	$150
Labour	$ 80
Vehicle	$ 45
Tools etc	$ 5
	$180

Assuming a working year of 200 days the cost of one gang per year is $36,000. A gang can maintain 100 kilometres (70 miles) of rehabilitated road in this way, hence three units will be capable of covering all the bituminous roads in the country at a cost of $108,000 per year when the 240 kilometres (150 miles) included in the rehabilitation programme has been sealed.

Cost of the Rehabilitation and Maintenance Programme

The average rehabilitation costs are given below but in practice they vary from road to road as can be more clearly seen in Table 1.

1.	Re-establishing earth side-drains	$1900 per kilometre ($3000 per mile)
2.	Patching potholes	$4300 per kilometre ($7000 per mile)
3.	Sandsealing	$5000 per kilometre for 3.7 metre road ($8000 per mile for a 12 ft. wide road)
		$6200 per kilometre for a 4.6 metre road ($10,000 per mile for a 15 ft wide road)

Maintenance costs after rehabilitation are:-

1.	Drainage	$950 per kilometre ($1500 per mile)
2.	Surface patching after rehabilitation	Average $300 per kilometre ($500 per mile)

1st year	Nil	
2nd year	$ 60 - $ 190 per km ($100 - $ 300 per mile)	Depending on the
3rd year	$190 - $ 620 per km ($300 - $1000 per mile)	traffic volume

Future maintenance costs are a matter of conjecture but the indications are that total recurrent costs for maintenance when the programme is completed will be:

Drainage	320 kilometres (200 miles	@ $ 950 = (@ $1,500)	$300,000
Surface patching	3 patching units	@ $36,000 =	$108,000
			$408,000

This is well within the annual maintenance budget and leaves $400,000 for additional surface dressing, widening and improvements.

The life of the sandseal cannot be predicted with any certainty as the first stretch was only completed in November 1976. However, observation indicates that on lightly trafficked roads a life of 5 to 10 years can be expected.

The Effect of the Improvements on Surface Roughness

The roughness of the roads included in this programme was measured using a vehicle mounted Bump Integrator Unit. Roughness measurements were taken before, during and after the rehabilitation operations. Typical results, together with rehabilitation and surfacing costs, are given in Table 1.

On the worst roads on the island roughness of nearly 10,000mm/km were recorded, whilst those recently completely reconstructed gave readings as low as 2500mm/km. It was found possible in the rehabilitation programme to reduce roads from 7000mm/km down to 4500mm/km by patching, and to achieve a further reduction to 4000mm/km by sand-sealing.

Derivation of the Vehicle Operation Costs

Methodology

The method used to calculate the vehicle operating costs for this evaluation is the same as that used in the TRRL Kenya study(1) where the various components of total vehicle operating costs were considered separately on a quantity rather than a cost basis: the cost at any particular time being obtained by applying the relevant unit costs in operation at that time.

The components of total vehicle operating cost used in compiling the figures calculated for this study were as follows:-

1. Fuel consumption.
2. Oil consumption.
3. Spare parts.
4. Maintenance labour.
5. Tyre consumption.

As the geometry of the road system in St Vincent is the main factor controlling the speed of vehicles rather than the condition of the road surface and distances travelled are short, very little change in journey times between various points on the island has occurred since the road improvements. The average annual useage of vehicles has also changed little and therefore the value of time and overheads has been virtually unchanged, although in the case of the latter there may have been a slight reduction due to the fall in vehicle maintenance requirements.

Vehicle Types Evaluated

Three types of vehicle were considered to be sufficient for the purpose of this study to represent the overall vehicle population travelling on the roads of St Vincent. They are:

1. A "European type" saloon car with a 1600cc petrol engine, three years old and having covered 32,000 kilometres (20,000 miles).
2. A large van with a 2000cc petrol engine and carrying capacity of 1 tonne, three years old and having covered 48,000 kilometres (30,000 miles).
3. A 7 tonne carrying capacity truck with a 5000cc engine, three years old and having covered 64,000 kilometres (40,000 miles).

Vehicle Operating Costs for each Vehicle Type

The following tables give the cost per kilometre, net of tax, for the components of vehicle operating cost included in the analysis both before and after the improvements to the road surfaces at the unit costs prevailing in 1978.

1. 1600cc saloon car (European type)

component	before	after
fuel	0.06	0.06
oil	0.01	0.01
parts	0.09	0.04
labour	0.04	0.02
tyres	0.08	0.04
total	0.28	0.17

ratio $\frac{\text{before}}{\text{after}} = 1.65$

reduction in cost = $0.11 per km ($0.18 per mile)

2. 2000cc 1 tonne van

component	before	after
fuel	0.07	0.07
oil	0.01	0.01
parts	0.12	0.06
labour	0.04	0.02
tyres	0.09	0.04
total	0.33	0.20

ratio $\frac{\text{before}}{\text{after}} = 1.65$

reduction in cost = $0.13 per km ($0.21 per mile)

3. 5000cc 7 tonne truck

component	before	after
fuel	0.11	0.11
oil	0.02	0.02
parts	0.11	0.07
labour	0.04	0.03
tyres	0.16	0.08
total	0.44	0.31

ratio $\frac{\text{before}}{\text{after}} = 1.42$

reduction in cost = $0.13 per km ($0.21 per mile)

The unit prices used in deriving these figures are:

	Car	Van	Truck
Vehicle cost	$20,000	$25,000	$45,000
Fuel (litre)	$0.49	$0.49	$0.40
Oil (litre)	$0.67	$0.67	$0.67
Labour (hour)	$6	$6	$6
Tyres	$72	$112	$260

At these prevailing units prices the direct savings in operating costs per vehicle kilometre realised by upgrading the road surfaces so that the surface roughness is reduced from 7000mm/km to 4000mm/km is $0.11 for a car, $0.13 for a 1 tonne van and $0.13 for a 7 tonne truck.

The relationships used to calculate the quantities of fuel, oil, spare parts and tyre consumption and to estimate the number of maintenance labour hours, are given in the TRRL Kenya Study report(1) and the Transportation Research Board, Special Report 160(3).

The Cost Effectiveness of the Road Improvements

In order to assess the cost savings likely to result from the improvements made to the roads, it is necessary to take into account both the cost of the initial rehabilitation and the likely future costs of maintaining the roads.

The average cost of rehabilitating one kilometre of road is $11,200 ($18,000 per mile) made up as follows:

improving drainage	$ 1900 per kilometre
filling potholes	$ 4300 per kilometre
sand sealing	$ 5000 per kilometre
total	$11,200 per kilometre

This is a once and for all expenditure provided that the annual maintenance programme described below is adhered to. The costs of this programme are:

clearing drains	$ 950 per kilometre
patching potholes	$ 340 per kilometre
re-sealing	$5000 per kilometre

The first two operations are carried out each year, but resealing is only undertaken when necessary, depending on the level of traffic on each particular road. Although none of the rehabilitated roads have yet reached the stage where further resealing is necessary the condition of those which have been trafficked for two years since being upgraded suggests that further resealing will not be necessary for at least another year for the most heavily trafficked roads. Three years has therefore been taken as the frequency with which the most heavily trafficked roads carrying at least 1000 vehicles a day will require resealing and four, five, six and seven years has been assumed for roads carrying 600-1000, 200-600, 100-200 and less than 100 vehicles a day respectively.

As stated above the savings in vehicle operating costs per vehicle kilometre resulting from the upgrading of the roads are $0.11, $0.13 and $0.13 for cars, light commercial and heavy commercial vehicles respectively. These give an average figure of $0.12 for all vehicles on the basis of the proportions of the different vehicle types in St Vincent.

In the analysis the cost effectiveness of the scheme is examined at various levels of traffic. The costs and benefits are discounted back to the base year in which reconstruction takes place and the number of years it takes to recover the initial reconstruction cost is calculated. The present best estimate of the rate of growth of traffic in St Vincent and the discount rate currently being used to assess road improvement schemes in the LDC's of the Eastern Caribbean are both 10%. Although some information existed on the cost of previous maintenance on the Vigi Highway, there was not sufficient to be able to include this generally in the analysis.

Table 2 compares the costs and benefits for each traffic level considered. It can be seen from the table that the cost of rehabilitating any road with traffic flows of more than 300 vehicles a day is recovered through savings in vehicle operating costs in the first year but it takes progressively longer at lower flows (2 years at 200 veh/d, 5 years at 100 veh/d) until at 50 veh/d it takes 12 years.

This progression is illustrated more clearly in the graph shown in Figure 8.

Summary

The simple labour-intensive methods of road rehabilitation and maintenance described in this paper were developed because of the necessity to find a cheap way of improving the roads of St Vincent. Full scale reconstruction was too expensive to be applied to the majority of the 320 kilometres (200 miles) of surfaced roads in need of rehabilitation.

The methods described will enable all the surfaced roads to be improved and maintained within the present annual maintenance budget, leaving some resources for improvements to the gradient, width and alignment of the roads each year. The savings in vehicle operating costs due to the improvement in the condition of the road surface equal the cost of the improvements to all the roads included in the scheme within two years, and from then on the net annual vehicle operating cost savings will substantially exceed the annual cost of maintaining the roads.

The labour-intensive method of sealing which has been adopted permits a very flexible approach to the management of road maintenance, it being possible to switch a maintenance gang from one area to another at a few hours' notice.

The maintenance technique adopted has greatly reduced the cost of operating vehicles in St Vincent and at the same time has increased the amount of work which can be carried out on the roads within the fixed budget available to the Roads Department.

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Table 1

Rehabilitation costs and surface roughness of some individual roads

Reference number	Location of road	Length kms	Rehabilitation costs* per km			Roughness (mm/km)			Vehicles per day
			Drainage	Patching	Sealing	Before patching	After patching	After sealing	
1	Vigi Highway (Mesopotamia - Arnos Vale)	8	$2500	$6200	$6200	7900	4300	3900	1540
2	Leeward Highway (Layou - Barouallie)	6.5	$2000	$2500	$5600	7500	4800	3800	250
3	Montreal Road	4	$1300	$6200	$5000	9300	5800	5400	560
4	Vermont Road	4	$1600	$3000	$5000	7500	4400	4200	140
5	Calder Road	3	$2500	$6200	$5300	9300	4800	4500	180
6	Clare Valley	2.5	$1000	$2000	$5000	7000	4600	4300	110

*Eastern Caribbean dollars. 1978 prices.

Table 2

The time taken to recover rehabilitation costs on low flow roads
(all costs are in EC dollars for 1 km of road)

Traffic flow (Veh/d)	Rehabilitation cost ($ x 10^6)	Annual maintenance cost ($ x 10^6)	Annual VOC savings ($ x 10^6)	Net annual savings per year ($ x 10^6)	Number of years to recover rehabilitation cost
400	0.0112	0.0023	0.0158	0.0135	0.8
300	0.0112	0.0023	0.0119	0.0096	1.2
200	0.0112	0.0022	0.0079	0.0057	2
150	0.0112	0.0021	0.0060	0.0039	3
100	0.0112	0.0021	0.0040	0.0019	5
50	0.0112	0.0020	0.0020	0.0000	12

Figure 1. MAP of St. Vincent showing the roads included in the rehabilitation scheme.

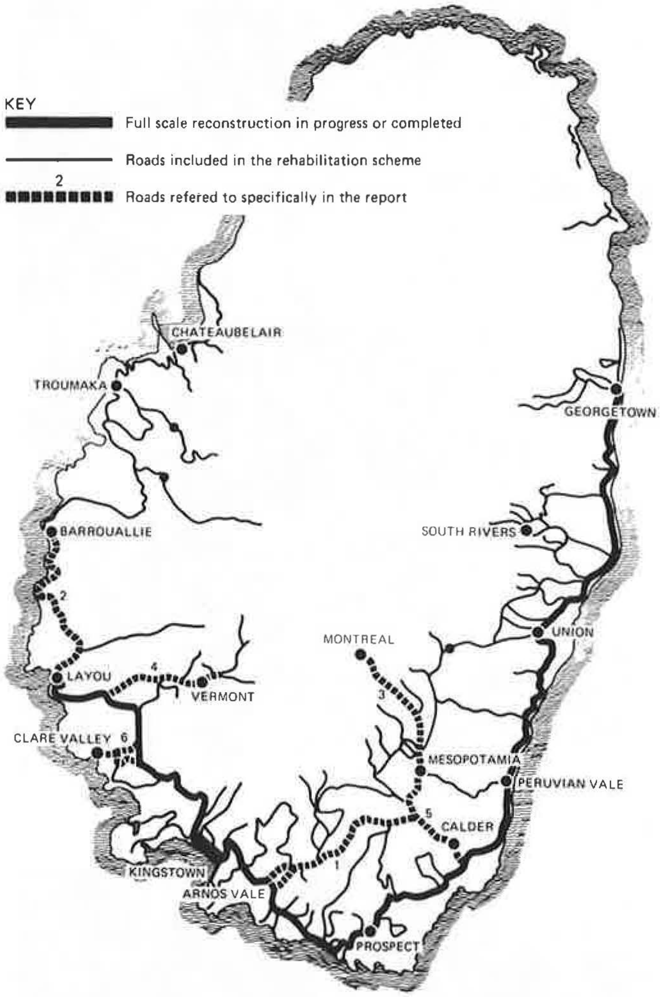

Figure 2.

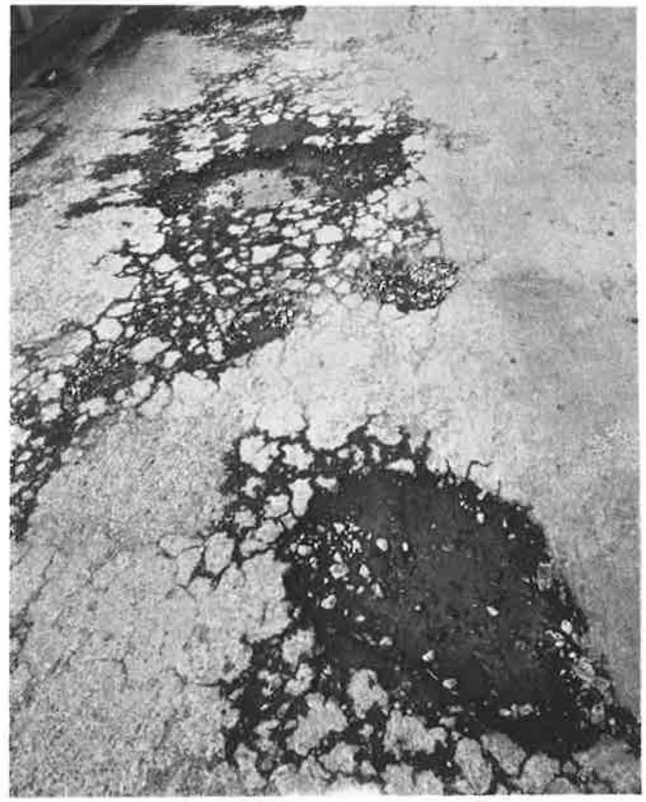

Figure 3.

Figure 4.

Figure 5.

Figure 6.

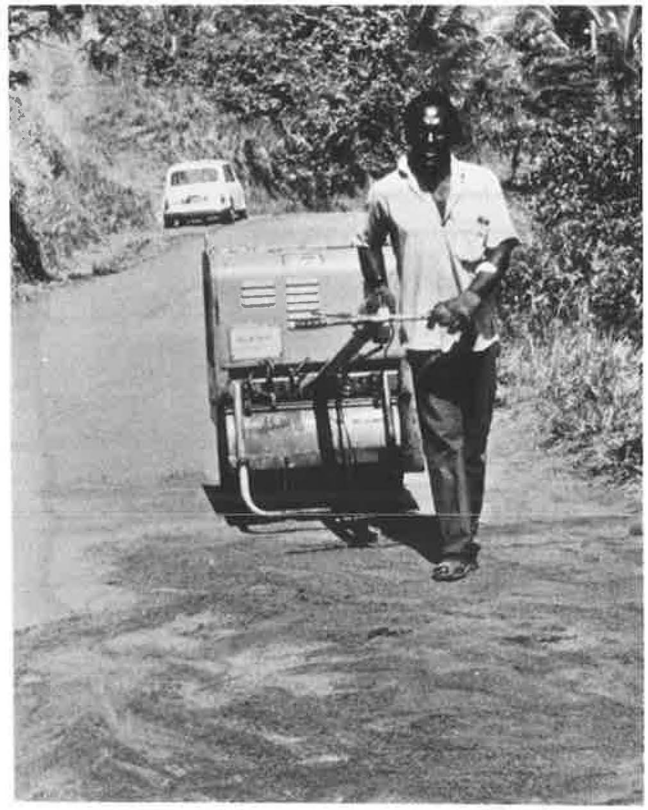

Figure 7.