Choice of Surface Treatment: Dependency on Level of Road Improvement and Maintenance Budget

ROGER M. WEATHERELL AND AMIN A. N. EBRAHIM

The "best" option for road improvement in Jamaica is dependent on the "most economic" and "least-cost" solutions described in this paper. The financial situation of the country at any particular time dictates the choice of solution. Subjecting the whole road network to this type of analysis could be a valuable method of determining the desired level of the total road improvement and maintenance budget for a 10-year period.

Use of microcomputers at the Ministry of Construction (Works) of Jamaica has made it possible to process objective data for every road to specify the "best" method of improvement and then to revisit the priority sites to confirm or amend the automatic choice using engineering judgment.

Jamaica has some 3,000 mi of main roads and about 7,000 mi of feeder roads. The economic methods of evaluation used for these two types of roads are quite different. For main roads, traffic is considered the proxy for all economic and social travel, and all benefits due to road improvement are assumed to be savings in vehicle operating cost (VOC). For feeder roads the benefits due to road improvement are assumed to be increases in agricultural production.

The "least-cost" feeder road option is the one that costs the least and improves the road surface to an acceptable standard. Main roads are evaluated in terms of the "most economic" in addition to the least-cost solution. The most economic solution is the one that provides the highest economic return on investment. The least-cost option does not provide the highest return but still allows the project to be economically viable. The idea of most economic and least-cost solutions should be of interest to readers.

In an economic boom, a country would prefer the most economic solutions, but, under the current financial constraints, most governments lean toward the least-cost solution for improving and maintaining as much of the road network as possible, thereby spreading the benefits to a wider population.

LEAST-COST SOLUTION FOR FEEDER ROADS

Four road surfacing options were considered for feeder road improvement. The four options were double seal, single seal, prime MC2 and grit, and gravel surface. The MC2 and grit is a thin bitumen spray dressed with a fine grit, which is known locally as oiling the road. (Sometimes site teams choose a combination of actions as most appropriate.)

The results for a representative sample of the projects are given in Table 1, in which are compared the net present values (NPV) of the four options for a representative sample of a total of 58 projects. Except for prime MC2 and grit, the computation is straightforward. In general, the NPV was computed by adding the improvement cost to 5.3 times the maintenance cost, which is the sum of maintenance costs over years 2–10 discounted at the rate of 12 percent. For simplicity of calculation, the residual value is ignored. In the case of prime MC2 and grit, it was assumed that the surface would have only a 4-year life, that it would be resurfaced in years 5 and 9, and that 7.5 percent of the surface area would need scarification in addition to resurfacing with prime MC2 and grit. The renewal of the surface treatments was discounted and added to the initial costs, and again any residual value was ignored.

Using the road surfacing option proposed by the site teams, the 1984 cost of improvement of 195.9 mi given in Table 1 would be J$18 million. By adopting the least-cost solution, this was reduced to J$15.6 million, though in the long term there is only a reduction of J$1.2 million in the NPV after the cost of maintenance has been taken into account. Of the 58 projects considered in the first phase of study (*1*), the MC2 and grit treatment was the least-cost option in 37 cases. This is because the improvement cost of prime MC2 and grit is much lower than the cost of double seal or even single seal. The maintenance cost of prime MC2 and grit is lower than that of the gravel option. A careful monitoring of the performance of this type of surface will be needed to confirm the assumptions made in specifying this as the best option in many situations.

BEST SOLUTION FOR MAIN ROADS

The so-called best solution for improving a main road depends on the threshold levels of traffic needed to justify the selection of the various surface treatments (Figure 1).

To investigate the effect of inflation on the feasibility of road improvement, it was decided to compare improvement thresholds in 1982 and 1984. The threshold indicates the level of traffic above which a road improvement is economically justified (i.e., benefits > costs). All benefits are assumed to arise from the vehicle operating cost savings, which in total are directly proportional to the traffic level.

In the following subsections the logic of Figure 1 and the construction of the threshold curves are briefly explained and their usefulness, application, and limitations are given.

R. M. Weatherell, T. P. O'Sullivan & Partners, 56–58 Putney High Street, London SW15 15F, England. A. A. N. Ebrahim, Ministry of Construction (Works), 140 Maxfield Avenue, Kingston 10, Jamaica.

TABLE 1 COMPARATIVE ANALYSES OF VARIOUS SURFACE TREATMENT OPTIONS

Project Number	Length (Miles)	Current Asphalt Length: Miles	Current Asphalt Length: %	NPV of Improvement and Maintenance Costs(1): Gravel	NPV: Double Seal	NPV: Single Seal	NPV: Prime MC2 & Grit	On-Site Proposal: Surface Type	On-Site Proposal: Improvement Cost	On-Site Proposal: NPV	Least Cost Recommendation: Surface Type	Least Cost Recommendation: Improvement Cost	Least Cost Recommendation: NPV
POR/016	2.75	0.00	0	598285	712599	654454	594078	DS+G	403871	601714	G	373255	598285
TRE/011	2.25	0.00	0	309387	406731	357870	335787	G	177519	309387	PS	:77519	309387
AND/012	1.66	0.10	6	319551	363722	329106	305621	SS+MC2+G	212533	311753	MC2	223743	305621
JAM/010	5.83	0.37	6	943689	1193035	1090960	1008376	SS+DS+G	621158	962986	G	567836	943683
AND/005	1.52	0.10	7	270336	338074	305385	290603	G	184449	270336	PS	184449	270336
CLA/010	1.46	0.26	18	255774	321233	291570	276500	G	179211	255774	PS	179211	255774
THO/013	6.26	1.21	19	1289860	1071955	1014814	983735	SS+DS+G	750469	1176884	MC2	652981	983735
CAT/010	4.83	1.00	21	788825	818653	740128	705666	DS+G	590630	821090	MC2	487056	705666
ELI/002	1.14	0.24	21	166373	188725	171006	161921	SS+G	107712	168319	MC2	112569	161921
MAR/001	8.71	2.20	25	1496804	1594936	1516089	1452733	SS+DS	1219998	1529493	MC2	1081757	1452733
CLA/001	6.60	1.98	30	1234675	1350068	1247919	1144962	DS	1166092	1350068	MC2	839977	1144962
ELI/021	2.69	0.98	36	344116	375797	347697	326886	DS+G	171575	355521	MC2	217995	326886
THO/019	2.43	1.49	61	253588	240153	221261	194472	MC2	122171	194472	MC2	122171	194472
CAT/011	2.19	1.37	63	N/A	346873	315603	302547	DS	286667	346873	MC2	207171	302547
HAN/012	1.74	1.36	78	N/A	321755	302714	288456	SS	256560	302914	MC2	256560	288456
CAT/002	4.45	3.56	80	375236	280904	244590	257097	SS	116558	244590	PS	116558	244590
MAN/003	5.30	5.30	100	N/A	535461	497370	492428	SS	356178	497370	MC2	303555	492428
MAR/008	2.67	2.67	100	N/A	268924	241329	N/A	DS	185967	268924	SS	149725	241329
TRE/010	4.24	4.24	100	N/A	175493	165656	N/A	SS	42718	165656	PS	42718	165656
(Representative sample of the projects showing at least one case for each category of surface treatment.)													
Summary Total of 58 Projects				18893058	28406969	26141356	24464688		18049097	25446114		15670383	24198790

Notes: (1) NPV of financial costs at July 1984, all discounted at 12% over 10 year period including renewals as applicable.
Legend: SS - single seal DS - double seal G - gravel MC2 - Prime MC2 and grit . PS - on-site proposal

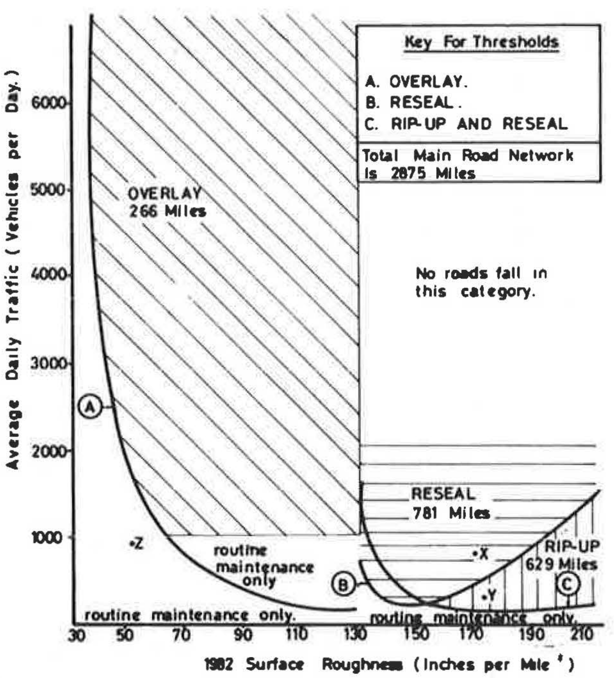

FIGURE 1 Average daily traffic threshold levels for selection of surface treatment.

Construction and Logic of the Threshold Curves

The threshold curves have been derived using

- Standard construction costs for overlay, double reseal, and "rip-up and seal," at 1984 prices, inclusive of all preparatory works;
- Vehicle operating costs according to the St. Lucia formulas (2) of the Transport and Road Research Laboratory (TRRL) at 1984 prices; and
- The deterioration model of roughness versus time generated from the data of the last complete road condition survey done in Jamaica during 1982.

The threshold average daily traffic (ADT) of a particular action depends mainly on the present roughness (R1) of the road, because it is the change in roughness due to the road improvement that gives the difference in the total vehicle operating costs (VOCs) with and without the project. This difference in VOCs determines the benefits. Table 2 gives the derivation of a threshold ADT of 1,030 vehicles per day. This ADT was arrived at to justify an overlay over an existing overlay that had an R1 of 60 in./mi. Figure 2 shows the VOCs that correspond with each new level of deteriorating surface roughness. A discount rate of 12 percent has been assumed and

TABLE 2 DERIVATION OF A PARTICULAR THRESHOLD TRAFFIC LEVEL

	Roughness (in./mi)[a]		Vehicle Operating Costs (J$/mi)[b]				
Year	With Treatment	Without Treatment	With Treatment	Without Treatment	Savings	Discount Factor[c]	Net Present Value
0	60	60	1.73	1.73	0	1	0
1	61.5	61.5	1.74	1.74	0	0.893	0
2	63.0	30.5	1.75	1.63	0.12	0.797	0.096
3	64.5	31.0	1.76	1.63	0.13	0.712	0.093
4	66.0	31.5	1.78	1.63	0.15	0.636	0.095
5	67.5	32.0	1.79	1.64	0.15	0.567	0.085
6	69.0	32.5	1.80	1.64	0.16	0.507	0.081
7	70.5	33.0	1.81	1.64	0.17	0.452	0.077
8	72.0	33.5	1.82	1.64	0.18	0.404	0.073
9	73.5	34.0	1.84	1.64	0.20	0.361	0.072
10	75.0	34.5	1.85	1.65	0.20	0.322	0.064

Note: Discounted benefits over a 10-year period per vehicle per mile = 0.736. Threshold ADT = Cost of 1 mi of overlay in Year 1/(365 × Benefits per vehicle) = 310,000/(365 × 0.736 × 1.12) = 1,030 vehicles per day.

[a]Roughnesses quoted are from Jamaica in-vehicle bump integrator (not the fifth-wheel bump integrator), and the 1982 condition survey indicated a range of linear deterioration for overlays of from 4.25 to 0.5 in./mi/year. This range was divided into five levels of deterioration. It is assumed that successive treatments will reduce the rate of deterioration by one level, in this case from 1.5 to 0.5 in./mi/year.

[b]In 1984 J$4.3 = U.S.$1.

[c]Includes 12 percent discount rate and 0 traffic growth.

the best estimate of overlay cost in 1984, including all preparatory works, was J$310,000 per mile. When 1982 construction and vehicle operating costs were used, the threshold was 853 vehicles per day, which indicates that between 1982 and 1984 construction costs rose faster than savings in vehicle operating costs.

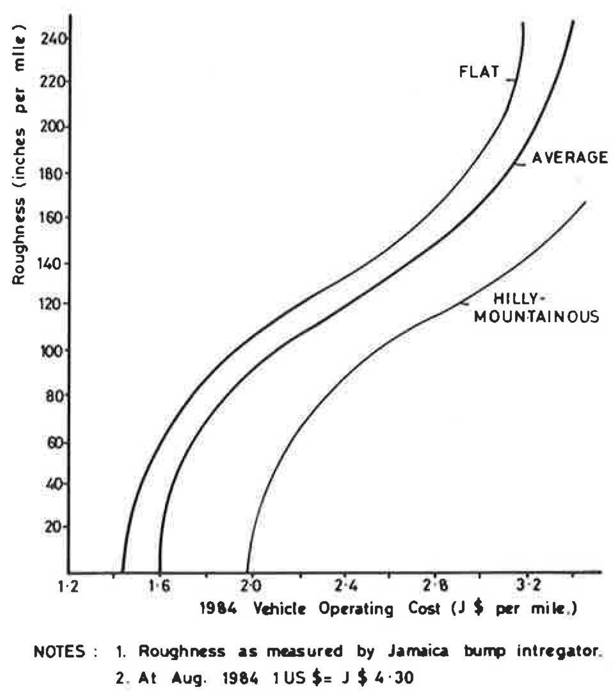

FIGURE 2 Vehicle operating costs versus surface roughness.

The following nominal standard costs (1984) were adopted:

Asphalt overlay	J$310,000/mi
Double reseal	J$120,000/mi
Rip-up and reseal	J$140,000/mi

It is useful to note that the surface roughnesses quoted throughout this paper refer to in-vehicle bump integrator readings not those from the standard towed fifth-wheel bump integrator. The following ranges of roughness were associated with these surface specifications:

Overlaid road	30 to 140 in./mi
Double seal	120 to 240 in./mi

The 120- to 140-in. range has very few miles of road in it because it embraces the limiting bad roughness of an overlaid surface with the very best possible from a seal. In discounting the VOC savings over a 10-year period, a zero traffic growth rate has been assumed.

Usefulness and Application of Threshold Curves

The use of threshold curves can be readily appreciated when trying to choose the best option for surface treatment. Normally, the best option would be the most economical one, that is, the one that represents the best return on investment. However, in the current Jamaican financial climate, the best option is in many cases the least-cost solution.

Road X in Figure 1 has an ADT of 500 vehicles, which makes it feasible either to reseal it (J$130,000 per mile) or to rip it up and seal it again (J$150,000 per mile). At an R1 of 170 in./mi, the threshold ADT for resealing would be 400, and for rip-up and seal it would be 157, so with an actual ADT of 500 the benefit-to-cost ratios of the respective treatments are 500/400 = 1.25 and 500/157 = 3.18. The least-cost (feasible) option of reseal is being adopted in the present financial circumstances.

In the case of Road Y it would only be feasible to rip up and seal, and in the case of Road Z no periodic action should be recommended. The only situation in which there is a real choice of action therefore is the case of Road X, where to double seal the surface is still economically feasible and it would clearly cost less than ripping up and resealing. In the other two cases the less costly action of double sealing should not be considered as a solution because it would not be economically feasible.

The overall effect of choosing the least-cost option in preference to the most economic option depends on the types and grouping of roads chosen for improvement, but some indications are given as a rough guide in Table 3.

By comparing the actual ADT with the threshold ADT at R1, it is possible simply to deduce the benefit-to-cost ratio and from this derive the net present value (NPV) or the more useful indicator of NPV/cost. Furthermore, this can be aggregated for whole road sections to arrive at a new national list of priorities, by road control section, according to the least-cost strategy. This was done by computer because the records of length, roughness, and ADT are already filed, and it was an easy matter to divide Figure 1 into zones for the four options: overlay, reseal, rip up and seal, and do nothing except routine maintenance.

Limitations of the Method

The application of these threshold curves is a simple matter, but there are certain limitations to their use:

- Construction costs have been standardized, but in practice these costs vary from job to job because they are largely dependent on the amount of preparatory work needed.
- If poor road condition is due to foundation failure of the road structure, a surface treatment cannot remedy the situation and extra costs will be incurred in preparing the road to receive surface treatment.
- Accurate traffic data and roughness measurements are required.
- Types of terrain and deterioration regimes are also standardized, though sensitivity tests show that, in practice, these variables have little effect on the thresholds.

The first two of the preceding items represent costing inaccuracies. Investigation of recently completed reseals has shown some relationship between initial surface roughness and the variable cost of preparatory work, and this refinement has been incorporated in the threshold curves. In any event, the threshold value can easily be reproportioned by the ratio of the final detailed estimate to the standard cost assumed.

The sensitivity of the choice of treatment to the traffic and roughness measurements obviously varies throughout the curves, and, where points are close to the threshold, thought must be given to the consequences of an over- or underestimation of roughness or traffic. Though the former more detailed method took into account four types of terrain and five rates of deterioration, it was found that the resulting benefits were generally within 10 percent of the average situation that has been assumed for the threshold diagram.

In any case, the priority works program should include only those road improvements that are well above the thresholds, where a 10 percent error is not crucial to the selection of the surface treatment.

ROAD IMPROVEMENT AND MAINTENANCE BUDGET

Figure 1 can be used to generate a sound least-cost program of periodic maintenance work. Every subsection is represented by a point (a subsection is, by definition, a length of road of consistent width, surface type, traffic, and roughness). A complete road control section can include as many as 15 subsections though the variation of traffic is usually small. The same

TABLE 3 TYPICAL 10-YEAR RETURNS FROM SURFACE TREATMENTS IN 1984

			Least-Cost Option			Most Economic Option		
Present Type	Surface Roughness (in./mi)[a]	Average Daily Traffic	Treatment	Benefits[b] (J$ 000s)	Costs[b] (J$ 000s)	Treatment	Benefits[b] (J$ 000s)	Costs[b] (J$ 000s)
Overlay	75	3,000	—[c]	—[c]		Overlay	1,603	310
Overlay	110	750	—[c]	—[c]		Overlay	894	310
Overlay	120	300	—[c]			Overlay	531	310
Seal	150	500	Reseal	236	110	Reseal	236	110
Seal	190	1,500	Reseal	297	150	Rip up and seal	1,746	170
Seal	210	300	Rip up and seal	380	190	Rip up and seal	380	190

[a]Range of roughness of overlays is 25 to 140 in./mi and 120 to 260 in./mi for seals. At 240 in./mi the surface is fairly poor and is considered to have failed, though vehicle operating costs do not increase significantly with roughness beyond 240 in./mi (see Figure 2) unless the road becomes impassable and diversion costs arise.

[b]In August 1984 J$4.3 = U.S.$1.

[c]Normally, surface dressing an overlay will make it rougher. However, if cracking can be effectively treated by surface dressing this can be a worthwhile measure to extend the life of the existing overlay. A different assessment method is needed for checking the feasibility of this type of treatment.

diagram can be used for choosing the most economical option.

The most powerful implication of these curves is not so much at the subsection, or even the control section, level but at the level of national planning. The 1982 road condition survey provided ADT and roughness data for all 3,188 subsections of the Main Road Network (2,876 mi). By integrating the length of roads that exhibit a particular traffic roughness characteristic with the least-cost option (or alternatively the most economical), the amount of money that could be economically justified for overlays, double seals, and rip up and reseals can be seen immediately. Preliminary indications were that, for the least-cost option, 269 mi of overlay, 792 mi of reseal, and 396 mi of rip up and reseal could be justified. The most economical solution indicated 1,718 mi of overlay, 91 mi of reseal, and 27 mi to be ripped up and resealed, but at much greater cost.

Necessary periodic maintenance should be spread over a number of years so that the financial and physical work load can be sensibly evened out. Allowing for a design life of approximately 10 years for seals and 15 years for overlays, all necessary maintenance work should be completed in a 10-year period, by which time many other roads will have crossed the threshold and become eligible for treatment.

Figure 1 is provisional; however, order-of-magnitude budget requirements can be obtained. For periodic maintenance these are

Least-cost option	J$23.3 million per year (1984 prices)
Economical option	J$54.4 million per year (1984 prices)

to which have to be added the costs of necessary administration, training, and technical assistance. The allocation for periodic maintenance in 1985–1986 was J$40 million.

CONCLUSION

Traffic threshold curves provide a powerful and rapid method for determining options for surface treatments, and such curves can indicate to national authorities what should be spent on road maintenance. The curves can be quickly updated as either vehicle operating costs or construction costs change, and they can be used for whole road sections to try to bring a greater consistency to the way periodic maintenance contracts are arranged. In the parishes of Jamaica they can be applied without even a calculator, let alone a computer.

ACKNOWLEDGMENTS

This work forms part of an overall planning system that is being developed for road investments by the Ministry of Construction (Works), Jamaica, (Permanent Secretary, G. R. Kirkpatrick). The authors wish to acknowledge the assistance by the staff of the Road Planning Unit, and in particular E. Arthurton, for computer modeling. Views expressed in this paper are not necessarily those of the Ministry of Construction (Works).

REFERENCES

1. T. P. O'Sullivan and Partners. *Road Improvement and Maintenance Project Phase 3.* Ministry of Construction (Works), Kingston, Jamaica, Oct. 1982.
2. H. Hide. *Vehicle Operating Costs in the Caribbean: Results of a Survey of Vehicle Operators.* TRRL Report 1031. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1982.

Publication of this paper sponsored by Committee on Pavement Maintenance.