be modified by discounting future costs for these stands to allow for the reduced early yield and still consider the much heavier final cut.

A forest plan is currently being developed for the Chequamegon National Forest. This plan considers public opinion and data about the natural resources found on the forest. The analysis portion of the plan will include calculations to determine the optimum time to cut the various timber stands while maintaining an even, sustained yield of timber and other resources from the forest. The road-density calculations will be matched with the harvest plans to develop the miles of road needed for timber harvest for the first 10 years of the plan. The construction cost by year, and the cost of road maintenance, will be a part of the plan and will be used to develop the forest budget.

CONCLUSIONS

The road-spacing equations work well for gentle topography. Optimum road spacing is fairly easy to calculate for different road and haul costs for two road standards, skidding costs, and timber densities. The minimum total cost of logging and hauling timber will be achieved at the optimum road spacing.

Roads are not laid out in straight lines. They curve around obstructions, which increase construction cost. The theoretical values can be compared with actual situations so that the true road lengths can be estimated.

The Chequamegon National Forest will need an additional 5100 miles of road to remove timber at an optimum least cost. These additional roads will cost about $42 000 000. Having a greater road density should save $180 000/year.

The optimum road-spacing equations, in conjunction with timber stand production data, will form the transportation planning portion of the Chequamegon's forest plan. The road-spacing, road, and road maintenance costs will be calculated for various planned timber harvests so that a firm budget can be developed.

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Classification of Unpaved Roads in Ontario

E.F. DOBSON AND L.J. POSTILL

Unpaved roads constitute a large portion of the total road network in Ontario. Currently, there is no program available to the municipalities that will enable them to classify their unpaved-road network and apportion their existing maintenance funds across the road system in a cost-effective manner. This paper outlines a simple but rational approach to classifying unpaved roads into three distinct classes by using four quality-of-service characteristics. A formula was developed that permits the existing maintenance expenditures to be apportioned over the three classes of unpaved roads. The conclusion is that classification of the unpaved roads in Ontario will permit the unpaved-road network to be elevated to the level of maintenance management now practiced on paved and surface-treated roads. Such a program will enhance the task of the roads manager and aid the taxpayer, traveler, and those who strive to conserve our natural resources for future generations.

Unpaved or aggregate-surfaced roads have been an integral part of the road and street network in Canada for the better part of a century. As the nation has grown, so has the road system, giving ever greater access to the frontier areas of Canada. Initially, roads were hewn out of the forests, and the existing soil formed the road surface. Maintenance requirements were nominal.

The development of the motorized carriage triggered a new era, and along with this industrial development came a need for improved roads. Industry and the engineering community responded, and today we have a great network of roads. In the Province of Ontario, there are 75 000 km of unpaved roads, of which 72 000 km are maintained by individual municipal governments. The responsibility for maintaining the unpaved-road network may be the county; the individual township within a county; the individual city, town, or village within a township; or the provincial body--the Ministry of Transportation and Communication (MTC). The greatest percentage of unpaved roads is under the jurisdiction of the township governments, as shown in Table 1 (from 1980 MTC data).

The network of roads continues to expand as the population grows and its needs increase. It is not practical to transform all of these unpaved surfaces into hardtop surfaces and, as a result, unpaved roads will continue to form an integral part of the total road network for the foreseeable future.

The costs for maintaining the road system have escalated dramatically since the mid-1970s and, in recent years, the municipalities have not been able to raise these increased costs from the ratepayers. As a result, there have been arbitrary cuts in some road programs to offset escalating costs in other

Table 1. Official road distances in Ontario.

Type of Road	Distance (km)	Type of Road	Distance (km)
Organized township roads		Regional municipal roads	
Concrete	12.4	Concrete	12.9
High-class bituminous	3 066.4	High-class bituminous	4 313.8
Low-class bituminous	7 759.9	Low-class bituminous	1 932.3
Gravel and crushed stone	54 243.2	Gravel and crushed stone	570.1
Earth	3 204.7	Earth	0.8
Other	6 663.1	Other	8.7
Total	74 949.7	Total	6 838.6
Unorganized township roads		Tertiary roads	
High-class bituminous	103.0	High-class bituminous	53.9
Low-class bituminous	202.9	Low-class bituminous	12.1
Gravel and crushed stone	8 695.1	Gravel and crushed stone	451.9
Earth	631.1	Total	517.9
Other	337.3	King's highway	
Total	9 969.4	Concrete	409.6
City, town, borough, and village streets		Asphalt on concrete	1 214.0
Concrete	306.9	High-class bituminous	13 477.1
High-class bituminous	17 333.7	Low-class bituminous	640.5
Low-class bituminous	7 088.3	Gravel and crushed stone	96.8
Gravel and crushed stone	6 262.4	Total	15 838.0
Earth	367.4	Metropolitan roads	
Other	2 160.5	Concrete	5.1
Total	33 519.2	High-class bituminous	712.9
County roads		Gravel and crushed stone	2.9
Concrete	20.9	Other	1.3
High-class bituminous	6 572.7	Total	722.2
Low-class bituminous	3 663.6	Total gravel and crushed-stone network	73 979.7
Gravel and crushed stone	2 318.4		
Earth	16.4	Total road system	160 155.6
Other	0.5		
Total	12 592.5		
Secondary highways			
High-class bituminous	882.4		
Low-class bituminous	2 986.8		
Gravel and crushed stone	1 338.9		
Total	5 208.1		

segments of the budget. These arbitrary decisions have not always served the best interests of the ratepayers. The situation exists elsewhere, as is illustrated by the following quotations, the first from the Maintenance of Unpaved Roads (1, p. 5), and the second from Decision Methodology for Maintenance and Upgrading: Costs, Traffic, and Benefits (2, p. 18):

> Government officials who must review and approve budget requests for highway maintenance operations have little basis for evaluating requests except by comparisons with previous years' expenditures. Proposed expenditures for payroll, equipment, and capital expenditures can be understood, but they give few clues as to what maintenance goals are required or the level of traffic service that will be provided. When the approved funding turns out to be less than the amount requested, the highway agency has difficulty identifying what the consequences might be in terms of reduced services....The answer to these problems is to develop, adapt, and follow a system of management practices.

> In the planning for any system of low-volume roads, especially in developing countries, the importance of proper maintenance must be emphasized and its probable costs indicated. Too often, maintenance is done as needed or as funds are available. The fact that maintenance needs to be initiated upon termination of construction is seldom noted. Deferring of such maintenance can mean the deterioration of the level of service, necessity for higher future expenditures, and possible loss of investment. Thus, the planning should have an important position in the development of low-volume-road systems.

Oglesby (3) has probably summarized the total problem of managing unpaved roads in his study, where he noted that low-volume roads have many unique characteristics and problems that call for well thought out and innovative approaches.

Maintenance management of paved-road systems has been implemented and successfully used in many Ontario municipalities, but the maintenance management concept for unpaved-road systems has been neglected, perhaps because of their deemed unimportance. However, preliminary studies that involved Ontario municipalities of various sizes indicate that up to 75 percent of the road budget is dedicated to the unpaved portion of the road network. It is, therefore, timely now to introduce one of the basic requirements for a maintenance system for unpaved roads, which is a classification system based on service criteria that will enable the roads supervisor and administrator to manage their road system within the framework of a mutually agreed on plan.

The classification of unpaved roads provides the nucleus for a maintenance management program that will result in many tangible and cost-effective benefits to those who administer the expenditures for roads and to those responsible for supervising the maintenance of the road network. The following are cited as the benefits that the British Columbia Ministry of Highways (4) believed would be derived from its system of road classification:

1. All roads in the same class are treated equally,
2. Funds for road maintenance are based on actual requirements that can be justified,
3. Money is saved on gravel and gradings,
4. Public relations and overall safety are improved,

5. It readily identifies personnel and equipment requirements,
6. Funding cutbacks can be spread throughout the entire maintenance area rather than in one portion of the maintenance activities, and
7. Budgeting process is simplified.

This paper proposes a classification system for unpaved roads, discusses quality-of-service characteristics on which the classification is based, and describes a procedure for developing unit costs of major maintenance activities. Forms and charts have been developed to compliment the classification process based on a preliminary study of three municipal agencies that have diverse levels of service and road maintenance budgets that range from $250 000 to $1.3 million. They also have a high ratio of unpaved to paved roads within their system.

Finally, the paper describes a plan for pilot testing the classification system on a provincewide basis. The preliminary study has led us to believe that there is a very real need and a sincere desire among administrators and road superintendents alike to improve the maintenance management of their unpaved-road network, and they believe that this proposed classification system will aid them in their efforts.

PROPOSED CLASSIFICATION SYSTEM

Background

A literature review of previous studies examined more than 150 works related to unpaved roads. Of this total, some 28 were felt to touch on the subject of classification and/or standards that relate to the maintenance of unpaved roads. At this point, it must be remembered that many researchers include prime and surface-treated roads as part of the low-volume-road network and reserve the term paved roads for those that are constructed from rigid or flexible pavements only. In this study, we classify only those roads that are gravel or aggregate surfaced and include the prime and surface-treated roads with the paved network.

The most notable work done in recent years is that reported at the workshop on Low-Volume Roads held in Boise, Idaho, in 1975 (5). A portion of the workshop was dedicated to the planning, economics, and operations of low-volume roads. Several researchers reported on road maintenance practices that are employed by both developing and developed countries to help reduce road deterioration and minimize vehicle operating costs. One report of particular significance to this study was that of Rolt (6), where he quantified the deterioration of unpaved roads in terms of surface roughness, depth of ruts, depth of loose surface material, and thickness of gravel layer. Road deterioration is related to traffic loading, maintenance policy in use, original design and construction standard of the roads, and environmental conditions.

The Forest Service, U.S. Department of Agriculture, through the work of Gomez and Oglesby (7), proposed an approach for setting out road maintenance levels for forest roads and proposed criteria that outlined how road type, length and width, and traffic volume reflect in maintenance levels. In Canada, Paterson, McFarlane, and Dohaney (8) designed a system for forest road classification in eastern Canada based on maximum axle load, desired vehicle speed, available daily traffic, and anticipated life.

In 1980, Rural and Urban Roads Magazine (9) reported on Sheflin's research concerning preventative maintenance of municipal roads and the need to be able to identify the cost penalties associated with poor maintenance practices.

All of these studies described some form of classification and/or maintenance criteria suitable for low-volume roads but appeared to be unworkable if applied to a gravel or aggregate-surfaced road network. None of the studies attempted to provide a formula for apportioning a fixed or existing maintenance budget against the classes. Such a process would enable the roads administrator to use his or her system of classified roads as a base for apportioning existing or budgeted maintenance funds.

The literature review did serve to identify many of the characteristics that previous researchers had either evaluated or used in the design of low-volume roads. Several of these characteristics were identical from study to study, and this added weight to their significance.

To be workable, a system must be able to draw on current data, so a review was made of the information that was readily available in Ontario municipalities. It was found that, in all cases, municipalities could provide a map with the lengths of unpaved roads within their jurisdiction and the overall costs required to maintain their road networks for the previous year. These facts were available in greater detail in the more urban municipalities; however, in no case was there any previous attempt to classify unpaved roads in Ontario.

Nevertheless, in view of the fact that most municipalities have a high proportion of unpaved roads and that there is the need for them to begin to manage their maintenance in a less haphazard way, it is essential to have a classification system that is based on the quality of service that they intend to provide to each class and develop the related schedules for needed maintenance activities.

Quality-of-Service Characteristics

The characteristics of unpaved roads that were considered as capturing the quality of service intended for all classes of unpaved roads are average daily traffic (ADT), visibility, ease of passage, and all-season travel. Further, in the interest of simplicity, only three unpaved-road classes were established in accordance with the quality-of-service criteria for each characteristic. They were identified as class 1, class 2, and class 3.

The following discussion describes each of the quality-of-service characteristics, and Table 2 shows how they differ in magnitude and description from class 1 to class 2 to class 3, respectively.

ADT

ADT is the accurate traffic count that exists for most unpaved-road networks. The exceptions are those roads that are programmed for asphalt surfacing or major reconstruction. In these latter cases, car counts have usually been established to support the requested changes to upgrade the road.

The daily car count (ADT) on a gravel-surfaced road can vary dramatically from 0 to 800 or higher, depending on the proximity to an urban area or on the season of the year (e.g., summer traffic to recreational areas). For unpaved-road systems, we chose a range from 0 to 400 because, when the ADT exceeds 400, some form of asphalt surfacing can sometimes be justified. There is an overlap of ADT from class to class (i.e., 0-150, 100-300, and 250-400+) to accommodate variations due to the other service characteristics and variables such as percentage of truck traffic and roadbed width. When truck traffic exceeds 13 percent of the total vehicular traffic, the road width has usually been in-

Table 2. Classification format.

Quality-of-Service Characteristic	Class 1	Class 2	Class 3
ADT	250-400+	100-300	0-150
Trucks (%)	13[a]	13[a]	13[a]
Road width (m)	≥6.7	4.9-6.7	4.9
Visibility			
Passing sight distance (m)	488	335	244
Stopping sight (m)	107	84	61
Ease of passage: rideability	Rutting, corrugation, and potholes are not tolerated	Slight rutting, corrugation, and potholes allowed	Rutting, corrugation, and potholes corrected seasonally
All-season travel	Open year round	Open year round	Seasonal closures allowed (i.e., cottage and recreational areas)

[a]Accepted average.

creased to permit safe passage. This fact has to be noted when classifying the road, since more dollars will likely be required to maintain that portion of the network where the truck count exceeds 13 percent of the ADT. Road width is another factor related to ADT. Because most unpaved roads were not designed but "just happened", the road width cannot be applied as a universal characteristic. From our preliminary study, the berm-to-berm width was from 4.9 m to more than 6.7 m for the majority of unpaved roads. Because there is currently no system for classifying unpaved roads, most municipalities do not have any guidelines for varying the design of the road width and, as a result, some roads are maintained or constructed wider than they need be.

Visibility

Visibility has to be considered when discussing gravel roads. One can consider two elements--passing sight distance or stopping sight distance--and either one or both will serve as a basis on which decisions can be taken to modify the alignment of a road. The passing sight distance was believed to increase from 244 to 488 m as road width increased. The corresponding stopping sight distance would likely increase from 61 to 197 m with similar road conditions.

It is obvious that encroachment of roadside shrubs and trees and the presence of dust or lack of it, as well as changes in the geography of the road, will impact on the passing and/or stopping sight distances.

The data that relate to visibility are not readily available, if available at all, in most municipalities. However, it is believed that maintenance practices will differ (e.g., roadside maintenance and the number of signs required to warn drivers of hazards). Also, the need for an effective dust-control program increases as visibility decreases.

Ease of Passage

Extensive research has been done on the correlation between road surface and ridability, vehicular maintenance costs, tire wear, and rider comfort. Vehicles that travel on rough roads are known to require higher levels of maintenance and also cost more to operate. These costs decrease as the quality of the road surface is improved (6).

An identifiable factor that relates to ease of passage is the degree to which rutting, corrugation, and potholes are present. Such conditions are not likely tolerated on a road with a high ADT, and they are probably corrected seasonally on a road that leads to a recreational site.

Identifying the ease-of-passage characteristic provides a guideline for the road supervisor in planning the necessary grading, blading, and shaping for any given road. Many grader operations start at one side of the network and work across the system rather than make efficient use of the grader by doing only selected roads that warrant the expense.

The speed limit is not generally posted on an unpaved road, yet cars often travel at speeds equal to those permitted on paved roads even when the road surface is not suitable for such speeds. However, as the ease of passage is improved, it is logical to assume that the safe speed level on the road will increase. It is our observation that a reasonable speed for an unpaved surface is between 50 and 90 km/h, depending on degree of rutting and corrugation and the accompanying factors associated with visibility.

All-Season Travel

The all-season travel quality-of-service characteristic was selected, as it is typical of most roads that have a very low ADT. It also typifies most recreational unpaved roads that are open only during the summer season. This type of road is the lowest class of unpaved road and would receive the smallest amount of maintenance dollars.

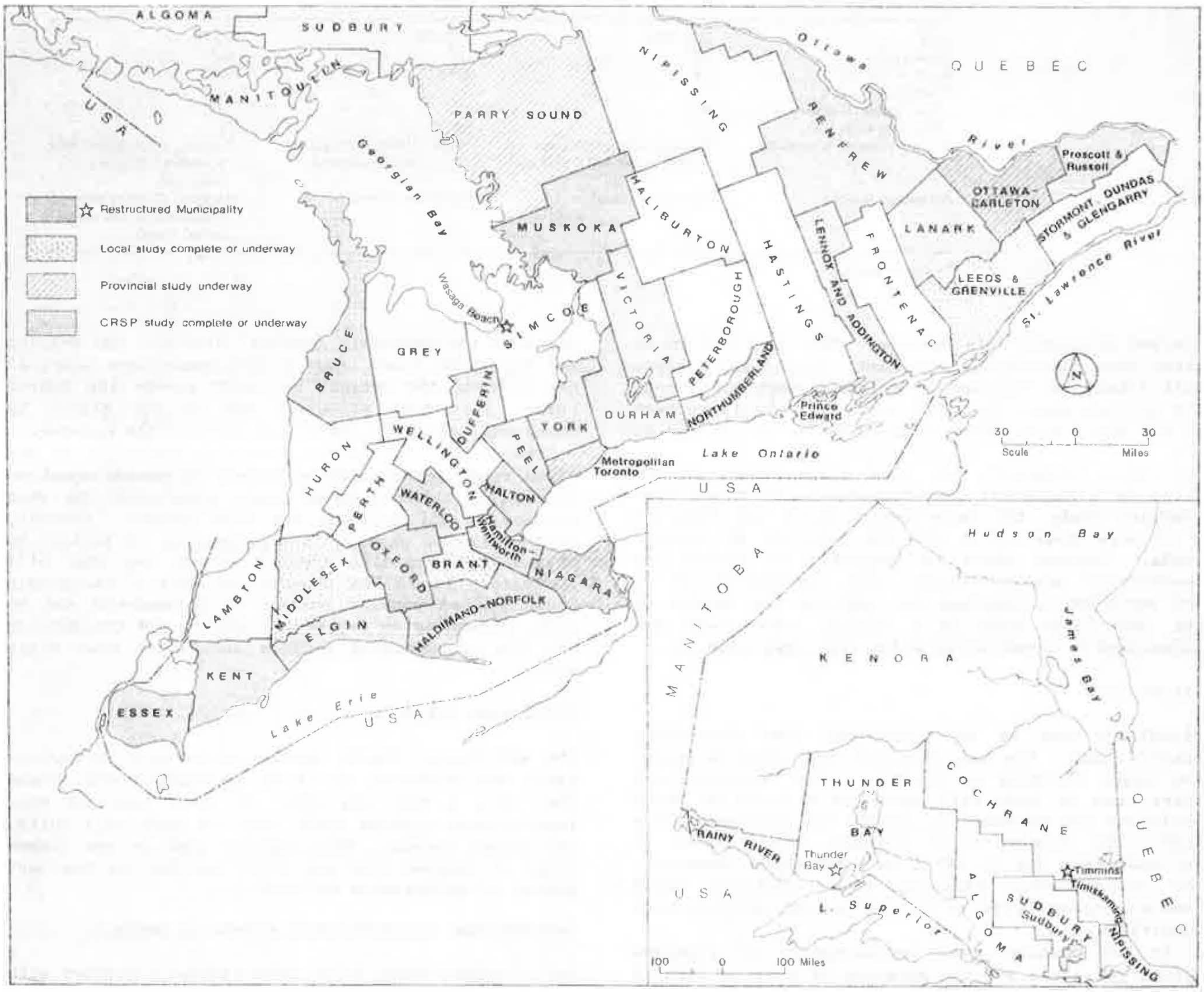
IMPLEMENTING CLASSIFICATION SYSTEM IN ONTARIO

The aforementioned three road classes, coupled with the varying quality-of-service characteristics, enables one to classify any unpaved-road network. The next step is to establish a plan to implement and review the proposed system.

Phase 1

The Province of Ontario can be divided into two geographic areas; namely, northern and southern Ontario (see Figure 1). Unlike northern Ontario, the southern portion is totally organized into a network of self-governing regional municipalities, counties, townships, cities, and towns, all of which are responsible for the unpaved-road network within their jurisdiction. The major portion of this unpaved-road network is under the jurisdiction of the townships, counties, and regional municipalities, which number 478, 27, and 11, respectively, making a total of 516 municipalities. To attempt to classify the unpaved roads of this number of municipalities in one year would be folly, and a decision was taken to carry out the classification in two phases. This would enable those municipalities selected for phase 1 of the project to start using the data received from the classification in the planning and management of their maintenance program. It would also enable us to examine the results and make any modifications that may be required prior to total implementation of the classification in phase 2.

Figure 1. Map of Ontario.



The objective of phase 1 was to introduce the concept of classifying unpaved roads to a predetermined number of municipalities. There are currently six Allied Chemical representatives who serve the Ontario market, and each one is responsible for a geographic area of the province. Each individual selected a predetermined number of municipalities from his or her area that they believed would be interested in cooperating in this study. One hundred and twenty-nine municipalities were proposed for the first phase (Table 3).

Seminars were scheduled in each territory to which the road superintendent and a member of his or her council responsible for road maintenance were invited. Several townships were invited to attend at any given time so that the number of seminars could be reduced to a manageable level.

At the seminar, an audio-visual slide presentation was shown that graphically described the concept, the quality-of-service characteristics, the benefits derived from a classification system, and what was required from the municipality if it wished to proceed with the classification system. Following a discussion on the concept, each participant was given a brochure that summarized the presentation. This brochure was prepared so that those who participated in the project could objectively discuss the concept at their council meeting, thus keeping everyone informed about the new system for classifying the unpaved roads.

No attempt was made at the seminar to classify a municipality's road system. This was reserved for a follow-up meeting, at which time the necessary data were available to a road superintendent and the Allied Chemical representative.

To complete the classification, three pieces of information were required from the municipality:

1. A detailed map of all roads within its jurisdiction (Figure 2),
2. A copy of the previous years maintenance and subsidy expenditure report (Figure 3), and
3. A detailed list of the municipalities road maintenance equipment and replacement costs (Table 4).

In addition to this information, it was necessary to sit down with the road superintendent or someone knowledgeable about the road network and shade in on the map those roads that are either planned for upgrading (e.g., prime and surface treatment or paving) in the next three years or those roads that are

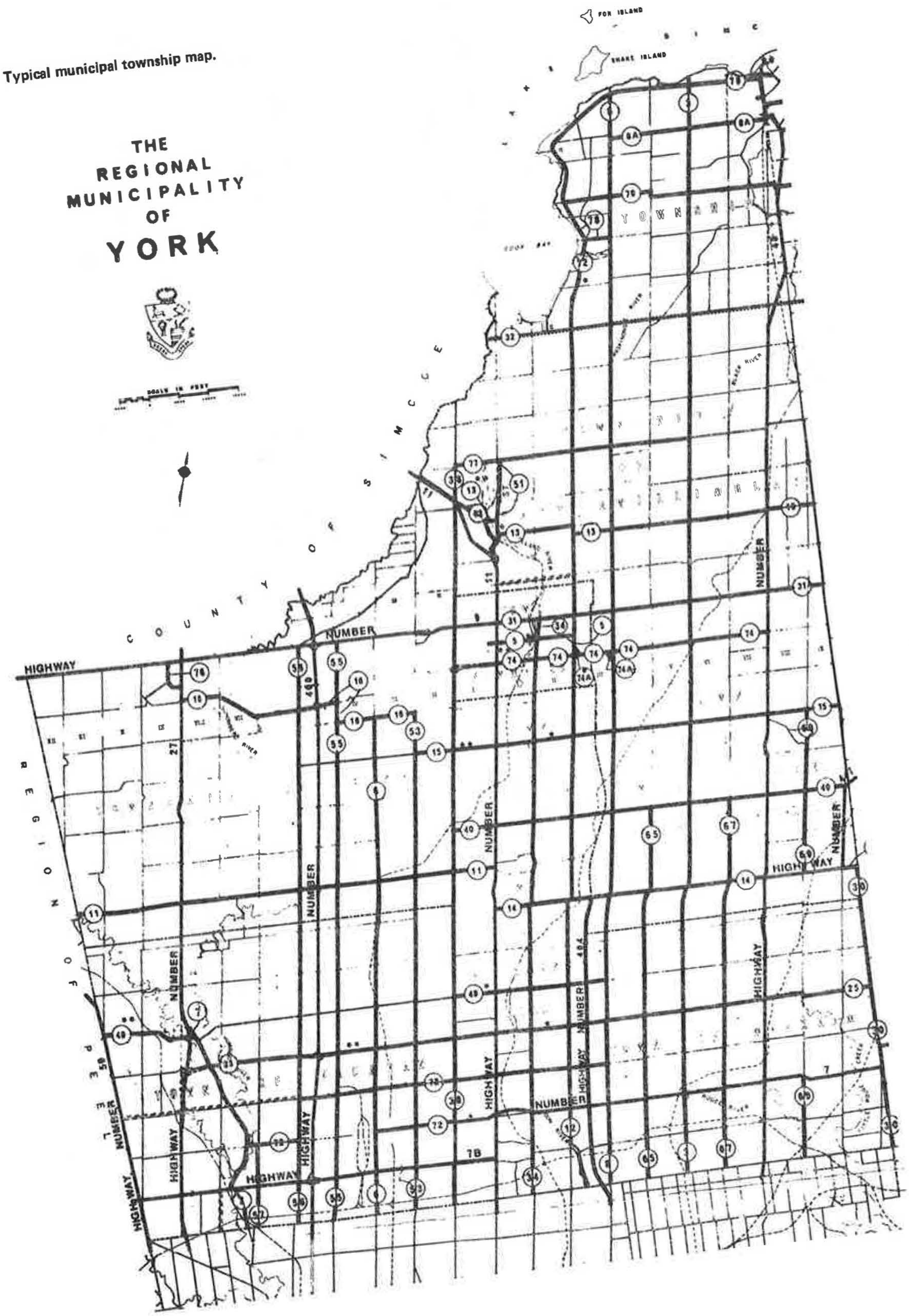
Table 3. Municipalities participating in phase 1 of classification.

Name	Classification	County, District or Region
Admaston	Township	Renfrew
Aldborough	Township	Elgin
Alnwick	Township	Northumberland
Amaranth	Township	Dufferin
Ancaster	Town	Hamilton-Wentworth
Arran	Township	Bruce
Artemesia	Township	Grey
Ashfield	Township	Huron
Assiginack	Township	Manitoulin
Barrie	Town	Frontenac
Bathurst	Township	Lanark
Beckwith	Township	Lanark
Bentinck	Township	Grey
Bexley	Township	Victoria
Billings	Township	Manitoulin
Black River-Matheson	Township	Cochrane
Blandford-Blenheim	Township	Oxford
Blanshard	Township	Perth
Brant	County	Brant
Bracebridge	Town	Muskoka
Brighton	Township	Northumberland
Brock	Township	Durham
Brooke	Township	Lambton
Brougham	Township	Renfrew
Burford	Township	Brant
Caledon	Town	Peel
Carnarvon	Township	Manitoulin
Carrick	Township	Bruce
Cavan	Township	Peterborough
Colchester North	Township	Essex
Culross	Township	Bruce
Delhi	Township	Haldimand-Norfolk
Dover	Township	Kent
Dunnville	Town	Haldimand-Norfolk
Dunwich	Township	Elgin
Durham	Region	Durham region
East Garafraxa	Township	Dufferin
East Gwillimbury	Town	York
East Luther	Township	Dufferin
East Williams	Township	Huron
Edwardsburgh	Township	Leeds and Grenville
Eldon	Township	Victoria
Elderslie	Township	Bruce
Elizabethtown	Township	Leeds and Grenville
Ellice	Township	Perth
Emily	Township	Victoria
Enniskillen	Township	Lambton
Ennismore	Township	Peterborough
Ernestown	Township	Lennox and Addington
Essex	County	Essex County
Facquier	Township	Cochrane
Fenelon	Township	Victoria
Flamborough	Township	Hamilton-Wentworth
Front of Leeds and Lansdowne	Township	Leeds and Grenville
Fullarton	Township	Perth
Georgian Bay	Township	Muskoka
Georgina	Township	York
Glenelg	Township	Grey
Gosfield South	Township	Essex
Gravenhurst	Town	Muskoka
Greenock	Township	Bruce
Grey	Township	Huron
Hagar	Township	Sudbury
Haldimand	Town	Haldimand-Norfolk
Hallowell	Township	Prince Edward
Halton Hills	Town	Halton
Hamilton	Township	Northumberland
Harvey	Township	Peterborough
Hope	Township	Northumberland
Howard	Township	Kent
Huntsville	Town	Muskoka
Iroquois Falls	Town	Cochrane
Kapuskasing	Town	Cochrane
Kent	County	Kent County
Kinloss	Township	Bruce
Lake of Bays	Township	Muskoka
Lanark	County	Lanark County
Laxton, Digby, and Longford; Leeds and Grenville	Township	Victoria
Lindsay	Township	Bruce
Loughborough	Township	Frontenac
Maidstone	Township	Essex
Manvers	Township	Victoria
Mara	Township	Simcoe
Mariposa	Township	Victoria
Markham	Town	York
McGillivray	Township	Middlesex
McKillop	Township	Huron
Mersea	Township	Essex
Milton	Town	Halton
Montague	Township	Lanark
Morris	Township	Huron
Muskoka Lakes	Township	Muskoka
Newcastle	Town	Durham
North Easthope	Township	Perth
Ops	Township	Victoria
Oro	Township	Simcoe
Oso	Township	Frontenac
Otonabee	Township	Peterborough
Pakenham	Township	Lanark
Peel	Regional municipality	Peel
Pelham	Town	Niagara
Percy	Township	Northumberland
Plympton	Township	Lambton
Portland	Township	Frontenac
Proton	Township	Grey
Raleigh	Township	Kent
Rama	Township	Simcoe
Ramsay	Township	Lanark
Rawdon	Township	Hastings
Rear of Leeds and Lansdowne	Township	Leeds and Grenville
Renfrew	County	Renfrew County
Rochester	Township	Essex
Ross	Township	Renfrew
Sarnia	Township	Lambton
Scugog	Township	Durham
Seymour	Township	Northumberland
Sherwood	Township	Renfrew
Sidney	Township	Hastings
Smith	Township	Peterborough
Sophiasburgh	Township	Prince Edward
South Dumfries	Township	Brant
South Easthope	Township	Perth
Stanley	Township	Huron
Stephen	Township	Huron
Storrington	Township	Frontenac
Sullivan	Township	Grey
Tehkummah	Township	Manitoulin
The Spanish River	Township	Sudbury
Thorold	Town	Niagara
Thurlow	Township	Hastings
Tilbury East	Township	Kent
Tilbury West	Township	Essex
Tyendinaga	Township	Hastings
Uxbridge	Township	Durham
Verulam	Township	Victoria
Wellesley	Township	Waterloo
West Gwillimbury	Township	Simcoe
West Lincoln	Township	Niagara
Whitchurch-Stoufville	Town	York
Woolwich	Township	Waterloo
Yarmouth	Township	Elgin
York	Region	York region
Zorra	Township	Oxford

not maintained for 12 months of the year.

These data were then returned to the office where a simple report was prepared that classified the municipalities' unpaved roads and apportioned the costs associated with maintaining each class of the system based on the actual expenses for the previous year.

Figure 2. Typical municipal township map.



Phase 2

The plans for phase 2 are to complete the preliminary reports discussed earlier for the balance of the municipalities in Ontario. In addition, we expect to prepare a computer program that will enable researchers to examine the real costs associated

Figure 3. Maintenance expenditure report.

	PROJECT	ESTIMATED FOR YEAR Expenditure	ESTIMATED FOR YEAR Subsidy	ACTUAL TO DATE Expenditure	ACTUAL TO DATE Subsidy
BRIDGES & CULVERTS					
A	Bridges and Culverts				
ROADSIDE MAINTENANCE					
B-1	Grass Mowing & Weed Spraying				
B-2	Brushing, Tree Trimming & Removal				
B-3	Ditching *				
B-4	Catch Basins, Curb & Gutter Cleaning Storm Sewers				
B-5	Debris & Litter Pick-up				
B	Total Roadside Maintenance				
HARDTOP MAINTENANCE					
C-1	Patching & Spray Patching				
C-2	Sweeping, Flushing, Cleaning				
C-3	Shoulder Maintenance - Grading Patching, Washouts, Dust Layer				
C-4	Resurfacing *				
C	Total Hardtop Maintenance				
LOOSETOP MAINTENANCE					
D-1	Patching & Washouts				
D-2	Grading & Scarifying				
D-3	Dust Layer				
D-4	~~Prime or Priming~~ Boundary Lines.				
D-5	Gravel Resurfacing *				
D	Total Loose Top Maintenance				
WINTER CONTROL					
E-1	Snow Plowing & Removal				
E-2	Sanding & Salting				
E-3	Snow Fence, Culvert Thawing Etc.				
E-4	Winter Standby *				
E	Total Winter Control				
SAFETY DEVICES					
F	Safety Devices, Signs, guiderails Rail road Maintenance				
MISCELLANEOUS					
G	Total for Miscellaneous				
	SUB-TOTAL (A to G)				
OVERHEAD					
H	Total Maintenance Overhead *				
	TOTAL(TO PAGE 1)				

Table 4. Road maintenance equipment replacement costs.

Item	No.	Replacement Costs ($)	Life (years)	Annual Cost ($)
Equipment				
Pick-up truck	5	50 000	3	16 600
Dump truck	8	320 000	7	45 700
Champion grader	3	330 000	12	27 500
Wabco grader	2	220 000	12	18 300
Case loader	4	240 000	10	24 000
Sander box	5	32 500	6	5 400
Water tank	3	5 000	5	3 000
Shop equipment		50 000	10	5 000
Hand tools		20 000	5	4 000
Total				149 500
Overhead				409 000
Annual fixed costs				558 500

Figure 4. Derived annual surface maintenance costs for various surfaces.

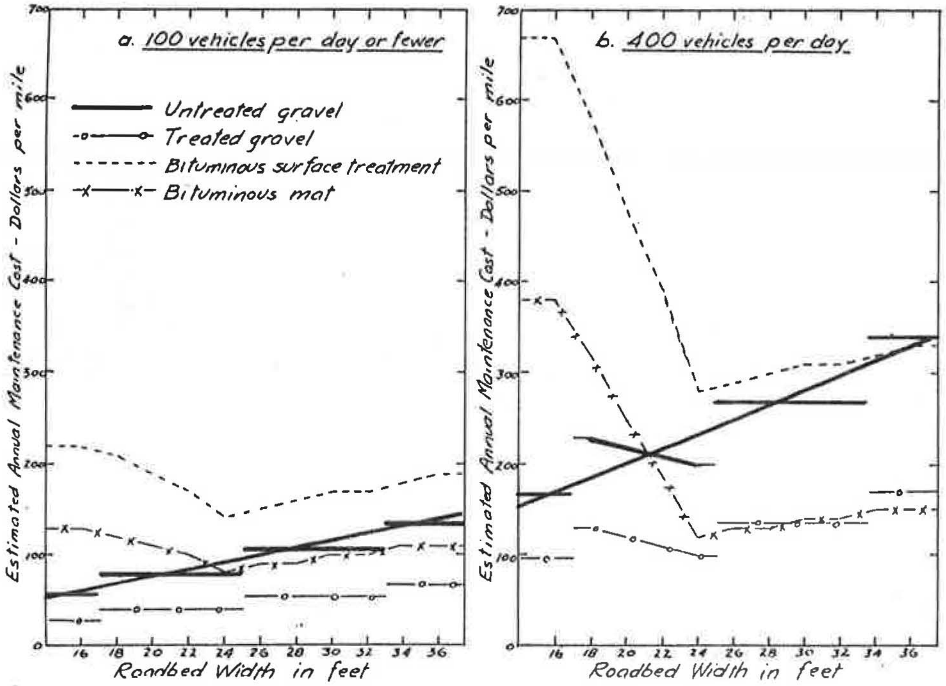
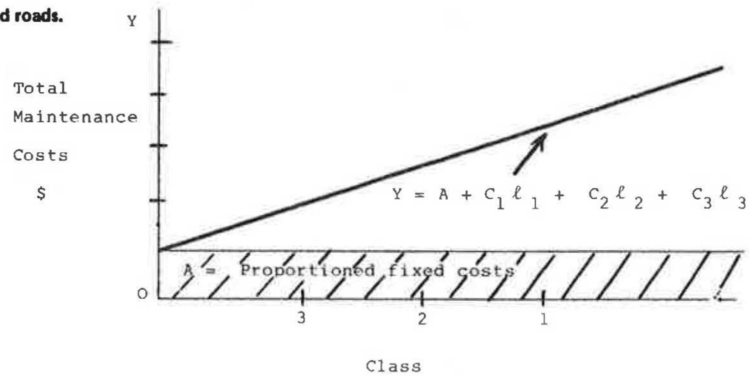


Figure 5. Maintenance costs for various classes of unpaved roads.



with maintaining the different classes of unpaved roads. Later in this paper we discuss the activities associated with maintaining unpaved roads, and with the aid of a computer program these can also be examined to determine the norms or level of frequency associated with each activity.

Classification of unpaved roads is a big step toward a self-sufficient maintenance management program. However, to complete this project it is essential that the road administrator or supervisor be able to identify what it costs to maintain each class of road. Once these unit costs are determined, decisions can be taken and future plans can be made that are based on facts.

DEVELOPING UNIT COSTS OF EACH CLASS

Background

In 1969, Oglesby and Altenhofen (10) examined the design standards for low-volume roads and the economics associated with various factors related to road maintenance of such roads. Of particular significance are two graphs from their report [see Figure 4 (9, p. 56)], which plot the estimated annual maintenance costs in dollars per mile against the roadbed width. It is clear that the maintenance costs for gravel surfaces increase in a linear manner as the road width increases.

The Transportation Research Board's report on low-volume roads (2) concludes that loose top maintenance costs increase with the road width and ADT.

Because both of these parameters--road width and ADT--are factors in the classification system, a formula can be developed that relates maintenance costs to each class in a linear manner. In other words, more dollars are spent maintaining a class 1 gravel road with 400+ ADT than a class 3 gravel road that experiences 30 vehicles/day and is closed during the winter months.

The actual frequency of maintenance activities will vary initially from municipality to municipality, but the principle that maintenance costs are linearly related to class holds true. The following formula and graphic display have been developed by using this theory.

Formula

To determine the costs that are to be apportioned against the class 3 segment of the road system, the following formula is used:

$$Y = A + C_1\ell_1 + C_2\ell_2 + C_3\ell_3 \quad (1)$$

where

Y = total annual maintenance costs for unpaved roads in a system;
A = proportioned fixed costs for maintaining unpaved roads;
C_1, C_2, C_3 = annual maintenance cost of class 1, 2, or 3 roads per kilometer, respectively; and
ℓ_1, ℓ_2, ℓ_3 = distance (km) of class 1, 2, and 3 roads, respectively; i.e.,

$$L = \ell_1 + \ell_2 + \ell_3 \quad (2)$$

where L is the total distance (km). Given the principle of proportionality of maintenance cost by road class, i.e., $C_1 = 3C_3$ and $C_2 = 2C_3$, then

$$Y/L = (A/L) + C_3\ [(3\ell_1/L) + (2\ell_2/L) + (\ell_3/L)] \quad (3)$$

The maintenance costs for the various classes of unpaved roads are shown in graphic form in Figure 5.

The final step involves the calculation of unit costs for each activity associated with maintenance. Some of the maintenance costs result from activities that are performed on the total road network (i.e., joint activities), while others can only be performed on unpaved surfaces.

Example

The following steps demonstrate how the costs are apportioned to each class and against the maintenance activities:

1. A road inventory worksheet (Table 5) is pre-

Table 5. Road inventory worksheet.

Section No.	Distance Unpaved (km)	Paved (km)	Estimated ADT	All-Season Travel	Class[a]
1	2.1		60		
2	2.4		150	Yes	3
3	2.3		240	Yes	2
4	4.8		130	Yes	2
5	2.7		15	No	3
6	0.6		420	Yes	1
.					
.					
.					
13		1.3	880	Yes	NA
14	3.1		310	Yes	1
15	3.2		140	Yes	2
16	0.8		30	No	3
.					
.					
.					
27	2.4		210	Yes	2
28		0.5	140	Yes	NA
29	2.3		420	Yes	1
30	1.6		180	Yes	2
31	1.1		210	Yes	2
32	3.2		590	Yes	1

Notes: Summary of unpaved roads is class 1 = 84.5 km, class 2 = 256.7 km, and class 3 = 137.2 km, for a total of 478.4 km.
There was a total of 133.2 km of paved roads in network.
[a]Classifications are assigned based on the quality-of-service characteristics criteria of Table 2. All characteristics may not be available, and classes may be assigned initially on the ADT and the all-season travel characteristics only.

Figure 6. Calculation of unit costs on C_3 value.

$Y = A + C_1\ell_1 + C_2\ell_2 + C_3\ell_3$

where $C_1 = 3C_3$ and $C_2 = 2C_3$. Then,

$Y/L = (A/L) + C_3\ [(3\ell_1/L) + (2\ell_2/L) + (\ell_3/L)]$

Then calculate the factor $(3\ell_1/L) + (2\ell_2/L) + (\ell_3/L)$, where

Class 1: $\ell_1 = 84.5 \therefore 3\ell_1/L = 0.5299$,
Class 2: $\ell_2 = 256.7 \therefore 2\ell_2/L = 1.0732$, and
Class 3: $\ell_3 = 137.2 \therefore \ell_3/L = 0.2868$.

Thus,

$Y/L = (A/L) + C_3\ (0.5299 + 1.0732 + 0.2868)$
$Y/L = (A/L) + C_3\ (1.8899)$

where $L = \ell_1 + \ell_2 + \ell_3$. Then,

$Y/L = (A/L) + 1.89C_3$

where L = 478.4, Y = 1 705 809, and A = 435 911. Then,

$1\ 705\ 809/478.4 = (435\ 911/478.4) + 1.89C_3$

$3566 = 911 + 1.89C_3$
$C_3 = (3566 - 911)/1.89$
$C_3 = \$1405$

Verification:

$\ell_3 \times C_3 = 137.2 \times 1405$	=	\$ 192 766
$\ell_2 \times 2C_3 = 256.7 \times (2 \times 1405)$	=	\$ 721 327
$\ell_3 \times 3C_3 = 84.5 \times (3 \times 1405)$	=	\$ 356 168
	A =	\$ 435 911
Total	Y =	\$1 706 172

Table 6. Summary of proportional costs and maintenance activities.

Item	Annual Costs[a] (\$)	Classified Portion[b] (%)	Total (\$)
General maintenance			
Blading and shaping	100 000		
Surface stabilization	268 860		
Aggregate addition	284 410		
Repair unstable area	136 570		
Total	789 840	100	789 840
Joint activity			
Drainage	180 060		
Roadside maintenance	157 400		
Snow and ice control	247 970		
Total	585 430	78	456 635
Supervision and contingencies	30 030	78	23 423
Fixed costs	558 800	78	435 911
Total cost	1 964 100		1 705 809

[a]Obtained from annual maintenance expenditure and subsidy, Figure 3.
[b]See Table 5.

Table 7. Maintenance activity costs per kilometer for class 3 roads.

Item	Cost Factor[a] (\$)	Class 3 Cost per Kilometer, C_3 (\$)
Gravel maintenance[b]		
Blading and shaping	100 000 x (f)	111
Surface stabilization	268 860 x (f)	297
Aggregate addition	284 410 x (f)	315
Repair unstable area	136 570 x (f)	151
Joint activity[c]		
Drainage	140 447 x (f)	155
Roadside maintenance	122 772 x (f)	136
Snow and ice control	193 417 x (f)	214
Supervision and contingencies	23 423 x (f)	26
Fixed cost	435 911/478.4	911
Total cost		2316

[a]$f = C_3/(Y - A) = 1405/1\ 269\ 898$. [b]At 100 percent. [c]At 78 percent.

Table 8. Summary of maintenance activity costs for classes 3, 2, and 1.

Item	Total ($)	Proportioned Total ($)	Class 3 Cost per Kilometer, C_3 ($)	$C_2 = 2 \times C_3$ ($)	$C_1 = 3 \times C_3$ ($)
Gravel maintenance[a]					
Blading and shaping	100 000	100 000	111	222	333
Surface stabilization	268 860	268 860	297	594	891
Aggregate addition	284 410	284 410	315	630	945
Repair unstable area	136 570	136 570	151	302	453
Joint activity[b]					
Drainage	180 060	140 447	155	310	465
Roadside maintenance	157 400	122 772	136	272	408
Snow and ice control	247 970	193 417	214	428	642
Supervision and contingencies	30 030	23 423	26	52	78
Fixed costs[b]	558 861	435 911	911	911	911
Total cost	1 964 161	1 705 810	2316	3721	5126

[a]At 100 percent. [b]At 78 percent.

pared from the map of the municipality. The classification of each road section is assigned in accordance with the classification system of Table 2.

2. A road inventory summary, which shows each class of road as a percentage of the total in the system, is prepared, as shown in the table below:

Road	Length (km)	Percentage of Total
Unpaved		
Class 1	84.5	14
Class 2	256.7	42
Class 3	137.2	22
Total	478.4	78
Other	133.2	22
Total	611.6	100

3. A summary of the proportional costs by maintenance activity is prepared (Table 6).

4. The unit costs of the class 3 roads are then calculated (Figure 6).

5. The maintenance activity costs are calculated for each kilometer of class 3 road (Table 7).

6. The maintenance activity costs are summarized for each kilometer of class 3, 2, and 1 roads, respectively (Table 8).

TESTING THE SYSTEM

Now that the municipal administrator and the road supervisor have a plan of the unpaved-road network as well as an estimate of what it currently costs to maintain each class of road as worked on in the example in Table 8, they can start to address the costs associated with the individual maintenance activities. In other words, What is the scope or frequency of each activity that their municipality can afford? They will start to test the system and establish some standards of performance for each maintenance activity, thus making maintenance a reality.

The unit costs of the various maintenance activities are calculated on the assumption of linear proportionality of costs for the three unpaved-road classes. As the system is tested, it may be found that some correction coefficient will need to be developed to more accurately represent reality.

Results of the phase 1 operation are expected to become available within the next year.

CONCLUDING REMARKS

In Ontario, there are more than 75 000 km of unpaved roads, and more than 95 percent of these roads are under the jurisdiction of regional municipalities, townships, or county governments. In today's world, these agencies are faced with maintaining their long distances of roads while at the same time their finances are shrinking. They have stated that a cost-effective plan would greatly assist in managing their road network and also enable them to live within their budgeted means.

Classification of the unpaved roads in each Ontario municipality will permit the unpaved-road network to be elevated to the level of maintenance management now practiced on paved and surface-treated roads. Such a program will not only enhance the task of the roads manager, but it will also aid the ratepayer, the traveler, and those who strive to conserve our material resources for future generations.

The approach used in this classification system has been simplistic so that it can be easily understood by nontechnical road managers and can be implemented with the aid of a few rudimentary facts that are readily available at every municipality, irrespective of size or complexity.

One only has to study the recent lists of research needs for low-volume roads to realize how critical the need is to resolve some of the important problems associated with maintaining gravel roads. It is our belief that our approach to classifying unpaved roads will enable researchers to attack these important issues and, in doing so, make a worthwhile contribution to the management and preservation of unpaved roads.

ACKNOWLEDGMENT

We wish to acknowledge the contribution made by W. Phang and A. Rutka of MTC. They were very helpful in the planning and design of this program, and their wealth of experience and encouragement has greatly assisted us in meeting our goal.

We wish to also acknowledge the management of Allied Chemical, which has encouraged us to pursue this goal, which we believe holds significant benefit to each municipality and provincial government throughout Canada.

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Simplified Cost-Estimation Method for Low-Volume Roads

THOMAS A. DURSTON AND FONG-LIEH OU

A reliable and fast response method for route alternative analysis is becoming a pressing need as cost-effectiveness becomes a more important factor for low-volume roads. A simplified method for low-volume-road cost estimation is presented. The method consists of estimating various quantities: excavation, clearing, grubbing, seeding, ditch relief culverts, drainage crossings, and surface rock. It is sensitive to design standards and can be used to evaluate various alternatives effectively. A program called ANALYTICAL ROAD COST has been written for the HP41C calculator and is very convenient for making cost-effective analysis. Compared with other methods of cost estimating, the program generally offers greater speed, accuracy, and/or flexibility in choice of design standards. The flexibility and precision inherent in the program provide very refined comparisons of alternative projects. The results obtained by applying the proposed estimation method to four roads were satisfactory. Its estimates were comparable with that made by the engineer after the completion of the design. The method has been adopted by the Gifford Pinchot National Forest in Washington State as a primary tool for cost estimation and can be applied to other low-volume-road systems outside forest lands.

In the early stages of transportation planning, route selection requires quantity and cost estimates for economic analysis. The accuracy of these estimations can be a vital factor in choosing the most economical route. However, accurately estimating road construction costs may be an involved and time-consuming process. Because high construction cost is increasingly becoming a major concern in low-volume roads, the development of an efficient and quick response method for estimating construction costs with higher accuracy and less time commitment is a pressing need. This need is confronted by the Forest Service, U.S. Department of Agriculture, which constructs more than 7000 miles (11 270 km) of new roads annually.

Traditionally in the Forest Service, preliminary construction costs have been estimated by two different approaches. The first and most common approach has been to compile the engineers' estimates for several recent construction contracts. In this approach, the previous cost estimates are grouped into categories based on average ground slope, and a total cost per mile is assigned to each category. The second approach has been to estimate construction quantities and apply unit costs. Quantities have been computed by hand by using simplified mathematical or graphical methods or have been taken from tables and nomographs. However, traditional cost-estimating methods have either been insensitive to variation in design standards or terrain or both, or they have been cumbersome and time consuming to use.

In order to overcome the shortcomings of traditional estimation methods, engineers of the Willamette National Forest in Eugene, Oregon, developed a computerized estimation method based on semi-empirical quantity estimates and a cost matrix. In this method, a construction quantity matrix was constructed by computing quantities based on the designer's aid program (1) for 17 preselected subgrade templates on 8 slope classes applying a set of adjustment factors derived from local experience. Unit costs vary for different slope classes and brush stocking levels. The estimation procedure is embodied in a computer program called Road Cost (which was developed and published by engineers at the Willamette National Forest).

Although this method may reduce computation time and increase accuracy when compared with traditional approaches, it does not allow sufficient flexibility in the choice of design parameters, such as construction slope ratios and amount of turnouts. Also, for application in different areas, a new construction quantity matrix should be developed by using adjustment factors for local conditions. Thus, the Willamette method has limits on its spatial transferability.

The purpose of this paper is to develop a simplified analytical method for estimating costs of low-volume roads by using a program written for the HP41C calculator. The analytical method overcomes the problems of flexibility and transferability. The applicability of the method was demonstrated by several case studies in the Gifford Pinchot National Forest in Washington State. The results of these studies were compared with estimates made by a traditional approach and with the actual quantities and costs as computed in the design.

METHODOLOGY

The primary objective of the proposed cost-estimation approach is to develop a calculating procedure that can be applied to various types of roads, including single-lane roads with and without turnouts and multiple-lane roads. The basic approach is based on generating a typical template that is assumed to be uniform except at drainage crossings. Design assumptions are patterned after those made in