viewed drafts of this report.

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Publication of this paper sponsored by Committee on Maintenance and Operations Systems.

Priority-Setting Method for Road Maintenance

HENRY M. STEINER AND ROBERT J. LYNCH, JR.

The Bureau of Indian Affairs (BIA) is responsible for maintaining approximately 25 500 miles of low-volume rural roads on the 179 Indian reservations. The BIA provides services to the Indian tribes through an agency organization that is located either on or near the reservation. The procedures described in this paper provide the BIA agency road engineer with a method for ranking the relative economic importance of the various routes within the reservation road network. This ranking provides a quantifiably supportable starting point for the tribal leaders to introduce the noneconomic considerations (i.e., the social needs and preferences of the tribes) to develop a maintenance priority listing that includes both economic and noneconomic considerations. A benefit-cost analysis approach is used. Input data currently available at BIA were identified and adapted to be used at the agency-tribal level without computer support. The method, described in the context of the BIA situation, is equally applicable to other activities involved with decision making about maintenance of low-volume rural road systems.

The Bureau of Indian Affairs (BIA) is responsible for maintaining approximately 25 500 miles of roads that are open to the public on the 179 Indian reservations. In 1978, this included 4777 miles of paved road, 3225 miles of gravel-surfaced road, and 17 546 miles of earth road (1).

The BIA provides services to the Indian tribes through an agency organization that is located either on or near the reservation. Usually a small maintenance section within the Branch of Roads at the BIA agency level maintains the roads on the one or more reservations that the agency serves. These maintenance sections consist of 8 to 10 persons and about the same number of pieces of (in most cases) antiquated, fully depreciated equipment. (For example, one agency road-maintenance section we visited in 1978 had a nine-person payroll, six road graders, one bulldozer, one oil distributor, one low-boy trailer, and one roller to maintain 948 miles of roads on 10 reservations.) In the practical sense, the agency road-maintenance section does the best it can with available resources to maintain the several hundred miles of roads within its responsibility. It not only must provide some semblance of scheduled maintenance to keep the roads open but must also be responsive to the changing day-to-day maintenance priorities specified by the tribal leaders. An agency road engineer, who heads a Branch of Roads, functions as the technical advisor to the tribes and is responsible to the agency superintendent for reservation road-construction and road-maintenance programs.

The agency road engineer works with the tribal governing body to establish road-maintenance priorities so that the highest level of service possible within funding limitations is provided. Since there are insufficient resources to provide optimum maintenance for all reservation roads, some trade-offs must be made. This is a two-step trade-off process. During the formal band analysis (described below), the tribal governing body determines what portion of the banded funds allocated to the tribe will be devoted to road maintenance. At a later time it determines how the road-maintenance funds will be applied to the reservation network. To facilitate this two-step process, we proposed, as a part of a research project conducted by George Washington University for the BIA, a simplified priority-setting method for road maintenance that can be used at the agency level. This paper describes the general approach and illustrates the method in the BIA context.

For the past few years, the BIA has used a system known as band analysis as a tool to provide opportunity for the local tribes to affect the budgetary process. Priorities established by the tribes provide the basis for determining total funding levels and distribution of funds to the various programs at the BIA level. This system does not provide additional funds but, rather, gives tribes a chance to allocate money among programs within established funding limits. Road maintenance is a banded program. Road construction is not a banded program.

ECONOMIC BENEFITS AND COSTS OF ROAD MAINTENANCE

The principal economic benefit of road maintenance is the avoidance of increased user costs that will result if maintenance is not performed. The user costs consist of vehicle-running and travel-time costs that will increase as road condition deteriorates. Poorer road-surface condition means slower average vehicle-operating speeds that account, in large part, for the increased user costs.

If the construction of all roads were based solely on economic considerations, each road route could be required to justify its own maintenance based on economic benefits that result from the avoidance of increased vehicle-running and time costs. However, many rural roads in the United States, including BIA roads, have been constructed or surfaced based on social considerations and the stated preferences of the county or reservation population. For example, a road to a religious shrine used only once or twice a year might have been paved, even though traffic alone would not have justified such an expenditure for economic reasons. Thus there may be benefits other than reduced vehicle-running and time costs to be considered in the establishment of road-maintenance priorities. If a road that has been paved as a result of social considerations is not maintained, it could eventually deteriorate to the point that it is no longer passable.

If this occurs and if the original justification for paving the road is still valid, rehabilitation of the road will require a significant expenditure of BIA road funds. Therefore, in addition to the economic benefit of the avoidance of increased vehicle-running and time costs, an economic benefit to be considered for roads is the reduction in the level of future maintenance and reconstruction expenditures that will be required to provide the same service standards if maintenance is not done in a timely manner on such "social" roads (2). For this case, where we are assuming equivalent annual maintenance costs, if road reconstruction is expected to cost F dollars at the end of n years, it is worth A dollars per year for maintenance to avoid the future reconstruction costs. This is the economic relationship shown by the equal-payment-series sinking-fund formula, which is A = F[(A/F) i,n], where i is the discount rate and the factor for the given i and n can be read from interest tables.

Since the maintenance priority-setting method does not include consideration of social factors, the priority for roads that cannot be justified on a strictly economic basis must be integrated into the maintenance priority listing based on tribal preferences. If a given road route has been paved because of erroneously established preferences and has a very low current use, the tribal governing body might well consider acceptance of a lower service standard for that route rather than its abandonment. However, it is up to the tribe to make such noneconomic decisions on maintenance. Thus a maintenance priority listing ranked according to diminishing benefit/cost (B/C) ratios provides a quantitatively supportable initial listing to be adjusted by the tribal governing body to best meet the overall needs of the reservation within funding limitations.

The method proposed to assist the tribal governing bodies in establishing the reservation road-maintenance priority listing is based on a benefit-cost analysis approach. Benefits to the Indian people are the avoidance of increased vehicle-running and time costs that will result if a road segment is allowed to deteriorate through lack of necessary maintenance. The costs considered are those of maintaining the road in its current condition so that user costs will not increase.

INPUT DATA REQUIREMENTS

The input data required to support the road-maintenance priority-setting method are

1. Average daily traffic (ADT) and the vehicle mix,
2. Road-condition inventory,
3. Vehicle-running and time costs, and
4. Road-maintenance costs.

The basic approach was to identify and use data readily available to BIA. It was also desired to have data in a form that could be used at the operational level (agency-tribal) without the necessity for computer support. The BIA Road Inventory and Needs Study (Turquoise Books) provides data on the existing BIA road system, including ADT and road-condition information by route for each reservation (3). Figure 1 is a sample page from the Southern Pueblos Turquoise Book for a road route on the Acoma Reservation. The Turquoise Books are a useful source of information to support economically based road-maintenance and construction priority-setting methods. Each of the input data requirements is discussed below as it relates to the proposed priority-setting method for road maintenance.

<u>ADT and Vehicle Mix</u>

The Turquoise Book shows an estimated ADT figure for each arterial and collector road route. During field trips it was reported to us that the figures recorded as existing in 1974 were, in many cases, still high compared with the actual 1978 ADT. It was not possible, however, to obtain data about the vehicle mix on the Indian reservations or any evidence that such information might be available. Since Indian-owned vehicles operating only on the reservation need not have a state license plate, it

Figure 1. Sample route sheet and benefit-cost calculation.

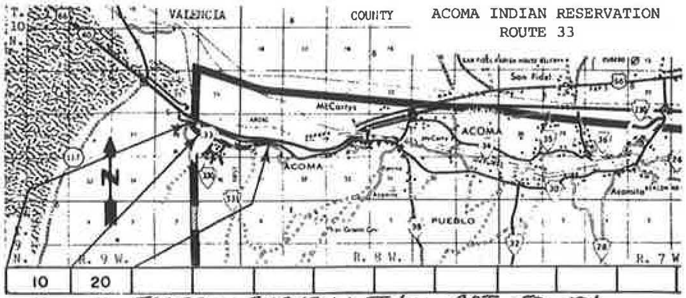
```
AREA        M   ALBUQUERQUE
        (CODE)           (NAME)
AGENCY    20   SOUTHERN PUEBLOS
        (CODE)           (NAME)
RESERVATION    703 ACOMA PUEBLO
               (CODE)     (NAME)
ROUTE 0033        2            2.4
      (NO.)    (CLASS)   (LENGTH MI.)

ESTIMATED COSTS FOR IMPROVEMENT
   RIGHT OF WAY                    M-$
   INCIDENTAL CONSTRUCTION              24.0
   GRADE & DRAIN                       216.0
   BASE AND/OR SURFACING               192.0
   BRIDGES

           TOTAL                   M-$ 432.0

DATE OF THIS REPORT      05/02/77

SECTION NUMBER                                  10     20
COUNTY                                          61     61
CONGRESSIONAL DISTRICT                           2      2
STATE                                           NM     NM
LENGTH                               (MILES)    .2    2.2
BRIDGE NUMBER                          (NO.)
       LENGTH                         (L.F.)
SURFACE WIDTH                          (FT.)    24     24
        TYPE                                  ERTH   HBIT
SHOULDER WIDTH                         (FT.)     0      2
         TYPE                                        ERTH
ROADWAY WIDTH                          (FT.)    24     28
RIGHT OF WAY WIDTH                     (FT.)    67     67
ADT (EXISTING)                         (YR.)  1974   1974
    (EXISTING)                      (V.P.D.)    50     50
    (ESTIMATED FOR YEAR 1990)(V.P.D.)           75     75
ADEQUACY DESIGN STANDARD NO.           (NO.)     8      8
FUTURE SURFACE TYPE                           HBIT   HBIT
RATING                                          49     72
  SURFACE WIDTH & TYPE                  (25)    12     25
  SHOULDER WIDTH & TYPE                  (6)     0      0
  STOPPING SIGHT DISTANCE                (8)     8      0
  NON-PASSING SIGHT DISTANCE             (6)     0      0
  HORIZONTAL ALIGNMENT                   (8)     8      8
  GRADIENT                               (6)     6      6
  SAFETY                                 (6)     0      0
  FOUNDATION CONDITION                  (15)    12     15
  WEARING SURFACE CONDITION             (10)     0      8
  DRAINAGE CONDITION                     (5)     3      5
  SHOULDER CONDITION                     (5)     0      5
```



TRAFFIC SURVEY: Total ADT <u>50</u> vpd
Cars <u>20</u>, Buses <u>5</u>, Pickups <u>20</u>, Trucks <u>5</u>

SECTION $\overset{*}{}$ 10 $\overset{*}{\text{EARTH}}$ FAIR*

$B = [20(.09) + 5(1.201) + 20(.088) + 5(\overset{*}{.501})]\,365\ \frac{\text{days}}{\text{yr.}}$

$= \$4{,}406$/mi/yr. (Users' VOC savings)

C (Road maint. Cost) = \$721/mi/yr (From Table 2)

SECTION 10 $B/C = \frac{4{,}406}{721} = \boxed{6.11}$

SECTION $\overset{*}{20}$ $\overset{*}{\text{HBIT}}$ FAIR*

$B = [20(.021) + 5(.255) + 20(.018) + 5(\overset{*}{.095})]\,365$

$= \$923$/mi/yr

C = \$1,560/mi/yr (From Table 2)

SECTION 20 $B/C = \frac{923}{1{,}560} = \boxed{0.59}$

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* From Table 1.

Table 1. Wearing-surface condition ratings.

Computer Code	Turquoise Book Rating	Priority-Setting Method Classification
0 No surfacing	0	–
1 Generally good (adequate)	10	Good
2 Serious to moderate deficiences (extensive repair, replacement, and/or rehabilitation required)	8	Fair
3 Condition critical for users (needs reconstruction of either the paved or gravel surface)	4	Bad
4 Condition critical (needs reconstruction of both the base course and paved surface)	2	Bad

Table 2. Total vehicle-running and travel-time costs.

Road Type	Road Condition	Average Speed (mph)	Cost ($/vehicle mile)			
			Passenger Car	Bus	Pickup	Truck
Paved	Good	45	0.128	0.727	0.142	0.415
	Fair	35	0.136	0.855	0.149	0.455
	Bad	25	0.157	1.110	0.167	0.550
Gravel	Good	35	0.166	0.919	0.183	0.519
	Fair	25	0.180	1.155	0.192	0.595
	Bad	15	0.225	1.777	0.236	0.844
Earth	Good	30	0.199	1.064	0.214	0.597
	Fair	20	0.214	1.419	0.227	0.719
	Bad	10	0.304	2.620	0.315	1.220

Note: Uniform speed on level tangents as of December 1977.

is not possible to examine state motor-vehicle-department statistics to determine the reservation's vehicle population and mix.

A determination of current ADT and vehicle-mix information on the various routes is required to support economically based methods for road-construction and road-maintenance priority setting.

Road Condition Inventory

The Turquoise Books provide condition ratings for foundation, surface, drainage, and shoulders for each route section, whereas the method proposed in this paper classifies road types and conditions as follows:

Surface Type	Surface Condition
Paved	Good, fair, or bad
Gravel	Good, fair, or bad
Earth	Fair

A match had to be made between the two systems. The method proposed herein uses wearing-surface condition rating to classify paved and gravel roads in accordance with the categories given above and the Turquoise Book descriptions and ratings (see Table 1).

The condition of earth roads, which are not considered all-weather roads, may fluctuate from good to fair to bad and back to good several times in a given year. For this reason, the method considers earth roads to be in fair condition (average) throughout the year but to deteriorate to a bad condition if required motor-grader bladings are not made.

The agency road engineer makes periodic inspections of the reservation road routes. These can provide more up-to-date road condition information than that contained in the Turquoise Book. There appears to be no difficulty in using existing road-inventory condition information to support the proposed method, particularly if Turquoise Book revision procedures can be adapted to provide for more-frequent updates of those data subject to periodic change.

Vehicle-Running Costs

Vehicle-running cost data are provided in the 1977 American Association of State Highway and Transportation Officials (AASHTO) Manual (4). Appendix B to that manual provides vehicle-running cost factors as functions of speed, highway gradient, and horizontal curvature for three types of vehicles. The components of running costs included in the tables of that appendix are fuel (excluding taxes), engine oil, tires, maintenance, and the portion of depreciation that varies with mileage driven.

The vehicle classes considered in the proposed road-maintenance priority-setting method are (a) 4-kip passenger cars, (b) buses (using 12-kip single-unit truck-running costs), (c) 5-kip pickup trucks, and (d) 12-kip single-unit trucks.

January 1975 vehicle-running costs are provided in the AASHTO Manual for the passenger car and the 12-kip truck. The manual indicates that the 12-kip truck class includes buses. Vehicle-running costs for these three classes of vehicles were obtained directly from appendix B of the AASHTO Manual and updated to December 1977 by individually updating each of the cost factors through use of the consumer price index (CPI) and producer price index (PPI), as specified in the manual. The manual treats pickups and commercial delivery trucks as passenger cars "because their costs do not vary significantly enough, considering their usual proportion in the total vehicle stream, to warrant a separate category." Because of indications that a large proportion of the vehicles on Indian reservations are pickup trucks, the research team included pickups as a separate vehicle class.

The method uses running costs at uniform speed on level tangents. The application of highway gradient and horizontal curvature and other considerations would overly complicate the procedure and provide a higher degree of apparent precision than is warranted by the data or needed for the method.

The AASHTO Manual provides running costs on high-design pavement only. The multiplicative factors to convert running cost on paved roads to cost on gravel and stone or earth roadway surfaces are provided in graphic form (4, p. 62). The curves were plotted from data extracted from Winfrey (5). Running costs on gravel and earth roads were calculated by using these conversion factors. The manual states that the effect of gravel and earth roads on highway speeds will vary with condition but, in general, the design speeds of high-design loose-surfaced roads are probably 20 percent, or about 10 mph, below those for surfaced roads and about 15 mph lower for unsurfaced sections. These assumptions were used as a basis for the average operating speeds shown in Table 2.

Travel-Time Costs

The value of travel-time savings is an important component of user benefits associated with road construction or maintenance. The unit value of time is usually the most significant decision variable in an economy study, and its magnitude should, first of all, be acceptable to the decision maker. Although considerable research has been conducted in an attempt to assign a dollar value to travel time, the choice of time value is an empirical judgment about the value of time and a social judgment of the weight to be given to these valuations. For purposes of demonstrating the method, the research team used the following vehicle loading and time values:

1. Passenger car: 1.8 passengers (including driver) per vehicle x $1.00/h per passenger = $1.80/h travel-time cost.
2. Bus: 32 passengers/bus x $0.50/h per passenger = $16.00/h per bus + driver wages at $8.00/h = $24.00/h per bus total travel-time cost.
3. Pickup truck: same as passenger car = $1.80/h per vehicle travel-time cost.
4. Single-unit truck: 1.25 occupants/truck (driver 100 percent of the time plus helper 25 percent of the time) x $8.00/h per occupant = $10.00/h per vehicle total travel-time cost.

Tables 2 and 3 present a summary of the total vehicle-running and travel-time costs and the savings per vehicle mile by road type and condition and vehicle type. The tables use data and updating procedures set forth in appendix B to the AASHTO Manual and the travel-time cost assumptions given above.

Road-Maintenance Costs

A survey of literature on road maintenance was made in an attempt to locate costing data for support of the proposed road-maintenance priority-setting method (6-9). Most of the literature examined presents information not readily adaptable to BIA use.

Table 3. Savings per vehicle mile.

Road-Type Comparison	Savings ($/vehicle mile)			
	Passenger Car	Bus	Pickup	Truck
Good paved versus fair paved	0.008	0.128	0.007	0.040
Fair paved versus bad paved	0.021	0.255	0.018	0.095
Bad paved versus bad gravel	0.068	0.667	0.069	0.294
Good gravel versus fair gravel	0.014	0.236	0.009	0.076
Fair gravel versus bad gravel	0.045	0.622	0.044	0.249
Bad gravel versus bad earth	0.079	0.843	0.079	0.376
Good earth versus fair earth	0.015	0.355	0.013	0.122
Fair earth versus bad earth	0.090	1.201	0.088	0.501

BIA currently uses a computerized road-maintenance model to support its road-maintenance costing estimates. The outputs from that model, contained in the BIA Summary Report of Road Maintenance Data, provide estimates of total road-maintenance funding needs for optimum maintenance of all BIA reservation roads. The program uses the basic data contained in the BIA Road Inventory and Needs Study computerized files. General maintenance costs for each route are calculated as a function of road type, ADT, roadway width, and wearing-surface condition. Snow and ice removal, which is not a part of the general maintenance, is shown as a separate cost on the summary report. Snow and ice removal is not included in the proposed method, which considers general maintenance priorities only.

The BIA computer road-maintenance costing program sums the maintenance input factors for ADT, roadway width, and wearing-surface conditions for the particular type of road surface. The sum of the individual input factors multiplied by the current average cost per mile per year for optimum maintenance for the particular surface type and by the length of the road segment gives an estimated total general maintenance cost for the road segment.

The research team considered the BIA road-maintenance model to be an available source of road-maintenance costing information suitable for the maintenance priority-setting method. To permit use at the agency-tribal level without the need for a computer, the general maintenance factor was calculated for each combination of road type, ADT, roadway width, and surface condition. Factors for ADTs up to 100 are shown in Table 4. Each factor multiplied by the appropriate current estimated optimum maintenance cost gives tabled costs of maintenance that can be easily used at the agency-tribal level. As average optimum maintenance costs change, new general maintenance cost-per-mile figures can be quickly calculated, since the general maintenance input factor remains unchanged.

The use of this average annual maintenance cost per mile implies that maintenance operations and costs will be constant for each year. This presupposes that a mile of road will receive the same amount of annual attention each year. Obviously

Table 4. Calculation of annual road-maintenance cost.

Road Type	Average Cost of Optimum Maintenance[a] ($/mile)	ADT	Road Condition	Roadway Width							
				8-20 ft		21-22 ft		23-24 ft		25 ft and Over	
				Factor	Cost ($/mile)	Factor	Cost ($/mile)	Factor	Cost ($/mile)	Factor	Cost ($/mile)
Earth	869	0-50	Fair	0.75	652	0.78	678	0.83	721	0.89	773
		51-100	Fair	1.00	869	1.03	895	1.08	939	1.14	990
Gravel	1281	0-50	Good	0.93	1191	0.98	1255	1.00	1281	1.02	1307
			Fair	1.03	1319	1.08	1383	1.10	1409	1.12	1435
			Bad	1.21	1550	1.26	1614	1.28	1640	1.30	1665
		51-100	Good	1.08	1383	1.13	1448	1.15	1473	1.17	1499
			Fair	1.18	1512	1.23	1576	1.25	1601	1.27	1627
			Bad	1.36	1742	1.41	1806	1.43	1832	1.45	1857
Paved[b]	1950	0-50	Good	0.65	1268	0.67	1306	0.68	1326	0.70	1365
			Fair	0.75	1462	0.77	1502	0.78	1521	0.80	1560
			Bad	0.93	1814	0.95	1852	0.96	1872	0.98	1911
		51-100	Good	0.75	1462	0.77	1502	0.78	1521	0.80	1560
			Fair	0.85	1658	0.87	1696	0.88	1716	0.90	1755
			Bad	1.03	2008	1.05	2048	1.06	2067	1.08	2106

[a] Costs in use by BIA in December 1977.
[b] High-design bituminous mat $>$ 2 in.

this is not the case, for all of the paved road segments will not require extensive maintenance each year. Greater expenditures on one segment will be balanced by lesser outlays on another. Maintenance-cost figures are assumed to represent the long-run equivalent annual costs of maintaining a mile of road.

PRIORITY-SETTING METHOD

The objective of the method is to provide the agency road engineer with a quantitative procedure for ranking the relative economic importance of the various routes within the reservation road network. This is a supportable starting point for the tribal governing body to rearrange the listing to meet the overall needs and political and social preferences of the tribe.

It is postulated that

1. Traffic on reservation roads is primarily Indian related, and vehicle-running and travel-time cost savings will accrue as benefits to Indians;
2. Failure to accomplish required maintenance during a given year will allow the road route segment to deteriorate to the next lower condition and create increased vehicle-running and travel-time costs; and
3. Many BIA roads may have been constructed or surfaced as a result of social considerations and tribal preferences (such roads may have a maintenance B/C ratio < 1.0 if only economic factors are considered.

Calculation of B/C Ratio

The output from the method provides a road-maintenance priority listing for performing maintenance ordered by decreasing values of the B/C ratio calculated for each reservation road route. Benefits of performing maintenance are the savings in vehicle-running and travel-time costs that accrue to the Indians by maintaining the road and by not allowing it to deteriorate to the next lower condition, at which vehicle-running and travel-time costs are higher. Tables 2 and 3 reflect the road deterioration pattern employed in the method, the total vehicle-running and time costs at the average speeds estimated for each road type and condition, and the savings between road-condition levels. Annual vehicle-running and travel-time cost savings (benefits) for a road in a given condition are calculated by

$$B = \sum_{i=1}^{4} \Delta C_i \, (ADT_i)(365) \qquad (1)$$

where

B = benefits ($/mile per year);
i = vehicle type;
ΔC = difference in vehicle-running and travel-time costs by vehicle type between present road condition and the next lower condition category, as shown in Table 3 ($/vehicle mile); and
365 = number of days in a year.

For example, what are the annual benefits per mile of maintaining a 24-ft gravel road in fair condition if the ADT is composed of 20 passenger cars, 5 buses, 20 pickups, and 5 single-unit trucks? Use of Table 2 and the above formula yields

B = [(20) (0.045) + (5) (0.622) + (20) (0.044) + (5) (0.249)] 365 = $2239/mile per year.

Costs are the annual maintenance costs for the particular road type, ADT, surface width, and surface condition, as shown in Table 4. That table indicates that the cost for maintaining in fair condition a gravel road that has a 24-ft-wide roadway and an ADT of 50 is $1409/mile per year.

The B/C ratio for this road route would then be

B/C = ($2239/mile per year)/($1409/mile per year) = 1.59.

Maintenance of this road route is justified based on economic considerations.

The B/C ratio is calculated for each reservation road route in this manner.

Preparing the Reservation Road-Maintenance Priority Listing

The research team found that the BIA Road Inventory and Needs Study (Turquoise Book) description for each road route provided a useful work sheet for applying the method. Copies of the route-report pages can be reproduced and used by the agency road engineer as work sheets to record results of traffic surveys as well as any changes to road-surface condition that might affect the calculation of the maintenance B/C ratio for that route.

The updated BIA road-route pages, the vehicle-running and time-cost data shown in Table 2, and the road-maintenance costs shown in Table 4 provide the necessary data to apply the method. The B/C ratio is calculated on the road-route page as illustrated in Figure 1, the Turquoise Book page for Acoma Route 33. Assumed updated traffic data on which the B/C computation is based are also shown. This example is more cluttered than a typical work sheet would be because of the parenthetical explanatory material included that would normally not appear.

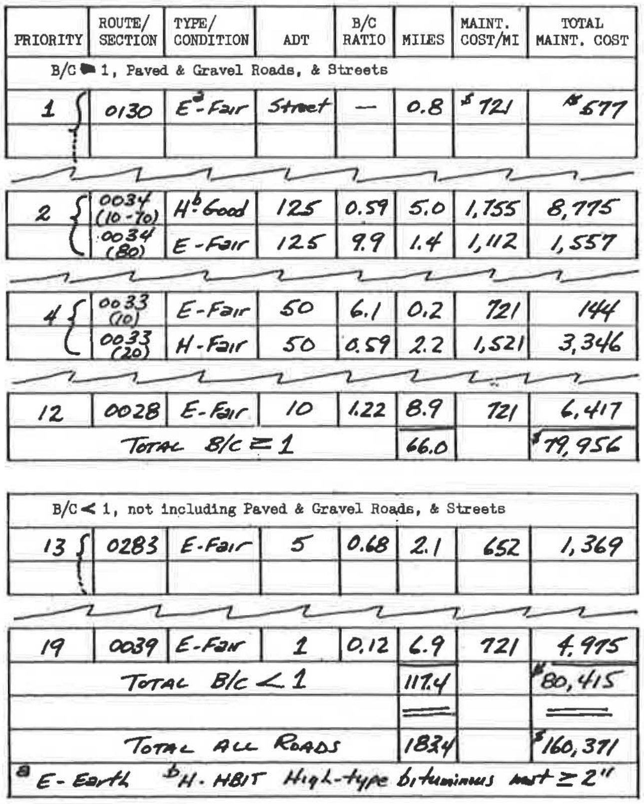
Such a calculation is made for each reservation route. The B/C ratio is recorded in the upper-right-hand corner of the sheet to facilitate later sequential arrangement of the route pages in order of decreasing B/C ratio.

After maintenance B/C ratios for all routes within the reservation have been calculated and road-route pages arranged in order of decreasing B/C ratio, the agency road engineer may draw up the reservation road-maintenance priority listing by using a locally prepared work sheet. Figure 2 gives examples of entries on such a priority listing for the Acoma Reservation, which is one of the 10 reservations supported by the Southern Pueblos Agency. Figure 2 assumes that the tribal governing body had specified to the agency road engineer that all existing paved and gravel roads and streets would be maintained even though the B/C ratio for such maintenance might turn out to be < 1.0. Therefore, all paved and gravel route segments and streets are listed with the earth roads as having a B/C ratio > 1.0.

Road Maintenance Map

To show the roads on which the maintenance effort should be concentrated, the paved and gravel roads and streets and those earth roads that have a maintenance B/C ratio > 1.0 are plotted on the highway system map for the particular reservation. The other roads for which the B/C ratios are < 1 are indicated in a contrasting manner. Such a plot is shown for part of the Acoma Reservation in Figure 3. The plot and the priority listing provide a useful starting point for the tribal governing body to look closely at the roads--earth, gravel, and paved--that have a maintenance B/C ratio < 1.

Figure 2. Example of priority-list entries for the Acoma Reservation.



PRIORITY	ROUTE/ SECTION	TYPE/ CONDITION	ADT	B/C RATIO	MILES	MAINT. COST/MI	TOTAL MAINT. COST
B/C ≥ 1, Paved & Gravel Roads, & Streets							
1	0130	E^a-Fair	Street	—	0.8	$721	$577
2	0034 (10-70)	H^b-Good	125	0.59	5.0	1,755	8,775
	0034 (80)	E-Fair	125	9.9	1.4	1,112	1,557
4	0033 (10)	E-Fair	50	6.1	0.2	721	144
	0033 (20)	H-Fair	50	0.59	2.2	1,521	3,346
12	0028	E-Fair	10	1.22	8.9	721	6,417
Total B/C ≥ 1					66.0		$79,956
B/C < 1, not including Paved & Gravel Roads, & Streets							
13	0283	E-Fair	5	0.68	2.1	652	1,369
19	0039	E-Fair	1	0.12	6.9	721	4,975
Total B/C < 1					117.4		$80,415
Total All Roads					183.4		$160,371

^a E-Earth ^b H-HBIT High-type bituminous mat ≥ 2"

Questions that might be asked are, Is there some reason why the road must be kept open even though the maintenance B/C, based on economics considered in this method, is < 1? If it is to be kept open, what trade-offs do we make on road maintenance or on other banded reservation programs to allow for its maintenance? Would it be possible to abandon certain of the roads that have a maintenance B/C < 1?

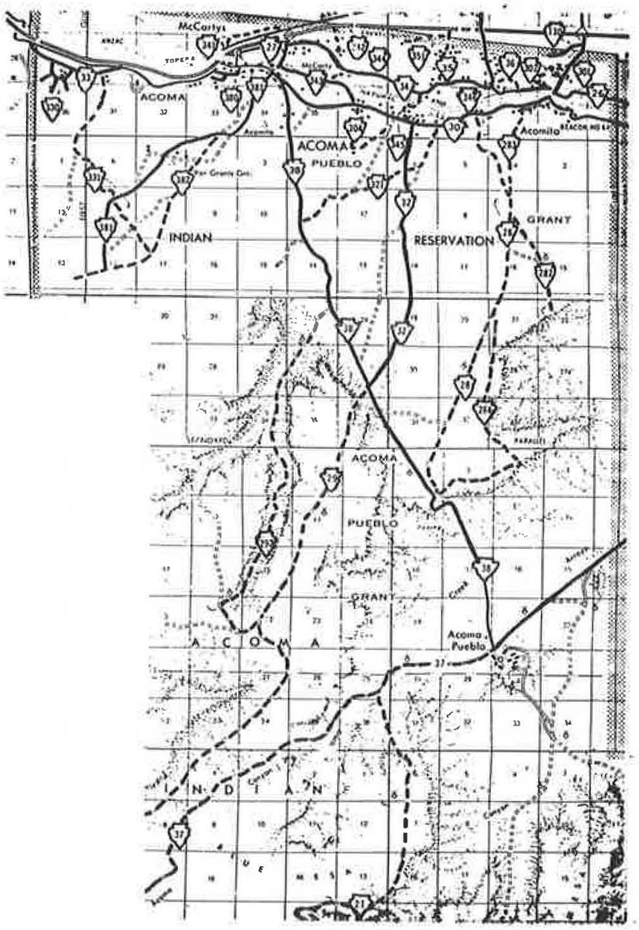
CONCLUSION

This road-maintenance priority-setting method can be applied readily at the operating level, in this case the agency-tribal level. The output provides understandable information that can cause the on-scene decision makers to examine their low-volume road network in the light of economic realities. A road-maintenance priority listing based solely on economic factors provides a supportable starting point for the application of noneconomic criteria in order to rearrange the listing in accordance with overall road needs and the political and social preferences of the users.

ACKNOWLEDGMENT

The research on which this paper is based was sponsored by the Division of Transportation of the Bureau of Indian Affairs under a U.S. Department of Interior contract. We are (as of summer 1980) applying this method to develop road route maintenance-priority listings for the 10 Southern Pueblos Agency reservations in the Albuquerque, New Mexico, area. This work is being accomplished under another U.S. Department of Interior contract.

Figure 3. Road-maintenance plot.



—— Roads with Maintenance B/C ≥ 1, Streets, Paved & Gravel Roads

----- Roads with Maintenance B/C < 1, not including Paved & Gravel Roads

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Publication of this paper sponsored by Committee on Maintenance and Operations Systems.

Highway-Maintenance Simulation Model

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The functions related to highway maintenance are often conceptually simple (repair the highway) and administratively complex (alternatives related to priorities, approaches, resources, and many others). Highway maintenance administrators are often faced with questions for which little or no definitive information exists and are asked to make the proper decisions. The highway-maintenance simulation model described in this paper is intended to help alleviate this problem by providing a flexible highway-maintenance decision laboratory in which alternative courses of action may be tested. An earlier version of the model included several simplifying assumptions that made actual considerations regarding highway maintenance operations unrealistic (e.g., one manpower type, one equipment type). The model development is now complete, however, so that typical highway maintenance dilemmas may be considered by using the simulation program. This paper includes an example that depicts model input, output, and interpretation of the results for one particular situation. Also included is a description of how the model works to simulate a highway maintenance operation.

Highway maintenance is an important function that is administratively complex. Virtually everything related to highways requires maintenance, and there are many types of maintenance activities. There are many types of highway surfaces; numerous types of defects, which often have varying approaches available for repair; a spectrum of weather conditions; an infinite number of terrain variations; a divided land-work area that may have overlapping assignments of responsibility; an ever-present element of danger; a variety of equipment types, quantities, and breakdown rates; and various numbers, levels, and types of personnel and abilities. This sampling of variations does not even mention the human considerations of personalities, interests, absentee levels, and interpersonal relationships. Also omitted from this discussion have been the unique and demanding tasks of planning, priority assignment, scheduling, monitoring, and controlling the maintenance activities. In addition, it should be mentioned that these tasks are all performed in a political arena, supported by the taxpayers' money. There is little question, after even cursory assessment, that administration of highway maintenance activities is a difficult and challenging task.

This paper describes an analytical tool capable of lending order, to some degree, to a number of the dilemmas that are frequently faced by highway maintenance administrators. A highway-maintenance simulation model is described that considers many of the interrelated factors already mentioned and provides quantitative output that allows orderly analysis of the situation.

PREVIOUS WORK

A thorough review of earlier work related to this area of study has been previously presented (1). The only directly related work described was the study Application of Systems Analysis to Highway Maintenance (completed in 1968) that was sponsored by the Office of Research and Development of the Bureau of Public Roads and conducted by the National Bureau of Standards (NBS) in two phases. Phase 1 was a broad examination of highway maintenance operations and the identification of problem areas in which systems analysis techniques appeared to offer some promise. At the conclusion of the phase 1 effort, it was decided that the remaining time and resources should be directed toward the application of some systems technique to a particular problem identified in the first phase. The development of a highway-maintenance simulation model was selected.

The phase 2 effort (2) was not sufficient, however, to develop a working simulation model to its full potential. The program had extensive detail in some areas and showed excellent potential in many ways, but it had one significant shortcoming: The simulation model would not run, at least not to the extent intended. The major error seems to have been in including too much detail too soon, in addition to the project's time restriction.

The NBS work did, however, indicate the promise and potential for simulation analysis of a highway maintenance system. Ten years later, sponsored jointly by the Louisiana Department of Transportation and Development (LDOTD) and the Federal Highway Administration, researchers in the Department of Industrial Engineering at Louisiana State University (LSU) began a new look at the same problem--the development of a highway-maintenance simulation model.

The LSU group had several advantages. First, they started with the NBS study; second, computer capabilities and simulation languages had been developing rapidly during the previous 10 years; third, highway maintenance engineers within LDOTD were eager to help develop such an analytical tool. This paper describes the model developed by the combined efforts of LSU researchers and LDOTD highway maintenance engineers.

MODEL OBJECTIVES AND MODEL USE

The purpose of the simulation model is to aid users in better understanding the response and behavior of the highway maintenance system under different conditions, that is, to provide highway maintenance engineers with a computer-aided simulation laboratory in which to test and evaluate various alternative courses of action.

For example, suppose a particular highway maintenance district requests two 5-ton dump trucks. How might such a request be evaluated? How much would these two trucks really help? Would they cause additional staff shortages? Would they sit idle too much of the time--and how much is too much? The