Flexible Analysis of Highway Needs in Manitoba

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A computer program was developed in Manitoba to determine physical road needs and costs. The program provided centralized control, greater accuracy with minimum personnel than usual methods of field estimating, and flexibility to alter standards. The latter is important in research related to cost consequences of different designs, amount and type of work required under varying conditions and policies, and the ultimate character of various road systems that would result. Examples are given, such as: lowering standards one level (below those considered desirable) reduces province-wide costs by about one-third; for light traffic local roads in a particular locality, increasing grade width from 24 to 30 ft increased total costs 8 percent for such roads. The paper outlines essential features of the appraisal process and the computer program that are adaptable to a wide range of physical and traffic conditions.

• ENGINEERING determination of highway needs has usually followed one of two general procedures:

1. A mile-by-mile field study of physical highway work and consequent costs required (if any) to improve the existing status to needed design and maintenance standards; or
2. A statistical study, based on sampling or trends, or both, projecting costs for mass mileages—usually segregated only by general design types within systems.

Experience has shown advantages and disadvantages of both methods. The Manitoba study of municipal (rural) roads attempted to secure the advantages of both and to minimize the disadvantages. At the same time, a new dimension of flexibility was provided to make possible further research into consequences of changes in design standards, or elements thereof, and of changing unit costs.

Most of the mile-by-mile needs studies involve establishing a fixed set of standards for various highway systems, conditions of traffic, terrain, etc., and subsequently, making field estimates of needs to meet those standards.

These estimates are generally made by many engineers who differ in experience, ability, concepts, and interpretation of instruction—despite all efforts to establish clear and uniform approaches to the wide variety of problems encountered. Therefore, it is essential for the project managers to establish several echelons of review procedure to correct errors, iron out inconsistencies, check validity of estimates and generally determine reasonableness of results. This is a time-consuming task, which also includes the necessity of numerous statistical checks.

A well-done job of this nature provides not only a solid basis for statewide long-range physical and fiscal planning, but also significant detailed facts for local planning, priority determination and both short- and long-range programing.

However, the mile-by-mile needs analysis is not very flexible; that is, once the basic premises are set, it is not readily possible to alter standards, instructions or unit costs without completely redoing the field estimates. As time passes, changing conditions

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are not easily accounted for and complete new studies may be needed periodically. The best, most experienced engineering talent available is required for this rather tedious and lengthy field operation.

STUDY OBJECTIVES AND PROBLEMS

The basic objectives of the Manitoba study were the following:

1. To obtain detailed data for planning of roadway and bridge improvements on the "Main Market Road System" (comparable to county primary or arterial roads in many states).
2. To obtain cost estimates adequate for development of improved long-range fiscal policy, including cost consequences of various alternatives, for both the Main Market Road System and the local roads.
3. To systematize operations to permit easy, quick and accurate re-evaluation from time to time, as progress is made, conditions change or policies are revised.
4. To accomplish the foregoing with the minimum amount of experienced engineering time, making best use of technicians.

When the study was begun in 1961, the administrative situation in Manitoba was such that the fourth objective was of considerable importance. At the same time, the physical situation, common to many of the north central states, was conducive to the approach finally adopted.

Administratively, the Highways Branch of the Manitoba Department of Public Works carries out an annual program of around $30 million for construction and maintenance of nearly 6,000 miles of Provincial Trunk Highways and some of the secondary roads. Additionally, the Highways Branch administers a grant-in-aid program for Main Market roads which are under the control of 109 organized rural municipalities outside of Metropolitan Winnipeg. That program involves approval and general supervision of construction requiring nearly $4 million annually of provincial funds—about one-half of total rural municipal construction and maintenance expenditures on all roads (including local). Other small specialized grant programs are also provided, including aid to cities, towns and villages.

That work is accomplished through a headquarters and eight district offices, with a total of only 96 full-time engineers (during 1961-62). None of the rural municipalities employ full-time engineering supervision, and only a few use consulting engineers for special work.

A complete mile-by-mile needs study of the Provincial Trunk Highway (PTH) had been completed by field estimating methods in 1959-60. The staff was therefore generally familiar with basic requirements for data and methods of analysis. However, this involved study of the roads and costs with which the branch engineers were most familiar and which were their prime responsibility. Even so, much basic data—including inventory, traffic and costs—had to be acquired, since the province had not had any systematic, full-scale data collection procedure previously. The engineering staff was hard pressed to provide it, along with regular work.

The "municipal road study" was under even more handicaps. No complete inventory of all roads existed. Maps were out of date or incomplete. Little or no traffic data on roads off the PTH system had ever been recorded. Cost data were totally inadequate. Within the two-year time limit for the study of what eventually proved to be 41,000 miles of rural roads, plus almost 500 miles of city streets (all outside metropolitan Winnipeg), it appeared nearly impossible to achieve a competent study by field estimating.

However, physical conditions of terrain, soils, culture, existing roads, traffic and standards of design—all as related to Main Market and local roads—were apparently sufficiently uniform over broad areas of the province to suggest the possibility of developing an adequate mass or statistical approach to determining needs.

Much of the south central area of Manitoba lies in the level flood plain of the Red River Valley—a rich agricultural area of black gumbo. Another large area north of Winnipeg is level, immature lime soil. Most of the rest of the populated area of the province is gently rolling prairie, including substantial sandy areas, formerly the beaches of old Lake Aggassiz, or glacial deposits. Some 60 percent of the total area

of 251,000 square miles is nonproductive land of muskeg and permafrost in the north, and another 16 percent is in lakes or rivers. The most difficult terrain is muskeg and the Pre-Cambrian rocky shield has few people or roads.

Outside metropolitan Winnipeg, population density seldom exceeds 20 people per square mile in rural areas. Half of the municipalities average between 10 and 15 rural people per mile of main roads (PTH and Main Market). Only three municipalities have over 30 people per mile, and eight have eight or less people per mile. Population is therefore relatively uniform within substantial areas of the province. Therefore, traffic is also relatively similar over large mileages.

Much of the terrain permits the development of a basic grid system of straight, level roads. Principal problems relate to cross-section and surfacing. Elevated grades are needed to permit wind clearance of snow. Good drainage is required, and all-weather surfaces are important on Main Market roads and the more generally used local roads. Standards, based on traffic and terrain, emphasized width of grade, elevation and surfacing.

Existing road conditions are also relatively uniform. For example, of 12,700 miles of Main Market roads, surfaces of 5,200 miles are only one foot or less above adjacent ground level, and two-thirds of the system has graded widths of 22 feet or less.

The combination of required standards and existing conditions, plus fairly uniform unit costs throughout the province (except for gravel haul) would have permitted mass statistical determination of province-wide costs within reasonable limits of accuracy. However, this single result would not have met other objectives of the study.

STUDY DESIGN—GENERAL

The basic concept of the study is similar to an earthwork program developed for electronic data processing. The appropriate standard cross-section for each roadway was established and used as a template for comparison with the actual cross-section, both on a mile-by-mile basis. An IBM 1620 computer program controlled calculations of grading quantities, if any, required to change the existing cross-section to the proper standard. Section area differences, modified by a shrinkage factor, multiplied by length of section (over which the same standard and existing conditions prevailed) yielded grading quantities for the specified length.

The program was extended to include basic analyses for drainage needs (dependent on grading requirements), surfacing quantities, right-of-way and fencing. Varying costs were applied to quantity estimates, engineering cost was calculated as varying percents of total cost, and all costs summed for each road section length. Per-mile cost was calculated for each to permit easy review. Field review verified results of the final program.

Standard procedures completed the analysis for Main Market roads by accumulating total costs, mileages involved in various categories, and certain other physical data, by road system and subclassification, by municipality and for the province as whole. Bridge costs were tabulated separately. Printouts were provided, listing data for each road section, grouped and summarized as desired by municipality, system, etc. Maintenance costs were estimated separately by standard procedures.

The foregoing suggests that standardized results, although based on certain varying existing conditions, would be expected. However, the design of the study recognized that abnormal conditions do exist and that these should be recognized. Abnormal would be those relatively few situations which deviated substantially from the usual conditions. In turn, the usual condition required a datum from which to judge the abnormal. Such a base has generally been missing from some other attempts to devise satisfactory techniques of standardizing needs analysis.

For local roads, eventually estimated to total 27,000 miles outside the Winnipeg area, a 10 percent simple random sample of 1,500 townships was made. All local roads in the sample, totaling 150 townships, were inventoried and analyzed in a manner similar to that done for Main Market roads. Bridge data for all local roads were available and analyzed separately; no sampling was necessary. Results of the local road study are, however, applicable only to province-wide data and the separate sample townships.

Although a Main Market road system had been identified prior to the study, inconsistencies and inadequacies were noted. Therefore, a separate classification study was undertaken to establish criteria for proper selection of Main Market roads and to identify each road with the appropriate system. Results indicated that some roads, previously selected as part of the Main Market system, should be classed as local roads, and vice versa. Additionally, about one-third of the selected Main Market system was identified as "community connectors" which were generally more important than the balance of the system. Such identification could have influence on fiscal arrangements and priority of improvement. Details of this separate study will not be discussed further in this paper, but the reader should be aware that it affected operations of the analysis.

FIELD OPERATIONS

Having given full consideration to objectives of the study and the desired methods of analysis, three basic field operations were established. These covered the fields of physical inventory, normal quantity/cost evaluation of a selected, typical standard project (the datum), and traffic volumes in each municipality.

Physical Inventory

Figure 1 shows the standard inventory sheet utilized by inventory parties who examined every mile of existing Main Market roads and selected local roads. Certain bridge data were recorded separately. Maps were also provided, together with log sheets for recording changes, cultural features, etc. The parties consisted of technicians or college students who were given detailed written instructions and training, and who were under general supervision of district engineers.

Items requiring substantial engineering judgment were minimized. Those that are significant to this report are described by excerpts from the instructions, as follows:

> In many cases it will be necessary to subdivide a Main Market road into two or more sections. This situation will occur where there is a change in the existing standard of road. The determination of the section limits is the responsibility of the inventory crew. Each section should be continuous of generally uniform characteristics. For newly constructed roads, the section limits will be the construction limits.
>
> * * *
>
> Item 19. Horizontal alignment is to be measured by the average safe driving speed that the prudent driver would use in good weather with few cars on the road. If necessary, make a few runs to establish what this speed would be on various roads of this same classification in the municipality. Then use judgment on the balance. Enter this value in miles per hour.
>
> * * *
>
> Item 22. To rate the present adequacy of the road cross-section, refer to the typical cross-section diagrams shown in Figure 2. Compare which of these most nearly fits the road section in question and then check the proper box.
>
> Good:
>
> A streamlined cross-section constructed to controlled horizontal and vertical alignment. Flat side slopes and broad ditches.
>
> Fair:
>
> A cross-section with sharp features. Excavated material is used to raise roadbed so snow will blow clear of surface. Steep side slopes and generally deep ditches.
>
> Poor:
>
> A cross-section with narrow, shallow ditches made by a few passes of a blade grader. Excavated material is spread across roadbed.

PW-hb-362

MUNICIPAL RURAL ROAD INVENTORY SHEET

DEPT. OF PUBLIC WORKS
HIGHWAYS BRANCH
PROVINCE OF MANITOBA

1. MUNICIPALITY of ________ Org. ☐ Disorg. ☐ Unorg. ☐
2. DISTRICT Nº. ________
3. EXISTING ROAD CLASSIFICATION:
   2. 100 % ☐ 3. Access ☐ 4. Secondary ☐
   5. Main Market ☐ 7. Local ☐
4. ROAD Nº. ________
5. SECTION Nº. ________
6. LOCATION from ________ to ________
7. LENGTH ________ Miles (to nearest tenth)
8. ODOMETER CORRECTION ________
9. CORRECTED LENGTH ________ Miles (to nearest tenth)
10. TERRAIN: 1. Flat ☐ 2. Other ☐ 3. Shield ☐
11. SURFACE TYPE:
    1. Earth ☐ 2. Gravel ☐ 3. Prime ☐
    4. Road Mix ☐ 5. Bit. Plant Mix ☐ 6. Concrete ☐

For Surface Types 3, 4, 5 & 6 only:

12. SURFACE WIDTH ________ Feet.
13. SURFACE CONDITION 1. Good ☐ 2. Fair ☐ 3. Poor ☐ 4. Bad ☐
14. BASE TYPE:
    1. Earth ☐ 2. Gravel ☐ 3. Stone ☐
    4. Lime Stab. ☐ 5. Asphalt Stab. ☐ 6. Asphalt Cement ☐
    7. Soil Cement ☐ 8. Concrete ☐
15. SHOULDER WIDTH ________ Feet.

16. EMBANKMENT WIDTH ________ Feet.
17. RIGHT-OF-WAY WIDTH ________ Feet.
18. GRADE LINE: Avg. Height from Prairie Level to Road Top = ________ Feet.
19. ALIGNMENT: Avg. Safe Speed = ________ M.P.H.
20. GRADIENT 1. Good ☐ 2. Fair ☐ 3. Poor ☐
21. DRAINAGE 1. Good ☐ 2. Fair ☐ 3. Poor ☐
22. CROSS SECTION 1. Good ☐ 2. Fair ☐ 3. Poor ☐ 4. Primitive ☐
23. Nº. OF BRIDGES ON THIS SECTION ________
24. Nº. OF R.R. GRADE CROSSINGS ON THIS SECTION ________

For Local Roads Only:

25. TYPE OF USE 1. Daily ☐ 2. Intermittent ☐
26. IS THIS ROAD MAINTAINED? 1. Yes ☐ 2. No ☐

Exclude Local Roads:

Type of Work:	Cost Factor: Low	Normal	High	None
27. RIGHT-OF-WAY	☐	☐	☐	☐
28. GRADING & DRAINAGE	☐	☐	☐	
29. GRAVELLING	☐	☐	☐	

30. REMARKS (Use Back of Sheet if Necessary) ________

31. PREPARED BY ________ DATE ________ 19____

Figure 1.

Primitive:

A cross-section with little more than two-wheel tracks. Little or no construction. No drainage.

* * *

Items 27, 28 and 29--General. First of all, assume that no road presently exists on the location of this road section just inventoried. Assume, secondly, that a new road is to be constructed on this same location and built to the design specifications of the STANDARD SECTION shown in Figure 3.

For conditions that are prevalent throughout the municipality within which this inventory road section is located, average quantities needed to build a new road have been estimated on a per mile basis. For the prevailing conditions in each municipality, normal quantities required for a TYPICAL MILE of new construction are listed in Figure 3.

Item 27. Appraise the right of way along the location of the inventory road section. Consider whether the value of land that would be needed for a new road is less than, the same as, or more than the normal cost per acre listed for the municipality in Figure 3. On this basis decide whether the cost for right of way is low, normal or high in comparison with the TYPICAL MILE. Accordingly, indicate low, normal or high by a check mark on the inventory sheet. The right of way cost may be considered normal unless it is estimated to be more than 20 percent lower or higher than the normal. If the cost for right of way is checked either "low" or "high," indicate under "Remarks" (Item 30) by approximately what percentage the land value departs from the normal. Check "none" if the right of way would be donated (as, for example, by the municipality).

Consider also whether the percentage of fence that would have to be moved is less than, the same as, or more than the normal percentage listed in Figure 3 and report this in Item 30 in a manner similar to that described for right of way.

Item 28. Compare the terrain and soil conditions along the location of the inventory road section with the prevailing conditions listed for the municipality in Figure 3. In this manner, consider whether the amount of grading that would be needed for a new road is less than, the same as, or more than the normal number of yards per mile listed in Figure 3. On this basis decide whether the total cost for grading is low, normal or high in comparison with the TYPICAL MILE. Accordingly, indicate low, normal or high by a check mark on the inventory sheet. The grading cost may be considered normal unless it is estimated to be more than 20 percent lower or higher than the normal.

Note: If the cost for grading is checked either "low" or "high," indicate under "Remarks" (Item 30) by approximately what percentage the amount of grading departs from the normal.

Item 29. Appraise the soil conditions along the location of the inventory road section and determine what depth of gravel surface would be required for a new road. Then estimate the amount of gravel per mile that would be necessary. Compare the actual soil conditions with the prevailing conditions listed for the municipality in Figure 3. In this manner, consider whether the amount of gravel that would be needed for a new road is less than, the same as, or more than the normal number of tons per mile listed in Figure 3. Consider also whether the haul distance for granular material is less than, the same as, or more than the normal distance listed in Figure 3. Combine the amount of gravel with the haul distance, and on this basis decide whether the total cost for graveling is low, normal or high in comparison with the TYPICAL MILE. Accordingly, indicate low, normal or high by a check mark on the inventory sheet. The graveling cost may be considered normal unless it is estimated to be more than 20 percent lower or higher than the normal.

Note: If the cost for graveling is checked either "low" or "high," indicate under "Remarks" (Item 30) by approximately what

percentage the amount of gravel and/or the haul distance for granular material depart from the normal.

Normal Quantity/Cost Evaluation

Figure 3 shows the standard section and a typical quantity sheet for normal construction of a completely new road, designed to the standard section. The amounts indicated for each (rural) municipality were estimated by competent engineers, based on average conditions in the municipality.

Rural municipalities in Manitoba average only about ten 36-section townships in area. Thus they are smaller than many U. S. counties. Coupled with the previously described broad uniformity of physical conditions in large areas of the province, the "average" condition in a municipality, therefore, ordinarily prevails for a large part of the mileage in the municipality. However, major deviations from normal, or average, conditions—even in one mile of roadway—were desirable to identify as indicated in Items 27, 28 and 29 of instructions.

The standard section was selected as the datum or base for quantity estimates because it was thought that the section represented a large mileage of construction need (it proved to be about 28 percent of the total), was not far below standards with which district engineers were familiar, and was midway in the general scale of standards (although it turned out that lower standards were suitable for 60 percent of the mileage).

The normal quantities (such as those indicated in Figure 3 for one highway district) depend, of course, on culture, land use, topography, soil and drainage conditions. Alignment standards (modified by terrain) also affected grading quantities, but generally were not a major factor except for short sections, usually at streams.

Gravel requirements (see Fig. 4 for 100-200 ADT) were based on 1,800 tons per mile for this standard section and the usual clay subgrades. Normal variations among municipalities did exist, however, depending on soil conditions; these were the variations recorded in Figure 3. Mile-by-mile variations (if more than 20 percent above or below the municipal amount) were noted in the inventory sheets (Fig. 1).

For each physical quantity indicated, district engineers were later asked for average unit prices applicable to each quantity in each municipality. Pricing and quantity determination were separated in order to obtain a more objective estimate of each. Unit prices were also checked against bid prices whereas unit (per mile) quantities were less readily available. The computer program, moreover, could calculate with reasonable accuracy grading, gravel, right-of-way acreage and fencing quantities, then calculate total costs.

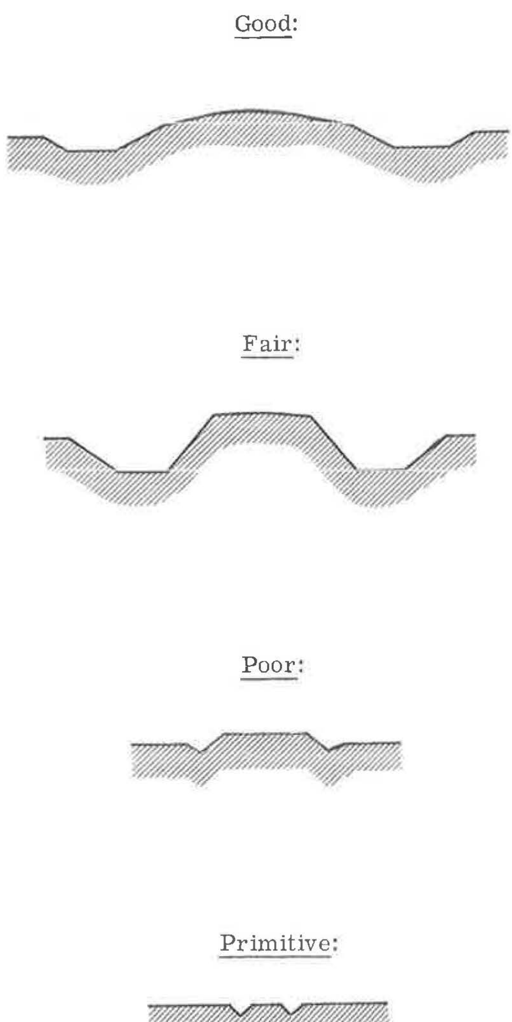

Figure 2.

FOR USE IN COMPLETING ITEMS 27, 28, & 29 OF THE ROAD INVENTORY SHEET

STANDARD SECTION

DESIGN SPECIFICATIONS

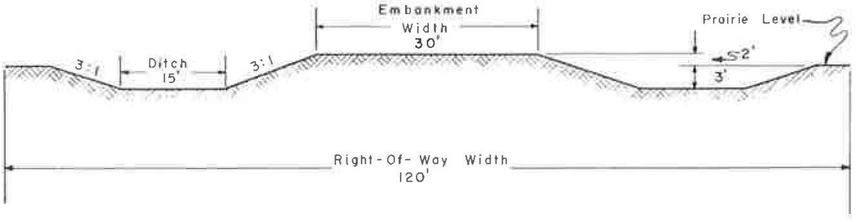

Table I

TYPICAL MILE

NEW CONSTRUCTION

District Nº. X

MUNICIPALITY	PREVAILING CONDITIONS		NORMAL QUANTITIES					
	Terrain	Type of Soil	R.O.W. Cost Per Acre	% Fence to be Moved	Grading Yds./Mi.	Drainage Cost Per Mile	Gravel Tons/Mi.	Gravel Haul Miles
1	Flat	Sand	$35	50	20,000	$ 700	1500	10
2	Rolling	Shale & Clay	$40	50	35,000	$2000	2200	10
3	Flat	Sand	$35	50	20,000	$1500	1500	8
4	Flat	Sand & Clay	$65	50	25,000	$1500	2000	12
5	Flat	Sand	$35	40	20,000	$1200	1800	8
6	Flat	Clay	$45	50	25,000	$1500	1800	5
7	Flat	Sand	$35	35	20,000	$ 700	1500	8
8	Flat	Clay	$45	60	25,000	$1500	1800	8
9	Rolling	Shale & Clay	$45	60	30,000	$1500	1800	14
10	Rolling	Clay	$60	60	30,000	$1500	1500	6
11	Rolling	Clay	$40	50	25,000	$1500	1800	10
12	Flat	Sand	$35	50	20,000	$1000	1500	5
13	Flat	Clay	$45	50	25,000	$1000	1500	6
14	Rolling	Clay	$45	50	25,000	$1000	1500	8
15	Flat	Sand	$35	40	20,000	$1000	1500	15
16	Flat	Sand	$40	50	20,000	$1000	1500	8
17	Rolling	Sand	$35	15	25,000	$1000	1500	10
18	Rolling	Clay	$45	50	25,000	$2500	1500	12
19	Rolling	Clay	$40	50	25,000	$1200	1500	10
20	Flat	Clay	$35	50	20,000	$1200	1500	10
21	Flat	Clay	$40	50	20,000	$1200	1500	8
22	Flat	Clay	$45	50	25,000	$1200	1500	10
23	Rolling	Sand	$40	40	25,000	$2000	1500	12

Figure 3.

DEPARTMENT OF PUBLIC WORKS
HIGHWAYS BRANCH
PROVINCE OF MANITOBA

DESIGN STANDARDS —— MAIN MARKET ROADS

STANDARD NUMBER	5	4	3	2	1
A.D.T. (Date + 15 Years)	under 50	50 - 100	100 - 200	200 - 400	over 400
SURFACE TYPE	Gravel	Gravel	Gravel	B.S.T.	pavement
SURFACE QUANTITY PER MILE OR WIDTH	1,200T	1,500T	1,800T	3,600T 20'	5,100T 22'
SUB-GRADE WIDTH	22'	24'	(1) 30'	(1) 32'	(2) 38'
GRADE LINE (Crown Elevation Above Prairie)	2'	2'	2'	$2\frac{1}{2}$'	$2\frac{1}{2}$'
R. O. W. WIDTH	99'	99'	120'	150'	150'
GRADIENT (Maximum)	10%	8%	7%	7%	6%
(3) ALIGNMENT - SAFE SPEED m/h	40	50	50	50	60
STRUCTURES					
LOADING	H-20	H-20	H-20	H20—S16	H20—S16
CLEAR WIDTH (Any Length)	24'	24'	24'	28'	28'
VERTICLE CLEARANCE	← 14' - 6" →				

—— NOTES ——

1 Reduce 2 feet for rolling or rocky terrain.
2 Reduce 4 feet for rolling or rocky terrain.
3 Reduce 5 - 10 M.P.H. for rolling or rocky terrain.

Figure 4.

DEPARTMENT OF PUBLIC WORKS

HIGHWAYS BRANCH

PROVINCE OF MANITOBA

DESIGN STANDARDS ____ LOCAL ROADS

Standard Number	9	8	7	6
ADT (No Traffic Growth)	0-10	10-50	50-100	100-200
ADT (100% Traffic Growth)	0-6	6-30	30-60	60-120
Criteria for Application	See "Local Road Analysis"			
Surface Type	Earth	Gravel	Gravel	Gravel
Surface Quantity per Mile	—	1,000T	1,200T	1,500T
Subgrade Width	18'	20'	① 22'	① 24'
Grade Line	—	1.5'	2.0'	2.0'
R.O.W. Width	—	99	99	99
Gradient (Maximum)	—	12%	10%	8%
Alignment (Safe Speed m/h)	—	30	② 40	② 50

NOTES

① Reduce 2 feet for rolling or rocky terrain

② Reduce 5-10 mph for rolling or rocky terrain

Figure 5.

Traffic Volume Estimates

The primary control for the actual design standard required on each Main Market road is the anticipated ADT, although some details are modified by terrain (Fig. 4). Existing ADT was determined by standard methods. However, the study design permitted some modification to reduce the number of locations counted.

Assuming a standardized 75 percent traffic growth in 15-20 years, the existing (1961) ADT that would characterize the future Main Market standard is as follows:

CODE SHEET
FOR
MUNICIPAL RURAL ROAD INVENTORY SHEETS

Card Control (1)	Municipality Number (2–4)	Mun. Type (5)	District No (6)	Exist. Class (7)	Future Class (8)	W. Mkt. Conn. (9)	Road Number (10–12)	Section Number (13–16)	Sub-Section (17–18)	Local Road Twp (19–20)	Local Road Rge (21–23)	Connected Mileage (24–26)	Terrain (27)	Surface Type (28)	Surface Width (29–30)	Surf. Condition (31)	Base Type (32)	Shoulder Width (33–34)
6	024	1	3	2	5	1	004	0110	—	—	—	010	1	3	20	2	2	04
6	024	1	3	2	5	1	004	0120	—	—	—	025	1	2	—	—	—	—
6	023	1	3	2	5	2	004	0130	—	—	—	128	1	2	—	—	—	—
6	023	1	3	2	5	1	004	0140	—	—	—	031	1	2	—	—	—	—
6	023	1	3	2	5	3	003	0302	01	—	—	005	1	2	—	—	—	—
6	023	1	3	2	5	3	003	0302	02	—	—	001	1	2	—	—	—	—
6	023	1	3	2	5	3	003	0101	—	—	—	007	1	1	—	—	—	—
6	023	1	3	2	5	0	001	0100	—	—	—	031	1	2	—	—	—	—
6	023	1	3	2	5	3	001	0200	—	—	—	010	1	2	—	—	—	—
6	023	1	3	2	5	0	001	0300	—	—	—	031	1	2	—	—	—	—
6	023	1	3	2	5	0	002	—	—	—	—	040	1	1	—	—	—	—
6	023	1	3	2	5	2	003	01	—	—	—	004	1	2	—	—	—	—
6	023	1	3	2	5	1	003	02	—	—	—	006	1	2	—	—	—	—
6	023	1	3	2	5	0	003	03	—	—	—	010	1	2	—	—	—	—
6	023	1	3	2	5	0	003	04	—	—	—	011	2	2	—	—	—	—
6																		
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Card Control (1)	Embankment Width (35–36)	R-of-W Width (37–39)	Height F to G (40)	Average Safe Speed (41–42)	Gradient (43)	Drainage (44)	Cross-Sect. (45)	Type of Use (46)	Maintained (47)	Cost Factors: Right of Way (48–50)	Cost Factors: Grade & Drainage (51–53)	Cost Factors: Gravel (54–56)	Average Daily Traffic (57–60)	Design Std (61)	Pole Lines (62–64)	65–80
6	28	099	2	30	1	1	1	—	—	127	100	100	0177	2	005	
6	34	180	5	50	1	1	1	—	—	100	075	070	0177	2	050	
6	34	180	5	50	1	1	1	—	—	100	075	070	0177	2	098	
6	30	150	5	45	1	1	1	—	—	100	100	060	0177	2	014	
6	26	099	6	40	1	1	2	—	—	100	100	100	0140	2	010	
6	24	066	0	20	1	1	3	—	—	130	100	100	0140	2	001	
6	25	099	6	30	1	1	1	—	—	100	100	100	0160	2	009	
6	18	099	8	35	1	1	2	—	—	100	100	100	0046	4	062	
6	18	099	8	35	1	1	2	—	—	100	100	100	0045	4	020	
6	18	099	8	35	1	1	2	—	—	100	100	100	0090	3	006	
6	22	099	5	40	1	1	2	—	—	100	100	135	0018	5	032	
6	28	099	3	20	1	1	2	—	—	125	100	065	0045	4	008	
6	24	066	2	35	1	1	2	—	—	050	100	070	0045	4	006	
6	24	066	2	35	1	1	2	—	—	050	100	070	0015	5	000	
6	22	066	4	30	2	1	2	—	—	0.50	100	075	0015	5	000	
6																
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Figure 7.

C. Calculate right of way costs:
   1. Compare existing ROW with standards.
   2. Multiply needed ROW width by unit cost ($ per foot per mile) and project length.
   3. Multiply percent fencing required by unit cost ($ per mile) and project length and add to ROW cost.
   4. Select cost adjustment factor and multiply.
   5. Multiply utility line mileage by unit moving cost ($ per mile).
   6. Add utility cost to ROW cost.
   7. Store and/or accumulate ROW costs.

D. Calculate surfacing costs:
   1. Compare present surface type with design standard (if grade was raised, skip this step).
   2. For type of surface required, obtain gravel factor and surface factor (zero for gravel surface) applicable.
   3. Multiply gravel factor by gravel cost ($ per mile).
   4. Multiply surface factor by surface cost ($ per mile).
   5. Select cost adjustment factor and multiply by cost and project length.
   6. Store and/or accumulate surfacing costs.

E. Output:
   1. Expand costs by applying factor for engineering.
   2. Write or punch tabulations of accumulated miles and costs.
   3. Punch cards showing inventory as on input, and various costs incurred for improvement.

Details of the actual computer program are not included in this paper. Copies may be obtained from the Planning and Design Division, Highways Branch, Manitoba Department of Public Works, Winnipeg 1, Manitoba, Canada. However, four types of special problems (A, B, C, D) are discussed because they required development of revised machine programs after study of initial runs.

Special Situations

A. The following corrections were inserted into the grading calculation program to handle the situations where either the existing height or width is greater than the standard. (See Fig. 8, with sketches of each following situation.)
   1. If the existing area is equal to or greater than the standard area:
      a. and existing height is greater than the standard height, the required grading area is the existing area above the standard area. (See also "B," following.)
      b. and existing width is greater than the standard width, the required grading area is that portion of the standard area above the existing area.
   2. If the standard area is greater than the existing area:
      a. and the existing height is above the standard height, the required grading area is that portion of the existing area above the standard area plus the calculated grading area (i.e., standard area minus existing area, which is in all instances determined prior to testing for these special situations).
      b. and existing width is greater than the standard width, the required grading area is that portion of the standard area above the existing area.

It was noted, by comparison of results obtained by using the original standards with those having the standards increased to the next higher group, that in certain cases the grade and drain costs did not increase for the increased standards, as would be expected.

SPECIAL SITUATIONS

GRADING AREA DETERMINATION

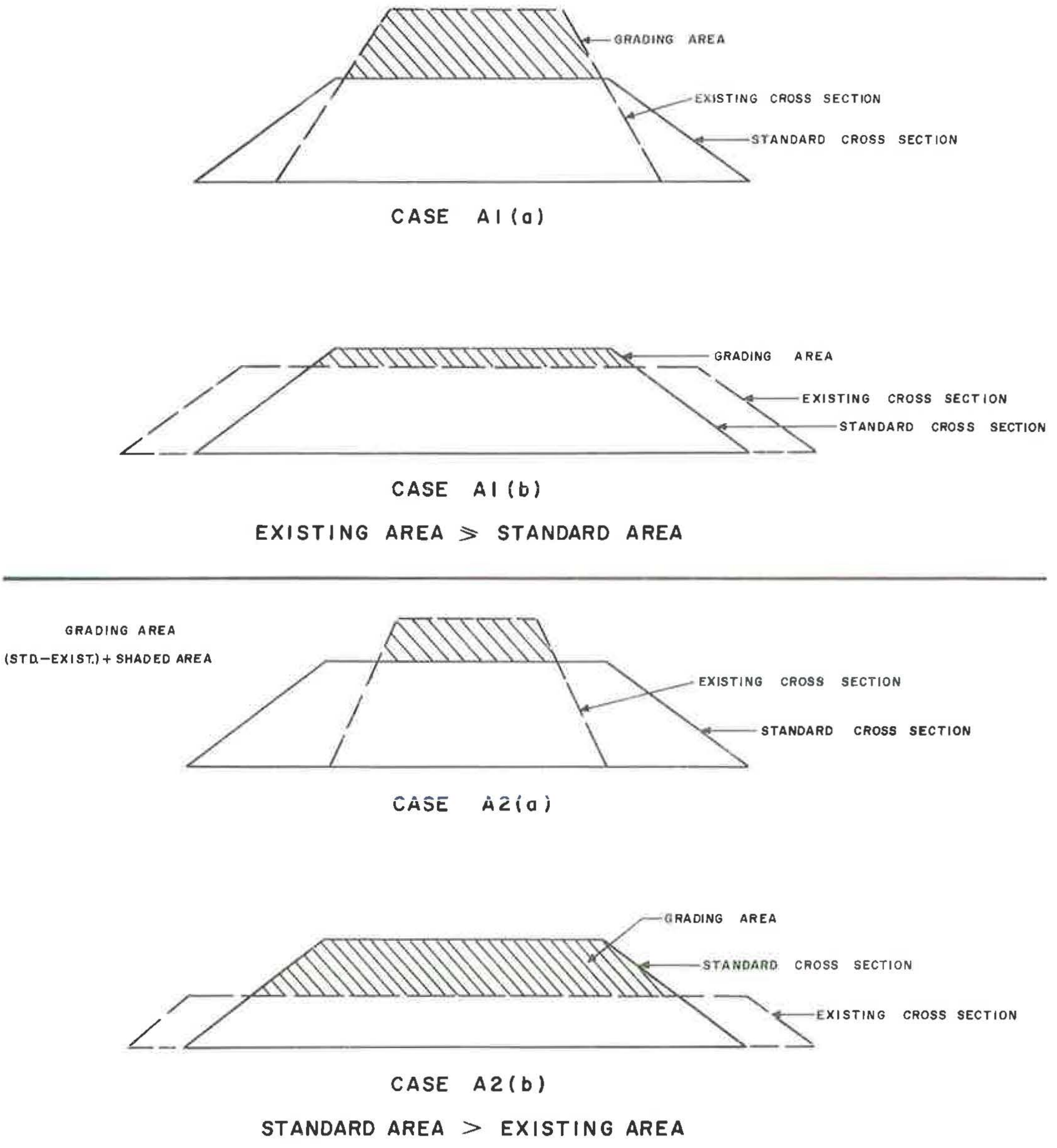


Figure 8.

This situation occurred in the cases where the existing area is greater than the standard, and the existing height is greater than the standard.

In these cases, even with addition of the above listed corrections, the program did not calculate the actual required embankment for the standard section, but instead calculated the existing area above the standard section. This calculation includes a certain amount of waste (which must be included in the cost determination), as well

as the required embankment quantity. In the case of the original standard, the calculation involves only a small part of embankment and quite a large portion of waste. By increasing the standard, the calculated grading area is decreased, even though the embankment quantities have increased, the waste material having become much less.

It should be pointed out, however, that in certain cases at least, this was not the only reason for the apparent decrease in costs after increasing standards. The following condition was mainly responsible for the greatest portion of the cost difference: Where the required grading quantities were light (within 50 percent of the design grading quantities), and gradient and drainage were coded "good," then only 50 percent of the standard drainage cost was used; however, should any one of the preceding conditions not exist, 100 percent of the drainage cost was used.

These problems required the development of special machine instructions as shown in "B," following. (See Fig. 9, with sketches of each situation.)

B. For the situation where the existing area and height are greater than the respective standards, two different possibilities may exist, assuming the two cross-sections are applied symmetrically for comparative purposes:
   1. Where the slopes of the existing cross-section intersect the standard cross-section along its top width,
   2. Where the existing cross-section completely envelops the standard, or the existing slopes intersect the slopes of the standard section.

In order to determine which condition exists, the "base width" of the existing section at the design height of the standard section must be calculated. This dimension, compared to the design width, categorizes the particular existing situation.

Where the base width is less than or equal to the design width (case B.1), the required grading area is calculated as being that area existing above the standard section (as stated in A.1.a, preceding).

Otherwise (for case B.2), the design width is, in effect, projected upwards to intersect the slopes of the existing section, that portion of the existing section above these intersecting points being calculated as the required grading requirements.

This procedure calculates a minimum of "waste area" as being a part of the actual grading requirements. By checking the extremities of this case, the calculated grading quantities will always be greater than the actual embankment demands necessary to meet the slope requirements of the design section, provided that a previously assigned stipulation, stating: "no grading required should the existing width be greater than 94 percent of the design standard width," remains in effect.

Further, in determining the applicable drainage costs, only the drainage and gradient are tested; whereas, should any condition other than the foregoing exist, then the required grading area is compared to 50 percent of the standard design area in addition to the above tests, in order to make this selection. Certain situations, involving a comparatively small amount of grading, such as for shoulder widening, would in actuality require higher costs than those incurred for normal grading operations. In order to provide for these higher costs, any required grading area which is less than a quarter of the Standard Design Area is increased by 25 percent.

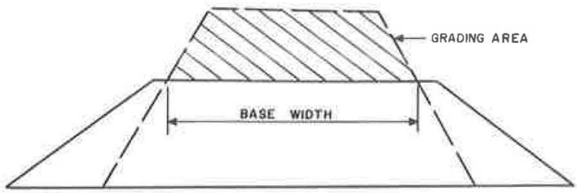
C. In some cases, roads having a paved surface are now in existence, but do not meet the required grading dimensions specified in the various standards (i.e., having more or less an urban cross-section). To eliminate the calculation of grading costs and thus re-paving costs, the program first identified paved roads and then canceled any further cost calculations.

While that was suitable for Manitoba situations, elsewhere this could be modified, for example according to observed pavement condition or width.

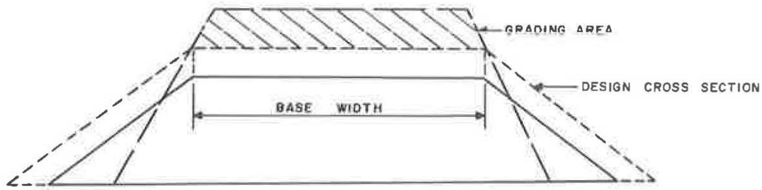
D. The cost-per-mile calculations were based on only the mileages corresponding to those roads <u>not</u> having zero total costs.

SPECIAL SITUATIONS

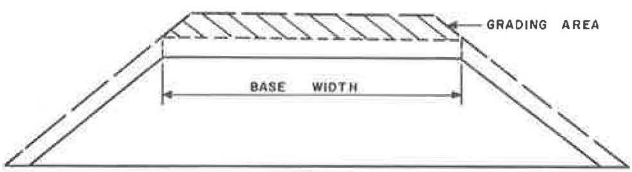
EXISTING AREA & HEIGHT
GREATER THAN STANDARD



CASE B1
EXISTING AREA SLOPES INTERSECT
TOP OF STANDARD AREA



CASE B2
EXISTING AREA SLOPES INTERSECT
STANDARD AREA SLOPES



CASE B2
EXISTING AREA COMPLETELY
ENVELOPES STANDARD AREA

Figure 9.

COMPARATIVE ANALYSIS

The method of needs analysis just described offers considerable opportunity for research into cost and other consequences of numerous variations in design standards. For example, in one rural municipality, the following results were easily obtained for the conditions existing on Main Market roads in that municipality.

1. For 41.4 miles of roads that should be developed to Standard No. 3 (see Fig. 4), the total cost to improve was $415,000 and averaged $10,000 per mile, ranging from $6,700 to $12,000.

2. The same mileage developed only to the next lower standard (No. 4) would cost only $63,000 (total for the municipality), averaging $6,600 per mile, ranging from $1,100 to $8,000 per mile, for the 9.6 miles on which any work was required. The remaining 31.8 miles already met or exceeded such a standard, whereas none of the mileage met Standard No. 3.

3. The same mileage developed to the next higher standard (No. 2) above No. 3 would require a total cost of $719,000, for an average cost per mile of $17,400—all mileage requiring work. Obviously, this was due mainly to heavier base and the bituminous surface treatment called for.

4. For the same mileage, and utilizing the original Standard No. 3 except for increasing the grade width from 30 to 32 ft (level terrain) the total cost was increased only $4,000, or an average of $100 per mile. Reducing the grade width from 30 to 24 ft cut total cost to $80,000 (only 19 percent of the basic cost), or to an average of $8,300 per mile for the 9.6 miles on which work was required.

5. Increasing the height of grade from 2.0 ft above surrounding ground to 2.5 ft increased cost about 2 percent, all other elements of the Standard No. 3 remaining the same. Reducing height made little difference.

* * *

6. Similarly, for 26.0 miles in this municipality that should be developed to Standard No. 4 (see Fig. 4), the total cost to improve was $189,000, for an average per mile cost of $7,600, excluding 1.2 miles on which no work was needed.

7. Reducing the standard to No. 5 dropped the total cost to $48,000, with an average cost per mile of $6,400 for the 7.5 miles that did not meet this standard.

8. Raising the standard to No. 3 would increase the cost to $247,000 or 32 percent, to an average cost of $10,000 per mile.

9. Utilizing Standard No. 4, except for increasing grade width from 24 to 30 feet, increased cost by 8 percent. Reducing the width, from 24 to 22 feet, cut the total cost from $189,000 to $54,000, and cut the average per-mile cost by 9.5 percent for the 7.5 miles that did not meet the 22-ft standard.

10. Increasing height of grade by 0.5 ft increased cost of Standard No. 4 by about 2 percent. Cutting height by 0.5 reduced costs by 7 percent.

Various elements of cost detail differentials may also be analyzed. For example, right-of-way requirements for the preceding example, items 1-4 inclusive, varied from the Standard No. 3 amount of $76,000 down to $5,000 for reduction to Standard No. 4 (only 9.6 miles of work needed); up to $91,000 for increased width required for Standard No. 3; no change for 2-ft grade width increase; and down to $15,000 for 6-ft grade width reduction.

Variations in grading, drainage and surfacing costs can be determined similarly for each standard group in each municipality, for each individual road section, for the totals of all roads in the municipality, highway district and the province (or state) as a whole.

Thus, it is possible to know quickly and reasonably accurately what standards can be provided with anticipated funds per road, per class of roads, per municipality, etc. In developing a feasible finance plan, the possible consequences in terms of physical development can be analyzed speedily. For more fundamental research, the economics of standards related to existing status of a road system can be developed with concomitant study of benefits provided. Further study would be required, however, concerning the effects of varying design standards on maintenance costs and salvage values.

For the proposed (reclassified) Main Market Road System in Manitoba, totaling about 12,700 miles, some results of the study, in percentage terms, are given in Table 1.

For about two-thirds of the "desirable standard" cost (for roadway improvements only), by 1982 some 58 percent of the system would be only light gravel on a 22-ft subgrade (Standard No. 5), compared to 9.6 percent of such roads if the full recommended expenditures were made (Table 1). Similarly, the lowered cost would permit about 4 percent of the system to be bituminous surface treated or paved (Standard Nos. 1 and 2), compared to 13.4 percent with desirable standards. Under the lower standards, about

TABLE 1

COMPARISON OF TWO ALTERNATIVES

Item	Desirable Standards	Standards Lowered*	
	Miles (%)	Miles (%)	
1982 status:			
Standard No. 1	2.5	0.8	
Standard No. 2	10.9	3.2	
Standard No. 3	28.5	9.3	
Standard No. 4	48.5	28.5	
Standard No. 5	9.6	58.2	
Total system	100.0	100.0	
Work required:			
None	10.0	26.7	
Surface only	2.8	2.8	
Grade, drain and surface	87.2	70.5	
Total system	100.0	100.0	
	Percent of Total	Percent of Total	Percent of Desirable
Roadway cost:			
ROW	11.1	6.3	38.2
Grade	58.7	69.2	38.2
Surface	30.2	24.5	54.0
Total needs	100.0	100.0	67.7

*Each traffic class improved (if needed) to a standard one level below the desirable standard (see Fig. 4).

26.7 percent of all roads already meet them and would require no improvements, if properly maintained, as compared with only 10 percent for desirable standards.

CONCLUSION

The flexible analysis of municipal road needs in Manitoba has demonstrated the practicality and utility of the method in areas which are relatively uniform in topography, soils, traffic and other physical conditions, and where reasonably uniform standards are applicable to substantial mileages.

As compared with past methods of field estimation, or with mass statistical estimating, it is believed that this newer method provides greater accuracy and considerable economy. These are obtained through centralized control of decisions, machine computation, and less use of engineering time—substituting technicians wherever possible. The objectives outlined at the beginning of this paper were fully achieved, including that of detailed data and cost applicable to each road section for future planning purposes—as distinguished from mass statistics, which were also obtained.

While alternative costs for alternative designs are the usual practice for individual projects, especially of the more complex nature, the computer program developed for this study now permits a wide range of alternatives to be studied. Consequences of possible decisions, in detail and on a broad scale, can be determined quickly. The data thus made available can provide better bases for objective research on standards which can lead to better understanding of development needs, and the improvements in fiscal programs.

This type of needs study will lend itself to upgrading and improvement as more complete information becomes available, and as further experience is obtained in its use over the years.

Appendix

The information contained on the municipal Header card and the units in which it is expressed is as follows:

	ITEM	UNITS
1.	ROW costs	\$/ft-mile
2.	Percent fenced	Percent
3.	Grade cost	\$/sq ft-mile
4.	Drain cost	\$/mile
5.	Gravel cost	\$/mile
6.	Grading quantity factor	

The grading quantity in "yd/mile" was obtained for the Standard Section (Fig. 3) to represent the normal quantities for each municipality. These quantities are reflected on the municipal Header card in the form of factors having 20,000 yd as a base (i.e., 30,000 yd = 1.50) which corresponds to the design quantity required for the Standard 3 specifications. For other standards, this base factor would correspond to either larger or smaller grading quantities dependent upon the appropriate standard dimension describing the cross-section.

For Standard 3, for example, the grading quantity for a completely new section would be

$$\text{Height (width + slope} \times \text{height)} \times \text{compaction factor} =$$
$$2\,(30 + 3 \times 2) \times 1.42 = 102.3 \text{ sq ft} \times 5{,}280/27 = 102.3 \times 195.5 = 20{,}000 \text{ yd/mile.}$$

Similarly for Standard 1, width = 38 ft and height = 2.5 ft, the grading quantity for a new section would be

$$2.5\,(38 + 3 \times 2.5) \times 1.42 = 161.5 \times 195.5 = 31{,}600 \text{ yd/mile.}$$

For a particular municipality, for which it is reported (see Fig. 3) that the normal grading quantity is 20,000 yd/mile, the grading quantity factor would be 1.00, which in the case of the Standard 1 specification would correspond to an actual grading quantity of 31,600 yd/mile; or for the Standard 5 specification, corresponds to 15,500 yd/mile.

As previously noted, the grading costs are coded in units of \$/sq ft-mile. For a municipality in which the average grading cost is reported to be 0.20¢/yd, this would be coded as cost/yd × 5,280/27 = 20 × 195.5 = \$39/sq ft-mile.

In the actual grading cost determination for a particular deficient road, in each case the appropriate design standard area is calculated, from which is subtracted any existing area to arrive at the needed grading quantity. By multiplying this required grading area by the grading quantity factor for the municipality, the header data are reflected in the results for each particular road.