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Foreword

Five of the six papers contained in this Record were presented at the 43rd Annual Meeting of the Highway Research Board in January 1964; the sixth was given at the 44th Annual Meeting the following year. Broad in geographical scope and inclusive in subject range, all of the papers bring up penetrating questions and then outline the procedures for obtaining and applying the answers.

"Sufficiency Rating by Investment Opportunity" by Evan H. Gardner and James B. Chiles outlines the computer-processing techniques for implementing the philosophy (set forth by Gardner in an earlier paper) that each alternative for improvement of a deficient highway section can be evaluated as an investment opportunity capable of yielding a specific rate of return in terms of congestion dollars.

The testing of a priority formula for programming urban arterial street improvements is described in the paper by Edward Hall and C. Dwight Hixon. These two men devised their formula from a six-year study of three cities. Recognizing that no formula is wholly adequate to the solution of specific problems in individual cities, the authors urge further testing and refinement of the tool they offer.

In "Multiple Project Scheduling of Preconstruction Engineering Activities," Marshall F. Reed, Jr., and R. E. Futrell approach the priority array of programmed projects in terms of allocating the fixed pool of classified manpower resources for a predetermined time interval or "balance period." The application of the science of multiple-project scheduling to the field of highway programming has significance for all units within a highway department.

A computer program to determine what highway design standards can be provided with anticipated funds is outlined by James B. Granum and Ronald M. Gordon in "Flexible Highway Analysis of Highway Needs in Manitoba." From the data provided on the consequences of alternative decisions, further research into the economics of standards as related to the existing status of a road system can be developed.

R. O. Kipp and W. T. Lussky describe the computer program used for a continuing trunk highway needs study in Minnesota—a study which is designed for periodic revision to take into account changes in design criteria, traffic data, and cost factors without disrupting the remaining basic information.

Also concerned with the need to furnish highway administrators with current information on time, cost, and physical performance of the highway program is the paper by D. G. Malcolm and D. R. Earich entitled "Development of an Integrated Management System." This paper stems from a West Virginia State Road Commission program to improve its planning, programming, scheduling, and control of operations in engineering, right-of-way, and construction through use of the Critical Path Method. It refers mainly to the second phase of the study which describes the system and the results achieved in its application to the Interstate program, but also outlines the accomplishments of Phase I in defining the overall highway program objectives and devising the management system.

As these brief reviews suggest, electronic data processing plays an essential role in virtually every phase of highway planning and programming. Yet each of the papers suggests that the computer is no substitute for informed personal judgment. Indispensable as the machine has become in meeting the enormous challenge of providing adequate highway systems, even more indispensable is the final individual decision based on experience, wisdom, and even intuition.

Contents

Sufficiency Rating by Investment Opportunity

EVAN H. GARDNER and JAMES B. CHILES
Respectively, Director and Acting Assistant Director, Bureau of Economic Research and Programming, Pennsylvania Department of Highways

Limitations to the sufficiency rating technique originally (2) proposed by the U. S. Bureau of Public Roads in 1948, and its many modifications by state highway departments in the ensuing decade (3) led to the formulation in 1958 of rating sufficiencies by the more objective method of obsolescence by calendar dates (1) as contrasted to subjective obsolescence points, and further proposed priority within a calendar year as a ratio of the time value of congestion which could be alleviated by the cost of making the improvement which would remove that amount of congestion.

Evolution of that philosophy since the original paper (1) recognizes that multiple alternatives are always available for improvement of any highway, and that each alternative is an investment opportunity yielding its peculiar rate of return in congestion dollars saved to the user for his dollars spent in the investment. The alternative yielding the greatest acceptable incremental rate of return (see text) is the best investment opportunity for that individual road section, and the rate of return on this optimum improvement is the measure of insufficiency of the highway, with zero percent being totally sufficient (resurfacing and reconstruction in kind being considered maintenance) and larger rates of return being proportional degrees of insufficiency.[1]

•MOST state highway departments and some local highway agencies derive their operating capital from the road users, either directly or from borrowings eventually refunded by the road users. This operating capital takes the form of taxes on gasoline, vehicle licenses, operator licenses, etc., and is usually dedicated to highway operations. Instead of paying taxes, then, the road user is buying capital stock in a utility, and the "plant" is the highway system.

A portion of the operating capital must be used in maintaining the plant in perpetuity. Such a static system is a tenable concept; generally, however, operating capital exceeds the amount necessary for maintenance, and the excess is used in making capital improvements to the plant (the highway system). Since the excess is obviously a capital investment, it is incumbent on the Board of Directors (the administrative agency) to invest soundly so as to yield the greatest profit to the "corporation of stockholders," the highway users. Dividends on these capital investments derive from time savings and decreased operating cost to the highway user, costs which otherwise he is paying out of pocket in addition to in-perpetuity maintenance costs. Thus, a unique corporation exists wherein the road user is both stockholder and consumer. Furthermore, in this concept the road user as a stockholder loses his indentity as an individual, and becomes unidentifiable in the corporation of total highway users.

[1] The term "sufficiency" as used in most other rating methods is relative, and would more factually be called insufficiency. The authors propose that a more objective understanding of sufficiency rating numbers would be obtained by subtracting the adjusted sufficiency number from 100, and designating it the insufficiency rating. Thus, a very poor road having a -sufficiency of 25 points would have an insufficiency of 75 points. The inversion, however, does not aid in definition of the insufficiencies (4).

Paper sponsored by Committee on Highway Programming and presented at the 43rd Annual Meeting.

The following principles are to be drawn from this concept:

1. The existing plant is to be preserved in kind, unless capital improvements will amortize their cost and yield a profit on the investment.
2. Capital improvements yielding the highest profits are to be preferred.
3. No capital improvement should be made which yields less profit than the "stockholder" can realize on another investment, i.e., U. S. Savings Bonds, insured savings accounts, and stock in some other corporation.

The means of implementing the foregoing principles were substantially presented in a previous paper (1). Subconsciously, the techniques contained therein had their axioms founded on the above philosophy. A greater consciousness of the philosophy has produced a truer application than is found in the original paper.

REVIEW OF "THE CONGESTION APPROACH TO RATIONAL PROGRAMMING"

A method of rational programming which emphasized structural failure and degree of congestion as the criteria for priorities in the programming of improvements to highways was presented in HRB Bulletin 249 (1).

In summary, the method forecasts the calendar year of structural obsolescence of the highway, and the calendar year of the functional obsolescence of that highway. The two dates do not necessarily coincide. When structural obsolescence occurs prior to functional obsolescence, the year of improvement is the year of structural obsolescence, so as to preserve the previous investment in that roadway. Should the functional obsolescence year precede the structural obsolescence year, a choice exists: to do nothing and allow congestion to pyramid until the structural obsolescence year, or to improve the highway immediately to alleviate congestion, possibly sacrificing the residual structural life. In either case, the alternatives[2] can be analyzed to determine the optimum improvement and the year in which the optimum improvement should be accomplished. By sorting of improvements within calendar years, a listing is made, first of those projects structurally obsolete (which are a must priority), then of the functionally obsolete projects, listed in descending values of a relationship between amount of congestion relieved and the cost of the improvement. Thus is established a priority listing, a needs study, and, with a strike-off point determined by available funds, a program.

In further summarization, structural obsolescence is forecasted by use of road life studies adjusted by empirical corrections based on traffic and truck volumes.[3] Functional obsolescence is forecasted as the year in which expected traffic volume equals the capacity of the highway at a desired level of speed. Congestion delay is determined as the difference in time between the desired rate of speed, and the speed as reduced by the excessive volume of traffic using the highway. It is calculated for only those hours of the day during which congestion occurs and accumulates during the years when the highway remains unimproved or partially improved, starting with the year of functional obsolescence and extending through the study period. Congestion delay cost is estimated by translating congestion delay hours by some acceptable value of time.[4] It is a road user cost which, if alleviated, becomes a road user benefit.

The previous paper would have determined a priority "number" by dividing the congestion delay cost by the improvement cost to alleviate the greatest amount of congestion by the least number of dollars. In early stages of testing, it was learned that using the alternative yielding the highest ratio, and therefore the greatest rate of return, often failed to reduce congestion cost to desirable levels.

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[2] The original paper would have considered only one method of reconstruction, e.g., widen to 24 feet, or construct 48 feet. In this paper, all increments of improvement are considered.

[3] A promising tool for more accurate forecasting of road life is the Present Serviceability Index developed from the AASHO Road Test.

[4] The cost of time saving recently proposed by Dan G. Haney of Stanford Research Institute holds promise of being a less empirical and less fluctuating measure and will be tested in future evaluations of the authors' philosophy.

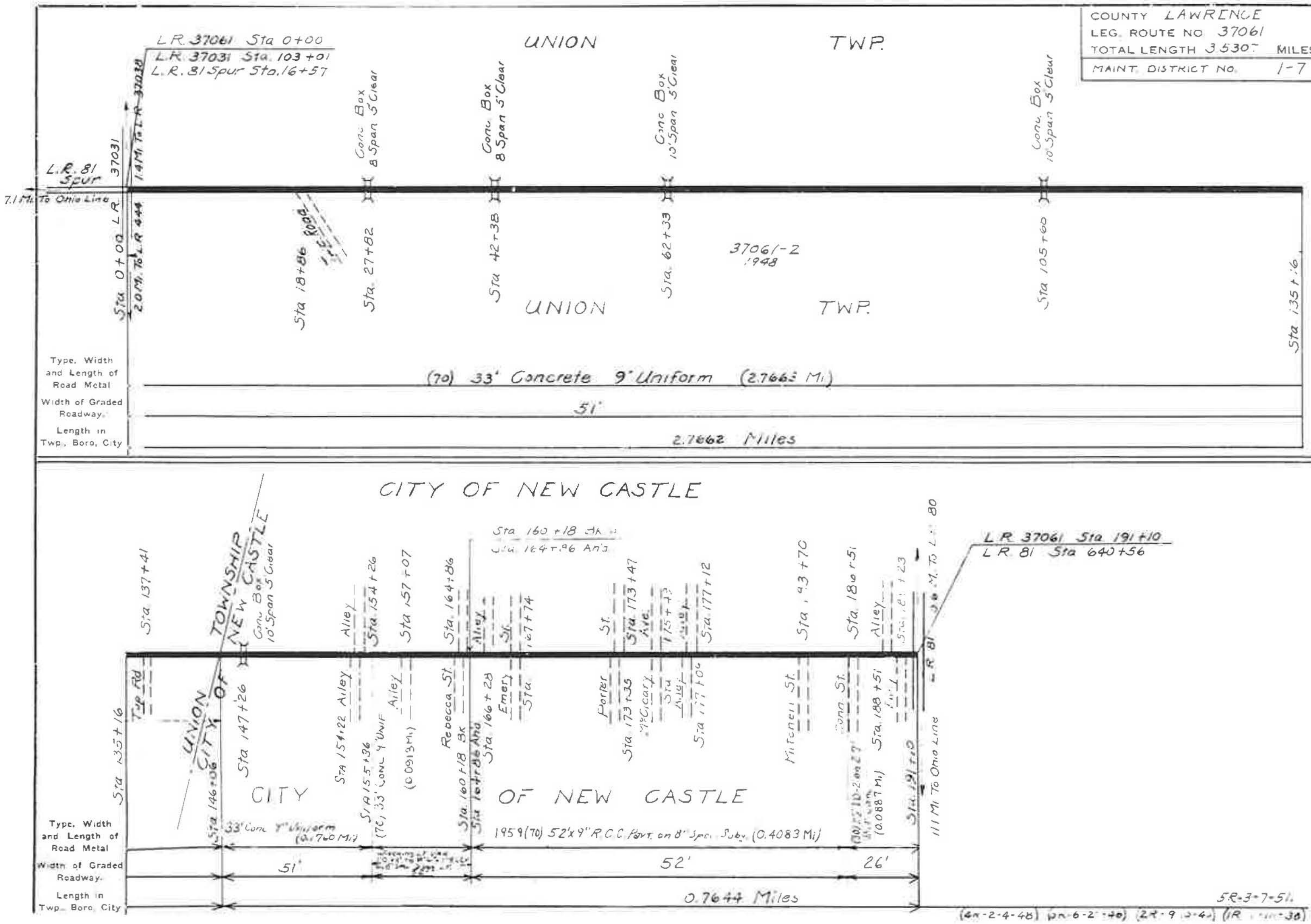

Figure 1. Original scale 1 inch = 1,000 ft (in boro or city 1 inch = 500 ft).

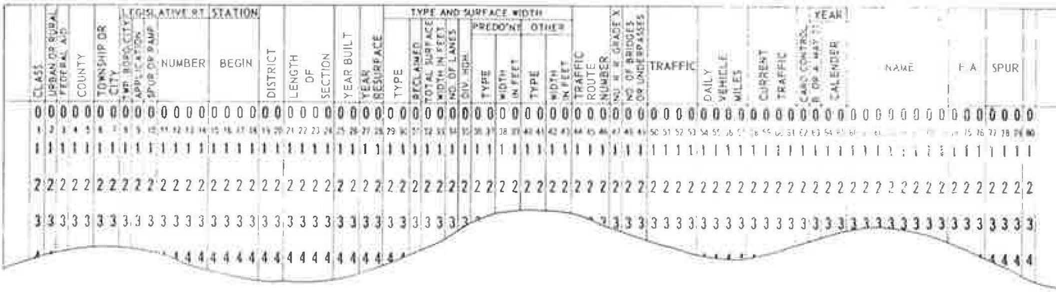

Figure 2. Road log.

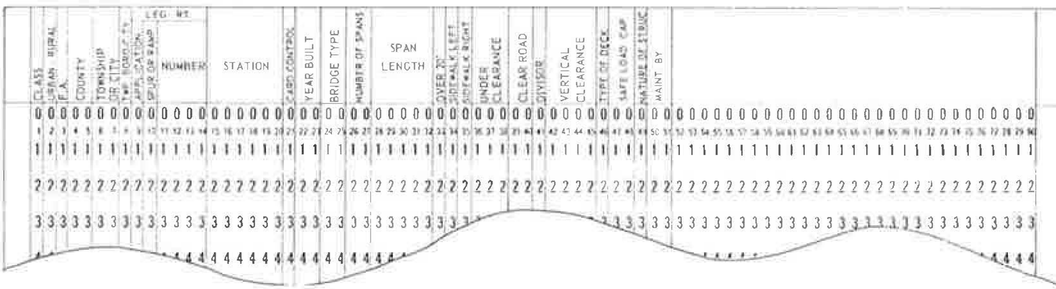

Figure 3. Bridge log.

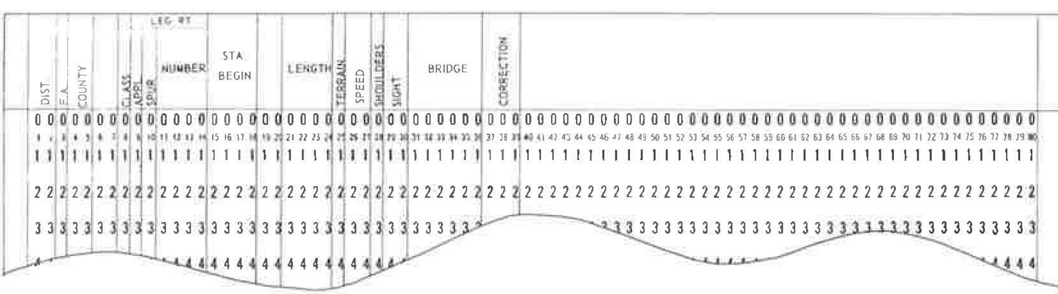

Figure 4. "210" Study.

Use of the approximate rate of return and incremental rate of return for comparison of alternates and ordering of investment priorities was subsequently adopted.

It is the purpose of this paper to demonstrate the implementation of these philosophies into the tool being given its District Engineers by the Pennsylvania Department of Highways to evaluate its plant, determine its needs, program its maintenance, and schedule its investments. Explanation by demonstration is deemed the best method of presentation.

With more than 42,000 miles of State highway system, comprising over 70,000 road "sections" to be analyzed, and each analysis requiring some 5000 mathematical operations and decisions, it is quite understandable that electronic data processing is used. It is also understandable that the process made possible by electronic computers of the vintage of the IBM 650 also made that vintage obsolete. The multiple passes described in the following pages are necessary because of the primitive brain of the 650 computer. The sophisticated brain of the 7040 computer would be capable of accomplishing the task in one operation if it were intelligent enough to verify field conditions. As it is not, there will be an irreducible "two pass" operation until our scientists evolve an omniscient computer.

ADAPTATION OF PHILOSOPHY TO COMPUTER PROCESSING

The source of the raw data for processing to rational priorities is as follows:

The department maintains an inventory of all highways under its jurisdiction. The original record is on straight line diagrams (Fig. 1) which show certain physical data for the highway as though its centerline were a continuous straight line; that is, change in curvature and grade are not shown. Pertinent data from the straight line diagrams have been transferred to IBM cards (Fig. 2) designated as Road Log cards. Similarly, an inventory of all bridges is maintained on punched cards, giving geometrics, safe loads and other pertinent data (Fig. 3). Certain raw data necessary to calculating capacities of the highway sections were obtained from a statewide study of highway needs made in 1956 in accordance with the provisions of Section 210 of the National Defense Highway Act of 1956 and known as the "210 Study." The specific items are sight distance, shoulder width, terrain, and design speed. Designated as "210 Cards," a sample is shown in Figure 4. Tables of road life expectancy derived from the Road Life Studies, highway capacities, and daily traffic increase forecasts constitute other sources of raw data.

SUMMARY OF PROCESSING

Because of the large number of arithmetic operations, the 2,000-word storage capacity of the IBM 650 was exceeded several times, requiring multiple passes on the computer. The first pass basically computes the structural and functional obsolescence dates of the road section and is designated Phase I.

In Phase II, tabulations of the outputs from Phase I are taken into the field for verification of various elements of the output. Available widths for widening and any deviations from the raw data are coded on forms for keypunching as partial input for Phase III.

Phase III analyzes multiple alternatives for improvement to the road section and selects the optimum improvement. The 2,000-word capacity of the computer was again too small for the analysis, and it was found necessary to separate the input cards into urban and rural road sections. Thus we have Phase III—Rural and Phase III—urban. The outputs of these are recombined into sequential sections of the respective routes.

Phase IV is a tabulating machine operation in which the optimum improvements are listed in straight line diagram format.

A manual combination of road sections into construction project lengths is made on the straight line diagrams, and keypunched as Phase V.

Phase VI uses the project card to direct the computer to select the designated alternative from each contained highway section and to accumulate the facts making up the combined economic analysis. The output of Phase VI is a punched card for each proposed construction project, containing the identification, type of improvement, year of need, initial cost, system, approximate rate of return, average annual congestion if no improvements were made and average annual congestion relieved by the improvement proposed.

Phase VII, a non-computer operation, sorts the construction project cards to produce multiple forms of tabulations, among which are total needs by calendar years; needs by systems; needs by county and highway district; and programs by years, by system, by county, by district.

Summarized, the operations (phases) are as follows:

I. Determine obsolescence dates
II. Recompute I as corrected by field observation
III. Reconcile obsolescence dates to determine economics of all possbile alternatives
IV. List optimum improvements in sequential sections
V. Combine road sections into project sections manually
VI. Compute economics of project sections

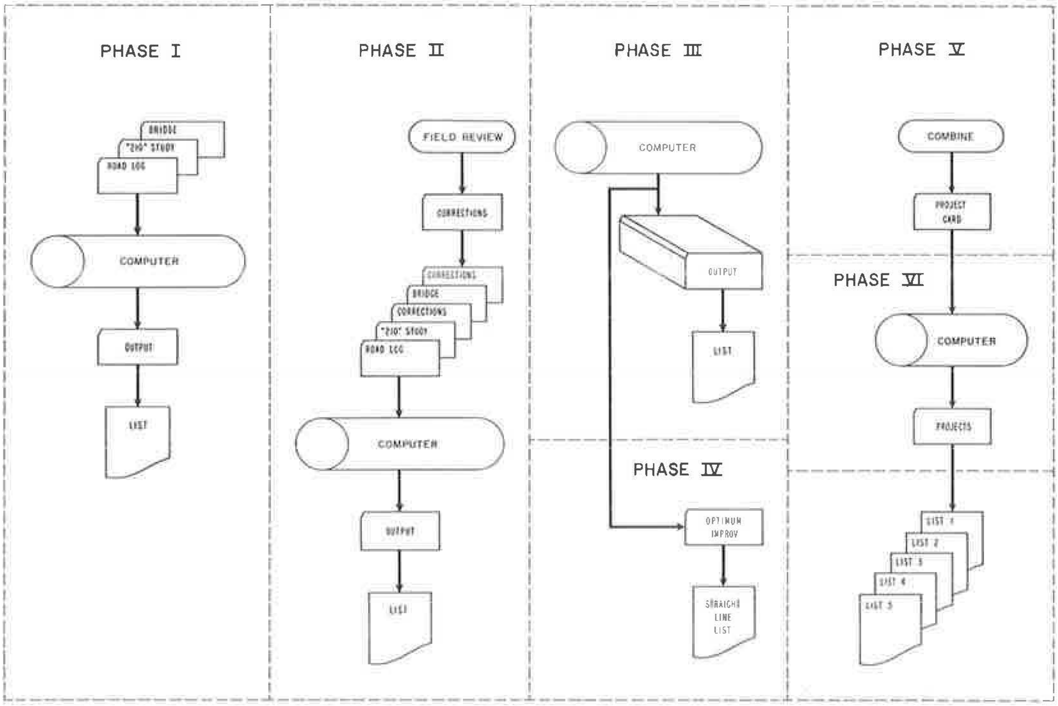

Figure 5.

VII. List arrangements into any format desired.

The graphic flow chart of these operations is shown in Figure 5.

METHODOLOGY

Phase I: Obsolescence Dates

The raw data of Road Log, Bridge Log, and 210 Study (Figs. 2, 3 and 4) are fed to the computer. The computations made will be explained as the output is described. Refer to Table 1 for the following explanation:

The columns headed LEGISLATIVE ROUTE, STATION BEGIN, and MILES LENGTH designate the legislative route number, the survey station number to the nearest 100 feet and the length of the section to the nearest one-hendredth of a mile. If the road section is part of a traffic route, the traffic route number is designated in that column. This combination of data locates and identifies the road section. The FUNCTIONAL CHARACTER is a single letter designation which indicates political subdivision B, C, F or S for borough, city, first class township or second class township, respectively. The column NAME gives the municipality in which the section occurs.

The next eleven sets of columns indicate inventory items for the section, and are successively year built, year resurfaced, paved width, paving material coded for type and total thickness, number of traveled lanes, divided or nondivided highway coded to indicate characteristics of the divisor and access control, annual average daily traffic for 1962 (variable with the year of the study), minimum shoulder width, type of terrain traversed, design speed and percent of 1,500-ft sight distance.

The computed obsolescence dates are shown in the next two columns: STRUCTURAL and FUNCTIONAL. The road system is next indicated, and the computed capacity, for use in Phase III, is shown in column CAPACITY.

Thus, reading the first line of data, the road section is on legislative route 79, beginning at station 0 having a length of 2.76 miles carrying Traffic Route 25 located in Second Class Union Township, was constructed in 1948 and has not been resurfaced (00). It has a paved width of 33 feet and is Type 70 (portland cement concrete). Three moving lanes of traffic operate on it. It is not divided and has no access control (0); and in 1962 it carried an average daily traffic of 6,100 vehicles. The minimum shoulder (right or left) is 0 feet; it traverses flat (F) terrain, has a design speed of 40 mph, and 40 percent of its length has at least 1,500-ft sight distance. Structurally, as calculated from road life curves, the section will require major repair in 1971. The functional obsolescence date (the date when the capacity of the section will constrain the using volume of traffic to travel at less than 50 mph) will occur in the year 1963. It is on the Federal-aid primary system, and its capacity at the legal speed of 50 mph is 0 vehicles per hour.[5]

Phase II: Field View

The structural obsolescence date calculated in Phase I is a "paper" value, and must be verified in the field. Visible failure of the surface and/or base is the authority for changing a calculated later date to an earlier date. Conversely, non-visible failure is the authority for changing an early calculated date to a later estimated one. Since the immediate objective for Pennsylvania was a 6-year program, the calculated date and the observed condition were supplemented by the question "Will this road require major structural attention before 1969?" If the answer to that question was "yes", and the calculated date was post-1968, the calculated date was changed to an estimated date between 1963 and 1968. If the question was answered "no," the calculated date was changed to 1970, anticipating another field view in 1970. Any calculated dates not falling into these two categories were held firm.

As part of the field view, the width of right-of-way available without abnormal acquisition or construction costs was recorded longhand as shown in Table 1. It is used in Phase III as the maximum widening feasible.

Also in the field view, the type of urban area and parking restriction was entered longhand, e.g., "CBD-no parking," "CBD-one way parking one side," and "Intermediate-Parking Allowed." Any change of a rural to an urban character was also noted, all in the column URBAN (Table 1), these items being intimately associated with capacity, hence functional obsolescence.

As a final element of the field view, a check was made of all other items in Table 1 for obvious errors, and corrections entered as shown.

Corrections and additions were coded, keypunched, and designated "Corrections Card."

Phase III: Alternatives for Reconstruction

Phase III analyzes the economics of successive alternatives for the maintaining and improving of the individual road sections and selects the optimum. The corrections cards, road log cards, 210 cards and bridge log cards, merged, become the input to Phase III. Again, the process is best explained by discussing the output of Phase III.

Identification of the road section must be carried over to the Phase III output (Table 2) thus:

Legislative Route	Station	Miles	System
79	0	2.76	FAP

duplicating the corresponding information in Table 1.

The first "improvement" is always to do nothing other than to preserve the existing condition. For this section the do-nothing (NULL) is to resurface the section when it becomes structurally obsolete in 1971 at a cost $119,000 showing in the tabulation thus:

[5] For this design speed and sight distance, travel speed is below 50 mph, hence the capacity at 50 mph is zero.

TABLE 1

PHASE I OUTPUT

LEGISLATIVE ROUTE	STATION BEGIN	MILES LENGTH	TRAFFIC ROUTE	FUNCTIONAL CHARACTER	NAME	YEAR BUILT	YEAR RESURFACE	WIDTH	TYPE	LANES	DIVIDED	ADT 1962	SHOULDER LOAD	TERRAIN	DESIGN SPEED	SIGHT DISTANCE	STRUCTURAL OBSOLESCENCE	FUNCTIONAL OBSOLESCENCE	SYSTEM	CAPACITY	AVAILABLE RIGHT OF WAY	URBAN
79	0	2.76	25	S	UNION	48	00	33	70	3	0	6100	0	F	40	40	71	63	FAP		UNL	
79	146	.18	25	C	NEW CASTLE	48	00	33	70	2	0	10900	0	R	45		~~63~~ 70	63	FAU	257	33	Outlying Urban Park All'd
79	155	.09	25	C	NEW CASTLE	48	00	34	70	2	0	10900	0	R	45		~~65~~ 70	63	FAU	264	34	
79	165	.41	25	C	NEW CASTLE	59	00	52	70	4	0	10900	0	R	45		80	63	FAU	407	52	
79	187	.09	25	C	NEW CASTLE	48	00	27	30	2	0	10900	0	R	45		~~63~~ 70	63	FAU	232	27	
79	192	.63	25	C	NEW CASTLE	30	57	30	60	2	0	14170	0	R	40		73	63	FAU	232	30	Outlying Urban No Park
79	225	.08	25	C	NEW CASTLE	07	54	40	60	2	0	~~1200~~ 14170	0	F	25		~~76~~ 70	~~10~~ 63	FAU	309	40	
79	229	.19	25	C	NEW CASTLE	34	54	46	60	3	0	~~1200~~ 14170	0	F	35		~~76~~ 70	~~10~~ 63	FAU	356	46	CBD No Park
79	239	.13	25	C	NEW CASTLE	34	54	40	60	2	0	~~1200~~ 14170	0	R	35		~~76~~ 70	~~10~~ 63	FAU	309	40	
	240	1.45			BRIDGE			40														
79	246	.02	25	C	NEW CASTLE	33	54	40	60	2	0	14170	0	R	35		70	63	FAU	309	40	CBD Park
79	247	.08	25	C	NEW CASTLE	33	54	38	60	2	0	14170	0	R	35		70	63	FAU	294	38	Outlying Urban Park
79	251	.03	25	C	NEW CASTLE	33	60	36	60	2	0	14170	0	R	35		76	63	FAU	279	36	
79	252	.35	25	C	NEW CASTLE	33	60	36	60	2	0	12320	0	R	35		76	63	FAU	279	36	

TABLE 1
(Continued)

LEGISLATIVE ROUTE	STATION BEGIN	MILES LENGTH	TRAFFIC ROUTE	FUNCTIONAL CHARACTER	NAME	YEAR BUILT	YEAR RESURFACE	WIDTH	TYPE	LANES	DIVIDED	ADT 1962	SHOULDER LOAD	TERRAIN	DESIGN SPEED	SIGHT DISTANCE	STRUCTURAL OBSOLESCENCE	FUNCTIONAL OBSOLESCENCE	SYSTEM	CAPACITY	AVAILABLE RIGHT OF WAY	URBAN
79	271	.44	25	C	NEW CASTLE	30	61	30	60	2	D	9050	0	R	35	40	77	63	FAU	232	30	Outlying Urban Park
79	294	.38	25	C	NEW CASTLE	07	61	30	60	2	D	9050	0	R	35	40	77	63	FAU	232	30	
79	315	.12	25	C	NEW CASTLE	07	61	30	60	2	D	7630	0	R	35	40	77	63	FAU	232	30	
79	321	.08	25	C	NEW CASTLE	51	~~00~~ 61	30	~~70~~ 60	2	D	7300	0	R	35	40	~~72~~ (77)	63	FAU	232	30	
79	325	.16	25	S	SHENANGO	51	00	46	70	4	D	7300	9	F	60	99	72	10	FAP	1274	46	
79	333	.10	25	S	SHENANGO	51	00	32	70	3	D	7300	8	F	~~50~~ 60	~~00~~ 60	72	63	FAP	~~8~~ (658)	UNL	
79	339	.62	25	S	SHENANGO	51	00	33	70	3	D	7300	8	F	60	60	72	94	FAP	739		
	359	.90			BRIDGE			52					20									
79	372	2.03	25	S	SHENANGO	51	00	33	70	3	D	6430	8	F	60	60	74	98	FAP	739		
	381	.32			BRIDGE			53					20									

XX = Field Correction

(XX) = Recalculation

TABLE 2

ANALYSIS OF ALTERNATIVES

LEGISLATIVE ROUTE	STATION	MILES	SYSTEM	ALTERNATIVE	IMPROVEMENT	RATE OF RETURN	INCREMENTAL RATE OF RETURN	YEAR RESURFACE	COST RESURFACE	YEAR WIDEN	COST WIDEN	YEAR CONSTRUCT	COST CONSTRUCT	YEAR BY PASS	COST BY PASS	YEAR BRIDGE	COST BRIDGE	ROAD USER COST	DEPARTMENT COST	TRANSPORTATION COST
79	0	2.76	FAP	1	NULL 33			71	119									88	6	94
				2	WIDE 40	51.79	51.79	71	144	63	155							0	20	20
				NA	CONS 18	-12.77	-107.89	88	63			63	348					126	29	154
				NA	CONS 20	- 5.31	- 68.42	88	72			63	386					105	32	138
				NA	CONS 22	0	- 46.28	88	80			63	425					88	35	124
				NA	CONS 24	5.54	- 28.38	88	86			63	464					66	38	105
				NA	NCON 18	6.04	- 7.66	88	63			63	795					44	66	110
				NA	NCON 20	7.71	- 3.70	88	72			63	883					25	73	98
				NA	NCON 22	8.86	- .95	88	80			63	972					8	80	88
				NA	CONS 48	8.83	0	88	171			63	1,052					0	87	88
				NA	NCON 24	8.85	.12	88	86			63	1,060					0	88	88
				2	WIDE 40	51.79	51.79	71	144	63	155							0	20	20

TABLE 2
(Continued)

LEGISLATIVE ROUTE	STATION	MILES	SYSTEM	ALTERNATIVE	IMPROVEMENT	RATE OF RETURN	INCREMENTAL RATE OF RETURN	YEAR RESURFACE	COST RESURFACE	YEAR WIDEN	COST WIDEN	YEAR CONSTRUCT	COST CONSTRUCT	YEAR BY PASS	COST BY PASS	YEAR BRIDGE	COST BRIDGE	ROAD USER COST	DEPARTMENT COST	TRANSPORTA-TION COST
79	146	0.18	FAU	1	NULL 33			70	8									132	0	132
				NA	N PAR													103	0	103
				NA	1 WAY													73	0	73
				4	B24 R33	226.42	226.42	70	8					63	53			12	5	17
				NA	WIDE 43	39.08	-252.94	70	11	63	85							98	8	106
				NA	B24 W43	97.86	19.54	70	11	63	85			63	53			- 5	12	7
				NA	WIDE 53	39.66	- 42.15	70	14	63	170							63	15	78
				NA	B24 W53	62.56	12.64	70	14	63	170			63	53			- 10	19	9
				NA	WIDE 64	37.55	- 8.80	70	16	63	264							31	23	54
				NA	B24 W64	44.10	8.18	70	16	63	264			63	53			- 10	27	17
				4	B24 R33	226.42	226.42	70	8					63	53			12	5	17

Year Resurface	Resurface Cost[6]
71	119

This resurfacing is expected to have a life of 20 years carrying the section until 1991. Thirty-eight years (1963-1991) is therefore used as the study period for the section.

Since the section is functionally obsolete in 1963, congestion will be present in increasing amounts from 1963 through 1991. Calculating congestion cost as dollars of time delay at $1.56 per hour as the value of time, accumulating the present worths of each year's delay costs, and using capital recovery of the accumulated amount, the equivalent uniform annual cost of delay is found to be $88,000. An interest rate of 7 percent is used for these and other conversions.

The initial cost of resurfacing has a capital recovery cost of $4,543 and annual maintenance cost of $1,457 for a total cost of $6,000 to the highway administration agency. The addition of the road user congestion cost and the department cost results in an equivalent uniform annual transportation cost of $94,000 thus:

Road User Congestion Cost	Annual Department Cost	Annual Transportation Cost
88	6	94

The composite tabulation is given in the first line of Table 2.

Alternative 2 analyzes the economics of widening the road section from 33 to 40 feet.[7] Since the section is functionally obsolete in 1963, it would be widened in 1963 at an initial cost of $155,000 and the widened width resurfaced in 1971 at an initial cost of $144,000. The increased capacity achieved by this improvement would reduce the congestion delays for the entire study period to zero. The amortized department cost (always including maintenance) would be $20,000 and the average annual transportation cost, $20,000.

The approximate rate of return, as given by

$$RR^{X-N} = \frac{AUC^{X} - AUC^{N} + AMC^{X} - AMC^{N}}{cc^{X} - cc^{N}} \qquad (1)$$

where

RR^{X-N} = approximate rate of return of Alternative X compared to the null,

AUC^{X} = annual user costs (congestion) Alternative X,

AUC^{N} = annual user costs, null condition,

AMC^{X} = annual maintenance costs of Alternative X,

AMC^{N} = annual maintenance costs of null,

cc^{X} = present worth first construction cost Alternative X, and

cc^{N} = present worth first construction cost null,

shows a basic rate of return of 51.79 percent. The incremental rate of return for the cheapest alternative above the NULL is always the same as the basic rate of return.

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[6] Analysis costs are rounded to the nearest $1,000.

[7] In explanation, the existing facility is used as a 3-lane highway with 11-ft lanes. By widening to 40 ft, four lanes of 10-ft widths are attained, and much higher capacity results.

Alternative 3 examines the economics of reconstructing the road section to 18-ft width[8] in lieu of the existing 33-ft width at a cost of $348,000 in 1963 and a resurfacing cost of $63,000 in 1988. It will be recalled that the study period extends through 1991; consequently, the present worth of the cost of resurfacing in 1988 minus the present worth of the salvage value of the remaining life of this construction in 1991 is included in the analysis. These calculations show the annual road user congestion cost is $126,000, and the department cost increases to $29,000 annually, resulting in a total transportation cost of $154,000 (rounding accounts for the differences of $1,000). Since the road user congestion cost is an increase over the NULL congestion cost, the rate of return becomes a negative value and is not an acceptable alternative. The computer has been instructed to designate this by NA in the alternative column (Table 2).

Successively, reconstruction to 20-ft width and to 22-ft width are analyzed, the 20-ft width showing a negative rate of return. That is, congestion remains at or above $88,000 per year and the initial cost of these alternatives has more than doubled that of alternative 1 so there is no positive rate of return on the additional investment over the NULL cost.

Reconstruction to a 24-ft width is the next alternative, at an initial cost of $464,000 in 1963, with a resurfacing cost of $86,000 in 1988. Congestion reduces to $66,000 per annum; the annual cost to the department becomes $38,000 for a total annual transportation cost of $105,000. This yields a basic rate of return of 5.54 percent, but compared to the previously acceptable improvement a negative incremental rate of return of 28.38 percent is indicated.

The incremental rate of return is given by the formula

$$rr^{ZX} = \frac{AUC^X - AUC^Z + AMC^Z - AMC^X}{cc^Z - cc^X} \qquad (2)$$

where

rr^{ZX} = incremental rate of return of Alternative Z compared to previous acceptable Alternative X,

AUC^Z = annual user cost of Alternative Z,

AUC^X = annual user cost of Alternative X,

AMC^Z = annual maintenance cost of Alternative Z,

AMC^X = annual maintenance cost of Alternative X,

cc^Z = present worth initial construction cost of Alternative Z, and

cc^X = present worth initial construction cost of Alternative X.

In the example $AUC^X = 0$, $AUC^Z = \$66,000$, hence rr^{ZX} is negative.

An early analysis indicated there would be many projects showing a rate of return of 20 percent or greater. In fact it was evident that such projects in excess of 20 percent would provide programs for many years to come. The policy decision was made, therefore, that no alternative would be acceptable unless it showed a minimum of 20 percent basic rate of return, nor would it be acceptable if the incremental rate of return was less than 20 percent. Thus, the basic rate of return for this alternative is not acceptable, nor is incremental rate of return of minus 28.38 percent. This decision is validated by comparison of the annual transportation cost of $105,000 for this alternative and $20,000 for alternative 2.

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[8] Since incremental rate of return is used in the determination of acceptable alternatives, each alternative must be analyzed in sequence of increasing initial cost as may be seen by examination of Eq. 2. From the above, if the cc^X cost exceeds the cc^Z cost, a negative incremental rate of return results, hence an improper answer. This will explain what might otherwise appear to be an irrational ordering of the successive improvements.

Successively, alternatives of constructing the facility on new alignment[9] (NCON) to widths of 18, 20, 22 and 24 ft, and construction on old alignment to 48 ft are found wanting in satisfactory rates of return and are not acceptable. The bottom line of this grouping selects the optimum improvement for the section, namely, widening the existing facility to 40 ft. This provides not only the highest rate of return, but also the lowest transportation cost.

Urban Highway Sections. —The analysis of urban highway sections follows a similar pattern, using a different set of possible improvements.

The road section used for explanation, shown on line 2 of Table 1 is on Legislative Route 79, begins at Station 146, has a length of 0.18 mile in the city of New Castle and an existing 33-ft width. It is functionally obsolete in 1963. As corrected by the field analysis, it is structurally obsolete in 1970, is "outlying urban" with parking permitted both sides, and cannot be widened beyond its present 33-ft width.

The "do nothing except preserve the existing investment" is again the first alternative considered (Table 2), i.e., resurface in 1970 at an initial cost of $8,000. This resurfacing has a 20-yr life; therefore, the analysis period for the section is 20 years, extending to 1990. During this period, converting to present worths and amortizing the accumulation, the average annual cost of congestion delay on the section is $132,000. Amortization of the resurfacing cost plus maintenance shows negligible average annual cost to the Department (less than $500), resulting in a transportation cost of $132,000.

Urban alternative 2 concerns the banning of parking from the street (N-PAR). This would increase the capacity, and decrease the congestion cost, but would require the road user to pay a parking fee or its equivalent, over and above meter parking, which would reduce the savings. Since all road users are also parkers, the net savings (congestion savings minus increase in parking fees) are considered the benefits. In this case, the net savings amount to $29,000 reducing the net road user cost to $103,000.

Urban alternative 3 considers the establishment of paired one-way streets, parking permitted on one side each, and distributes traffic between the pair, adding 10 percent for the traffic previously using the converted street. The cost of conversion is considered negligible for reasons noted below. The road user cost for this section of street is seen to be $73,000 annually (Table 2), the department cost negligible and the transportation cost $73,000.

In Pennsylvania, although the department is empowered to ban parking, and to establish one-way streets, it is rarely politically feasible to do so except for temporary emergencies. Most often these alternatives are established as expedients by local government, sometimes acting at the suggestion of the department. In the analysis, they are designated as not acceptable (NA) so that the computer will not regard them as optimum improvements.

Urban alternative 4, being the next improvement having the least initial cost, considers the building of a bypass, doing nothing to the existing street. A percentage of the traffic volume varying with the size of the municipality is considered to be the through traffic which will be diverted to the bypass. The diverted volume, expanded to the volume at the life expectancy of the bypass is used to determine the roadway width of the bypass; therefore, no congestion (road user cost) will accrue during the study period. Design standards used to arrive at the estimated bypass costs are based on 50-mph travel speed for 2 lanes, and 60-mph travel speed for 4 or more lanes. Consequently, the road user saving to the diverted vehicles is the difference in travel time on the congested street, e.g., 18 mph and 50 or 60 mph on the bypass. The residual volume on the city street moves faster, so road user savings also accrue to the non-diverted traffic. The summation of these two savings frequently exceeds the "do nothing" congestion cost. Although this condition was indicated (1), it is repeated here to answer the question which will be raised, e.g., alternate 6 indicating a road user cost of minus $5,000 (Table 2).

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[9]Construction on new alignment is based on design criteria insuring operating speeds of 50 mph at the respective capacities per width.

Returning to urban alternate 4, the diverted volume calls for a 24-ft wide bypass to be built in 1963 at a cost of \$53,000 (0.18 mi long), and resurfacing the existing street in 1970 at a cost of \$8,000 (Table 2). The amortized cost, allowing salvage at the end of the 27-year study period, plus the maintenance cost of both facilities, gives a Department cost of \$5,000. Road user costs are reduced to \$12,000, for a transportation cost of \$17,000. The rate of return on the investment is shown to be 226.42 percent.

Urban alternative 5, the next higher cost, assumes widening the existing street 10 feet[10] (no bypass). The initial costs are \$85,000 for widening in 1963, resurfacing the entire width in 1970 at a cost of \$11,000. Amortized, again allowing salvage at the end of the study period, and adding maintenance cost, the Department cost is \$8,000. The road user cost will be reduced to \$98,000 and the transportation cost becomes \$106,000. Although the rate of return on this investment is 39.08 percent, the road user savings are negative. The alternative, therefore, is not acceptable (NA).

Urban alternative 6 would build the 24-ft bypass and widen the existing street by 10 ft. The transportation cost would reduce to \$7,000, the rate of return is 97.86 percent, however the incremental rate of return is only 19.54 percent (compared with alternative 4); that is, the additional \$53,000 initial cost has a rate of return less than the acceptable rate of return of 20 percent and, therefore, is not acceptable (NA)[11].

Successively, the alternatives of widening the existing street in 10-ft increments and building a bypass, and widening only up to the right-of-way available, are considered with the results shown in Table 2. Each fails to meet the criterion of 20 percent. The optimum improvement selected is to maintain the existing street (R33) and construct a 24-ft bypass (B24) or, as coded in Table 2, B24 R33. The analysis shows all alternatives considered if right-of-way is available. In actual practice, the analysis would cut off at alternative 4, since the existing street cannot be feasibly widened (Table 1).

The foregoing examples describe all the alternatives considered, with the exception of those cases where the existing facility has had a resurfacing. As previously noted, policy stated that these would not be resurfaced, but would be reconstructed in kind; correspondingly, there could be no widening per se. It would be treated instead as reconstruction to a new width, and the costs indicated under the heading "CONSTRUCT." (See footnote 13.)

Another condition can prevail. In considering alternatives, bridge improvement costs are included in the initial cost. Occasionally, when a facility is otherwise tolerable (NULL), bridges substandard in roadway width or load capacity may exist. These defy computer analysis for economics, yet they cannot be ignored. The computer recognizes the presence of these bridges, and calls attention to them by indicating in the NULL alternative the cost of their improvement or replacement. This cost is tabulated under the heading BRIDGE COST.

Phase IV: Listing of Optimum Improvements

The optimum improvement cards from each road section are separated from the output of Phase III and tabulated in the form of straight line diagrams (Table 3). The first two entries thereon are the road sections we have previously described, so the optimum improvement to Legislative Route 79 between Stations 0 and 146, a length of 2.76 mi, is to widen the existing 33-ft road to 40 ft. The year for widening (construct) is 1963, and it will be resurfaced in the structural obsolescent year 1971. The section between Stations 146 and 155, 0.18 mi long, requires a bypass in 1963 and resurfacing of the existing 33-ft street in 1970. Table 3 continues the listing through and beyond an actual urban area.

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[10] In early studies, it was found that widening city streets in smaller increments did not give significant differences, therefore widening in 10-ft increments saved computer time.

[11] On first consideration the reader may feel this is splitting hairs. But when it is fully understood the many improvements which will yield greater than 100 percent it becomes apparent that this \$53,000 can be better invested elsewhere. The really "sticky" question is, should the minimum rate of return be set as low as 20 percent. Before making any hasty conclusions, the reader should observe that the higher the minimum is set, the more the out-of-pocket cost to the road user. The authors in the past have invited a paper on this subject, and herewith repeat the invitation.

TABLE 3

STRAIGHT LINE DIAGRAM OF OPTIMUM IMPROVEMENTS

LEGISLATIVE ROUTE	STATION	MILES	IMPROVEMENT TYPE	YEAR CONSTRUCT	YEAR RESURFACE	YEAR BY PASS	YEAR BRIDGE	COMBINATION ANALYSIS
79	0							
		2.76	33 WIDE 40	63	71	00		OK
79	146							
		.18	B24 R33	00	70	63		RESURFACE TO EXISTING WIDTH 1970
79	155							
		.09	B24 R34	00	70	63		
79	165							B 24
		.41	B24 R52	00	80	63		RESURFACE 1980
79	187							
		.09	B24 R27	00	70	63		
79	192							
		.63	B48 C30	73	00	63		RECONSTRUCT 1973
79	225							
		.08	B48 C40	70	00	63		
79	229							
		.19	B48 C46	70	00	63		
79	239							
		.13	B48 C40	70	00	63	63	B 48 — RECONSTRUCT TO EXISTING WIDTH 1970
79	246							
		.02	B48 C40	70	00	63		
79	247							
		.08	B48 C38	70	00	63		
79	251							
		.03	B48 C36	76	00	63		RECONSTRUCT 1976
79	252							

TABLE 3

(Continued)

LEGISLATIVE ROUTE	STATION	MILES	IMPROVEMENT TYPE	YEAR CONSTRUCT	YEAR RESURFACE	YEAR BY PASS	YEAR BRIDGE	COMBINATION ANALYSIS
		.35	B24 C36	76	00	63		
79	271							
		.44	B24 C 30	77	00	63		B 24 — RECONSTRUCT TO EXISTING WIDTH 1977
79	294							
		.38	B24 C30	77	00	63		
79	315							
		.12	B22 C30	77	00	63		
79	321							
		.08	B22 C30	77	00	63		
79	325							
		.16	NUL R46	00	72	00		
79	333							
		.10	NUL R33	00	72	00		RESURFACE EXISTING WIDTH 1972
79	339							
		.62	NUL R33	00	72	00		
79	372							
		2.03	NUL R33	00	74	00		OK

Phase V: Analysis of Optimum Improvements

Many of the road sections are of very short lengths. Obviously, these would not be improved individually, but would combine with adjacent sections to form a project, and the year of construction modified to the grouping. Since the grouping is an "irrational" process (a human judgment) and since computers are not omniscient nor can they make judgments beyond certain limitations, the combining process must be a manual one, and is given in Table 3 by the longhand entries. Table 3, in practice, is a worksheet to produce the final statement of needs.

The analyst has designated Stations 0-146, a 2.76-mi length, to be a constructable length and accepts the optimum improvement. This then is a final designated project. Between Stations 146 and 325 there is more than one analysis involved, namely a bypass and the existing street.

Scanning the bypass entries, a variable width is called for, 24 ft wide between Stations 146-192, 252-325, and 48 ft wide between Stations 192-252, all of which are needed in 1963. The 48-ft section requirements occur because of other traffic routes being superimposed on Traffic Route 25 in these areas. From Station 252 to 325, a 22-ft and 24-ft bypass is called for, and will be constructed a uniform 24-ft width.

The analyst then examines the needs on the existing street, and will resurface Stations 146-165 to present width in 1970 and resurface Station 165-187 in 1980. Between Stations 192 and 271, since the street has previously been resurfaced, it will be reconstructed to existing width. The year of need varies from 1970 to 1976; therefore, the entire reconstruct section will be designated as shown between 70 and 76.[12] Similarly reconstruction in 1977 will be designated between Stations 271 and 321. Between Station 325 and 372, resurfacing will be done in 1972, and the remaining section in 1974.

The right hand side of Table 3 is used as a work sheet by the analyst to make the decisions. When he is satisfied that he has the correct combination, the selected combinations are coded by circling the key symbols for key punching. Thus in Table 3, the keypunch operator has been instructed to punch a card for L. R. 79 Station 0, widen 40, 1963, and a card L. R. 79 Station 0, resurface 1971. Next punch a card L. R. 146, bypass 24 ft in 1963, and resurface in 1970. Skip the next entry (no circling shown). Punch a card L. R. 79 Station 165, resurface 1980. Skip the next entry and punch a card L. R. 79 Station 192, bypass 48 in 1963 and reconstruct existing width in 1973, etc. These cards are designated header cards.

Phase VI: Projects Economics

The header cards are merged with the Phase III NULL and OPTIMUM output cards, and the computer is programmed to read the header card, combine the Phase III information for that type of improvement ignoring the dates on Phase III cards, and substitute the header card date. It is to continue accumulating this data until another header card cancels the instruction. Thus, the computer will read a header card. The next group of cards are the Phase III cards. On reading the Null card, it will store the road user cost, i.e., the congestion cost, if no improvement were made. It will read the card calling for widen 40-ft (Table 2), storing all the data from this Phase III card. The computer continues to read cards, rejecting all others for Station 0. If a nonheader card appears with a new station number, the computer will combine this new information with the stored information adding the road user cost from this Null card.

When a new header card is read, the computer will calculate the project cost, rate of return and the transportation costs on the combined lengths, and punch out the project card(s). For Station 0, then, since no new station cards follow and the header card appears next, the computer will punch a card having the same information as the Phase III card but in the different format shown in Table 4. Next reading the header card from Station 146, the control card sets the computer to accumulate the 24-ft bypass through Station 146 to Station 192 (where the bypass changes to 48 feet) and accumulate the resurface to existing width to Station 165 (where the date changes to 1980). A project card is punched out for each of these projects. Thus for every circled item under Improvement Type, Table 3, there will be a project card.

NEEDS STUDY

Table 4 lists the project cards, and, as it is arranged, is a needs study for Legislative Route 79 by sequence of stations. If the similar data for all routes were ordered

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[12] Note from Table 1 that a single uniform width is not obtainable (except by Urban Renewal). Final Design might take out some irregularity by reducing cartway and increasing footway, but the present purpose is not to Final Design.

TABLE 4

PROJECT LISTINGS

LEGISLATIVE ROUTE	STATION	POLITICAL SUB-DIVISION	MILES	TYPE OF IMPROVEMENT	YEAR	PROJECT COST	RATE OF RETURN	ROAD USER COST BEFORE	ROAD USER COST AFTER
79	0	S UNION	2.76	WIDE 40	63	155	51.79	88	0
79	0	S UNION	2.76	RESUR 40	71	144			
79	146 192 252	NEW CASTLE	.77 1.16 1.37	B 24 B 48 B 24	63	1343	165.00	2380	181
79	146 187	NEW CASTLE	.27 .09	R EXIST	70	20			
79	165	NEW CASTLE	.41	R EXIST	80	30			
79	192	NEW CASTLE	.63	C EXIST	73	189			
79	225	NEW CASTLE	.50	C EXIST	70	209			
79	251	NEW CASTLE	.38	C EXIST	76	137			
79	271	NEW CASTLE	1.02	C EXIST	77	306			
79	325	S SHENANGO	.88	R EXIST	72	41			
79	372	S SHENANGO	2.03	RESUR 33	74	87			

in sequence of route numbers, a ready reference for needs on any road section is immediately available, e.g., an inquiry is made by some interested group, "When will Main Street in New Castle (L. R. 79 Station 155) be fixed?" The answer is readily available, "Not before 1970."[13]

The "not before" qualification is because this is the year of need, but the year of available funds may be somewhat later. It is therefore necessary to order the projects according to their year of need and their priority within that year. Thus is obtained the needs by year of need shown in Table 5.

[13] The demonstration data are fictitious for reasons of clarity. The actual data for one Pennsylvania county pertinent to this ordering are available from the Highway Research Board at cost of Xerox reproduction and handling—Supplement XS-3 (Highway Research Record 87), 8 pages.

TABLE 5

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD COST	USER BEFOR	ROAD COST	USER AFTER	ADT CONST YR
37015			TAYLOR	3.63	R EXIST	63	86			83			10010
315		13	ELLWOOD CITY	.17	R EXIST	63	10			24			9000
444			MAHONING	3.26	R EXIST	63	85			43			4610
238			WILMINGTON	.50	R EXIST	63	14			2			4050
37040			WILMINGTON	2.44	R EXIST	63	70						3370
246		305	SCOTT	4.85	R EXIST	63	120			4			3100
233		77	HICKORY	3.15	R EXIST	63	88			3			2922
693			PULASKI	3.96	R EXIST	63	93			1			1580
37010	1		MAHONING	.37	R EXIST	63	9			1			1240
37013		15	WAYNE	2.10	R EXIST	63	42						1040
37023			SLIPERY ROCK	3.07	R EXIST	63	64						930
37022			PERRY	.95	R EXIST	63	17						450
37012			WAYNE	.76	R EXIST	63	16						420
37043		108	SCOTT	1.82	R EXIST	63	33						390
37088			TAYLOR	.98	R EXIST	63	42						380
37080			WASHINGTON	2.46	R EXIST	63	45						170
614			NEW CASTLE	.48	C EXIST	63	89			8			4050
265		712	TAYLOR	.09	C EXIST	63	12			2			3260
37019			PERRY	.76	C EXIST	63	85						390
37030		57	MAHONING	2.54	C EXIST	63	285						340
37080		130	WASHINGTON	2.02	C EXIST	63	226						170
37024		120	SLIPERY ROCK	2.06	C EXIST	63	231						140
37065			PLAIN GROVE	1.77	C EXIST	63	198						140
37007			BIG BEAVER	.37	C EXIST	63	41						110
37062			HICKORY	3.44	C EXIST	63	385						90
37064			WASHINGTON	1.95	C EXIST	63	218						70
37073		51	NORTH BEAVER	.87	C EXIST	63	97						50
37004			LITTLE BEAVR	3.38	C EXIST	63	374						30
79	7		NEW CASTLE	.96	BPASS24	63	283	229.97		734		85	
79			NEW CASTLE	1.90	BPASS24	63	561	156.23		1,087		211	
37015		194	NEW CASTLE	1.41	BPASS18	63	259	147.41		1,033		658	
315		572	NEW CASTLE	1.93	BPASS22	63	479	128.73		1,213		602	
80			NEW CASTLE	2.28	BPASS48	63	1,731	127.67		2,152		57-	
37028		146	NEW CASTLE	1.39	BPASS18	63	256	111.65		492		214	
37061		146	NEW CASTLE	.77	BPASS48	63	584	103.59		595			
77		523	NEW CASTLE	1.71	BPASS18	63	315	99.95		576		261	
233			NEW CASTLE	1.45	BPASS18	63	267	83.06		258		41	
37061			UNION	2.76	WIDE 40	63	97	78.30		88			
81		504	UNION	1.59	CONS 46	63	620	22.96		117			
37015		194	NEW CASTLE		BRIDGE	63	77						11253

TABLE 5 (Continued)

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD USER COST BEFOR	ROAD USER COST AFTER	ADT CONST YR
315		22	ELLWOOD CITY		BRIDGE	63	492				10691
37015		194	NEW CASTLE		BRIDGE	63	64				10007
315		13	ELLWOOD CITY		BRIDGE	63	68				9000
315		572	NEW CASTLE		BRIDGE	63	24				8771
315		572	NEW CASTLE		BRIDGE	63	18				8771
81		504	UNION		BRIDGE	63	154				7872
77		523	NEW CASTLE		BRIDGE	63	67				7317
315		85	WAYNE		BRIDGE	63	16				6300
350		39	ELLWOOD CITY		BRIDGE	63	85				4840
444		172	MAHONING		BRIDGE	63	73				4607
11623			BESSEMER		BRIDGE	63	28				4160
11623			BESSEMER		BRIDGE	63	24				4160
482			WAYNE		BRIDGE	63	35				3937
246		2	SLIPERY ROCK		BRIDGE	63	103				3487
246		2	SLIPERY ROCK		BRIDGE	63	71				3372
265		712	TAYLOR		BRIDGE	63	108				3260
77		314	NORTH BEAVER		BRIDGE	63	64				3151
482			WAYNE		BRIDGE	63	249				2922
614		25	HICKORY		BRIDGE	63	30				2917
37081			BESSEMER		BRIDGE	63	11				2642
37055			PULASKI		BRIDGE	63	85				1966
80		332	WILMINGTON		BRIDGE	63	33				1798
37045			WILMINGTON		BRIDGE	63	46				1689
37039		69	NESHANNOCK		BRIDGE	63	11				1582
37039		69	NESHANNOCK		BRIDGE	63	26				1582
614		25	HICKORY		BRIDGE	63	30				1347
614		178	HICKORY		BRIDGE	63	12				1347
37013		229	SHENANGO		BRIDGE	63	25				1293
37045			WILMINGTON		BRIDGE	63	29				1291
37045			WILMINGTON		BRIDGE	63	106				1291
265		472	NORTH BEAVER		BRIDGE	63	26				1118
37034			PULASKI		BRIDGE	63	15				1102
37009			PULASKI		BRIDGE	63	61				1043
694			PULASKI		BRIDGE	63	34				901
37028		134	NEW CASTLE		BRIDGE	63	12				899
37031		92	NESHANNOCK		BRIDGE	63	58				828
37006			BIG BEAVER		BRIDGE	63	22				730
37006			BIG BEAVER		BRIDGE	63	18				730
265		82	LITTLE BEAVR		BRIDGE	63	40				617

TABLE 5 (Continued)

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD COST BEFOR	USER BEFOR	ROAD COST AFTER	USER AFTER	ADT CONST YR
539		10	LITTLE BEAVR		BRIDGE	63	24						573
37013		129	SHENANGO		BRIDGE	63	9						513
37012			WAYNE		BRIDGE	63	10						420
81		414	UNION		BRIDGE	63	15						393
37038		283	PULASKI		BRIDGE	63	23						392
37043		108	SCOTT		BRIDGE	63	12						390
37030		57	MAHONING		BRIDGE	63	22						340
37059			NORTH BEAVER		BRIDGE	63	21						337
37020			PERRY		BRIDGE	63	18						300
37035			PULASKI		BRIDGE	63	10						256
37024			SLIPERY ROCK		BRIDGE	63	8						233
37026		21	SHENANGO		BRIDGE	63	9						229
37026		21	SHENANGO		BRIDGE	63	26						212
37026		21	SHENANGO		BRIDGE	63	12						212
37054			WASHINGTON		BRIDGE	63	12						173
37079			SLIPERY ROCK		BRIDGE	63	10						170
37065			PLAIN GROVE		BRIDGE	63	10						140
37026		268	SLIPERY ROCK		BRIDGE	63	34						137
37048			PLAIN GROVE		BRIDGE	63	12						137
37047			PLAIN GROVE		BRIDGE	63	9						136
37057			BIG BEAVER		BRIDGE	63	14						91
37057			BIG BEAVER		BRIDGE	63	14						91
37062			HICKORY		BRIDGE	63	26						90
37062			HICKORY		BRIDGE	63	29						90
37004			LITTLE BEAVR		BRIDGE	63	33						30
37011			ELLWOOD CITY	.57	WANDR24	63	40	12.97		15		12	
614		178	HICKORY	5.01	R EXIST	64	118			31			4290
37018			PERRY	.21	R EXIST	64	5			1			1920
37042		252	WILMINGTON	1.50	R EXIST	64	27						460
37043			WASHINGTON	2.04	R EXIST	64	37						400
37024			SLIPERY ROCK	2.28	R EXIST	64	41						330
37049			PLAIN GROVE	1.58	R EXIST	64	29						240
37005			LITTLE BEAVR	4.48	R EXIST	64	83						180
37027			SCOTT	.33	R EXIST	64	6						180
614		443	WASHINGTON	1.00	C EXIST	64	116			11			4290
482		209	WAYNE	.76	C EXIST	64	111			2			3010
37075			PERRY	2.26	C EXIST	64	253						10
233			NEW CASTLE	1.45	R EXIST	65	62			258			10190
37089			TAYLOR	.24	R EXIST	65	6						960
88005			NW WILMINGTN	.33	R EXIST	65	8						810

TABLE 5 (Continued)

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD COST	USER BEFOR	ROAD COST	USER AFTER	ADT CONST YR
539			LITTLE BEAVR	.20	R EXIST	65	4						710
37031			UNION	1.74	R EXIST	65	31						610
37066			SHENANGO	1.10	R EXIST	65	23						540
81		589	NEW CASTLE	1.61	BPASS24	65	475	173.75		910		88	
37041		106	NESHANNOCK	1.97	R EXIST	66	46			21			6060
37068			PULASKI	.79	R EXIST	66	16						1230
37031		92	NESHANNOCK	1.64	R EXIST	66	30						1180
37016			SHENANGO	7.33	R EXIST	66	152						1140
37030		192	MAHONING	1.35	R EXIST	66	25						1110
37012		192	WAYNE	.34	R EXIST	66	7						1061
694			PULASKI	.94	R EXIST	66	20						990
37023		305	HICKORY	2.23	R EXIST	66	46						710
37042		135	WILMINGTON	2.21	R EXIST	66	41						490
37020			PERRY	2.50	R EXIST	66	47						460
37019		40	PERRY	1.41	R EXIST	66	26						430
37038		96	NESHANNOCK	3.50	R EXIST	66	73						430
37022		298	SLIPERY ROCK	2.43	R EXIST	66	45						410
37037			PULASKI	.54	R EXIST	66	13						370
37059			NORTH BEAVER	2.08	R EXIST	66	38						370
37002			NORTH BEAVER	3.09	R EXIST	66	64						310
37030			MAHONING	1.09	R EXIST	66	22						249
37054			WASHINGTON	3.37	R EXIST	66	70						190
37047			PLAIN GROVE	3.06	R EXIST	66	55						149
37078			SLIPERY ROCK	.49	R EXIST	66	9						120
77		499	NEW CASTLE	.45	BPASS18	66	83	89.18		97		23	
350		131	WAYNE	6.21	R EXIST	67	149			10			3820
37034			PULASKI	3.65	R EXIST	67	86			2			2870
760			TAYLOR	1.34	R EXIST	67	29			11			2170
37014			TAYLOR	1.19	R EXIST	67	27						1270
37022		50	SLIPERY ROCK	4.68	R EXIST	67	89						510
37060			SHENANGO	1.25	R EXIST	67	23						440
37023	1		HICKORY	.36	R EXIST	67	7						390
37035			PULASKI	1.79	R EXIST	67	33						290
37026		21	SHENANGO	4.67	R EXIST	67	97						260
37046			WASHINGTON	2.22	R EXIST	67	46						240
37051			PLAIN GROVE	2.13	R EXIST	67	45						240
37069			PULASKI	2.04	R EXIST	67	37						240
37052			PERRY	5.37	R EXIST	67	97						191
37038			NESHANNOCK	1.82	C EXIST	67	204						1530

TABLE 5 (Continued)

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD COST BEFOR	USER BEFOR	ROAD COST AFTER	USER AFTER	ADT CONST YR
37008			BIG BEAVER	3.17	R EXIST	68	60						700
17224			PLAIN GROVE	2.00	R EXIST	68	47						530
37033			PULASKI	1.87	R EXIST	68	39						460
37025			SCOTT	1.63	R EXIST	68	30						400
37021			PERRY	1.33	R EXIST	68	24						270
37026		268	SLIPERY ROCK	3.68	R EXIST	68	76						270
37070			SCOTT	1.03	R EXIST	68	19						270
37048			PLAIN GROVE	2.46	R EXIST	68	45						200
37053			SHENANGO	1.76	R EXIST	68	32						200
37067			SLIPERY ROCK	1.78	R EXIST	68	37						90
81		618	NEW CASTLE	1.06	C EXIST	68	340			691			17110
37013		129	SHENANGO	1.89	C EXIST	68	212						600
80		135	NESHANNOCK	3.66	R EXIST	69	164			7			10721
37056			LITTLE BEAVR	3.00	R EXIST	69	55						280
37071			WASHINGTON	1.82	R EXIST	69	38						170
37061		146	NEW CASTLE	.77	R EXIST	70	45			595			14589
37001			MAHONING	2.32	R EXIST	70	52						2700
37055			PULASKI	.26	R EXIST	70	6			2			2450
88009			ENON VALLEY	.22	R EXIST	70	7						1371
37009			PULASKI	4.04	R EXIST	70	74			3			1300
37006			BIG BEAVER	5.56	R EXIST	70	119						910
37010			NORTH BEAVER	1.14	R EXIST	70	30						910
37028			UNION	1.49	R EXIST	70	35						830
37087			NEW CASTLE	.39	R EXIST	70	25						710
37072			NORTH BEAVER	3.62	R EXIST	70	75						211
37086			PULASKI	.86	R EXIST	70	26						159
80			NEW CASTLE	2.28	C EXIST	70	810			2,152			26630
315		85	WAYNE	4.43	C EXIST	70	681			491			8830
265		548	NORTH BEAVER	3.11	C EXIST	70	414			50			5261
81			PULASKI	6.82	R EXIST	71	292			24			8681
37061			UNION	2.76	R EXIST	71	144			88			8101
81	1		UNION	.31	R EXIST	71	13						7090
77		485	NEW CASTLE	.13	R EXIST	71	4			3			4489
37082			PERRY	.79	R EXIST	71	18						1070
77		523	NEW CASTLE	1.71	C EXIST	71	511			576			9410
77		499	NEW CASTLE	.45	C EXIST	71	112			97			7380
77		491	NEW CASTLE	.14	C EXIST	71	30			6			4489
79		100	SHENANGO	.88	R EXIST	72	41			10			9990
233	7		NEW CASTLE	.38	R EXIST	72	19			9			8360
37042		35	WILMINGTON	1.90	R EXIST	72	44			2			2531

TABLE 5 (Continued)

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD USER COST BEFOR	ROAD USER COST AFTER	ADT CONST YR
37079		89	SCOTT	.88	R EXIST	72	18				230
37042			NW WILMINGTN	.65	C EXIST	72	163		82		5830
238		78	BIG BEAVER	.30	C EXIST	72	50		4		3870
233		244	HICKORY	1.05	R EXIST	73	27		2		2930
265		356	NORTH BEAVER	2.19	C EXIST	73	307		4		9239
233		299	SCOTT	6.23	C EXIST	73	875		14		3229
37012		40	WAYNE	2.88	C EXIST	73	323				570
37041			NEW CASTLE	2.01	BPASS18	73	370	53.03	372	184	
79		147	SHENANGO	7.52	R EXIST	74	338		7		9379
238		26	WILMINGTON	.97	R EXIST	74	28		3		3500
37015		194	NEW CASTLE	1.41	C EXIST	74	511		1,033		28439
37028		146	NEW CASTLE	1.39	C EXIST	74	372		492		12720
37041			NEW CASTLE	.40	C EXIST	74	140		62		7160
80		332	WILMINGTON	3.24	C EXIST	74	488		28		5571
265		472	NORTH BEAVER	1.44	C EXIST	74	202				1580
37028		134	NEW CASTLE	.22	C EXIST	74	40				1270
539		10	LITTLE BEAVR	3.86	C EXIST	74	594				950
37041		210	NESHANNOCK	2.55	R EXIST	75	60		40		5090
79	7		NEW CASTLE	.96	C EXIST	75	334		734		16404
80		121	NESHANNOCK	.26	C EXIST	75	55		29		12950
265		82	LITTLE BEAVR	5.22	C EXIST	75	739		142		9840
482			WAYNE	3.94	C EXIST	75	606		72		6070
315		572	NEW CASTLE	1.93	R EXIST	76	79		1,213		17791
315		463	SHENANGO	2.05	R EXIST	76	64		40		7779
79			NEW CASTLE	1.90	C EXIST	76	652		1,087		22008
350			ELLWOOD CITY	.74	C EXIST	76	233		647		19970
315		22	ELLWOOD CITY	1.20	C EXIST	76	416		581		16090
37029			MAHONING	1.09	C EXIST	76	138				810
77			BIG BEAVER	4.86	R EXIST	77	151		45		6821
37076		28	WAYNE	2.24	R EXIST	77	46				790
37011		30	ELLWOOD CITY	1.05	C EXIST	77	396		138		11689
444		291	MAHONING	1.59	C EXIST	77	244		67		8200
11623			BESSEMER	1.41	C EXIST	77	344		259		6460
614			NEW CASTLE	.48	BPASS18	77	88	16.96	8		
88102		8	PLAIN GROVE	.16	R EXIST	78	3				220
37074			WILMINGTON	.63	R EXIST	78	14				34
37011	7		ELLWOOD CITY	.21	C EXIST	78	82		50		10280
315		319	SLIPERY ROCK	2.73	C EXIST	78	458		60		9200
37041		21	NEW CASTLE	1.61	C EXIST	78	580		310		8130

TABLE 5 (Continued)

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD COST	USER BEFOR	ROAD COST	USER AFTER	ADT CONST YR
14918			NORTH BEAVER	1.10	C EXIST	78	155			6			3430
37057			BIG BEAVER	1.87	R EXIST	79	39						151
81		589	NEW CASTLE	.55	C EXIST	79	165			219			14889
315			ELLWOOD CITY	.24	C EXIST	79	80			84			14889
347			ELLWOOD CITY	.06	C EXIST	79	19			20			11730
444		172	MAHONING	2.25	C EXIST	79	330			81			7820
37036			SHENANGO	2.14	C EXIST	79	270			20			4471
11623		75	NORTH BEAVER	2.36	C EXIST	79	364			7			3540
81		414	UNION	1.70	C EXIST	79	264						1211
37010		60	MAHONING	2.27	C EXIST	79	318						1211
37041		345	WILMINGTON	2.49	C EXIST	79	281						840
37058			MAHONING	2.94	C EXIST	79	329						430
37065		93	PLAIN GROVE	.74	C EXIST	79	83						230
37039		69	NESHANNOCK	3.74	R EXIST	80	97			12			3761
37079			SLIPERY ROCK	1.68	R EXIST	80	32						290
614		25	HICKORY	2.86	C EXIST	80	439			16			4979
37081			BESSEMER	1.46	C EXIST	80	244			26			4510
37029		123	PULASKI	5.78	C EXIST	80	708			6			2700
37013			WAYNE	.28	C EXIST	80	35						1780
647			PULASKI	1.60	C EXIST	80	180						1540
37039			NESHANNOCK	1.31	R EXIST	81	34						691
37029		58	MAHONING	1.23	R EXIST	81	29						601
37085			NEW CASTLE	1.66	R EXIST	81	52						261
37083			PERRY	1.78	R EXIST	81	41						180
809			NESHANNOCK	1.78	C EXIST	81	200			11			3281
37014		64	SHENANGO	1.99	C EXIST	81	251						1290
88022			ENON VALLEY	.34	C EXIST	81	54						900
37038		283	PULASKI	3.12	C EXIST	81	349						691
77		485	NEW CASTLE	.27	BPASS20	81	55	19.92		9		2-	
37013		229	SHENANGO	4.13	C EXIST	82	556			86			9821
246		2	SLIPERY ROCK	5.75	C EXIST	82	973			51			6339
37026			NEW CASTLE	.46	C EXIST	82	117			18			4710
37017			WAYNE	1.81	C EXIST	82	203						1640
37003			NORTH BEAVER	3.52	C EXIST	82	421						820
37078		27	PERRY	2.46	R EXIST	83	51						210
350		39	ELLWOOD CITY	1.07	C EXIST	83	236			263			9080
37023		163	SHENANGO	2.71	C EXIST	83	303						1647
37028		79	UNION	1.04	C EXIST	83	131						1261
77		314	NORTH BEAVER	3.24	R EXIST	84	101			25			6759
37044			SCOTT	4.75	R EXIST	84	100						989

TABLE 5 (Continued)

L R	SP	STATN	LOCATION	MILES	IMPROVMT	YEAR	PROJ COST	RATE RETURN	ROAD USER COST BEFOR	ROAD USER COST AFTER	ADT CONST YR
37045			WILMINGTON	4.24	C EXIST	84	679		9		4360
614	7		WASHINGTON	.01	C EXIST	84	1				3270
265			LITTLE BEAVR	1.54	C EXIST	84	194				2170
37050			PLAIN GROVE	3.52	C EXIST	84	394				660
37032			MAHONING	2.07	C EXIST	84	262				269
37063			SCOTT	.87	C EXIST	84	110				139
37084			SHENANGO	.85	R EXIST	85	22				280
350		95	PERRY	.67	C EXIST	85	104		43		5179
37026			NEW CASTLE	.46	3PASS20	88	94	33.91	18	6-	

In ordering within a particular year, structural obsolescence takes priority over functional obsolescence; that is to say, if Route B has structural obsolescence in 1963 and its improvement gives a 50 percent rate of return, and Route M has a functional obsolescence in 1963, a structural obsolescence in 1970 and a rate of return of 200 percent, Route B has priority since Route M can be tolerated until 1970 if funds are not sufficient to do both projects but Route B must receive attention in 1963.

Similarly, roads structurally obsolete and requiring the null improvement (resurfacing or reconstruction in kind), because they require the least financing, and are operating expense as against investments, take priority over improvements which show even the least rate of return (20 percent). There is further ordering of the null improvements in that higher ADT routes take precedence, and within ADT groupings road user costs take precedence.

Following the null structural obsolescent, the remaining structural obsolescent projects are ordered in descending values of their rates of return. Table 5, a summary of these needs by year, is the tabulation of this arrangement of needs for one county in Pennsylvania. The 1963 needs are quite substantially in excess of the needs of succeeding years; in fact, the succeeding years show a relatively constant need. The reason is obvious. All the needs deferred from prior years are added to the normal needs of the initial year of study.[14]

The total study for Pennsylvania has not been completed. An extrapolation from a sampling of 20 percent of the 67 counties shows 1963 needs of $3.7 billion, exclusive of the Interstate System needs—certainly a figure well nigh impossible to obtain, but one which is confirmed by Pennsylvania's independent 210 Study.

PROGRAM

The reason for ordering the needs study becomes apparent when the selection of a

[14] It is suggested that the 210 Study lulled participants into some sense of false security by inferring that the 15-yr needs could be distributed over a 15-yr period. It is estimated that over 65 percent of the 15-yr needs were urgent and critical in the initial year (1956).

program of improvements is to be made. Although needs far exceed fiscal capability, the program cannot exceed fiscal capability; therefore, as we have ordered the needs, the 1963 program includes those consecutive projects listed whose cumulative costs equal the available funds allocated. Assuming that $575,000 have been allocated for the 1963 resurfacing program, a strike-off after L. R. 37010, Spur 1, Station 0 would equal the allocated amount. The remaining 1963 resurfacing projects are, therefore, carried over into 1964, and this carry-over plus the 1964 resurfacing needs are ordered to secure a strike-off for the 1964 resurfacing program, and so on for each type of construction program or Federal-aid program.

The explanation is oversimplified to introduce clarity, and is sufficient for the purpose of this paper. It is pointed out, however, that programming must recognize systems so that Federal aid may be utilized—in a sense creating programs within programs.

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Multiple Project Scheduling of Preconstruction Engineering Activities

MARSHALL F. REED, JR., and R. E. FUTRELL
Respectively, Highway Planning Engineer and Highway Engineer, Automotive Safety Foundation

Systematic methods for scheduling the preconstruction engineering and right-of-way activities of the various state highway programs are revealed in several approaches. In each approach the schedules are arrived at by allocating the assumed fixed pool of classified manpower resources to a priority array of programed projects.

The "balance-period approach" is a theoretical procedure which outlines a set of rules that is applied in an iterative manner for the entire highway program period. Each repeat of the procedures is for a predetermined time interval or balance period. During the balance period the entire pool of fixed manner resources is applied to the priority array of projects. Network diagrams of each project and critical path methods are utilized to allocate the resources and thus create a schedule of preconstruction activities.

The application of the balance-period method, along with several correlating rules for activity continuity, produces a schedule that is based on project priority and the availability of manpower resources. Furthermore, the balance-period method is mechanical and thus suitable to be written as a computer program.

The similarities and differences between RAMPS and RPSM were explored by testing sample problems with each program. The practical aspects of using either the theoretical balance-period approach, the RAMPS program, or the RPSM program are presented. Highway department policies and operating methods have substantial effects on the feasibility of these approaches. Numerous technical problems must be solved to achieve fully objectives of highway program administrators.

•RESEARCH was initiated in 1963 by the staff of the Automotive Safety Foundation in the "execution phase" of highway programing. Specifically, the work has been confined to studies of the schedule and control of preconstruction activities for the multiplicity of projects that comprise the state highway programs.

This area was set apart for attention due to results of a cooperative survey conducted by the U. S. Bureau of Public Roads and the Automotive Safety Foundation for the Highway Programming Committee of the Highway Research Board. The objective of the survey was to investigate the methods used by 35 states to schedule precontract activities and to make available for general use any significant findings. In summary, the conclusions reveal a wide diversity in the extent and degree to which work schedules

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are planned in advance, and more importantly, the various work schedules devised were not the result of clearly defined, systematic procedures that related the work required to the availability of manpower resources.

The Regional Conference on improved Highway Engineering Productivity, held by the AASHO Committee on Electronics in April 1963, indicated the progress several states had made in the application of the Critical Path Method (CPM) to the highway program. Of the six states that reported their activities in this area, two states had used CPM to schedule various construction projects, three states were applying CPM to preconstruction engineering, and one state was engaged in both research and indoctrination of personnel on the possible application of CPM. Since this conference, it has become apparent that other highway departments are making use of critical path theory and associated computer programs to schedule both construction contracts and preconstruction engineering.

The value of the CPM to the scheduling of single projects that draw on unlimited resources has been well demonstrated in many engineering fields. However, the possible extension of this technique to a multiplicity of projects that rely on a limited manpower pool has not been widely explored.

Research was first begun in theoretical areas, and then in study of practical application of procedures that attempt to allocate more efficiently the available manpower to establish a realistic highway program schedule.

The theoretical balance-period approach to multiple project scheduling is discussed first. It is anticipated that this research could lead to procedures that would be reiterated periodically to provide an effective method for monitoring the precontract phases of the various programed projects.

While studying the theoretical approach, it became apparent that other organizations had been successful in developing multiple-project scheduling methods for other industries. Several of these techniques and some of the aspects of practical application of any one of these methods are discussed.

BALANCE-PERIOD APPROACH TO MULTIPLE-PROJECT SCHEDULING

The balance-period approach was developed to offer a theoretical solution to the problem of scheduling the preconstruction engineering and right-of-way activities of state highway programs. It is based on the premise that the availability of manpower and the priority ranking of projects are the critical features that determine the schedule. The principle involved is that for standard units of time, herein referred to as balance periods, the entire manpower pool is allocated to the programed projects. The allocation procedure is repeated for each balance period until the manpower requirements of every programed project are met. The result is a schedule.

Hypotheses

To detail the approach more specifically, it is necessary to establish the frame of reference on which the balance-period approach is founded. Five assumptions are made:

1. A program of specified projects exists.
2. The programed projects are ranked in relative order of priority or urgency. (It is not pertinent to this study to decide how this should be done.)
3. Funds will be available during the program period to finance all preconstruction activities of the programed projects.
4. The highway departments have a limited pool of available personnel that may be assigned to preconstruction engineering and right-of-way tasks. This pool is fixed and will remain so within the program period.
5. The network or arrow diagraming process is of benefit in the planning of preconstruction activities, and thus, it is feasible to portray all programed projects in network diagram form.

It is recognized that modification, additions, or deletions are necessary to accommodate a specific highway department's scheduling problem. However, it is on these five particular features that the theory of the balance-period method has been designed.

Objectives

Within this framework and without further guidelines, the principle of balancing manpower and projects within standard units of time could be accomplished. However, to establish systematic procedures, the balancing process should have specific goals to accomplish at each iteration. After considering a range of possibilities, the following three objectives were established as being reasonable goals for highway scheduling:

1. The procedures must schedule the projects based on the relative priority ranking;
2. The procedures must make maximum utilization of the fixed manpower pool; and
3. The procedures must schedule each project to completion in the minimum possible time.

Other objectives, such as scheduling projects to meet predetermined advertising, were not included in this preliminary search for systematic scheduling techniques.

Network Diagrams

The type of network diagram used in the balance-period approach is shown in Figure 1. This is simply the type of diagram used in normal CPM operations for single project schedules. The arrows indicate the activities and the nodes represent events or the instants in time that an activity or group of activities originates or ends. Dummy activities that show a dependency or time relationship between events are indicated by dashed arrows. The events are designated by numbers and the activities are described by the event numbers that directly precede and follow the activity. By way of illustration, event 3 might be "final highway design complete," and activity 3-5 might represent the work required to prepare the project's contract plans. Event 5 might indicate the completion of the preconstruction engineering and right-of-way activities necessary to offer the contract for bid advertising. The dashed dummy activity 2-4 indicates that activity 4-5 cannot commence until the completion of activity 1-2.

Sample Problem Solution

A hypothetical and very simplified problem was designed to develop the balance-period method. The problem employs but four projects that involve only 24 activities; however, it should suffice to illustrate the method. The projects are shown in network diagram form on the right side of Figure 2. Each diagram, at first glance, looks like all others; closer examination reveals the differences between projects.

To proceed with the scheduling of the sample problem, certain basic information must be provided.

1. The programed projects must be identified and arranged in priority sequence. For the problem, the project number indicates the priority. Project No. 1 is the most urgently needed project.

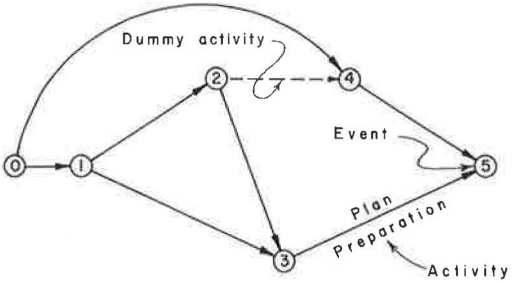


Figure 1. Network diagram (arrow diagram).

2. Manpower available for assignment must be classified and tabulated according to skill. For the sample problem, only two skills and a total of three men are available to accomplish the work of the problem. The skills are R and B. There is one R skill and two B skills.

3. The skills required of each activity must be determined. The letter designation R or B along the arrows describes the skill necessary to perform the activity. Event and activity names are disregarded for the sample problem.

4. The work required in each project must be estimated in terms of basic time

Project	Balance Period	Man	Activity	Work	Time Units	Work Remaining	Man	Activity	Work	Time Units	Work Remaining
		MANPOWER ALLOCATION									
1	0					19					21
	1	R_1	1 - 2	8		11	B_1	1 - 3	8		13
							B_2	0 - 4	4		9
	2	R_1	2 - 3	6		5	B_1	4 - 5	8		1
		R_1	3 - 5	2		3					
	3	R_1	3 - 5	3		0	B_1	4 - 5	1		0
2	0					13					27
	1						B_2	1 - 2	4		23
	2						B_2	1 - 2	4		19
							B_2	1 - 3	4		15
	3	R_1	0 - 4	4		9	B_2	1 - 3	4		11
		R_1	4 - 5	1		8	B_1	2 - 3	6		5
							B_1	3 - 5	1		4
	4	R_1	4 - 5	8		0	B_1	3 - 5	4		0
3	0					4					36
	3						B_2	1 - 2	4		32
	4						B_2	1 - 2	4		28
							B_1	1 - 3	4		24
							B_2	2 - 3	4		20
	5	R_1	0 - 4	4		0	B_1	1 - 3	4		16
							B_2	2 - 3	2		14
							B_2	4 - 5	4		10
							B_1	3 - 5	4		6
	6						B_2	4 - 5	5		1
							B_1	3 - 5	1		0
4	0					12					12
	5	R_1	1 - 3	4		8	B_2	0 - 4	2		10
	6	R_1	1 - 3	5		3	B_1	1 - 2	2		8
		R_1	3 - 5	3		0	B_1	2 - 3	2		6
							B_2	4 - 5	3		3
	7						B_2	4 - 5	3		0

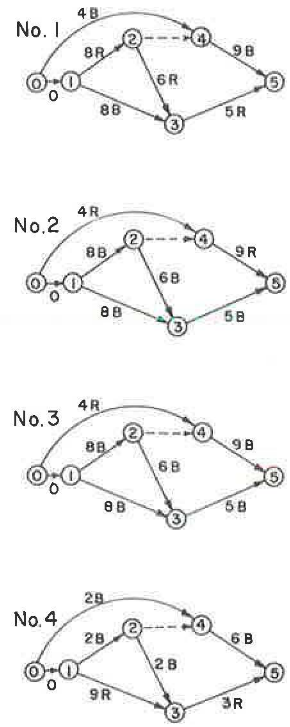


Figure 2. Chart of balance-period method.

units. The number beside the arrows of the network diagrams indicates the work required to accomplish the activity. Thus, for activity 1-2 of project No. 1, the figure "8" represents the fact that 8 time units are required to complete the activity. For the sample problem only one man may be utilized to accomplish an activity.

5. The smallest indivisible time unit that is practical to schedule is chosen as the basic time unit. This might be hours, days, weeks, or months, depending on whether the schedule is to be utilized at the production level or at a higher management stratum.

6. A logical accumulation of basic time units determines the balance period. For example, if the basic time unit is a day, then the logical balance period is a week. The balance period comprises eight basic time units in the sample problem.

With this information and suitable charts, the scheduling process begins. Personnel are allocated, within the balance periods, to the highest priority, uncompleted projects. Where the network diagram indicates that some personnel cannot be utilized in the highest priority, uncompleted project, they are assigned to the next-to-the-highest priority project or to the first project in the descending list of projects that can utilize these people. All personnel are allocated before proceeding to the next balance period.

The primary importance of the network diagram is disclosed in the allocation process. The diagram portrays the activities that can be started and the activities that must be held off until an uncompleted activity is finished. This importance is further amplified in the case of the activity that depends upon the completion of two or more activities.

The priority ranking of projects is also vital to the balance-period method. It is this feature that allows a mechanical allocation of personnel between projects. For each balance period, all activities that compete for the men of a specified skill are ranked in order of their project priority, and allocation is made according to this priority ranking.

But the translation of project priority to activity priority does not take into account the case in which several activities of the same project are competing for the same man. Both activities would have the same priority, and thus critical path procedures are relied on to determine which activity the resource is to be assigned.

In the first balance period, it is shown on the network diagrams that all resources can be scheduled to start work on Project 1. R_1 is assigned to activity 1-2, B_1 is scheduled for activity 1-3, and B_2 is scheduled for activity 0-4. R_1 and B_1 will be occupied for the entire balance period on their activities, but B_2 completes activity 0-4 in the first four basic time units.

In the search for an assignment for B_2, in the latter four basic time units of the balance period, it is noted that the first project requires a B skill to accomplish activity 4-5. But the network diagram indicates a dependency between 4-5 and both 0-4 and 1-2. This dependency precludes the scheduling of work on 4-5 until both 0-4 and 1-2 are complete. Since 1-2 will not be finished until the end of the first balance period, and our objective is to make maximum utilization of available men, B_2 is scheduled to work on Project 2 for the remaining four basic time units of the first balance period.

A choice is now presented on whether to schedule activity 1-2 or 1-3 of the second project. Critical path analysis is relied on for the decision. A check of all time paths through the project reveals that path 1-2-3-5 requires 19 time units while 1-3-5 requires 13 time units. In an effort to complete the project in the earliest possible time, B_2 is assigned to the activity that lies on the longest path. Thus, B_2 is scheduled for the last four time units of the first balance period to activity 1-2 of Project 2.

In scheduling the second balance period, attention is still applied to Project 1—the highest priority, uncompleted project. It is realized that activities 0-4, 1-2, and 1-3 are completed and that 2-3, 3-5, and 4-5 will have precedence over activities of other projects. R_1 is assigned to 2-3 for the first six time units, and for the last two time units R_1 is scheduled to start 3-5. B_1 is scheduled to work on 4-5 for the entire eight-unit balance period. There remains one time unit of work in Project 1 that requires a B skill. This is the ninth unit of the work required on activity 4-5 and thus cannot be scheduled for the second balance period. Therefore, B_2 must be allocated again to Project 2.

A choice still exists on assignment of B_2 to 1-2 or 1-3 of Project 2; but in an attempt not to break the continuity of an activity, the choice is obviated and B_2 is therefore scheduled for the first four time units to complete activity 1-2.

Faced with the choice of assignment of B_2 to 1-3 or 2-3 for the last four time units of the balance period, the time paths of the uncompleted activities are again checked to aid in the decision. Activity 2-3 is on the path 2-3-5 and requires 6 + 5 or 11 time units to complete. Activity 1-3 is on the path 1-3-5 and requires 8 + 5 or 13 time units to complete. B_2 is, therefore, assigned to the longest path or to activity 1-3 for the latter four time units of the balance period.

At this point, with the principles of the balance-period method demonstrated, the remainder of the problem is not discussed.

In summary, the CPM, the network diagrams, the priority ranking of projects and the fixed pool of manpower resources form the elements of the theory utilized in the balance-period approach to scheduling. This schedule is a calendar time allocation of each resource to activities each can do, when it can be done, and in sequence of project priority.

The fixed pool of resources has a major bearing on the schedule. For each balance period, the entire manpower pool is applied to the priority array of projects. With the aid of network diagrams, a search is made for activities that can utilize the manpower. The search descends through the project array. The men are allocated to the highest priority project possible. When an allocation choice exists, the time paths through the project are checked and the man is allocated to the activity on the longest path. This conforms to the critical path method of scheduling.

Iterative Procedures

The sample problem is enormously simplified and could be solved without the aid of a computer. However, when 500 to 1,000 projects are involved with an even larger number of engineers, technicians, draftsmen, right-of-way specialists, etc., the problem probably requires solution by electronic computer. Furthermore, several variations of the problem should be solved and analyzed prior to adopting any schedule.

Therefore, the balance-period approach is more explicitly described in a five-step procedure that is to be repeated for each balance period.

1. Determine the initial critical path of each project. This is accomplished by examining all paths through the project to determine the path that requires a maximum of time to accomplish. Assuming manpower is available during all time periods, the critical path establishes the total time necessary to accomplish the project.
2. Assign personnel to the critical path of highest priority project not yet completed.
3. For the highest priority uncompleted project, examine the remaining time paths to complete the project and assign available personnel. Where activities compete for a resource, precedence is given to the activity on the longest path.
4. Personnel not assigned to the highest priority, uncompleted project are then available for assignment to the next highest priority, uncompleted project. The time paths are examined and personnel are assigned in the same manner as in the prior project. The resources are applied down through the priority list in like manner until all resources are exhausted.
5. Proceed to the next balance period and iterate steps 1 through 5. In the second and all subsequent iterations, the assignment must be somewhat altered. This is done to preserve activity continuity, and is accomplished by inserting the statement that once an activity has commenced, work should proceed until the activity is accomplished. To this rule there is one exception: in the case where a man has been scheduled in the previous balance period to a secondary project but is now needed on the critical path of the highest priority project, he is shifted so that he can be scheduled on the priority project—thus the continuity of his original assignment is broken. Activity continuity of the priority project is never disturbed—not even for assignment to the critical path.

The problem and schedule (Fig. 3) demonstrate the exceptional case that calls for activity interruption. For the first balance period on this problem, R_1 was scheduled to work on activity 1-2 of Project 2. This was done because Project 1 activity requiring an R skill cannot be scheduled until the B work on activity 1-2 of Project 1 has been completed. Proceeding to the second balance period, activity 2-4 of Project 1 is on the critical path and requires the assignment of an R skill. The continuity of activity 1-2 of Project 2 is thus broken to schedule the R skill to activity 2-4 of Project 1.

The purpose of interrupting the continuity of an activity is also seen in the problem and schedule of Figure 3. Had activity 1-2 of Project 2 been scheduled in the second balance, Project 1 could not be scheduled to completion until the end of time period 12. This delay would be contrary to our basic objective of bringing projects to completion in a minimum possible time.

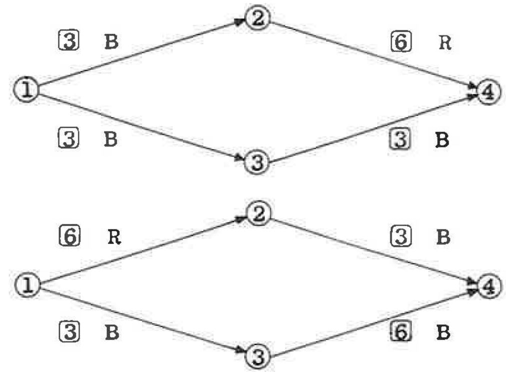
While on the subject of activity continuity, it is pertinent to note the other cases where activity splitting is a possibility but is, in general, an unacceptable procedure.

1. An activity of the highest priority project is not broken in order to schedule the critical path of this or any other project. Although such a practice might bring the project to completion in shorter time, the relatively greater number of activity splits that results probably does not warrant the savings in time. Figure 4 illustrates what would happen if activity continuity were ignored and the schedule planned according to strict critical path methods. (Only the activities indicated by solid lines scheduled.)

With the balance period equal to the basic time unit, the critical path shifts at every change in time. Manpower is allocated to activities that lie on the two highest time paths. The resultant schedule of the three activities shows activity 1-3 broken for a two-week period and activity 1-4 interrupted for one week.

Project 1
First Priority

Project 2
Second Priority

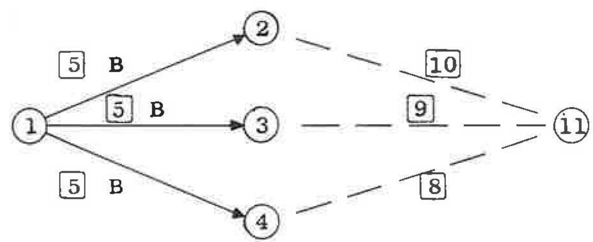


Manpower Pool: 2 B Skills
1 R Skill

Balance Period: 3 weeks
Basic Time Units: week

Project	Activity	SCHEDULE — Basic Time Units 0–3	3–6	6–9	9–12	12–15
1	1-2	B_1				
	1-3	B_2				
	2-4		R_1	R_1		
	3-4		B_1			
2	1-2	R_1			R_1	
	1-3		B_2			
	2-4			B_1		
	3-4			B_2	B_2	

Figure 3. Continuity analysis.



Manpower Pool: 2 B Skills

Balance Period: 1 week

Basic Time Units: weeks

Project	Activity	SCHEDULE* — Time Periods 1	2	3	4	5	6	7	8
	1-2	B_1	B_1	B_1	B_1	B_1			
	1-3	B_2	B_2			B_2	B_2	B_2	
	1-4			B_2	B_2		B_1	B_1	B_1

* For first three activities only.

Figure 4. Critical path scheduling.

The schedule that does not allow activity interruption is as follows:

activity 1-2—time periods 1 through 5
activity 1-3—time periods 1 through 5
activity 1-4—time periods 6 through 10.

This latter case results in an overall increase of two weeks to complete activities 1-2, 1-3, and 1-4.

2. An activity of a secondary project is not broken to allow the scheduling of a non-critical activity in a higher priority project. This is based on the premise that the critical path, and thus project duration, would not be shortened in the higher priority project; and therefore, there is no warrant for interrupting an activity.

Evaluation

This evaluation is directed toward the quality of the schedule that results from utilization of the balance-period method. Limitations are also discussed, but remarks in regard to problems of practical application are taken up later.

Figure 5 represents the schedule of activities and the manpower utilization that pertain to the hypothetical sample problem in Figure 2.

Examination of Figure 5 along with the project network diagrams of Figure 2, shows a fundamental feature of the balance-period approach to scheduling. It appears that, with due consideration for available manpower, project priority, time paths, and activity continuity, activities are scheduled at the earliest possible start time. The network diagram for Project 1 indicates that at time zero the critical path is 1-2-3-5. Therefore, the activities 1-2, 2-3, 3-5 have no float; but 0-4, 4-5, and 1-3 all possess float. In other words, the activities with float could be scheduled within a range of time units without altering overall project duration. Activity 0-4 could be scheduled to commence in either the first, second, third, or fourth time units of the first balance period without changing the project completion date. Thus, activity 0-4 has four time units of float. By the same reasoning, activity 1-3 has six time units of float, and activity 4-5 has two time units of float.

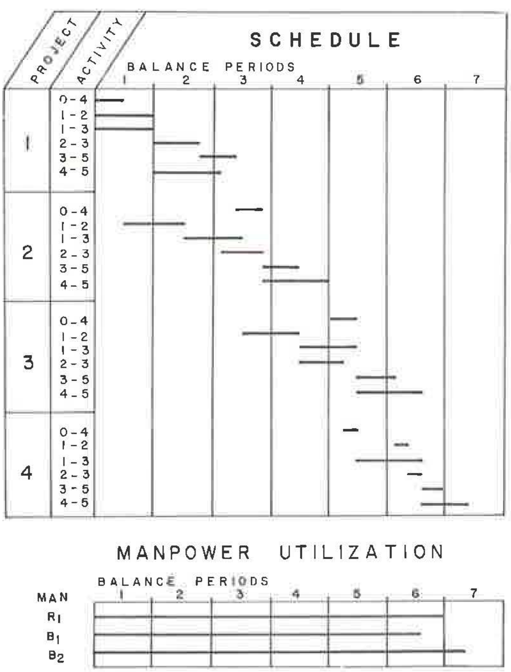


Figure 5. Schedule and manpower usage chart.

Although the balance-period method discriminates between the activities with float and the critical path activities, the method gives no consideration for the amount of float. The activities with float are scheduled at the earliest possible time. Therefore, the schedule may not be an optimum. The optimum schedule might be approached by sliding to the right on the bar chart some of the activities with float. This might allow the commencement of some critical activities at an earlier time than allowed by the balance-period method. This process would be used to reduce project completion dates of priority projects. Such a procedure has not been incorporated into the balance-period approach and is subject to further research.

The balance-period approach uses the project priority as key information in the scheduling procedure; project completion dates are merely end products. Thus, in order to arrive at a predetermined set of completion dates, several trial arrays of project priority must be analyzed. Adaptations of the balance-period method that utilize completion dates rather than project priorities are also the subject of future research.

But within these possible limitations, the balance-period method does provide a schedule of multiple projects that may meet the requirements of highway departments. Further, it appears that the procedure is mechanical and is suitable to be programed on high-speed computers.

OTHER APPROACHES TO MULTIPLE-PROJECT SCHEDULING

The ultimate goal is to develop systematic procedures to schedule the preconstruction phases of the highway program. The balance-period method established that such a goal is realistic. The balance period represents the joining of several paramount aspects of the highway program with the recently developed principles of network diagraming and critical path scheduling. The resultant schedules meet some of the requirements of the highway industry.

The real significance of the balance-period approach is that it is possible to develop systematic procedures for manpower allocation and multiple-project scheduling. It is of secondary importance that the balance-period method does not, perhaps, embrace all requirements for scheduling the preconstruction phases of the highway program.

To proceed in the research of systematic scheduling procedures, two alternative paths were possible. On the one hand, a computer program could have been developed for the balance-period method. This would have led to further testing of the approach and possibly a practical application. On the other hand, a search for parallel ideas in various industries might uncover superior approaches to the goal. A cursory study revealed that operational computer programs were available, thus possibly obviating the requirement for a new computer program. Therefore, the latter alternative was deemed most useful at the time, with the further objective of studying what revisions, if any, might be needed in existing computer programs to meet needs of highway departments.

Through contact with highway departments, the Bureau of Public Roads, universities, computer "hardware" and "software" firms, management consultants, the U. S. Navy and others, the following organizations appeared to have advanced their research of manpower allocation and multiple project scheduling to a point where computer programs were either operational or very close to operational:

Organization	Computer Program
Carnegie Institute of Technology	$(MS)^2$: Multiship, Multishop, Workload-Smoothing
C-E-I-R, Inc.	RAMPS: Resource Allocation and Multi-project Scheduling
General Electric Co.	
IBM, Inc.	Man-Scheduling Program
Mauchly Associates, Inc.	RPSM: Resource Planning and Scheduling Methods

Another firm, Management Studies, Inc., has an analog computer mechanical approach that is a very definite contribution. Other firms and researchers may have made progress unknown to the authors.

Available computer systems were reviewed. A decision was made to test the RPSM and the RAMPS programs with a sample problem. The $(MS)^2$, the Man-Scheduling, and the GE programs did not (at the time of these studies) appear to be at a point where tests would be useful.

It is essential to outline some of the basic similarities and differences between the balance-period method and the RAMPS and RPSM systems. The three objectives of the balance-period method were previously discussed. Identified in an abbreviated form, the first two objectives are to schedule according to (a) project priorities and (b) limited manpower pool.

Investigation of possible objectives for scheduling with either the RPSM or RAMPS program adds the following three items: (a) unlimited manpower pool, (b) project start dates, and (c) project completion dates.

These five items can be combined into optional sets of objectives. Each set will provide a unique schedule. The objective which calls for scheduling each project to completion in a minimum possible time is not listed. It is, in varying degrees, basic to all schedules that are the result of the balance-period method, RPSM program or the RAMPS program. In describing the sets of schedule objectives, it is obvious that either unlimited manpower resources or limited manpower resources must be specified. Time and manpower are dependent variables that determine the schedule. The limiting of one precludes the limiting of the other.

This is the actual case with RPSM. However, in the RAMPS program, the incorporation of a "project delay penalty" (in the form of $/day of delay beyond a specified completion date) allows both resources and project duration (time) to be specified. The resource limits will never be exceeded, but the time limitation may be prolonged at an added project cost.

Should manpower be limited, then it is not feasible to specify both project start and completion dates. Conversely, with unlimited manpower resources, both dates can be accommodated. Project priorities, identified collectively as an independent variable, may be utilized in any situation, but must be used when project start or completion dates are not specified.

Thus, RPSM or RAMPS will design a meaningful schedule according to any of the following optional sets of objectives:

Unlimited manpower pool
Project start dates
Project priorities

Limited manpower pool
Project start dates
Project priorities

Unlimited manpower pool
Project completion dates
Project priorities

Limited manpower pool
Project completion dates
Project priorities

Unlimited manpower pool
Project priorities

Limited manpower pool
Project priorities

Unlimited manpower pool
Project start and completion dates

Unlimited manpower pool
Project start and completion dates
Project priorities

Individual characteristics of both RPSM and RAMPS allow for other management objectives. However, the objectives listed appear to be the most useful for the scheduling of preconstruction activities of state highway department programs.

It is quickly recognized that RPSM and RAMPS will provide schedules according to a variety of objectives, while the balance-period method is restricted at this time to a schedule that relies on a limited manpower pool and project priorities. But of the seven other objectives, five rely on the restricted supposition that manpower is unlimited. Small alteration to the balance-period method would provide a realistic schedule for the limited manpower-project start dates-project priorities set of objectives. Major alterations would be required to schedule according to the remaining set which provides for project completion dates.

Like the balance-period method, both RPSM and RAMPS employ the networking method of project planning and the critical path concept of work scheduling. Basic input information required is similar to the balance-period method:

______name of activities within each project,
______estimate of time and type of resources needed to complete each activity, and
______specified quantities of each available resource.

However, project priorities, start dates or completion dates may be supplied in the RPSM or RAMPS program, depending on management objectives.

The proprietary nature of both the RPSM and RAMPS programs precludes a detailed discussion of the procedure for scheduling each basic time unit. It is possible, however, to relate the procedures generally.

The problem is divided into time periods of an hour, day, month or any predetermined length of time. For each period, RPSM or RAMPS computes a combination of scheduled, delayed or interrupted activities according to resource availability and management objectives.

Beginning with the first time period, reanalyzing remainder after each time period, and continuing until all activities are scheduled, the RAMPS program performs the following steps to schedule each time period:

1. Computes the critical path in each project to determine critical activities
2. Computes the earliest start times and the latest completion times for activities to determine the possibilities for delay or interruption
3. Determines the activities available for scheduling during the current period, including activities scheduled earlier
4. Computes the resource requirements of each available activity
5. Generates a variety of possible schedules for the time period
6. Evaluates each possible schedule according to the degree to which it conforms to the desired scheduling objectives of management
7. Selects the best schedule according to the algorithms involved.

The RPSM computational procedures are not known other than the fact that critical path methods are employed.

The RAMPS program is processed on the IBM 7090 computer and has the capacity of approximately 700 activities. The RPSM program is processed on the IBM 1620 and is capable of handling approximately 1, 400 activities. The capabilities of both are dependent on the variety of resource skills specified.

A sample problem was designed to test the RAMPS and RPSM programs. It is shown in network-diagram form in Figure 6. Twelve projects arrayed in priority sequence comprise the problem. A limited manpower pool (32 men) of six skill classifications was randomly established (see Figs. 14 and 15). The objective was to provide schedules based on the use of a limited manpower pool and project priorities.

Samples of the computer output are shown in Figures 7 through 11. The problem was originally designed in the highway context. Thus, "typical" highway activities were designated, i.e., "location," and "preliminary survey." The skill classifications were likewise typical highway designations: H - highway designers; S - survey crews; T - traffic engineers; P - highway planning engineers; B - bridge engineers; R - ROW engineers.

The actual schedules and manpower usage charts are shown in Figures 12 through 15. Comparison of the schedules (Figs. 12 and 13) yields the following observations:

______the RPSM program utilized a total problem time of 96 periods and the RAMPS program 88 periods
______only project 3 had identical project completion times in both programs
______the RAMPS program split nine activities
______the spread between project start and finish increased as project priority diminished

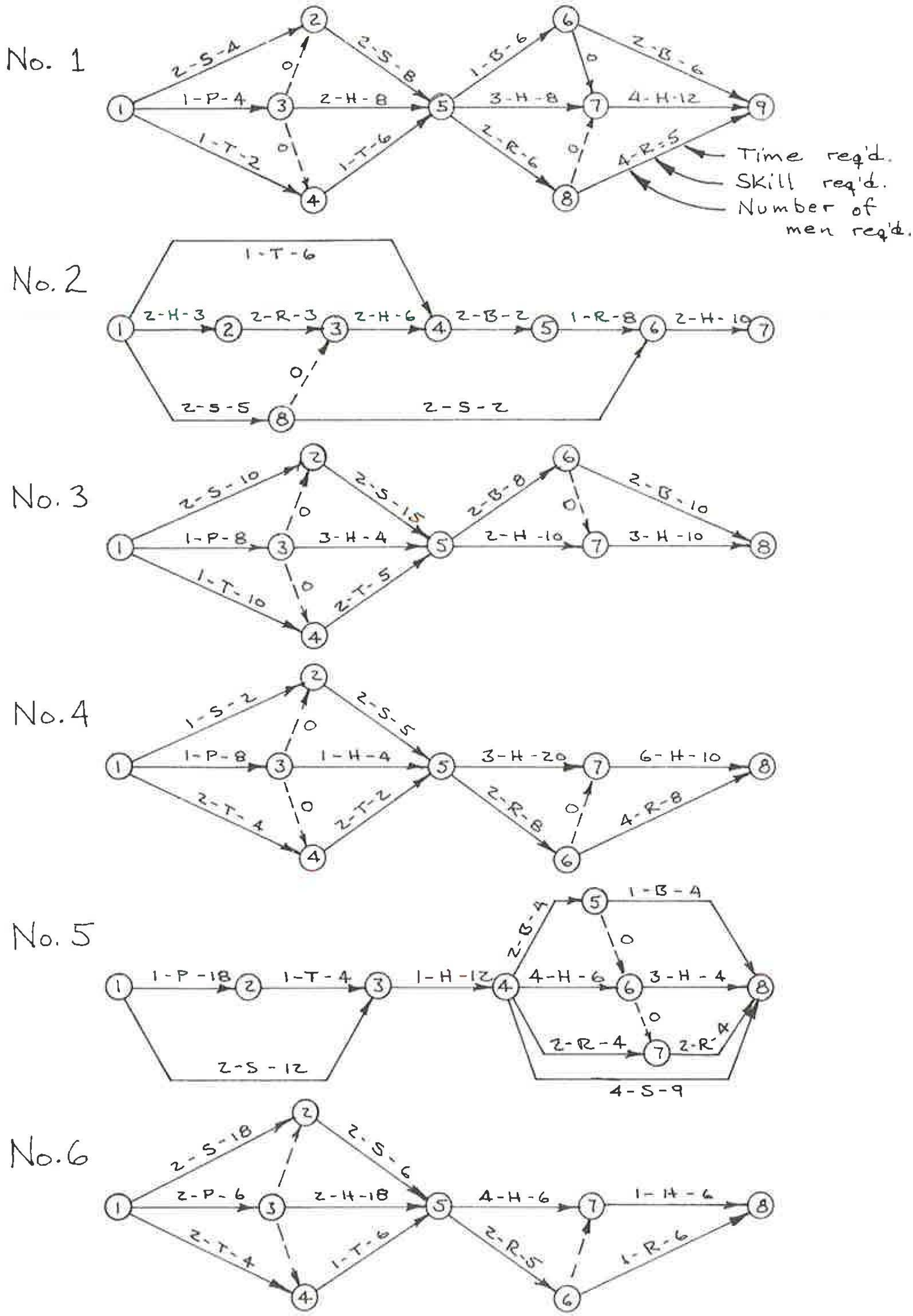


Figure 6. Sample problem.

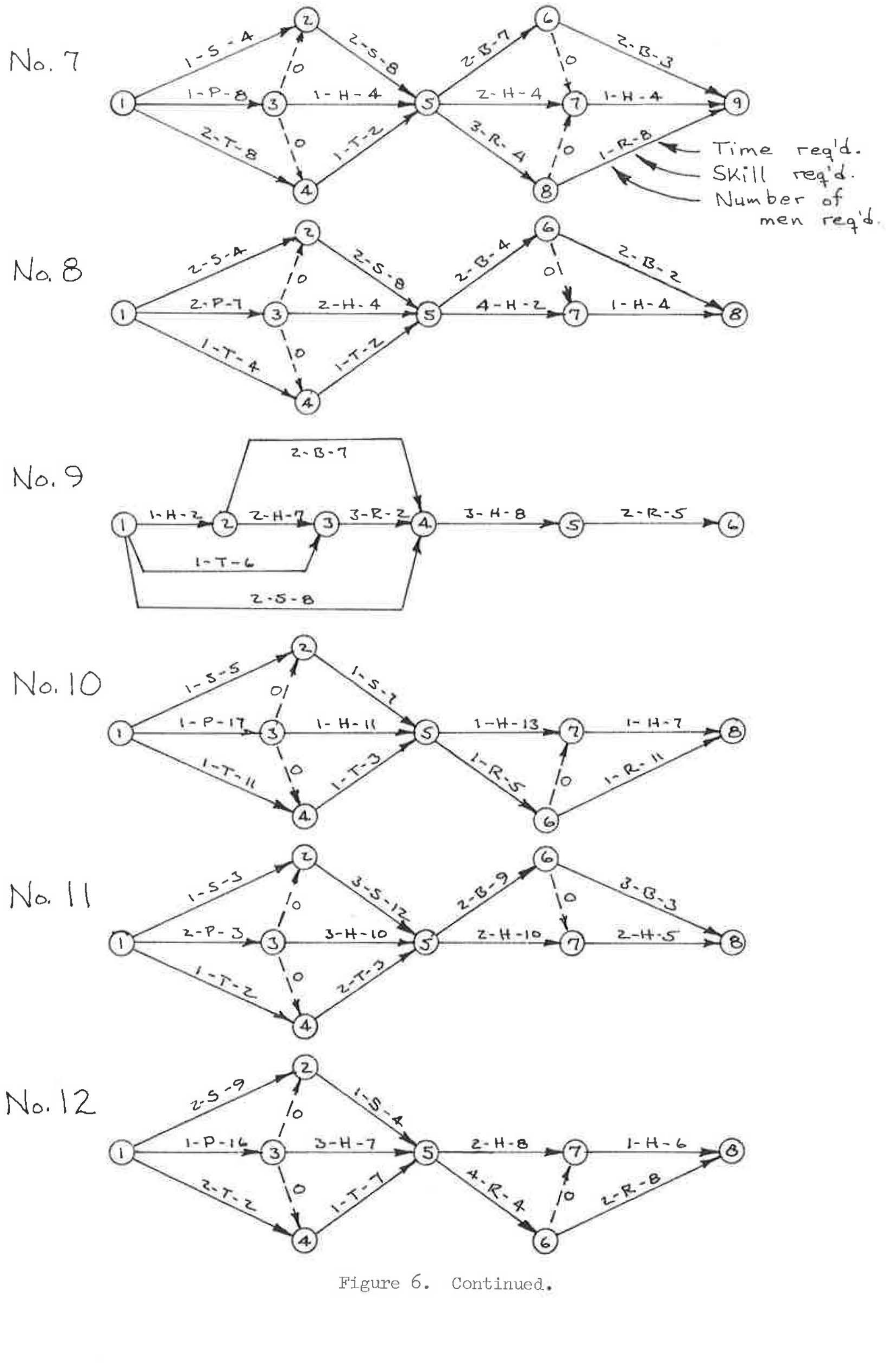


Figure 6. Continued.

AUTOMOTIVE SAFETY FOUNDATION
STUDY PROBLEM 201
AUGUST 20,1963
RPSM SIMULATIONS BY
MAUCHLY ASSOCIATES,INCORPORATED
FORT WASHINGTON,PENNSYLVANIA
RESOURCES LIMITED RUN
TIME UNITS ARE IN WEEKS

I	J	DUR.	COST	DESCRIPTION		START	END	--CODES--			
1	13	4	640	LOCATION	1	1	4	P	1		
1	12	4	5600	PRELIM SURVEY	1	1	4	S	2		
1	14	2	320	TRAFFIC EVALUATION	1	1	2	T	1		
13	12			DUMMY	1	5	4				
12	15	8	11200	FINAL SURVEY	1	5	12	S	2		
13	15	8	4560	PRELIM DESIGN	1	5	12	H	2	D	2
13	14			DUMMY	1	5	4				
14	15	6	960	TRAFFIC ASSIGN	1	5	10	T	1		
15	17	8	6840	HIGHWAY DESIGN	1	13	20	H	3	D	3
15	16	6	1710	STRUCTURAL DESIGN	1	13	18	B	1	D	1
15	18	6	3420	ROW PLAN PREPARATION	1	13	18	R	2	D	2

Figure 7. Example of RPSM output—activity schedule.

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STUDY PROBLEM 201
AUGUST 20,1963
RPSM SIMULATIONS BY
MAUCHLY ASSOCIATES,INCORPORATED
FORT WASHINGTON,PENNSYLVANIA
RESOURCES LIMITED RUN
TIME UNITS ARE IN WEEKS

RESOURCE USAGE TABLE

IME		B	D	H	P	R	S	T
1	U		4	3	2		7	2
2	U		4	3	2		7	2
3	U	2	6	4	2		8	2
4	U	2	6	2	2	2	8	2
5	U	2	8	4	2	2	8	2
6	U	2	8	4	2	2	8	2
7	U	2	4	6	2		8	2
8	U	2	4	6	2		8	2
9	U	2	7	9	2		8	2
10	U		5	7	2		8	2
11	U		5	7	2		8	2
12	U		5	7	2		8	2

Figure 8. Example of RPSM output—resource usage table.

AUTOMOTIVE SAFETY FOUNDATION
STUDY PROBLEM 201
AUGUST 20,1963
RPSM SIMULATIONS BY
MAUCHLY ASSOCIATES,INCORPORATED
FORT WASHINGTON,PENNSYLVANIA
RESOURCES LIMITED RUN
TIME UNITS ARE IN WEEKS

RESOURCES REMAINING TABLE

TIME		B	D	H	P	R	S	T
1	R	3	26	10		4	1	
2	R	3	26	10		4	1	
3	R	1	24	9		4		
4	R	1	24	11		2		
5	R	1	22	9		2		
6	R	1	22	9		2		
7	R	1	26	7		4		
8	R	1	26	7		4		
9	R	1	23	4		4		
10	R	3	25	6		4		
11	R	3	25	6		4		
12	R	3	25	6		4		

Figure 9. Example of RPSM output—resource remaining table.

```
P A1                    STATE HWY DESIGN PROJ

      AVAILABLE START TIME=              1
      DESIRED COMPLETION TIME=           5
      SCHEDULED COMPLETION TIME=        39
      DELAY COST AT $   120000=$   4080000

   TASK    ACCOUNT NO.                    WORK                  PERIODS    1      THROUGH   24
           RESOURCE TEAM     RATES             1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

                    PREL SURVEY            8
   1    2 SURVEY            2   20             2  2  2  2

                    TRAFFIC EVAL           2
   1    4 TRAFEN            1   10             1  1

                    LOCATION               4
   1    3 PLANNE            1   10             1  1  1  1

                    FINAL SURVEY          16
   2    5 SURVEY            2   20                         2  2  2  2  2  2  2  2

                    TRAF ASSIGN            6
   4    5 TRAFEN            1   10                               1  1  1  1  1  1

                    PREL DESIGN           16
   3    5 HWYDES            2   20                         2  2  2  2  2  2  2  2
   3    5 DRAFTS            2   20                         2  2  2  2  2  2  2  2
```

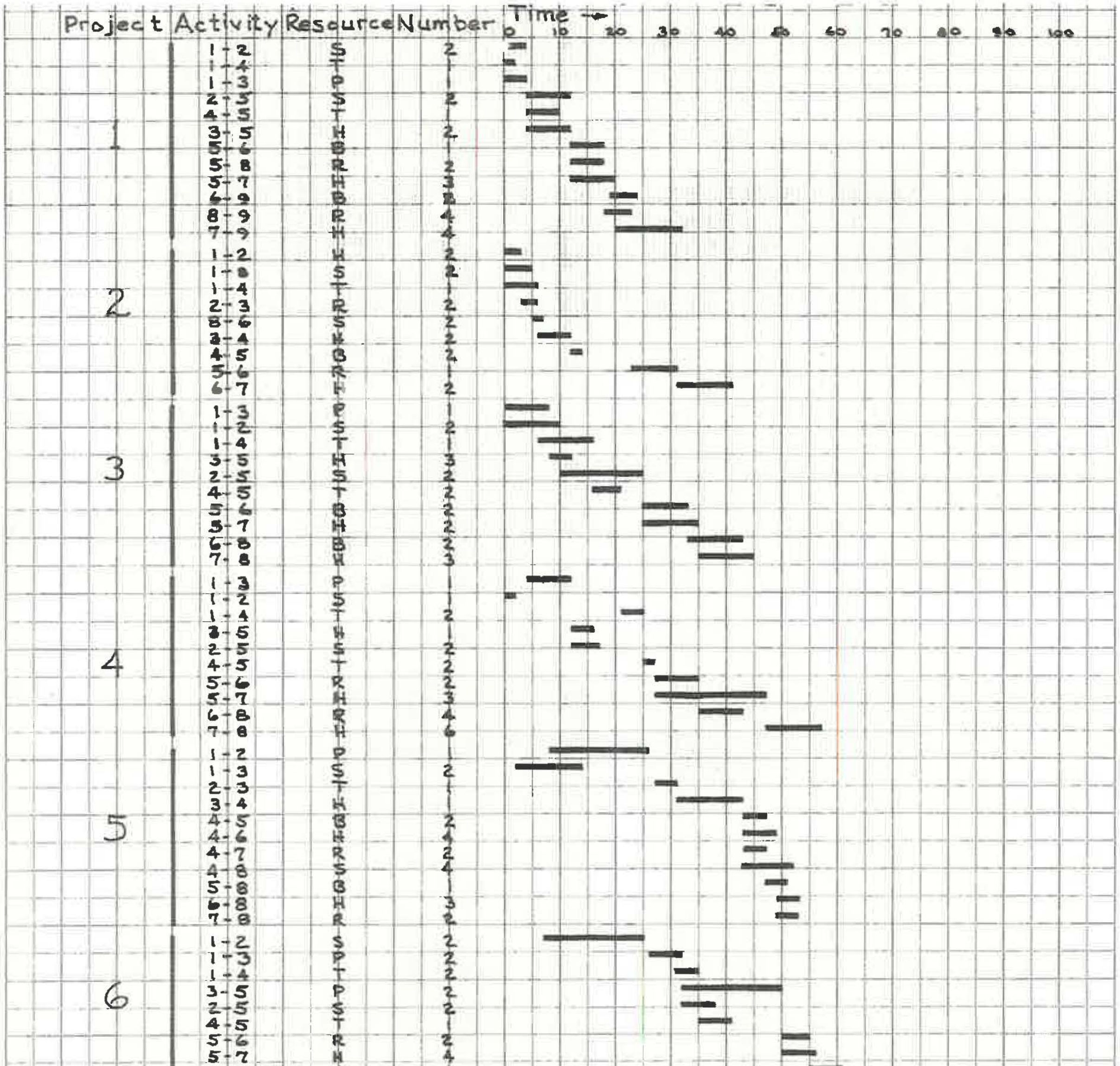
Figure 10. Example of RAMPS output—activity schedule.

```
 RESOURCE        SURVEYORS

PROJECT   TASK  ACCOUNT NO. IDENTIFICATION  WORK                  PERIODS    1      THROUGH   24
                                                 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
P A3       1     2          PREL  SURVEY     20  2  2  2  2  2  2  2  2  2  2
P A4       1     2          PREL  SURVEY      2  1  1
P A2       1     8          PREL  SURVEY     10  2  2  2  2  2
P A1       1     2          PREL  SURVEY      8  2  2  2  2
P A11      1     2          PREL  SURVEY      3  1     1  1
P A7       1     2          PREL  SURVEY      4     1  1  1  1
P A10      1     2          PREL  SURVEY      5              1
P A1       2     5          FINAL SURVEY     16              2  2  2  2  2  2  2  2
P A2       8     6          FINAL SURVEY     40                 2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
P A9       1     4          SURVEY           16                 2  2  2  2  2  2  2  2
P A3       2     5          FINAL SURVEY     30                                2  2  2  2  2  2  2  2  2  2  2  2  2  2
P A4       2     5          FINAL SURVEY     10                                      2  2  2  2  2
P A6       1     2          PREL  SURVEY     36                                         2  2  2  2  2  2  2  2  2  2  2
P A5       1     3          PREL  SURVEY     24                                                     2  2  2
P A7       2     5          FINAL SURVEY     16                                                              2  2  2  2

          TOTAL REQUIRED                         8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8
          TOTAL AVAILABLE                        8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8
          TOTAL IDLE (-ACQ.)
```

Figure 11. Example of RAMPS output—resource usage table.


Project
Activity
Resource
Number
Time
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6

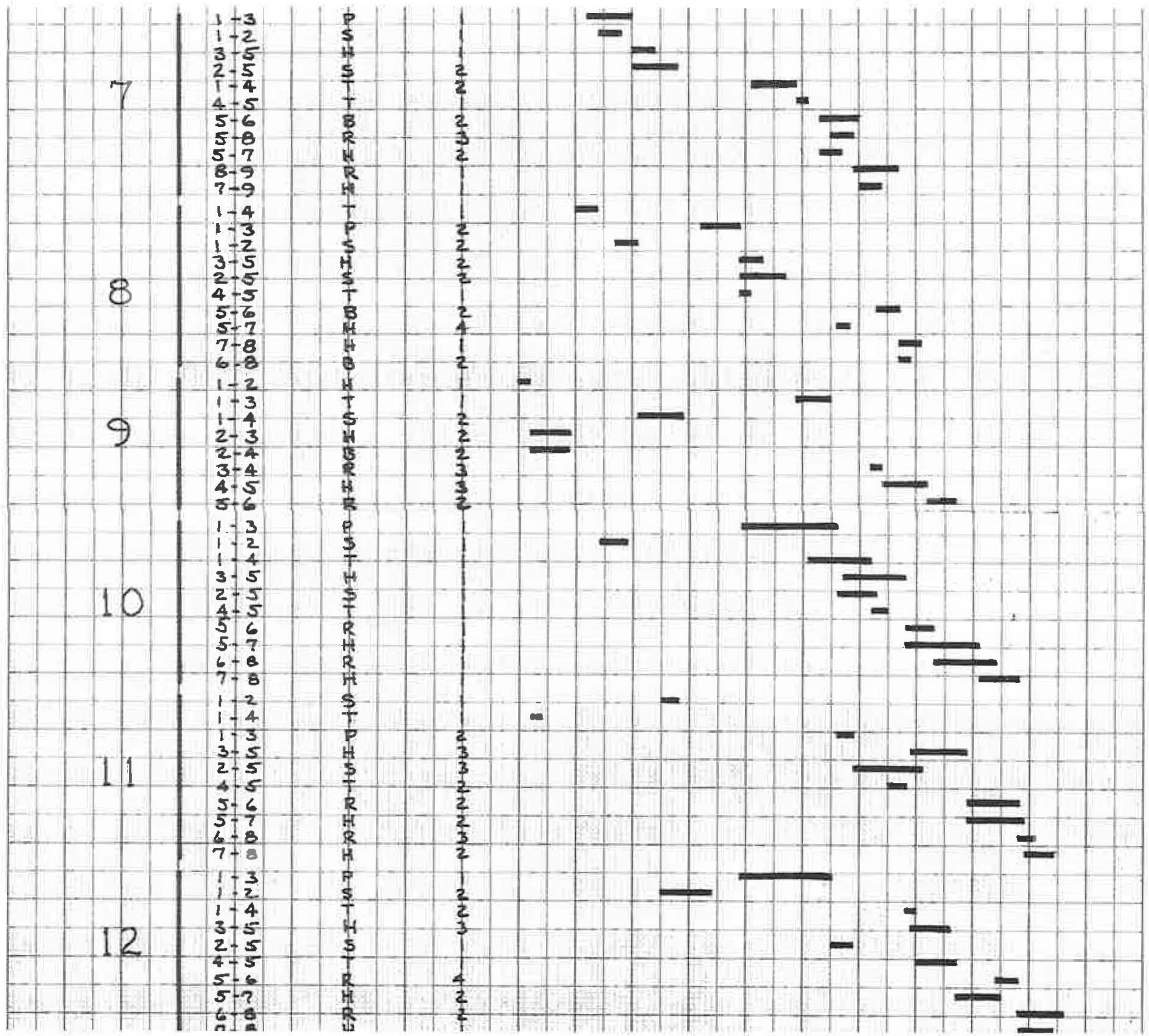
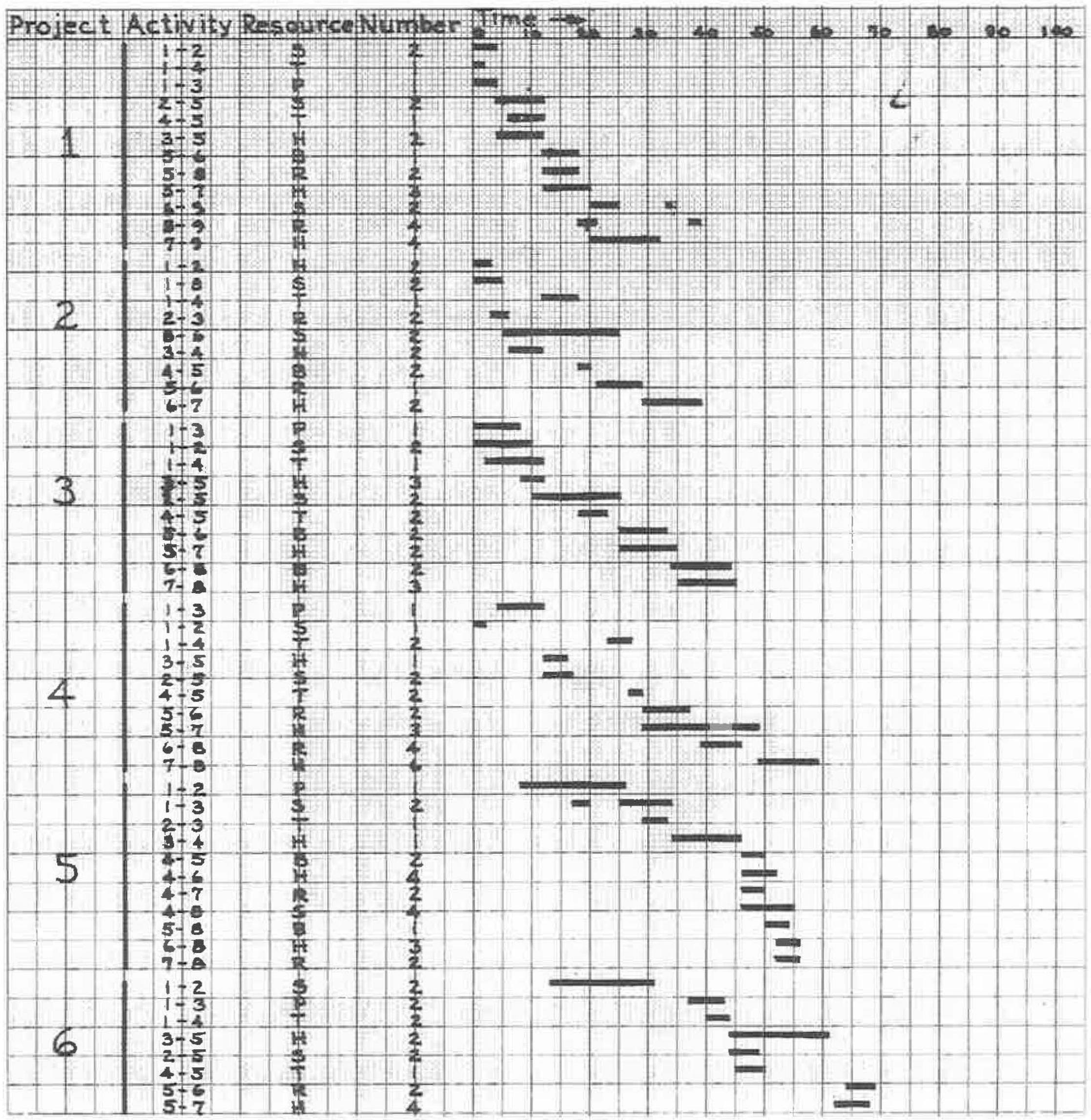


Figure 12. RPSM schedule chart.


Project
Activity
Resource
Number
Time →
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6

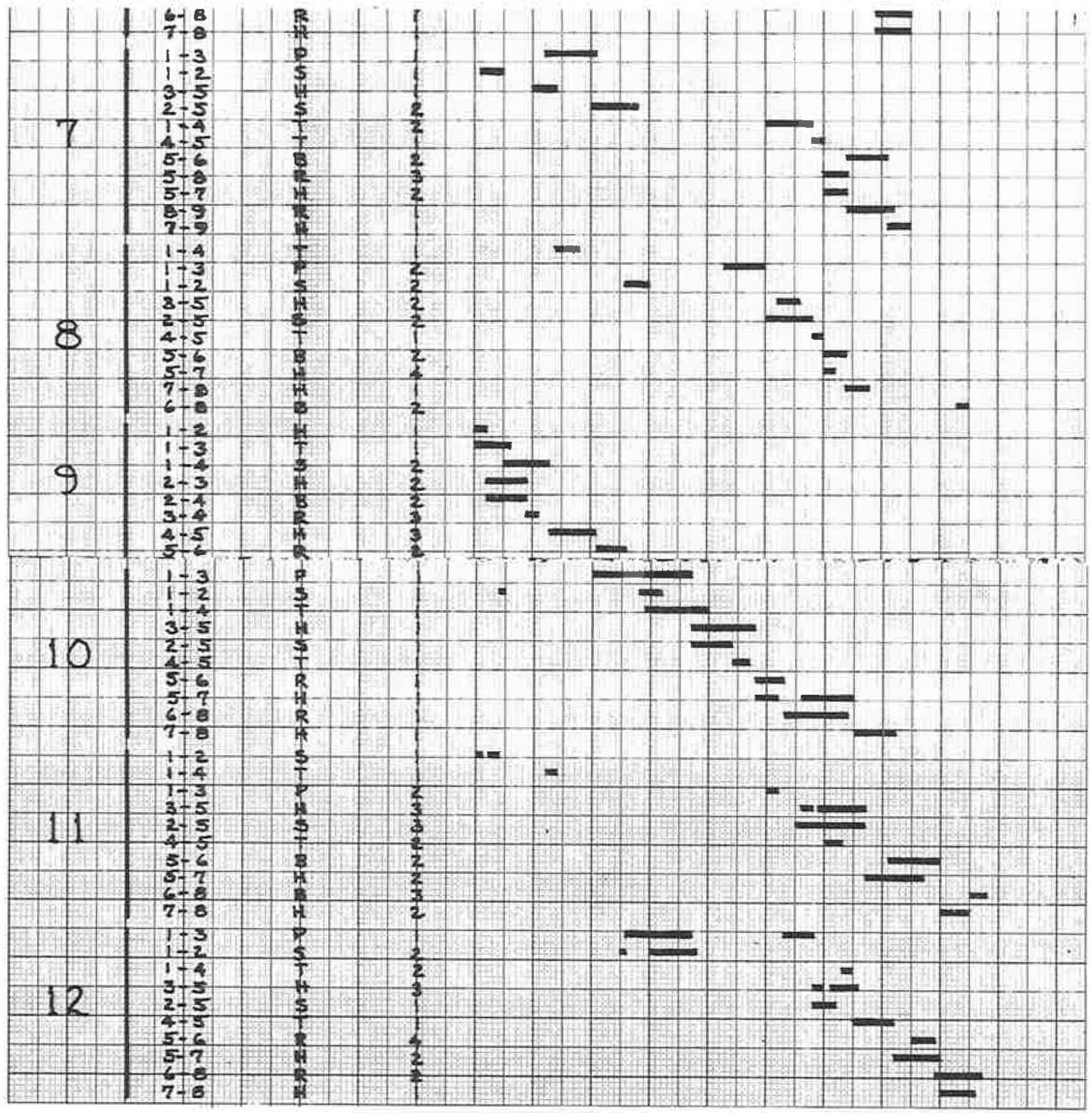


Figure 13. RAMPS schedule chart.

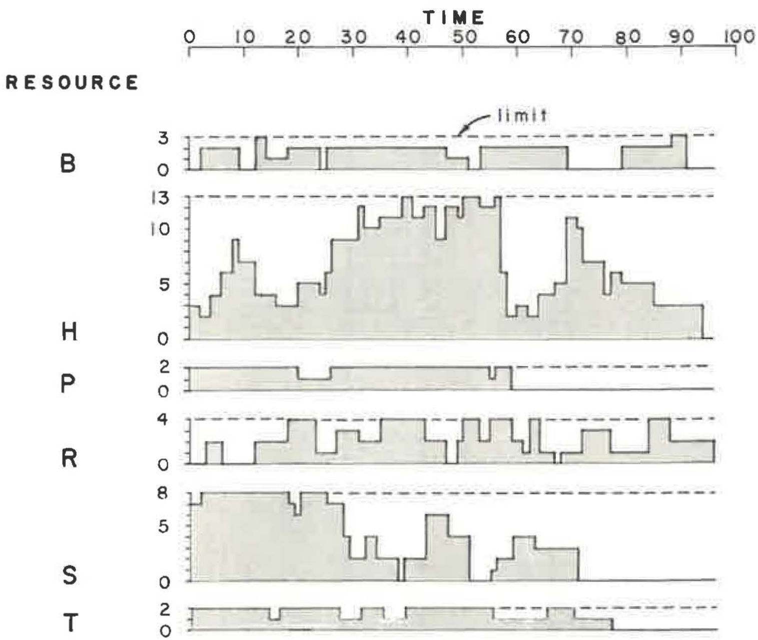


Figure 14. RPSM resource usage chart.

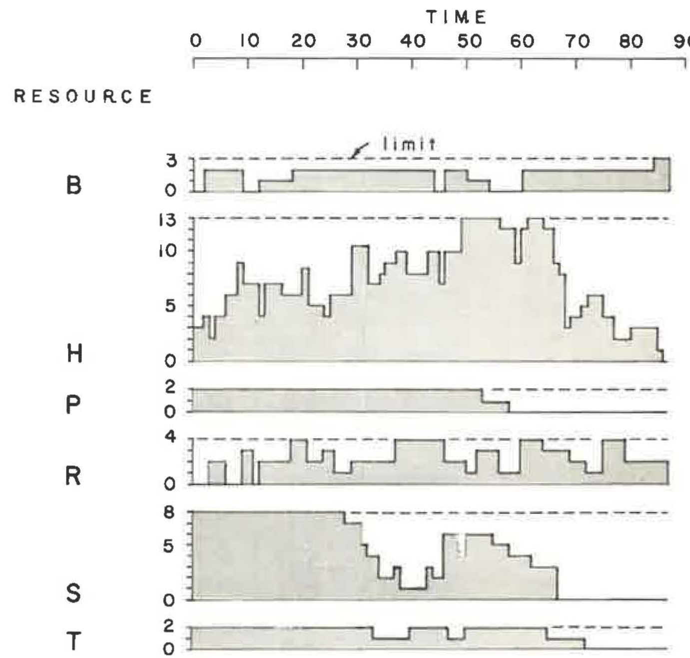


Figure 15. RAMPS resource usage chart.

- ______the RAMPS program expedited project 9 (completed in time period 26) with apparent disregard for its relatively low priority
- ______with the exception of project 9 in the RAMPS schedule, all other projects appear to be scheduled according to priority.

The resource usage charts (Figs. 14 and 15) indicate the amount of each skill classification that was allocated at each time period to form the schedule. In examining the charts, it must be recognized that this sample problem is set in a wholly unrealistic background. There are no projects under way prior to time zero and the problem contains only 12 projects. Furthermore, the projects involve the application of P, S and T skills, along with a limited number of H skills, to only the early half of each project. Conversely, the latter half of each project requires B, R and many H skilled personnel. Therefore, it is to be expected that maximum utility of P, S and T skills will be made in the early portions of the total problem duration, and maximum utility of B and R skills in the later portions of the duration. In this situation (problem), therefore, it is impossible to achieve full utilization of all skills, as suggested in the different problem used to describe the balance-period method.

Even considering the fact that the charts do not present a realistic situation, their ragged nature indicates either:

- ______the problem was not designed to allow maximum utilization of manpower, or
- ______that neither computer program emphasizes a manpower leveling feature.

It is, however, safe to assume that analysis of the charts and subsequent changes in the manpower limitations and/or project priorities will provide more even manpower utilization. Further research will be directed toward evaluating and testing the manpower leveling capabilities of both programs.

In regard to the RAMPS program, it is known that various "weightings" of manpower leveling and several other "management controls" are available. The weights applicable are from 0 to 100, but a standard weight of one was established for the sample problem. A higher weight applied to "manpower leveling" would probably smooth the resource usage charts at a level somewhat below the maximums shown in Figure 15, but problem duration, and thus project completion dates, would probably be extended.

It is pointed out that to schedule this problem by the manual, balance-period method would be extremely tedious. For this reason, no comparative analysis of a balance-period schedule can be made at this time.

There are other ramifications available with the RAMPS and RPSM programs, for example:

- ______cost analysis
- ______teaming of resources
- ______optional activity work rates (RAMPS only)
- ______management controls.

Some of these items have important contributions to make to the theory of scheduling. However, the authors believe that further explanation and exposition of these items would not add materially, at this time, to the general applicability of these programs to the highway program.

The SMD PLANALOG as developed by Management Studies, Inc., is a device that can be manually manipulated to plan and schedule single or multiple projects. The PLANALOG is a grooved metal board. The grooves are designed to engage a variety of plastic blocks and to allow lateral movement of the blocks. A time scale is taped to the boards.

The blocks represent project activities and are of various lengths to express different activity time durations. They can be color-coded to portray the skill required to accomplish the activity. Cost information and varying manpower rates can also be placed on the blocks.

Serrated metal plates called "fences" are provided. These fit transversely across the board to indicate the instant in time when several project activities may commence or end. The fences provide the interrelationships between the activities and perform the computing and forecasting function for the PLANALOG.

In general, a multiplicity of projects can be described on a series of the boards. From examination of the color codes and employment of manpower usage charts, various schedules that meet a variety of management objectives can be portrayed. This device appears useful for scheduling and resource allocation of:

______single projects of 20 to 1,000 activities
______a large number of simple (5 to 100 activities) projects
______several complex projects totaling 1,000 activities
______a large number of complex projects that are reduced to simple form.

Further research is necessary to evaluate the SMD PLANALOG adequately. Management Studies reports that SMD PLANALOG has been successfully field tested with regards to multiple-project scheduling.

ASPECTS OF PRACTICAL APPLICATION

Policies and operating methods of highway departments have substantial effects on feasibility and methods of scheduling and control of preconstruction activities. In addition, there are numerous technical problems that remain to be solved to achieve objectives of highway program administrators.

Principles and methods previously described offer some hope that present procedures can be improved, but only if some prerequisites are fixed:

1. Projects are identified and priority is established;
2. A complete and adequate network diagram for each project is prepared;
3. Realistic time and resource estimates are provided for each activity; and
4. An adequate reporting system is in operation, in order to permit periodic schedule revisions.

This paper also is based on only a few of management's objectives:

1. Available manpower resources shall be assigned first to the top priority project and to its most critical activity. Subsequent assignments are to be made in sequence of project priority and criticality of activities.
2. All available manpower shall be used productively, in line with the preceding objective.
3. Each project shall be completed, ready for contract award, in the least possible time and preferably in priority sequence.

Prerequisites for Systematic Scheduling

1(a). Project Identification. "Projects" may be described differently at different stages of their development. What ends as a specific location, design and length, often has begun as part of a broad area-wide study, progresses through several alternatives, and ends as only a portion of what may have been conceived initially.

1(b). Project Priority. This is easier said than done, especially with any reasonable degree of stability. Many factors must be considered, and priority may vary logically (or illogically) from time to time. It should be obvious to management, however, that instability of decisions reduces, in direct proportion, the adequacy of any advance scheduling method. Project priority is affected by methods of determining relative needs, availability of funds, requirements of stage construction or continuity of design, agreements with other agencies of government (or their action or inaction), political decisions and other factors.

2. Network Diagrams. The requirements, even for single project scheduling, are subjects of much literature. Problems are multiplied when considering requirements of multiproject scheduling. Resource (manpower) allocation may require very complete diagrams in order to account for all tasks. (See item 3, following.) However, as the level of management interest rises from that concerned with a single project, to top levels concerned with numerous projects and long-range operations, details become less essential. The nature of detail required for general management objectives remains to be studied to determine whether meaningful scheduling can be accomplished with a minimum of complexity. Moreover, the diagraming will vary, depending on nature of the project and on its stage of development, as mentioned in item 1(a).

3. Time and Resource Estimates. Necessity for and problems of establishing realistic time estimates for each activity have been discussed in numerous other papers. When considering resources (manpower) allocation, the methods discussed in this paper seem to require indivisible units of manpower and time. To meet the condensed or simplified needs of top management as pointed out in item 2, broader terms are desirable, but these must account for time and manpower requirements if basic schedules are to be derived there-from.

For example, a broad activity identified as "design" (part of a condensed diagram for a specific project) involves work by design personnel, but certain phases of the design work may depend upon completion of assignments by soils, traffic, bridge, and computer personnel over which the responsible originator of the identified design activity has little or no control. The originator of this activity, however, must produce an estimate of the time required for its completion. The problem of how to establish the time estimate, and what method can best portray resources required and their allocation to a series of projects, remains to be resolved.

Some clues may be available in computer programs that include "leading" and "trailing" resources—the latter being dependent on allocation and time of the leading resource. However, the application of this procedure to the problem of condensing networks is not clear.

When estimating time and resource individual projects, it is assumed that manpower and funds will be available in efficient or normal quantities for each activity. However, the pool from which manpower is drawn for a group of competing projects is not unlimited. Therefore, that pool must be determined, and may have to be divided into parts (such as highway districts and categories of projects, e.g., Interstate) before the total pool available to work on particular groups of projects is established.

4. Reporting System. Initial schedules may be produced as indicated herein, but they must remain flexible and subject to quick revision to account for the numerous changes that will occur. Therefore, any procedure that is devised should consider the essential reporting procedures required to provide flexible, accurate control and revision. Questions that need study include:

a. What methods and frequency of reporting are required?
b. Are the scheduling techniques adaptable to a uniform reporting procedure?
c. Can revisions be assimilated, analyzed and a revised schedule produced within a reasonable amount of time?
d. Do all projects require the same degree or level of control and reporting frequency to insure compliance with schedules? To provide for revisions?

e. If outside agencies (public or private) are involved, can their terminology and working procedures be adapted to the method and frequency of reporting?

Limited Management Objectives

1. Priority Assignment of Resources. Although this is basically desirable, there will be numerous variations with which to contend. It was previously suggested that project priority may be assigned within categories or classes of projects, rather than on a statewide basis. If this is done, then resource pools must be allocated to each category before manpower allocation methods become useful.

Another problem relates to time requirements for total completion of single projects. For example, if the first priority project requires three years to complete all precontract activities, it is not realistic to allocate all possible manpower to that project—to the exclusion of work on some projects of short duration, even though of lesser priority. Completion of projects must be considered, as well as starting times.

2. Manpower Utilization. Techniques discussed in this paper do not provide for any pool of "unallocated" work. Some experience suggests that this is necessary to provide productive work when planned assignments are temporarily interrupted. Theoretically, the procedure would indicate the next most likely project, but it must provide for the basic problem of emergency assignments.

Of greater importance is the need for careful management analysis of adequacy or inadequacy of the manpower pool, in relation to its required work. The pool may be badly unbalanced with lack of critical skills or, conversely, an excess of noncritical personnel. In the latter event, scheduled assignments would tend to result in work on projects of least priority, long before it was essential.

Other related questions may be asked, and should be studied:

a. Will geographic location of projects affect manpower utilization and the application of the suggested techniques of scheduling?
b. How far apart can projects be and permit an effective interchange of resources on an activity basis? On a project basis?
c. Can the techniques be adapted to give recognition to projects that must be worked on seasonally?
d. Is it practical to group projects geographically for scheduling purposes?
e. Will the type of organization (centralized or decentralized) have any effect on this possibility?
f. Is it reasonable to anticipate interchange of resources on a project activity basis, regardless of geographic location, or proximity to the resource pool?

3. Least Time Completion. This involves redetermination of the critical path at each time period, which may be impractical except with the most sophisticated computer techniques. Moreover, as previously suggested, completion in the least possible time may not always be compatible with other management objectives.

Other Management Objectives and Problems

1. Basic to any schedule of preconstruction activities is a schedule of construction based on required expenditures related to funds available over various calendar time periods. Presumably this schedule, calling for contract awards on specified dates, would have to be compared to a feasible preconstruction activity schedule. Thereupon, adjustments in one or the other, or both, will be needed. If the construction schedule must be held firm, then management can analyze feasibility through methods suggested here and take necessary action to increase (or decrease) the resource pool (or pools). This type of combination and relation between schedules controlled by different limitations may, some day, be subject to a more systematic analysis than appears available now.

To arrive at a workable schedule, adjustments may be required to conform with stage construction, outside agency construction schedules, management desires, policy decisions, statutory controls and funds. Questions raised include:

a. Are the techniques discussed sufficiently flexible to produce alternatives for these conditions?
b. Can the alternatives be analyzed and combined to produce a schedule more nearly compatible with all desires?

2. Can the operating procedures of agencies outside a highway department be adapted to the scheduling techniques discussed? Such agencies include consultants, public utilities, private utilities, railroads, courts, title companies, and all other agencies (cities, counties, etc.) which have an effect on preconstruction activities.

3. Will the techniques described, or to be developed, provide adequate control of operations by each division head, district engineer, etc., responsible for major phases of the program? Perhaps some adaptation would give better internal control of manpower, and provide top management with a better overall view of program operation and forecasted achievements.

Must this, or any similar system, be centrally controlled, or may it be divided successfully into components? If so, what are they, and how would they be combined or condensed to meet overall management needs?

4. Would these techniques, if successfully developed, best be implemented a step at a time, e.g., by systems, and districts? What type of training program would be required, and how might it be instituted? What would be the cost of developing, installing and operating?

The application of a systematic technique of scheduling which will produce a smooth flow of projects to the contract stage has many advantages. Moreover, any procedure developed that can cope with the problems in this area probably has much to contribute to the scheduling and control of construction engineering operations.

Many benefits can be foreseen by applying the techniques discussed. The authors have also endeavored to focus attention on some of the operational problems that exist in the application of any scheduling technique. The theory advanced is believed to be sufficiently flexible to cope with many of them. However, it is recognized and acknowledged that the majority of the questions remain unanswered.

They have been posed with the thought that, through continued efforts of collective exchange, development, and research of this problem of scheduling and control, a technique can be developed to provide a solution to the majority of the very complicated problems associated with this phase of highway programing operations.

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4. Levy, F. K., Thompson, G. I., and Weist, J. D. MS^2: Multiship, Multishop, Workload-Smoothing Program. Graduate School of Industrial Administration Reprint No. 96, Carnegie Institute of Technology, 1962.
5. Man-Scheduling Program for the IBM 1620. (Revised) IBM 1620 General Program Library 10.3.013.

Discussion

PALMER N. STEARNS, JR., Bureau of Public Roads—The mechanics of scheduling should be placed in proper perspective as related to the overall function of a highway department. An important development in the last few years in aiding management to accomplish its objectives has been the trend toward the integrated management information and control system. This system is aimed at improving the enterprise as a whole rather than the operation of one particular unit or endeavor within the enterprise. The system is designed to better inform management at the decision-making levels and to enable management to control entire projects by concentrating its efforts on 10 to 20 percent of the activities in the projects. The system is designed to channel information to appropriate individuals at each administrative level.

Network diagraming and computer analysis have been important tools in developing these information and control systems. However, these tools are a means to an end. Improved network diagraming methods and machines with faster speeds and bigger memories do not automatically provide a better information and control system. In fact, if adopted unnecessarily, they could impede the efficiency of the system. It is important that the system be analyzed first to determine what information management needs at each level for decision making and what feedback information is necessary for monitoring purposes. Only then, will a dollar spent be returned in a sound investment manner.

There appear to be certain peculiarities in the RAMPS and RPSM programs and the balance-period method which warrant further discussion, particularly relating to the practicability of controlling individual manpower skills with specific job tasks and the manner in which individuals are transferred from job to job.

The authors attempt to set up individual work assignments for professional personnel on an assembly-line basis looking only for production. It appears that the authors have carried network diagraming to an extreme. To attempt to control progress in the manner advocated would tend to decrease the quality of performance of the professional engineers and technicians whose responsibilities and duties cannot be compared with factory workers whose operations are repetitive and predictable. For instance, if a little more thought and imagination than estimated is required on a complex design problem or if a little more time than estimated is required to acquire a right-of-way parcel in an urban area at a reasonable price, there would be a tendency for the individuals responsible to place a greater degree of emphasis on meeting the predetermined schedule progress than would necessarily be justified from a quality standpoint.

The assignment of individual manpower and skills to specific job tasks would tend to indicate that low echelon operations have been very carefully studied and analyzed. This means that the supervisor or individual who must make the assignments must involve himself with a vast amount of detail and devote a large amount of his time to this work; that is, if any degree of accuracy is to result from the estimates. Events not previously scheduled could occur—illnesses, conferences, resignations, errors in calculation, etc.—and of course, a difference in the rate of progress from that estimated would occur for many jobs. As soon as the actual progress differs from the estimated progress, it would be necessary to reschedule the uncompleted work. Each time a rescheduling operation occurred, individual manpower skills would be reapportioned to many of the uncompleted jobs. The resulting consequence of breaking job continuity and jumping individuals from job to job could become costly and inefficient. To complete a certain task partially, then to begin work on another task, then to finish another uncompleted task before returning to the partially completed task could cause more time lost than under conventional supervisory methods. Each time the work is changed, the individual must reorient himself with the work at hand. Furthermore, the supervisor would be incessantly burdened with reanalyzing and reapportioning manpower and skills to the uncompleted jobs.

Pertaining to the aforementioned criticism, however, I do feel that the methods or similar methods proposed in the paper could be used for forecasting manpower and other resource requirements. The machine output would be in the form of summations of resource requirements at specified intervals in time rather than an individual manpower and skill assignment to tasks. The forecasts, of course, must be updated as frequently as necessary to maintain a current realistic picture in light of policy changes, obsolescence of methods or any unforeseeable changes that could alter the resource situation. These forecasts would provide management with a decision-making tool that would permit timely action in acquiring new resources or in reprograming available resources.

I do not mean to discount the value of network diagraming as a tool for the first line supervisor. It is excellent for providing a time reference for activities and showing the interdependency of activities. However, control of individual job assignments is something different. This should be handled through the skill of the supervisor. After all, in a highway department small groups under a first-line supervisor handle particular work assignments; i.e., squads handle design assignments, survey parties handle surveying assignments and soil crews handle soils investigation assignments. Members of these small units are not so specialized that they cannot perform many duties necessary to the completion of an assignment. At the level of the first-line supervisor, intuitive supervision accomplishes the job cheaper.

Effective scheduling procedures and methods should deal with a large amount of detail and confirmation of target dates for preletting activities in the initial portion of the project. The degree of detail and the preciseness of target dates should involve less detail on the later parts of projects as adjustments between theoretical and actual performance will generally be necessary. This will prevent wasted and unnecessary work. The authors did not mention how far ahead they intended the scheduling process to carry and still conform to their proposed mechanical methods. This is an important factor that is overlooked in RAMPS, RPSM, and the balance-period method.

An important subject related to multiple project scheduling that was not mentioned deals with the volume and complexity of data that a highway department must have in order to receive advantages from balancing resources and scheduling by machine methods.

The authors stated: "The ultimate goal is to develop systematic procedures to schedule the preconstruction phases of a highway program." Certainly this objective has significant merit in developing realistic schedules and in achieving optimum efficiency for highway department operations, especially in the face of today's ever growing complexities and problems. However, the authors immediately proceed to develop their subject apparently assuming that the "systematic procedures" must consist of a computer analysis of such sophistication that the input will be processed in a manner that will produce an output solution that will solve the resource and coordination problems connected with preconstruction work.

Certainly, any operation that may be accomplished by machine methods may also be accomplished by manual methods. Therefore, it would seem that there is a point of diminishing returns involved in the process of converting from manual to machine methods. In order to analyze where this point of diminishing returns should be, it is necessary to explore the advantages associated with the computerizing of manual methods and to derive some type of approach in weighing the benefits of each.

A computer cannot tell management what decisions to make, how to use the data, or what data for the computer to utilize. The quality of those decisions remains for the responsible individuals in management. Therefore, the advantages that an electronic computer can give to a highway department lie in the quickness of supplying decision-making data or the speed of calculation, the accuracy of the data, and the lesser cost of processing the larger amount of data.

Possibly some highway departments could profit by the use of a computer program in the nature of a modified version of either RAMPS, RPSM, or the balance-period method. However, there are other highway departments which do not posses the volume or complexity of data that would justify these types of programs. It would be difficult to establish quantitative criteria that would show when benefits would accrue if computer analysis of resource allocation and multi-project scheduling was adopted. A qualitative approach would be more in line. This approach would involve questioning each element in the computer operation and questioning the entire computer operation as related to the total management process of programing and scheduling in the highway department. Some of the important steps that a manager should do in considering the shift to computer analysis are as follows:

1. Define the objectives of the highway department.
2. Determine the information that is needed to accomplish the objectives.
3. Evaluate the present system of scheduling operations to determine its adequacy in providing the necessary information and accomplishing the objectives.
4. Determine if computer assistance in resource balancing and scheduling will provide better management information for decision making and aid in accomplishing the objectives.
5. Make sure the total cost and cost of operation will be justified and that the new system will work out more satisfactorily than the old method. Insure that the new system can be fixed with sufficient stability.

Another point of significance in the paper that is of concern is the character of the man-machine relationship that is engendered from computer programs of the RAMPS and RPSM nature. A programing and scheduling process utilizing machine assistance should adapt the machine to the man, rather than the man to the machine. It should use the machine to improve the speed, accuracy, and quality of performance of the man. Of utmost importance, the process should be flexible enough to consider the human ingenuity involved in programing and scheduling.

The RAMPS and RPSM programs are designed to produce output solutions that carry through the entire scheduling function uninterrupted. All logic pertaining to the scheduling of manpower availability, starting and completion dates, and project priorities has been preestablished and is contained in the coded instructions of the program. How does management know that this preestablished logic will apply under all types of conditions? What about decisions that favor courses of action, such as over or under staffing, awarding overtime or subcontracting? Is it practical to handle these decisions through a set of predetermined quantitative rules?

Even if many run-throughs of a problem were made to explore the alternative plans for the rearrangement of resources and projects and the different assignment of objectives, an awkward analysis would still result because of the difficulty in identifying the areas of critical decision that take place within the machine. In other words, it appears that the methodology of these proprietary programs is directed towards accepting the machine "printout" as a schedule and is not conducive to the flexibility and imagination that management personnel should possess and use.

When any program is written for a computer, it is necessary to transfer thought processes into rules that can be written mathematically. Consequently, one frequently does not look for or make use of all the facts, but looks instead for a formula or limiting formulas. The skill associated with decision-making includes the ability to determine all the facts that are needed as well as the ability to consider the relative importance of the facts that are available. Therefore, one must be careful that the decision rules programed into a computer are explicit and steadfast, and the decision rules that are not explicit and steadfast are left to management's judgment.

For the present stage of development in automatic data processing, a computer program should end at the point where management judgment must be exercised, and a new program should begin at the point where preconceived computation or routine processing must be accomplished prior to the next phase of management judgment. In this regard, certain phases of resource allocation and multi-project scheduling could be computerized. Gaps would remain between programs so that judgment could be exercised. Of utmost importance, the programs should be designed to supply the ammunition for decision making—not to perform the act of decision making.

The Use of a Priority Formula in Urban Street Programming

EDWARD M. HALL, Street Improvement Administrator,
City of Phoenix, Arizona, and
C. DWIGHT HIXON, Director of Traffic Engineering, Metropolitan Government of Nashville and Davidson County, Tennessee

There is a need for a simple formula that would aid in developing major arterial street improvement programs in urban areas. The need for careful capital programming is emphasized by the general lack of local government funds for such purposes.

Research from three cities (San Diego, Phoenix, and Nashville) covering a span of about six years is presented. As these studies proceeded, three basic test formulas were developed and evaluated. Further variations of the most recent formula were intensively evaluated, and a test formula is presented. The results of the work in the three cities indicate that an urban street construction priority formula should not be too complex, certainly minimize the judgment elements that go into it, and be based on facts. The formula makes possible the presentation of various projects in a relative priority list. At this point, administration, coordination, and budget considerations and judgment can most properly be applied to develop a capital program that will provide maximum benefit to the public.

•WITH THE DEMAND for governmental services constantly increasing at all levels of government, there is a noticeable and growing trend for the public to resist increased taxes and turn down bond programs. Nowhere is this paradox more acutely felt than at the local level of government. Our urban areas are faced with ever-increasing numbers of people and their desire to move in individual vehicles.

Urban streets are costly—a mile of modern 4-lane major street will cost nearly $500,000 for engineering, right-of-way and construction—and urban street funds are difficult to find. The problem of the city of Phoenix, Ariz., (Table 1) illustrates the point. The 1963 lesgislature increased the state motor fuel taxes 1 cent—to 6 cents per gallon, providing Phoenix with an additional $1.6 million per year. These funds were secured only after three years of increasingly intense, well-organized effort by a large number of organizations and citizens. The need for these new funds was glaringly apparent and was well-recognized by the general public.

The adopted 6-year major street and highway capital improvement program anticipates constructing nearly 28 miles of major arterial street and two railroad grade separation structures at a cost in excess of $20.5 million by 1969. This is about four miles of major arterial street a year.

Phoenix is used merely to emphasize that the limited funds for the improvement of major arterial streets in urban areas must be carefully programmed to insure the maximum return to the motorist for his investment. Such programs must be based on factual priorities that can be understood by the public.

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TABLE 1

City of Phoenix, Arizona

Street & Freeway Financing—Next 20 Years

THE PROBLEM

		Millions Total	Millions Per Year
Total Deficiencies & Needs – *1962*		$333.8	
LESS: Freeways Financed by Other Agencies	$90.5		
Local & Collector Streets Financed by Property Owners	106.7		
Total Financed by Other than City		-197.2	
CITY OF PHOENIX RESPONSIBILITY		$136.6 . . .	$6.8
Revenue for Construction—Existing Sources		- 24.3 . . .	-1.2
SHORT - *1962*		$112.3 . . .	$5.6
New Funds From 1963 Legislature			- *$1.6*
Still **SHORT**			*$4.0*

BACKGROUND

The need for a simple formula to aid in establishing the priority for streets to be constructed in urban areas has long been recognized. Certainly such a formula would not replace judgment but would be a device to list urban projects as to their relative importance.

Recognizing the need for urban program priority procedures has led to significant contributions in this direction. Among the most notable are the carefully detailed program of Milwaukee, Wis., the Kentucky Urban Program Priority Procedures developed in 1957, the Tennessee Priority Method, and the recent work done by the Automotive Safety Foundation in cooperation with the Washington State Highway Commission.

Possibly urban street priorities must be based on the individual characteristics of each urban area as available data, the recognition of the need, and available funds vary from city to city and state to state. However, there would be considerable merit in a simple, easily applied urban street construction priority formula susceptible to certain types of national summary and analysis. Perhaps this would be a means of developing a clear and more factual evaluation of the critical needs for additional funds to provide necessary urban transportation systems.

There are several areas where priority formulas will prove useful—resurfacing programs, freeway construction, traffic signal installations, and arterial street construction. This paper is confined to the development and testing of an urban major arterial street construction priority formula which may have wider application.

A list of major street construction projects based on a priority formula could be a significant aid to the development of a recommended capital improvement program for urban areas. A major concept in the development of a formula is to reduce judgment in the formula to the absolute minimum, thus making the formula as factual as possible. Judgment and budgetary elements would be brought into the final selection of the actual projects for the recommended program.

In September 1960, the Highway Research Board sponsored a workshop conference on formulating highway construction programs; the results were published (HRB Special Report 62, 1961) and are an important contribution by the Department of Economics, Finance and Administration. A similar conference directed primarily at problems of formulating major street and freeway construction programs in urban areas would also be a significant contribution to this field. The American Public Works Association Transportation Committee is now studying major street construction priorities for urban areas. This committee hopes it will develop a useful publication. One objective is to include several priority formulas developed for use in urban areas. In the background is also the work of the National Committee on Urban Transportation. The subcommittee on Developing Project Priorities for Transportation Improvement summarized their work in Procedure Manual 10-A of the National Committee series. This procedure manual developed a suggested technique and form for the complete evaluation of a

TABLE 2

PROPOSED GUIDING PRIORITY RATING METHOD[1]
(San Diego Metropolitan Area Transportation Study)

$$\text{Priority Index} = \frac{\text{Project Cost per Vehicle-Mile}}{\text{Project Benefit Index}}$$

Project Benefit Index		Relative Weight	
Community service:			
Pattern and continuity		15	
Coordinating and timing		15	
Roadbed condition		5	
Present capacity ratio		15	
Long-range future service		10	
Subtotal			60
User benefits:			
Time saving-delay rate:			
Present	5		
5-yr future	5		
Subtotal		10	
Duration of deficiency		5	
Distance saving of improvement, 5-yr avg.		5	
Accident rate, 2 year		15	
Time to amortize investment		5	
Subtotal			40
Total			100
Project Cost			
Right-of-way plus construction per vehicle-mile (10 yr)			

[1]Priority rating index should be based on the expected improvement in deficient conditions.

project, including street classification, when the project is needed, administrative and budgetary considerations, and service considerations. This paper is concerned with formulating a simple factual analysis of the service considerations, a continuation of the programs undertaken by San Diego, Phoenix, and Nashville.

SAN DIEGO EFFORT

The city of San Diego, Calif., has been publishing an annual 6-yr capital improvement program for many years. As a part of the pilot city program of the National Committee on Urban Transportation, efforts were made to develop a capital improvement program priority formula for major street construction. Two of the earliest formulas were based primarily on traffic data. In one of these, priority was determined by the percent capacity overload, a second combined volume, speed and delay, and accident rates into a priority formula. Both these efforts were helpful but were not the sought-for formula.

Table 2 gives a guiding priority rating method developed in 1958. The basic philosophy of the formula was to weight community service 60 percent and user benefits 40 percent. The final priority index brought cost into the picture by dividing the cost per vehicle mile by the project benefit index. In an effort to test this formula, 25 projects were selected. Eleven people having knowledge and responsibilities in administration, planning or engineering, who participated in the capital improvement program project selection, were asked to rank the 25 projects. As this test proceeded, it became obvious that the formula itself included judgment in all of the community service benefits as well as some of the user benefits. At least 70 points out of 100 in this formula were basically judgment ratings. Thus, the proposed priority rating formula simply provided a judgment ordering of the projects, essentially no different from the results obtained by the capital improvement committee using the same basic factual data. In short, the formula was too complicated and included entirely too much judgment to be of real use.

San Diego has continued its work in this area and is currently testing the same formula discussed in this paper. They are also developing and testing several variations as part of a "three city" research project.

PHOENIX FORMULA AND TEST

The city of Phoenix completed a street deficiency study in December 1961, which found that approximately 152 miles out of 260 miles of major arterial streets were deficient. The limitation of funds makes it essential that the priority of projects be carefully determined to insure the maximum benefit to the motoring public.

From the San Diego effort, Formula B was developed (Table 3). Again it is clear that there is a considerable amount of judgment in the elements to be rated. For this reason Formula C (Table 4) was developed for test purposes.

Formula C reduces judgment to a minimum and contains four basic elements: delay rate, safety record, structural condition, and traffic service. Delay rate is assigned a relative weight of 50 percent. Delay during the peak hour is an excellent direct and indirect measure of the service provided by a street. Indirectly it measures side friction, capacity, congestion, psychological impact on driver and, in a sense, the accident rate. In an urban area the time a driver takes to go from A to B is a most important yardstick of the quality of traffic service of the transportation system. The collision index recognizes the safety record of the facility, which although important, is difficult to measure truly.

Structural condition is important; however, in an urban area it is felt to be of relatively much less importance than the delay or traffic service element. The structural condition element is broken into surface and drainage portions. In some areas the drainage may assume relatively more importance than the surface and subsurface condition, or vice versa. It is important that structural condition itself is 15 percent of the total relative weight.

Traffic volume itself is the final element in a street improvement formula. Traffic volumes are included in the delay rate, but they are also included in the formula because

TABLE 3

PHOENIX MAJOR STREET IMPROVEMENT PRIORITY, FORMULA B
(Jan. 12, 1961)

Element		Relative Weight (points)	
Community Service			
Master plan-continuity of route development		10	
Coordination and timing in relation to other projects and jurisdictions		10	
Structural condition		15	
Surface	2		
Subsurface	8		
Drainage	5		
Ratio of $\frac{\text{future (design)}}{\text{present}}$ traffic volumes		10	
Present capacity ratio		10	
Subtotal			55
User Service			
2-yr accident rate/mile + accident/mile		10	
Duration of deficiency		10	
Time saving			
Delay rate "after" less delay rate "before"		15	
Time to amortize investment		10	
Subtotal			45
Possible points			100

Highest point value = most needed facility

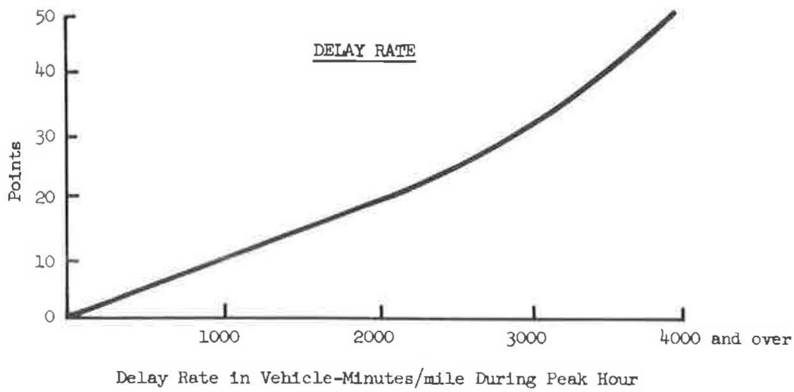
TABLE 4

PHOENIX MAJOR STREET IMPROVEMENT PRIORITY, FORMULA C

Element		Relative Weight (points)
Delay rate per mile during peak hour		50
Collision index—2-yr accidents/mile plus accident rate/mile		15
Structural condition		15
Surface and subsurface	5	
Drainage	10	
Traffic - $\frac{\text{present ADT}}{2{,}000} + \frac{\text{future (5-yr forecast) ADT}}{\text{present ADT}}$		20
Possible points		100

Highest point value = most needed facility

of their importance. The aim was to give an important weight within the traffic element to the present traffic and yet recognize the future traffic needs. Toward this end, a 5-yr forecast is suggested. At first glance this may appear to be too short a time; however, the traffic element in the formula indicates that present traffic needs generally outweigh future needs. The formula gives heavy weight to future traffic volumes where a very rapid growth in traffic is envisioned. The 5-yr forecast period acknowledges the limitations that apply to 20-yr forecasts on specific major arterial streets, whereas normally, capital programs are for 5- or 6-yr periods.



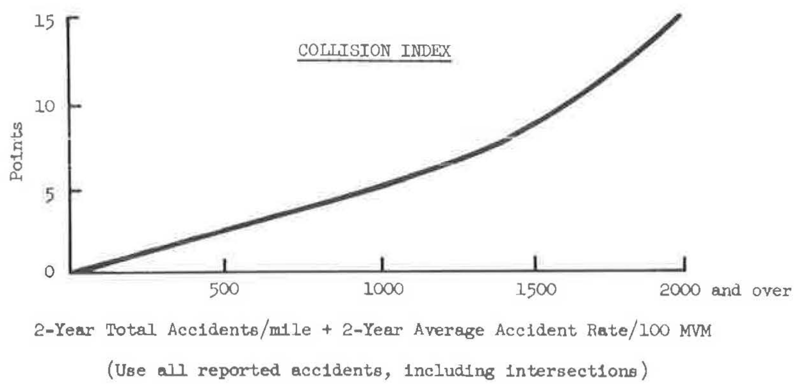


Figure 1. Major street improvement priority, Formula C, rating scales.

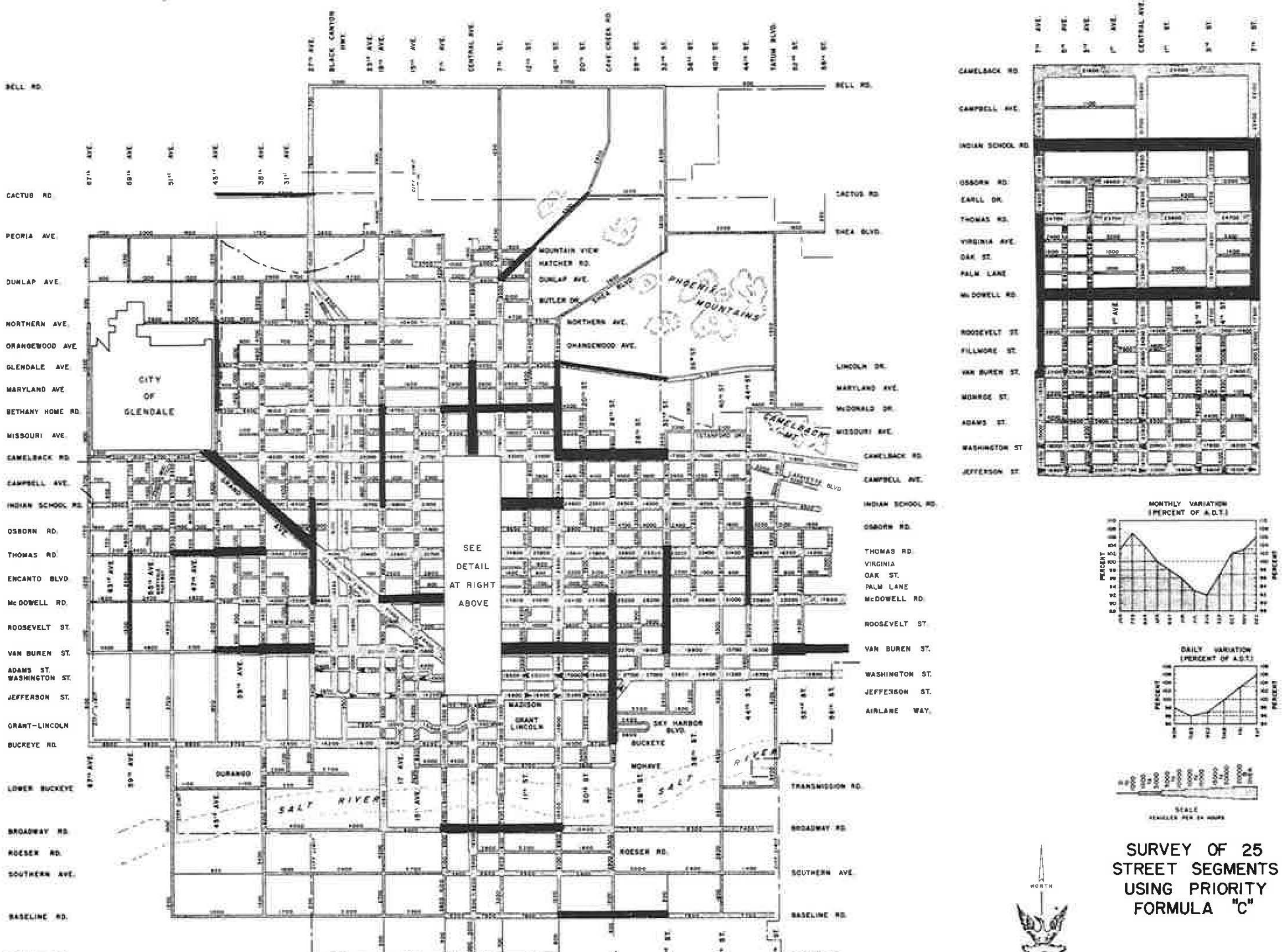
In conjunction with Formula C, two rating scales were developed to determine the points for the delay rate and collision index. These curves (Fig. 1) were developed using existing data from Phoenix and San Diego combined with the following points of view:

1. The delay rate should give relatively few points in the lower scale of delay but the number of points should increase more rapidly as greater delay rates are experienced.
2. Accident rates should be used but tempered with the total number of accidents. Otherwise, erroneous conclusions can be drawn from either the accident rate or the use of total accidents.

Twenty-five street segments (a total of 51.5 miles) (Fig. 2) were selected to test the formula. The selection of these segments was carefully done to insure a range of projects from those recently completed through projects obviously extremely low on the priority scale. The completed projects were rated as they existed prior to their recent improvement. Asked to participate in the judgment ratings were nineteen individuals having responsibility in the areas of administration, planning, public works, traffic engineering, engineering, and street maintenance.

TEST RESULTS

Table 5 gives the result of the judgment ratings and demonstrates the widespread dispersion of the judgment of individual raters, all experienced people in positions of



SURVEY OF 25 STREET SEGMENTS USING PRIORITY FORMULA "C"

Figure 2.

TABLE 5

PHOENIX FORMULA C JUDGMENT RATINGS

Segment	Location	Relative Order by Individual Raters																			Priority (avg.)
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
A	59th Ave. Van Buren—Thomas	22	25	23	24	24	25	25	23	22	25	20	24	25	18	19	19	24	25	25	25
B	43rd Ave. Bethany—Northern	18	20	24	20	23	24	20	18	21	17	19	23	23	24	9	22	21	21	17	22
C	27th Ave. McDowell—Ind. Sch.	17	14	8	19	14	17	13	10	16	13	10	16	15	17	4	16	16	15	9	14
D	19th Ave. Ind. Sch.—Bethany	6	5	5	7	12	12	10	7	6	21	18	15	13	13	8	3	6	13	16	8
E	7th Ave. Van Buren—Thomas	4	2	3	4	4	5	4	2	15	6	3	2	4	8	3	2	3	1	3	3
F	Central Camelback—Glendale	10	16	22	8	11	6	16	14	17	1	1	17	7	11	21	5	11	23	23	12
G	7th St. McDowell—Ind. Sch.	1	1	1	2	1	3	2	3	2	4	7	3	2	1	25	1	4	2	2	1
H	16th St. Camelback—Glendale	9	6	16	9	13	11	7	9	14	7	17	12	11	7	14	14	12	9	10	10
I	24th St. Buckeye—McDowell	7	4	4	3	5	4	5	5	3	2	2	5	3	5	2	17	5	5	5	4
J	32nd St. Van Buren—Thomas	12	15	19	5	6	18	8	11	7	5	8	7	6	6	12	13	17	8	8	7
K	44th St. McDowell—Ind. Sch.	14	9	11	18	15	19	15	12	20	9	9	21	8	12	11	12	18	11	12	13
L	Baseline 16th St.—32nd St.	24	24	21	12	22	16	23	24	13	24	21	22	21	22	13	20	25	19	22	23
M	Broadway 7th Ave.—16th St.	21	10	13	17	17	9	12	20	19	16	14	10	12	20	10	10	23	10	15	16
N	Van Buren 43rd Ave.—27th Ave.	13	11	6	14	7	7	6	15	12	19	4	8	5	14	5	11	14	7	6	6
O	Van Buren 7th St.—24th St.	23	22	20	23	20	20	18	6	4	8	13	11	17	4	24	9	19	17	20	19
P	Van Buren 48th St.—60th St.	19	19	18	22	21	8	22	17	23	18	23	20	20	23	22	21	8	16	21	20
Q	McDowell 19th Ave.—7th St.	2	3	2	1	2	1	3	1	1	3	6	4	1	3	23	7	1	4	1	2
R	Thomas 51st Ave.—35th Ave.	11	13	9	15	10	10	14	16	18	15	22	18	18	16	17	15	20	14	11	18
S	Ind. Sch. 7th Ave.—16th St.	5	17	15	21	16	21	1	4	10	12	12	6	22	2	20	6	2	6	7	9
T	Camelback 16th St.—32nd St.	25	18	10	10	9	15	19	8	11	11	11	14	9	21	16	18	10	18	19	15
U	Bethany 7th Ave.—16th St.	20	8	14	11	8	13	17	13	8	10	15	9	14	9	7	8	15	12	13	11
V	Glendale 16th St.—32nd St.	15	21	17	13	19	23	24	22	24	22	16	19	19	19	15	23	7	22	24	21
W	Cave Creek 7th St.—20th St.	8	12	12	16	18	14	9	21	9	23	24	13	16	10	1	25	13	20	14	17
X	"Q" Ave. 43rd Ave.—Black Canyon	16	23	25	25	25	22	21	25	25	20	25	20	24	25	18	24	22	24	18	24
Y	Grand Ave. Thomas—Camelback	3	7	7	6	3	2	11	19	5	14	5	2	10	15	6	4	9	3	4	5

responsibility in the street program of a major city. Usually one or two raters were rather far off the mean. Alternate efforts were made to reduce the spread of judgment ratings. For example, the highest and lowest rater were eliminated; then the two high and two low. These efforts produced no significant difference in the order of the judgment ratings. Table 5 also demonstrates that any one project may receive a spread in judgment rating from nearly the highest to the lowest. Because judgment is not infallible, it is difficult to determine whether the formula or the combined judgment of the raters is correct. Perhaps these factors emphasize best the need for a major street improvement priority formula.

Table 6 compares these judgment ratings to the order of priority developed by the formula. The difference in positions between the judgment and formula ratings for each street segment is given in the final column. The individual segments with a difference of position of five or more are indicated.

The largest deviation of 16 positions occurred on Segment O, obviously in need of improvement. However, this 4-lane facility is presently in an intensively developed area and is fully improved. As a practical matter, significant relief will come from a nearby parallel freeway included in the adopted major street and highway plan. Here is a situation where the priority formula gave a high rating but judgment would remove it from the construction program. This demonstrates the judgment and funding considerations that must be applied in the development of a capital improvement program.

Table 7 gives the specific points for each element of the formula for the 25 projects. Review of this table gives insight into the other projects where there is a significant deviation between the formula and the judgment ratings as follows:

TABLE 6

PHOENIX COMPARISON OF JUDGMENT AND FORMULA C RATINGS

Segment	Location	Judgment Priority	Formula Priority	Position Difference
A	59th Ave. Van Buren—Thomas	25	21	4
B	43rd Ave. Bethany Home—Northern	22	19	3
C	27th Ave. McDowell—Indian School	14	8	6*
D	19th Ave. Indian School—Bethany Home	8	17	9*
E	7th Ave. Van Buren—Thomas	3	6	3
F	Central Camelback—Glendale	12	12	0
G	7th St. McDowell—Indian School	1	5	4
H	16th St. Camelback—Glendale	10	15	5*
I	24th St. Buckeye—McDowell	4	7	3
J	32nd St. Van Buren—Thomas	7	9	2
K	44th St. McDowell—Indian School	13	10	3
L	Baseline 16th St.—32nd St.	23	25	2
M	Broadway 7th Ave.—16th St.	16	18	2
N	Van Buren 43rd Ave.—27th Ave.	6	11	5*
O	Van Buren 7th St.—24th St.	19	3	16*
P	Van Buren 48th St.—60th St.	20	23	3
Q	McDowell 19th Ave.—7th St.	2	1	1
R	Thomas 51st Ave.—35th Ave.	18	22	4
S	Indian School 7th Ave.—16th St.	9	4	5*
T	Camelback 16th St.—32nd St.	15	13	2
U	Bethany Home 7th Ave.—16th St.	11	14	3
V	Glendale 16th St.—32nd St.	21	24	3
W	Cave Creek 7th St.—20th St.	17	16	1
X	"Q" Ave. 43rd Ave.—Black Canyon	24	20	4
Y	Grand Ave. Thomas—Camelback	5	2	3

*Difference of 5 or more between judgment and formula order of priority.

TABLE 7

PHOENIX FORMULA C

Segment	Location	Relative Weight (points)				Total Points (100 max.)	Formula Rank
		Delay Rate (50 max.)	Collision Index (15 max.)	Structural Condition (15 max.)	Traffic (20 max.)		
A	59th Ave. Van Buren—Thomas	0	3	12	4	19	21
B	43rd Ave. Bethany—Northern	½	2	15	4½	22	19
C	27th Ave. McDowell—Ind. School	6	5	15	5	31	8
D	19th Ave. Ind. School—Bethany	1½	6	9	6	22½	17
E	7th Ave. Van Buren—Thomas	7	6	13	8	34	6
F	Central Ave. Camelback—Glendale	3½	6	7	8½	25	12
G	7th St. McDowell—Ind. School (as it was)	7½	6	13	9½	36	5
H	16th St. Camelback—Glendale	1½	6	9	7	23½	15
I	24th St. Buckeye—McDowell	7½	12	14	8½	32	7
J	32nd St. Van Buren—Thomas	2½	7	12	8	29½	9
K	44th St. McDowell—Ind. School	4	5	12	6½	27½	10
L	Baseline 16th St.—32nd St.	0	2	1	5½	8½	25
M	Broadway 7th Ave.—16th St	1	7	7	7	22	18
N	Van Buren 43rd Ave.—27th Ave.	0	6	13	7½	26½	11
O	Van Buren 7th St.—24th St.	9½	15	3	12½	40	3
P	Van Buren 48th St.—60th St.	0	2	3	9	14	23
Q	McDowell 19th Ave.—7th St. (as it was)	32	15	13	13	73	1
R	Thomas 51st Ave.—35th Ave.	0	4	8	6½	18½	22
S	Ind. School 7th Ave.—16th St.	11	8	4	15	38	4
T	Camelback 16th St.—32nd St.	3½	4	5	12	24½	13
U	Bethany 7th Ave.—16th St.	1	6	12	5½	24½	14
V	Glendale 16th St.—32nd St.	0	2	7	5	14	24
W	Cave Creek 7th St.—20th St.	½	4	15	4	23½	16
X	"Q" Ave. 43rd Ave.—Black Canyon	0	2	15	3½	20½	20
Y	Grand Ave. Thomas—Camelback	7½	15	13	9½	45	2

1. Segment C project is one-fourth mile away from a completed urban freeway and the poor structural condition of the facility combined with some delay produced a higher priority by the formula. As on Segment O, judgment would tend to weigh the existence of the freeway and thus lower the final priority.

2. Segment D has a low delay but a considerably higher rating on structural condition. The various raters had a wide spread of opinion on the relative priority of this particular project. This may well be due to its being parallel to and approximately three-fourths mile away from a completed freeway.

3. Segment H received a low number of delay and traffic points but a number of structural condition points; thus, the priority formula produced a somewhat lower rating than judgment.

4. Segment N, which judgment said should be among the very earliest, received zero points on the delay rate and relatively few points on traffic but a high number of points on structural condition. As in Segment H, judgment assigned a higher position than did the formula.

5. Segment S rated high by the priority formula due to the relatively high delay rate and traffic points received. Judgment lowered the priority because this segment had been improved to modern 4-lane standards within the last seven years.

TABLE 8

FORMULA C—ANALYSIS OF TRAFFIC ELEMENT

Segment	Location	1962 ADT	1967 ADT	Traffic Points		
				A[1]	B[2]	C[3]
A	59th Ave. Van Buren-Thomas	2,000	6,000	4.0	2.7	2.8
B	43rd Ave. Bethany-Northern	2,500	8,000	4.5	3.0	3.3
C	27th Ave. McDowell-Ind. School	6,500	10,000	5.0	4.5	5.1
D	19th Ave. Ind. School-Bethany	9.200	14,000	6.0	6.0	6.9
E	7th Ave. Van Buren-Thomas	12,200	20,000	8.0	7.8	9.0
F	Central Camelback-Glendale	12,700	24,000	8.5	8.3	9.5
G	7th St. McDowell-Ind. School (as it was)	15,600	26,000	9.5	9.7	11.2
H	16th St. Camelback-Glendale	11,600	16,000	7.0	7.4	8.5
I	24th St. Backeye-McDowell	14,000	20,000	8.5	8.7	10.3
J	32nd St. Van Buren-Thomas	13,000	17,000	8.0	8.2	9.4
K	44th St. McDowell-Ind. School	10,200	14,000	6.5	6.6	7.5
L	Baseline 16th St.-32nd St.	7,800	11,000	5.5	5.2	5.9
M	Broadway 7th Ave.-16th St.	11,500	16,000	7.0	7.3	8.4
N	Van Buren 43rd Ave.-27th Ave.	12,700	17,000	7.5	8.0	9.2
O	Van Buren 7th St.-24th St.	22,700	26,000	12.5	13.6	15.7
P	Van Buren 48th St.-60th St.	14,800	20,000	9.0	9.2	10.6
Q	McDowell 19th Ave.-7th St. (as it was)	23,100	28,000	1.30	13.8	16.0
R	Thomas 51st Ave.-35th Ave.	10,200	14,000	6.5	6.5	7.5
S	Ind. School 7th Ave.-16th St.	27,400	31,000	15.0	16.3	18.7
T	Camelback 16th St.-32nd St.	21,300	26,000	12.0	12.8	14.8
U	Bethany 7th Ave.-16th St.	7,700	14,000	5.5	5.3	6.1
V	Glendale 16th St.-32nd St.	6,300	12,000	5.0	4.6	5.2
W	Cave Creek 7th St.-20th St.	3,800	8,000	4.0	3.3	3.6
X	"Q" Ave. 43rd Ave.-Blk. Canyon	1,500	4,000	3.5	2.2	2.3
Y	Grand Ave. Thomas-Camelback	16,200	24,000	9.5	10.0	11.5

[1] Present volume ÷ 2,000 + 5-yr forecast ÷ present volume.
[2] Present volume ÷ 1,750 + 5-yr forecast ÷ 2 × present volume.
[3] Present volume ÷ 1,500 + 5-yr forecast ÷ 2 × present volume.

It is interesting that few of the street segments received a high number of points for delay rate. The cause of this is not fully understood. Certainly, the delay rate curve shown in Figure 1 could possibly be adjusted; however, it is based on the point of view that the relative points should increase more rapidly as the delay increases. If the shape of the curve were varied a relatively large number of points for a relatively small amount of delay might well be found. This is not considered proper rating. The second possible cause is that congestion in Phoenix has not yet reached the point where maximum delays are the norm rather than the exception. The shape of the curve deserves further research. Perhaps a family of curves for different urban characteristics is needed.

Table 7 shows good spread was obtained by collision index and structural condition ratings. However, the spread of traffic volume rating was not as broad as expected. The highest rating was 15 out of 20 points; the lowest, $3\frac{1}{2}$. The traffic volume component in Formula C places heavy value on present volumes and adds the 5-yr forecast growth ratio, which attempts to reach a balance between present and future needs in capital programming.

In view of the lack of spread in the original traffic elements of the formula, a study was made of the effect of changing the constants in the formula (Table 8). The final formula (C in Table 8), present volume divided by 1,500 plus a 5-yr traffic forecast divided by 2 times the present average daily traffic volume, appeared to give the best results from the standpoint of differentiating between the various projects.

The overall results obtained from the first test of Formula C were encouraging. The inconsistencies developed by the formula were explainable and no worse than the inconsistencies demonstrated by the spread in the individual judgment of the several raters. The lack of spread in the delay rate points (Table 7) is cause for concern, but this can possibly be explained as previously indicated.

BROADER TEST OF FORMULA C

Following the original test, 48 miles of major arterial streets which were being considered for a tentative 6-yr capital program were rated by the original test Formula C. These streets were combined with the 25 sections included in the first test and then all were rated by Formula C. Table 9 demonstrates a very good spread in the total points being rated. However, in the middle ranges there was only a slight variation from project to project. Either all of the projects are about the same or the formula needs further refinement in order to give better separation.

Table 10 was prepared to indicate how the major street improvement priority formula could be used in the preparation of a 6-yr program. In the development of a program it is necessary to consider available funds, the continuity of particular projects, and the disruptions of traffic in various parts of the community. Table 10 demonstrates the results of the application of these several considerations to a priority listing.

The results of the broader test continued to be encouraging. This broader test included 88.9 miles of major arterial street.

TEST USING CAPITAL PROGRAM

The tentative 6-yr capital program that was tested, was based on anticipation that a 2 cent per gallon city gasoline tax would produce about \$3.2 million per year in new revenue for the city. Inasmuch as the city gasoline tax was invalidated by the Supreme Court of Arizona, and subsequently the state legislature increased the state gasoline tax 1 cent with 80 percent of the revenue going to cities and towns, a new 6-yr capital improvement program had to be developed.

The program under way is based on the estimate of an additional \$1.6 million per year for construction of major arterial streets by the city. The traffic element of Formula C was modified as previously suggested to develop Formula D (Table 11). Table 12 is a summary of the application of Formula D to the projects in the adopted program plus the original 25 test segments. This test included 75.3 miles of major arterial street.

TABLE 9

FORMULA C APPLIED TO TENTATIVE 6-YEAR PROGRAM AND 25 TEST SEGMENTS

Major Arterial Street	Relative Weight (points)				Total Points (100 max.)	Rank
	Delay Rate (50 max.)	Collision Index (15 max.)	Structural Condition (15 max.)	Traffic (20 max.)		
Thomas Rd. Black Canyon to 19th Ave.	50	15	10	11½	86½	1
* McDowell Rd. 19th Ave. to 7th St. (as it was)**	32	15	13	13	73	2
Indian School Rd. 35th Ave. to Black Canyon	18	15	8	10	51	3
7th St. Maricopa Freeway to Van Buren	17	15	11	7½	50½	4
* Grand Ave. Thomas to Camelback	7½	15	13	9½	45	5
19th Ave. Buckeye to Van Buren	14½	15	8	5	42½	6
* 24th St. Buckeye to McDowell	7½	12	14	8½	42	7
16th St. Buckeye to Van Buren	11	15	8	8	42	8
* Van Buren 7th St. to 24th St.	9½	15	3	12½	40	9
7th Ave. Osborn to Camelback	9½	11	8	10½	39	10
Indian School Rd. Grand Canal to 24th St.	2½	15	8	13	38½	11
* Indian School Rd. 7th Ave. to 16th St.	11	8	4	15	38	12
* 7th St. McDowell to Indian School (as it was)**	7½	6	13	9½	36	13
* 7th Ave. Van Buren to Thomas	7	6	13	8	34	14
Camelback Rd. 7th Ave. to 16th St.	4	12	4	13	33	15
44th St. Thomas to Camelback	2½	15	9	6½	33	16
Camelback Rd. Black Canyon to 7th Ave.	4	7	10	11½	32½	17
McDowell Rd. 44th St. to 52nd St.	0	15	6	11½	32½	18
Van Buren 39th Ave. to Black Canyon	4½	6½	11	9	31	19
24th St. Maricopa Freeway to Buckeye	0	15	11	5	31	20
* 27th Ave. McDowell to Indian School	6	5	15	5	31	21
Washington & Adams 9th Ave. to 12th Ave.	0	15	12	4	31	22
Papago Park Rd. Van Buren to McDowell	0	0	15	15	30	23
* 32nd St. Van Buren to Thomas	2½	7	12	8	29½	24
McDowell Rd. 28th St. to 44th St.	3½	7½	6	12½	29½	25
Broadway Rd. 19th Ave. to 7th St.	½	15	7	6½	29	26
7th St. Camelback to Glendale	2	6	12	9	29	27
24th St. Indian School to Lincoln	½	8	13	6	27½	28
* 44th St. McDowell to Indian School	4	5	12	6½	27½	29
* Van Buren 43rd Ave. to 27th Ave.	0	6	13	7½	26½	30
* Central Ave. Camelback to Glendale	3½	6	7	8½	25	31
* Camelback 16th St. to 32nd St.	½	8	6	10	24½	32
Indian School 51st Ave. to 35th Ave.	½	8	6	10	24½	33
* Bethany Home 7th Ave. to 16th St.	1	6	12	5½	24½	34
16th St. Grand Canal to Bethany Home	1	6	8	9	24	35
* 16th St. Camelback to Glendale	1½	6	9	7	23½	36
* Cave Creek 7th St. to 20th St.	½	4	15	4	23½	37
16th St. Broadway to Buckeye	5	6½	5	7	23½	38
7th St. Glendale to Dunlap	1½	4	10	7	22½	39
* 19th Ave. Indian School to Bethany Home	1½	6	9	6	22½	40
* Broadway 7th Ave. to 16th St.	1	7	7	7	22	41
* 43rd Ave. Bethany Home to Northern	½	2	15	4½	22	42
Thomas Rd. 43rd Ave. to 27th Ave.	1	6	7	8	22	43
44th St. Washington to McDowell	½	5½	9	5½	20½	44
* "Q" Ave. 43rd Ave. to Black Canyon	0	2	15	3½	20½	45
* 59th Ave. Van Buren to Thomas	0	3	12	4	19	46
* Thomas Rd. 51st Ave. to 35th Ave.	0	4	8	6½	18½	47
Bethany Home 43rd Ave. to 35th Ave.	0	4	8	5	17	48
16th St. Bethany Home to Northern	0	3½	7	5½	16	49
Indian School 67th Ave. to 51st Ave.	0	3	5	7	15	50
* Van Buren 48th St. to 60th St.	0	2	3	9	14	51
* Glendale Ave. 16th St. to 32nd St.	0	2	7	5	14	52
* Baseline Rd. 16th St. to 32nd St.	0	2	1	5½	8½	53

* 25 test segments.

** Construction completed.

Note: 88.9 miles of major arterial street rated.

TABLE 10

FORMULA C APPLIED TO TENTATIVE 6-YEAR PROGRAM AND 25 TEST SEGMENTS

	Major Arterial Street	Total Points (100 max.)	Year Scheduled (6-yr program)
	Thomas Rd. Black Canyon to 19th Ave.	86½	1
*	McDowell Rd. 19th Ave. to 7th St. (as it was)	73	**
	Indian School Rd. 35th Ave. to Black Canyon	51	3
	7th St. Maricopa Freeway to Van Buren	50½	2
*	Grand Ave. Thomas to Camelback	45	Budgeted
	19th Ave. Buckeye to Van Buren	42½	3
*	24th St. Buckeye to McDowell	42	Budgeted
	16th St. Buckeye to Van Buren	42	3
*	Van Buren 7th St. to 24th St.	40	
	7th Ave. Osborn to Camelback	39	4
	Indian School Rd. Grand Canal to 24th St.	38½	6
*	Indian School Rd. 7th Ave. to 16th St.	38	
*	7th St. McDowell to Indian School (as it was)	36	**
*	7th Ave. Van Buren to Thomas	34	Budgeted
	Camelback Rd. 7th Ave. to 16th St.	33	4
	44th St. Thomas to Camelback	33	5
	Camelback Rd. Black Canyon to 7th Ave.	32½	6
	McDowell Rd. 44th St. to 52nd St.	32½	5
	Van Buren 39th Ave. to Black Canyon	31	1
	24th St. Maricopa Freeway to Buckeye	31	4
*	27th Ave. McDowell to Indian School	31	
	Washington & Adams 9th Ave. to 12th Ave.	31	3
	Papago Park Rd. Van Buren to McDowell	30	5
*	32nd St. Van Buren to Thomas	29½	
	McDowell Rd. 28th St. to 44th St.	29½	5
	Broadway Rd. 19th Ave. to 7th St.	29	5
	7th St. Camelback to Glendale	29	1
	24th St. Indian School to Lincoln	27½	1 & 4
*	44th St. McDowell to Indian School	27½	
*	Van Buren 43rd Ave. to 27th Ave.	26½	
*	Central Ave. Camelback to Glendale	25	
*	Camelback 16th St. to 32nd St.	24½	
	Indian School Rd. 51st Ave. to 35th Ave.	24½	3
*	Bethany Home Rd. 7th Ave. to 16th St.	24½	2
	16th St. Grand Canal to Bethany Home	24	3 & 6
*	16th St. Camelback to Glendale	23½	
*	Cave Creek 7th St. to 20th St.	23½	
	16th St. Broadway to Buckeye	23½	4
	7th St. Glendale to Dunlap	22½	2
*	19th Ave. Indian School to Bethany Home	22½	1 Mile Budgeted
*	Broadway Road 7th Ave. to 16th St.	22	
*	43rd Ave. Bethany Home to Northern	22	
	Thomas Road 43rd Ave. to 27th Ave.	22	4
	44th St. Washington to McDowell	20½	5
*	"Q" Ave. 43rd Ave. to Black Canyon	20½	
*	59th Ave. Van Buren to Thomas	19	
*	Thomas 51st Ave. to 35th Ave.	18½	
	Bethany Home Rd. 43rd Ave. to 35th Ave.	17	6
	16th St. Bethany Home to Northern	16	6
	Indian School Rd. 67th Ave. to 51st Ave.	15	5
*	Van Buren 48th St. to 60th St.	14	
*	Glendale Ave. 16th St. to 32nd St.	14	
*	Baseline Rd. 16th St. to 32nd St.	8½	

* 25 test segments.
** Construction completed.
Note: 88.9 miles of major arterial street rated.

TABLE 11

MAJOR STREET IMPROVEMENT PRIORITY, FORMULA D[1]

Element		Relative Weight (points)
Delay rate per mile during peak hour		50
Collision index: 2-yr accidents/mile plus accident rate/mile		15
Structural condition		15
Surface and base	5	
Drainage	10	
Traffic: $\frac{\text{present ADT}}{1500} + \frac{\text{5-yr future forecast ADT}}{\text{2 (present ADT)}}$		20
Max. possible points		100
List projects in order of highest point value		

[1] Program developed from list of projects and evaluation of budgetary and administrative considerations.

TABLE 12

FORMULA D APPLIED TO ADOPTED 6-YEAR PROGRAM AND 25 TEST SEGMENTS

Major Arterial Street	Relative Weight (points)				Total Points (100 max.)	Rank
	Delay Rate (50 max.)	Collision Index (15 max.)	Structural Condition (15 max.)	Traffic (20 max.)		
Thomas Rd. Black Canyon to 19th Ave.	50	15	10	14.3	89.3	1
7th Ave. RR Structure/Jefferson to Grant-Lincoln	50	15	7	8.9	80.9	2
* McDowell Rd. 19th Ave. to 7th St. (as it was)**	32	15	13	16	76.0	3
Indian School Rd. 35th Ave. to Black Canyon	18	15	8	12.1	53.1	4
7th St. Maricopa Freeway to Grant-Lincoln	17	15	11	9.3	52.3	5
* Grand Ave. Thomas to Camelback (as it was)**	7.5	15	13	11.5	47.0	6
* 24th St. Buckeye to McDowell (as it was)**	7.5	12	14	10.3	43.8	7
19th Ave. Buckeye to Van Buren	14.5	15	8	6.3	43.8	8
16th St. Buckeye to Van Buren	11	15	8	9.8	43.8	9
* Van Buren 7th St. to 24th St.	9.5	15	3	15.7	43.2	10
* Indian School Rd. 7th Ave. to 16th St.	11	8	4	18.7	41.7	11
7th Ave. Osborn to Bethany Home	9.5	11	8	13.0	41.5	12
* 7th St. McDowell to Indian School (as it was)**	7.5	6	13	11.2	37.7	13
* 7th Ave. Van Buren to Thomas	7	6	13	9.0	35.0	14
44th St. Thomas to Camelback	2.5	15	9	7.7	34.2	15
Van Buren 39th Ave. to Black Canyon	4.5	6.5	11	10.7	32.7	16
* 27th Ave. McDowell to Indian School	6	5	15	5.1	31.1	17
24th St. Maricopa Freeway to Buckeye	0	15	11	5.0	31.0	18
Washington & Adams Tie-in	0	15	12	3.9	30.9	19
* 32nd St. Van Buren to Thomas	2.5	7	12	9.4	30.9	20
7th St. Camelback to Glendale	2	6	12	10.8	30.8	21
* Camelback 16th St. to 32nd St.	0.5	8	6	14.8	29.3	22
Dunlap 7th Ave. to Central	4	6	13	6.2	29.2	23
* 44th St. McDowell to Indian School	4	5	12	7.5	28.5	24
* Van Buren 43rd Ave. to 27th Ave.	0	6	13	9.2	28.2	25
24th St. Missouri to Lincoln Drive	0.5	8	13	6.5	28.0	26
Indian School 51st Ave. to 35th Ave.	0.5	8	6	12.0	26.5	27
* Central Ave. Camelback to Glendale	3.5	6	7	9.5	26.0	28
16th St. Grand Canal to Camelback	1	6	8	11.0	26.0	29
* 16th St. Camelback to Glendale	1.5	6	9	8.5	25.0	30
16th St. Broadway to Buckeye	5	6.5	5	8.4	24.9	31
* Bethany 7th Ave. to 16th St.	1	6	12	5.2	24.2	32
7th St. Glendale to Dunlap	1.5	4	10	8.1	23.6	33
Thomas Rd. 43rd Ave. to 27th Ave.	1	6	7	9.4	23.4	34
* Broadway 7th Ave. to 16th St.	1	7	7	8.4	23.4	35
* 19th Ave. Indian School to Bethany Home	1.5	6	9	6.9	23.4	36
* Cave Creek 7th St. to 20th St.	0.5	4	15	3.6	23.1	37
Papago Park Road Van Buren to McDowell**	0	0	15	7.8	22.8	38
44th St. Washington to McDowell	0.5	5.5	9	6.1	21.1	39
* 43rd Ave. Bethany Home to Northern	0.5	2	15	3.3	20.8	40
* Thomas Rd. 51st Ave. to 35th Ave.	0	4	8	7.5	19.5	41
* "Q" Ave. 43rd Ave. to Black Canyon	0	2	15	2.3	19.3	42
* 59th Ave. Van Buren to Thomas	0	3	12	2.8	17.8	43
* Van Buren 48th St. to 60th St.	0	2	3	10.6	15.6	44
* Glendale Ave. 16th St. to 32nd St.	0	2	7	5.2	14.2	45
* Baseline Rd. 16th St. to 32nd St.	0	2	1	5.9	8.9	46

* Test segments.
** Construction completed.
Note: 75.3 miles of major arterial street rated.

Table 13 lists the projects in the adopted 6-yr capital program and the 25 test segments and compares the total points for each project to the year scheduled in the 6-yr program. In the adopted program we specifically identify the projects only in the first three years. In order to retain flexibility, the projects for the second 3-yr period are simply listed as high-priority projects without being identified by specific year. Thus, in Table 13 years 4 through 6 for any project appear in the second half of the program. Each year the program will move forward one year and certain projects will be identified as specific projects in year 3; thus, the engineering and right-of-way acquisition can begin.

Again the usefulness of the priority formula is illustrated. The formula was used as a guide and a means of summarizing the factual elements that go into the final determination of priority. The availability of funds, right-of-way acquisition problem, continuity of program, traffic disruption, and the need to connect to completed or programmed urban freeways being built by the State Highway Department, are all important considerations that weigh in the final determination of a major street construction program.

TABLE 13

FORMULA D APPLIED TO ADOPTED 6-YEAR PROGRAM AND 25 TEST SEGMENTS

Major Arterial Street	Total Points (100 max.)	Year Scheduled (6-yr program)
Thomas Rd. Black Canyon to 19th Ave.	89.3	3
7th Ave. RR Structure/Jefferson to Grant Lincoln	80.9	1
* McDowell Rd. 19th Ave. to 7th St. (as it was)	76.0	**
Indian School Rd. 35th Ave. to Black Canyon	53.1	4-6
7th St. Maricopa Freeway to Grant-Lincoln	52.3	2
* Grand Ave. Thomas to Camelback (as it was)	47.0	**
* 24th St. Buckeye to McDowell (as it was)	43.8	**
19th Ave. Buckeye to Van Buren	43.8	2
16th St. Buckeye to Van Buren	43.8	3
* Van Buren 7th St. to 24th St.	43.2	
* Indian School Rd. 7th Ave. to 16th St.	41.7	
7th Ave. Osborn to Bethany Home	41.5	4-6
* 7th St. McDowell to Indian School (as it was)	37.7	**
* 7th Ave. Van Buren to Thomas	35.0	**
44th St. Thomas to Camelback	34.2	4-6
Van Buren 39th Ave. to Black Canyon	32.7	2
* 27th Ave. McDowell to Indian School	31.1	
24th St. Maricopa Freeway to Buckeye	31.0	4-6
Washington & Adams Tie-in	30.9	1
* 32nd St. Van Buren to Thomas	30.9	
7th St. Camelback to Glendale	30.8	2
* Camelback 16th St. to 32nd St.	29.3	
Dunlap 7th Ave. to Central	29.2	1
* 44th St. McDowell to Indian School	28.5	
* Van Buren 43rd Ave. to 27th Ave.	28.2	
24th St. Missouri to Lincoln Drive	28.0	4-6
Indian School 51st Ave. to 35th Ave.	26.5	4-6
* Central Ave. Camelback to Glendale	26.0	
16th St. Grand Canal to Camelback	26.0	
* 16th St. Camelback to Glendale	25.0	
16th St. Broadway to Buckeye	24.9	4-6
* Bethany Home 7th Ave. to 16th St.	24.2	3
7th St. Glendale to Dunlap	23.6	3
Thomas Rd. 43rd Ave. to 27th Ave.	23.4	4-6
* Broadway 7th Ave. to 16th St.	23.4	
* 19th Ave. Indian School to Bethany Home	23.4	
* Cave Creek 7th St. to 20th St.	23.1	**
Papago Park Rd Van Buren to McDowell	22.8	**
44th St. Washington to McDowell	21.1	4-6
* 43rd Ave. Bethany Home to Northern	20.8	
* Thomas Rd. 51st Ave. to 35th Ave.	19.5	
* "Q" Ave. 43rd Ave. to Black Canyon	19.3	
* 59th Ave. Van Buren to Thomas	17.8	
* Van Buren 48th St. to 60th St.	15.6	
* Glendale Ave. 16th St. to 32nd St.	14.2	
* Baseline Rd. 16th St. to 32nd St.	8.9	

* Test segments.
** Construction completed.
Note: 75.3 miles of major arterial street rated.

NASHVILLE TEST

In spring 1962 work on a priority rating in Nashville, Tenn., began in earnest in much the same manner as in Phoenix. Responsible members of the engineering, traffic engineering, and planning staffs were asked to rate 28 street sections in the order in which improvement was needed. These sections ranged from probably not needing improvement to obviously needing it. Figure 3 shows their geographic relationship to each other and Table 14 gives the range of ratings for each section. Obviously there is considerable discrepancy between some of the ratings. Also given is the rating for each street section obtained by using Formula C. Again there is a deviation between the formula rating and the mean of the ratings by the individuals.

At this point, the Nashville test differs from that conducted in Phoenix. There having been no opportunity to put the formula to work in testing an actual capital improvement program, the efforts put into this research have been directed toward refining the test formula. In order to do this, certain assumptions had to be made. The first was that the mean of the ratings by individuals was as good a priority ranking as

Figure 3. Urban street priorities—test street sections, Nashville, Tenn.

TABLE 14

COMPARISON OF JUDGMENT AND FORMULA RATINGS, NASHVILLE

Street Section	Range of Personnel Ratings	Formula C Rating
12th Ave. Charlotte to Demonbreun	4-22	1
Charlotte L&N RR to 19th Ave.	1-3	9
Charlotte 25th Ave. to 33rd Ave.	3-15	13T
Nolensville RR Overpass to Wallace Rd.	6-20	18
Woodmont Harding Rd. to Hillsboro Rd.	7-24	19
46th Ave. No. Murphy to Charlotte	14-27	15
Centennial 39th Ave. to 51st Ave.	7-20	16
Centennial 28th Ave. to 39th Ave.	5-22	12
Jefferson 9th Ave. to 18th Ave.	5-17	5
Woodmont Granny White to Franklin Rd.	10-27	25
Gallatin Rd. Main to Cahal	2-27	7T
12th Ave. So. Demonbreun to Acklen	5-18	13T
Charlotte Lellyett to Brook Hollow	12-27	26
21st Ave. Charlotte to Grand	1-19	3
21st Ave. Grand to Blair	4-25	4
Belcourt-Acklen 21st Ave. to 12th Ave.	7-18	7T
Shelby 2nd St. to 11th St.	6-25	11
Belmont Belcourt to TC RR	22-27	24
Hillsboro Hobbs to Harding Rd.	17-26	23
Hillsboro Harding Pl. to Old Hickory	24-26	27
White Bridge Rd. Harding Rd. to Charlotte	6-18	22
Old Hickory Lanier to Robinson	11-24	17
Granny White Glenwood to Sewanee	16-25	20
Trinity Lane Gallatin to Dickerson	13-21	21
1st Ave. Public Sq. to Broad	1-24	2
Hermitage Peabody to TC RR	1-5	6
Woodland 2nd St. to 11th St.	4-20	10

NOTE: "T" by Formula C rating indicates tie.

could be achieved. With this assumption it became necessary to attempt to tailor Formula C to yield the same answers as the individual rating.

Staying within the framework of delay, safety, structural condition and traffic volume and growth, the following variations were made:

1. Formula C-1 was identical in form to Formula C. However, the delay element is based on delay for <u>both</u> peak hours.
2. Formula C-2 varied the accident element by giving equal weight to the accident rate per mile and the accident rate per 100 million vehicle-miles. Formula C added the two together which made the accident rate per mile simply a modifying factor due to its smaller magnitude. The other elements do not change.
3. Formula C-3 used both variations.
4. Formula C-4 has been experimented with only to a small extent. It uses the logic that if a street is anticipated to have considerable traffic growth then it should receive extra points; then a street on which a decline in traffic is anticipated should lose points. The traffic formula becomes:

$$\frac{\text{Present ADT}}{6,000} + \frac{\text{1968 ADT - 1963 ADT}}{600}$$

TABLE 15

TEST RESULTS—FORMULA C VARIATIONS

	Con Sec.	Composite of Raters	Delay = 40%, Collision = 15%, Strctl. = 15%, Traffic = 30% — FORMULAS A	B	C	D	Delay = 40%, Collision = 20%, Strctl. = 15%, Traffic = 25% — FORMULAS A	B	C	D	Delay = 40%, Collision = 25%, Strctl. = 15%, Traffic = 20% — FORMULAS A	B	C	D	Delay = 45%, Collision = 15%, Strctl. = 15%, Traffic = 25% — FORMULAS A	B	C	D
Charlotte	03	1	8	7	9	7	7	8	9	7	7	8	9	9	9	8	9	8
Hermitage	03	2	6	4	8	5	6	4	8	6	6	6	8	5	6	4	8	6
1st Avenue North	01	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
12th Avenue	74	4	2	2	2	4	2	2	2	2	2	2	1	2	2	2	1	2
Charlotte	06	5	12	11	12	12	12	13	12	12	13	13	12	12	12	13	14	13
12th Avenue South	02	6	14	13	13	13	14	12	14	13	14	11	14	13	16	12	13	12
Jefferson	03	7	5	8	6	8	5	6	6	7	5	6	5	8	5	7	5	7
Woodland Street		8	9	9	11	10	9	9	11	9	8	7	10	10	8	9	10	10
Nolensville Road	07	9	18	22	18	20	19	25	18	21	21	25	18	22	18	22	19	20
Centennial	05	10	13	14	14	14	13	14	13	14	12	16	13	14	13	14	12	14
21st Avenue	04	11	4	5	4	3	4	5	4	4	4	5	4	3	4	5	4	3
White Bridge Road	08	12	22	21	22	23	21	21	22	23	20	20	22	21	22	20	21	22
21st Avenue	73	13	3	3	3	5	3	3	3	5	3	3	3	6	3	3	3	5
Centennial	06	14	16	15	17	17	16	15	16	16	15	14	14	15	15	15	15	16
Shelby Avenue	02	15	11	10	10	9	11	10	10	10	10	10	10	10	11	10	11	11
Trinity Lane	04	16	20	19	25	24	20	19	23	23	19	19	23	22	21	27	23	24
Belcourt-Acklen	75	17	10	12	7	10	10	11	7	11	11	11	7	7	10	11	6	9
Gallatin	05	18	7	6	5	2	7	7	5	3	9	9	6	4	7	6	7	9
Woodmont	07	19	19	18	19	18	18	18	19	18	18	18	18	18	19	18	20	18
Old Hickory	04	20	17	16	16	16	17	17	17	15	17	17	17	17	17	17	17	15
Charlotte	19	21	26	26	26	26	26	26	26	26	26	26	26	26	25	25	26	26
Woodmont	05	22	25	24	23	22	25	24	25	22	25	24	25	25	27	24	25	23
Granny White	05	23	23	22	20	19	24	20	20	19	22	21	20	19	20	19	18	19
46th Avenue North	02	24	15	16	15	15	15	16	15	17	16	15	15	16	14	16	15	16
Hillsboro	08	25	20	19	21	21	22	22	21	20	23	22	21	20	22	20	21	21
Hillsboro	09	26	27	27	27	27	27	27	27	27	27	27	27	27	26	26	27	27
Belmont	03	27	24	24	24	25	23	23	23	25	23	23	23	24	24	23	23	24

	Con Sec.	Composite of Raters	Delay = 45%, Collision = 20%, Strctl. = 10%, Traffic = 25% — FORMULAS A	B	C	D	Delay = 45%, Collision = 25%, Strctl. = 15%, Traffic = 15% — FORMULAS A	B	C	D	Delay = 50%, Collision = 15%, Strctl. = 15%, Traffic = 20% — FORMULAS A	B	C	D	Delay = 30%, Collision = 30%, Strctl. = 20%, Traffic = 20% — FORMULAS A	B	C	D
Charlotte	03	1	7	9	9	7	7	8	9	8	9	9	9	10	7	6	7	7
Hermitage	03	2	6	4	8	6	6	4	8	5	6	4	8	6	6	3	8	5
1st Avenue North	01	3	1	1	1	1	1	1	2	1	2	1	2	1	1	1	1	1
12th Avenue	74	4	2	2	2	2	2	2	1	2	1	2	1	2	2	2	2	2
Charlotte	06	5	12	13	12	13	14	15	14	13	13	13	12	13	13	12	12	11
12th Avenue South	02	6	14	12	11	12	13	13	13	12	13	12	14	12	14	12	14	13
Jefferson	03	7	5	7	5	8	5	4	5	7	5	7	5	7	4	5	5	8
Woodland Street		8	9	8	11	9	9	7	10	9	10	8	11	9	8	8	10	9
Nolensville Road	07	9	18	23	17	20	21	25	19	23	18	22	18	20	25	26	22	25
Centennial	05	10	13	14	14	14	12	14	12	14	12	14	13	14	12	11	13	14
21st Avenue	04	11	4	5	4	3	4	5	4	4	4	5	4	4	5	7	4	4
White Bridge Road	08	12	21	20	21	22	21	20	21	20	22	20	22	22	21	21	20	20
21st Avenue	73	13	3	3	3	5	3	3	3	3	3	3	3	3	3	4	3	6
Centennial	06	14	16	16	16	17	15	16	15	15	16	15	16	15	15	15	15	15
Shelby Avenue	02	15	11	10	10	10	11	10	11	11	11	10	10	11	10	10	11	10
Trinity Lane	04	16	19	18	22	23	19	19	23	22	21	19	24	24	19	20	23	22
Belcourt-Acklen	75	17	10	11	7	11	10	12	6	10	7	12	6	8	11	14	9	12
Gallatin	05	18	8	6	6	4	6	9	7	6	7	6	7	5	9	9	6	3
Woodmont	07	19	[illegible]	19	19	19	18	18	20	18	19	17	20	19	18	18	19	19
Old Hickory	04	20	17	17	17	16	17	11	17	19	17	22	17	17	17	17	16	16
Charlotte	19	21	25	25	25	26	26	26	26	26	26	26	25	26	26	25	26	26
Woodmont	05	22	25	24	23	23	25	24	25	25	25	25	24	24	24	24	25	24
Granny White	05	23	26	26	25	18	20	21	18	17	20	18	19	18	20	19	18	17
46th Avenue North	02	24	15	15	15	15	16	17	15	16	15	16	15	16	16	16	17	18
Hillsboro	08	25	22	21	20	21	24	23	21	20	23	21	21	21	23	22	20	20
Hillsboro	09	26	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Belmont	03	27	23	22	23	25	23	22	23	23	24	24	23	23	22	23	24	23

	Con Sec.	Composite of Raters	Delay = 25%, Collision = 25%, Strctl. = 25%, Traffic = 25% — FORMULAS A	B	C	D	Delay = 30%, Collision = 30%, Strctl. = 10%, Traffic = 30% — FORMULAS A	B	C	D	Delay = 30%, Collision = 30%, Strctl. = 15%, Traffic = 25% — FORMULAS A	B	C	D
Charlotte	03	1	7	7	8	7	7	6			7	7		
Hermitage	03	2	6	2	7	4	6	3			6	3		
1st Avenue North	01	3	1	1	1	1	1	1			1	1		
12th Avenue	74	4	2	2	2	3	2	2			2	2		
Charlotte	06	5	13	11	11	11	12	11			13	11		
12th Avenue South	02	6	14	13	14	14	14	12			14	12		
Jefferson	03	7	5	5	6	8	5	7			5	5		
Woodland Street		8	9	9	12	9	8	8			8	8		
Nolensville Road	07	9	25	26	22	25	21	25			23	26		
Centennial	05	10	12	12	13	13	13	13			12	13		
21st Avenue	04	11	4	6	4	4	4	5			4	6		
White Bridge Road	08	12	21	21	21	21	20	20			20	20		
21st Avenue	73	13	3	4	3	5	3	4			3	4		
Centennial	06	14	15	15	15	15	16	16			15	15		
Shelby Avenue	02	15	10	10	10	10	10	10			10	10		
Trinity Lane	04	16	20	20	23	22	17	17			18	18		
Belcourt-Acklen	75	17	11	14	9	12	11	14			11	14		
Gallatin	05	18	8	8	5	2	9	8			9	9		
Woodmont	07	19	19	18	18	18	19	19			19	19		
Old Hickory	04	20	16	16	16	16	17	17			17	17		
Charlotte	19	21	26	25	26	26	25	24			26	25		
Woodmont	05	22	24	24	24	23	24	23			24	23		
Granny White	05	23	18	17	17	17	26	26			25	24		
46th Avenue North	02	24	17	19	19	19	15	15			16	16		
Hillsboro	08	25	22	22	20	20	21	21			21	21		
Hillsboro	09	26	27	27	27	27	27	27			27	27		
Belmont	03	27	23	23	24	24	24	22			21	22		

Next, the weights given each element were varied. The variations were quite large. The delay factor varied from a weight of 25 percent of the total to 50 percent. Accidents were weighted from 15 percent to 30 percent. Structural condition varied between 10 percent and 25 percent and the growth factor varied from 15 percent to 30 percent of the total.

Ultimately there were 40 variations of Formula C. The test results of each are shown in Table 15. The ratings obtained from each set were then compared to the mean ratings of the individuals. Essentially, ratings obtained from each formula variation compared as well to the mean subjective ratings as the rating obtained from the other variations. (The average deviations ranged from 4.2 to 5.4.) The results obtained using Formula C-4, with the modified delay factor, tended to compare a little more closely to the mean subjective ratings than the others; but for the most part the changes in the formula seemed to have little effect on whether or not the resulting rating approximated the subjective rating.

The mean for each section rating was calculated from the 40 formulas. The average deviation for all sections from this mean was 0.97. One formula had an average deviation of 1.3 from this mean and at the other end an average deviation of 0.44 was encountered. In other words, the various formulas yield results that vary only slightly. This indicates that the particular formula used does not matter a great deal so long as the selected formula is consistently used.

At this point doubts were raised as to whether the formula could be tested against the subjective rating. The project proceeded to evaluate the original assumption that judgment was a valid criterion against which to test the formula.

The same group that rated the street sections originally was asked to do so again. Approximately 4½ months had elapsed since the first rating and one of the street segments had been resurfaced. The objective was to study the consistency or inconsistency of these judgment ratings. Each rater's results were compared to his earlier efforts. The comparison was expected to show differences but nothing was expected like the actual results (Table 16). The lowest average deviation from the first rating was 3.6 and the

TABLE 16

COMPARISON OF FIRST AND SECOND JUDGMENT RATINGS, NASHVILLE

Street Section	Participant's Initials							
	WL	RP	JC	OA	IH	JH	TL	AH
12th Ave. Charlotte to Demonbreun	+ 2	- 5	- 4	+11	+ 7	- 2	- 1	-17
Charlotte L&N RR to 19th Ave.	0	+ 2	+ 2	+ 9	+ 3	0	+ 1	0
Charlotte 25th Ave. to 33rd Ave.	+ 2	+10	+23	+ 2	+ 3	- 5	+ 9	+ 2
Nolensville RR Overpass to Wallace Rd.	- 5	0	+11	- 5	+ 4	+ 5	- 3	+ 2
Woodmont Harding Rd. to Hillsboro Rd.	+ 5	- 5	+ 2	+ 2	+ 6	- 4	- 6	- 2
46th Ave. No. Murphy to Charlotte	- 3	- 8	- 2	+ 5	- 1	+ 3	-10	- 4
Centennial 39th Ave. to 51st Ave.	- 6	+ 8	+ 5	+11	- 4	+ 7	+ 5	+17
Centennial 28th Ave. to 39th Ave.	+ 2	+ 6	+12	- 4	- 6	+ 7	+ 2	+19
Jefferson 9th Ave. to 18th Ave.	- 3	0	+ 8	- 4	- 8	- 1	- 1	- 1
Woodmont Granny White to Franklin Rd.	- 2	- 5	- 9	0	+ 2	+ 7	-10	- 7
Gallatin Rd. Main to Cahal	+ 7	- 6	+ 9	-10	-18	+ 5	+ 5	+ 2
12th Ave. So. Demonbreun to Acklen	- 3	- 1	+ 1	+ 1	+ 9	+ 7	+ 2	- 9
Charlotte Lellyett to Brook Hollow	- 2	- 2	- 3	+10	- 6	+ 5	+ 1	+ 3
21st Ave. Charlotte to Grand	+10	+ 2	- 3	+ 4	- 5	-13	+ 1	+ 2
21st Ave. Grand to Blair	+ 7	+10	-12	- 1	+ 5	+ 1	- 1	- 9
Belcourt-Acklen 21st Ave. to 12th Ave.	- 1	- 2	-12	- 3	+ 6	+ 4	+ 3	+ 1
Shelby 2nd St. to 11th St.	-11	+ 4	- 5	-20	-20	- 5	- 3	-17
Belmont Belcourt to TC RR	+ 1	0	-13	- 2	- 5	0	- 4	- 7
Hillsboro Hobbs to Harding Rd.	+ 7	0	0	+ 5	- 1	- 2	0	+ 2
Hillsboro Harding Pl. to Old Hickory	+ 2	+ 2	0	- 6	0	- 2	- 1	0
White Bridge Rd. Harding Rd. to Charlotte	+ 2	+ 3	+ 9	0	+11	+ 2	- 6	- 6
Old Hickory Lanier to Robinson	- 5	- 3	- 2	+ 1	+ 6	- 2	+10	+16
Granny White Glenwood to Sewanee	- 3	- 1	- 8	- 4	+ 2	- 1	+ 7	-11
Trinity Lane Gallatin to Dickerson	- 1	- 4	- 2	- 5	- 7	- 2	+ 4	0
1st Ave. Public Sq. to Broad	0	- 2	- 1	- 1	- 1	- 4	- 2	+ 1
Hermitage Peabody to TC RR	- 2	- 3	+ 5	+ 1	+ 1	- 1	0	- 1
Woodland 2nd St. to 11th St.	0	0	- 3	+ 3	- 7	- 9	- 2	+ 2

highest was 6.8. The deviation for individual sections ranged from 1.1 to 12.6. Just what this could mean on an individual street section is illustrated by this example: A 10-block long section on Shelby Avenue was rated as the fifth priority by one rater the first time. Four months later he rated it the 26th priority. At the same time another rater placed this section as 28th priority the first time but changed it to 10th on the second rating. Thus, there were two complete reversals in thought on one section but they were in the opposite direction.

A definite advantage of a formula rating had thus evolved. There is no apparent consistency to a rating which an individual might make in spite of all conscientious effort he might put forth. It became clear that judgment could best be applied to the formula ordered list of projects to arrive at a program priority.

One final experiment was tried using the data that had been assembled. It has been mentioned earlier that there is no intent to develop a formula that is a final work. The priority ratings derived from the formula are an aid to actual programming. The projects presented in the test might represent a 5- or 6-yr program of improvements. This being the case, there would be five or six projects per year.

Then, the object of a priority rating becomes, not naming a project 1st, 2nd or 3rd priority, but 1st year, 2nd year, etc. So the real problem becomes what do the various formulas do to the yearly groupings.

Of the 40 formulas used, only one of them varied a project by more than one year from where the other formulas placed it. It appears that variations of the basic formula have little effect on its overall usefulness. So long as it is applied uniformly, the results are quite similar.

CONCLUSIONS

The results of the test of an urban major arterial street construction priority formula in Nashville and Phoenix have been encouraging. Formula D incorporates the experience obtained to date in these two cities. The formula is simple and the elements that go into it are rather easily obtained.

As with any tool, it is important that it be used properly. The objective is simply to order projects under consideration in a factual way. Following this, the other important administrative, fiscal, coordination with other agencies, and area-wide considerations must be applied in the development of the capital program.

The results of the work in San Diego, Phoenix and Nashville indicate that an urban street construction priority formula should not be too complex and should certainly minimize the judgment elements that go into it. A priority formula should be based upon facts.

The studies demonstrate that one of the more difficult situations for priority formulas to recognize and evaluate is a facility that has been improved to reasonable standards, or a facility that is parallel to an existing or planned freeway. Another problem is that of the nonexisting street with zero present ADT. Here, as in the parallel freeway situation, judgment is the obvious solution. The authors do not believe that one formula can "solve" all the individual cases.

All the studies have indicated that the formula itself is not nearly as important as its consistent application. The Nashville analysis clearly demonstrates this principle.

It is difficult to evaluate a major street improvement priority formula because of the wide variances in judgment that have been obtained from the several studies. This emphasizes the need to develop a simple, easily applied, factual major street improvement priority formula for urban areas.

It is hoped that other urban areas will test Formula D and then improve it, and that these studies can be disseminated so that progress can be made in the direction of capital programming in urban areas.

A major street improvement priority formula for urban areas is needed. Such a formula can be an extremely useful tool to those responsible for developing a capital improvement program for major streets in cities. The formula makes possible the presentation of various projects in a relative priority list based on facts. At this point administrative and budgetary considerations and judgment can most properly be applied to develop the capital improvement program that will provide maximum benefits to the public.

Flexible Analysis of Highway Needs in Manitoba

JAMES O. GRANUM, Deputy Chief Engineer, Highways Division, Automotive Safety Foundation, and
RONALD M. GORDON, Assistant District Engineer, Highways Branch, Manitoba Department of Public Works

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.
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> * * *
>
> 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.

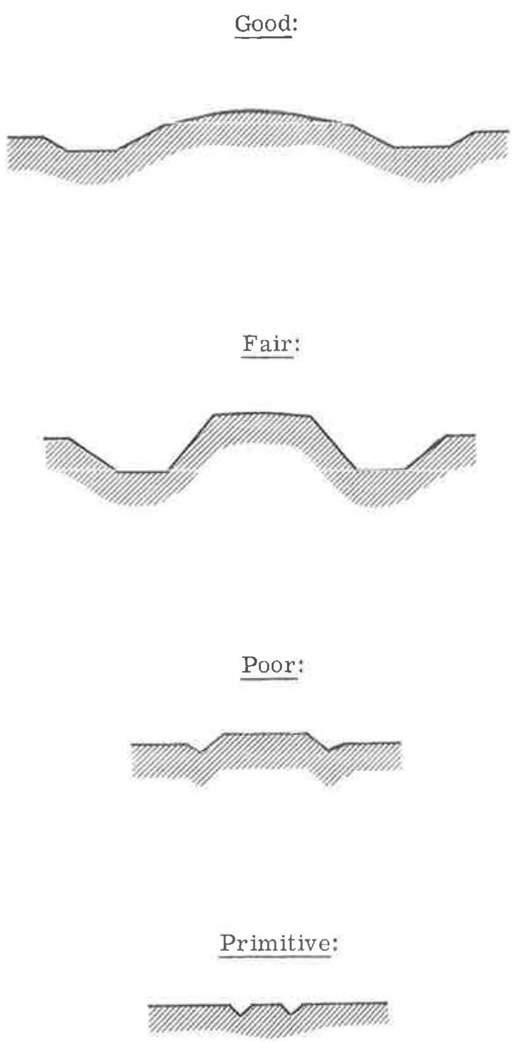

Figure 2.

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

STANDARD SECTION

DESIGN SPECIFICATIONS

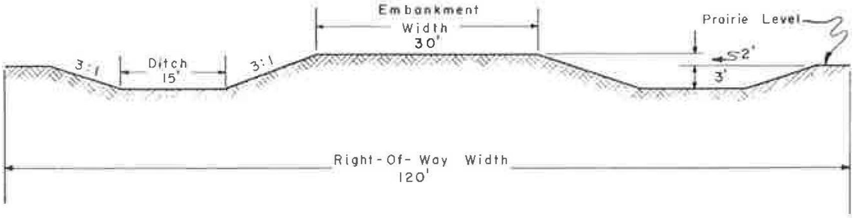

Table I

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'	2½'	2½'
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)	Corrected Mileage (24–26)	Terrain (27)	Surface Type (28)	Surface Width (29–30)	Surf. Condition (31)	Base Type (32)	Shoulder Width (33–34)	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	024	1	3	2	5	1	004	0110	—	—	—	010	1	3	20	2	2	04	28	099	2	30	1	1	1	—	—	127	100	100	0177	2	005	
6	024	1	3	2	5	1	004	0120	—	—	—	025	1	2	—	—	—	—	34	186	5	50	1	1	1	—	—	100	075	070	0177	2	050	
6	023	1	3	2	5	2	004	0130	—	—	—	128	1	2	—	—	—	—	34	180	5	50	1	1	1	—	—	100	075	070	0177	2	098	
6	023	1	3	2	5	1	004	0140	—	—	—	031	1	2	—	—	—	—	30	150	5	45	1	1	1	—	—	100	100	060	0177	2	014	
6	023	1	3	2	5	3	003	0302	01	—	—	005	1	2	—	—	—	—	26	099	6	40	1	1	2	—	—	100	100	100	0140	2	010	
6	023	1	3	2	5	3	003	0302	02	—	—	001	1	2	—	—	—	—	24	066	0	20	1	1	3	—	—	130	100	100	0140	2	001	
6	023	1	3	2	5	3	003	0101	—	—	—	007	1	1	—	—	—	—	25	099	6	30	1	1	1	—	—	100	100	100	0160	2	009	
6	023	1	3	2	5	0	001	0100	—	—	—	031	1	2	—	—	—	—	18	099	8	35	1	1	2	—	—	100	100	100	0046	4	062	
6	023	1	3	2	5	3	001	0200	—	—	—	010	1	2	—	—	—	—	18	099	8	35	1	1	2	—	—	100	100	100	0045	4	020	
6	023	1	3	2	5	0	001	0300	—	—	—	031	1	2	—	—	—	—	18	099	8	35	1	1	2	—	—	100	100	100	0090	3	006	
6	023	1	3	2	5	0	002	—	—	—	—	040	1	1	—	—	—	—	22	099	5	40	1	1	2	—	—	100	100	135	0018	5	032	
6	023	1	3	2	5	2	003	01	—	—	—	004	1	2	—	—	—	—	28	099	3	20	1	1	2	—	—	125	100	065	0045	4	008	
6	023	1	3	2	5	1	003	02	—	—	—	006	1	2	—	—	—	—	24	066	2	35	1	1	2	—	—	050	100	070	0045	4	006	
6	023	1	3	2	5	0	003	03	—	—	—	010	1	2	—	—	—	—	24	066	2	35	1	1	2	—	—	050	100	070	0015	5	000	
6	023	1	3	2	5	0	003	04	—	—	—	011	2	2	—	—	—	—	22	066	4	30	2	1	2	—	—	050	100	075	0015	5	000	
6																																		
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

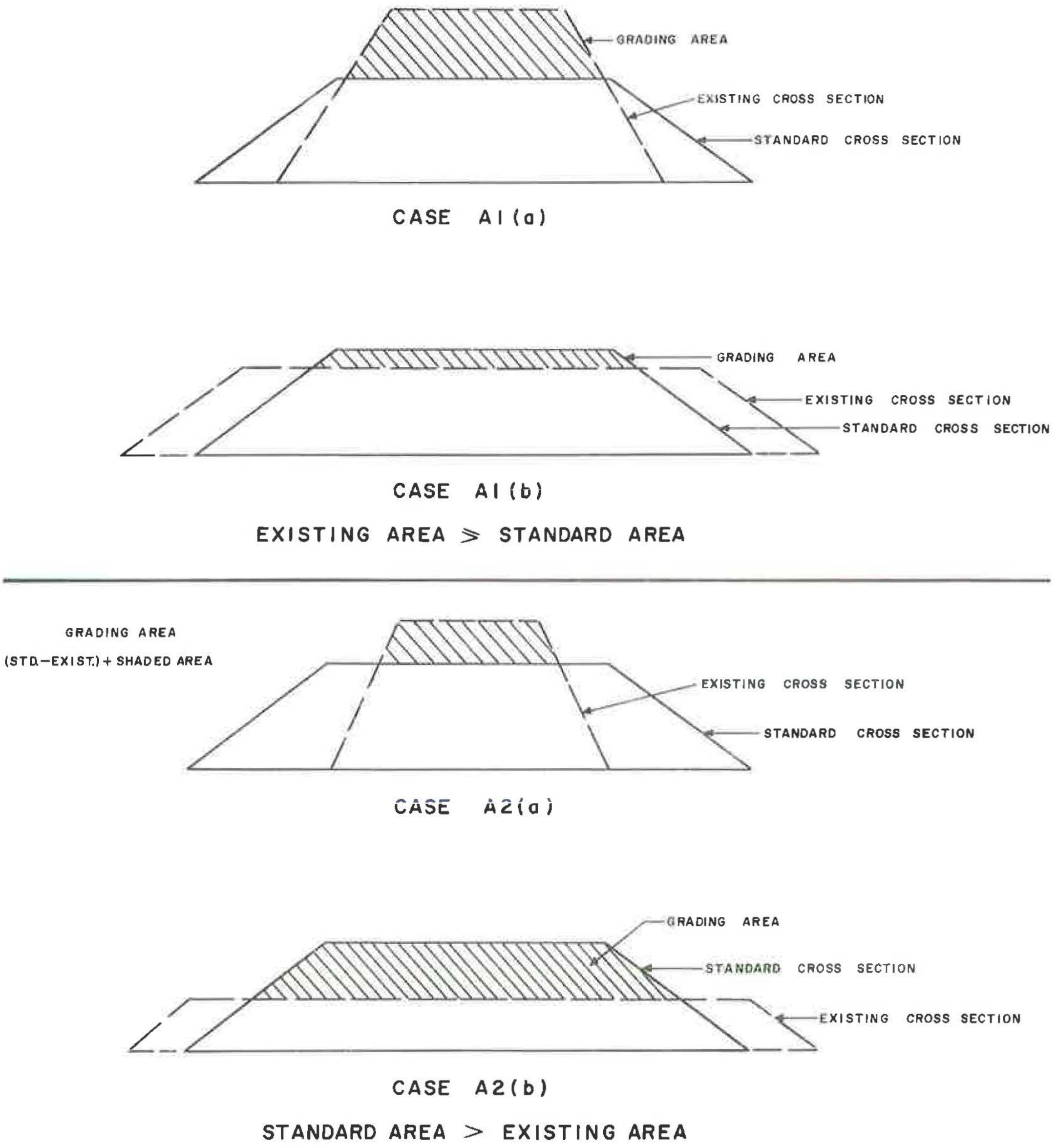


Figure 8.

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.

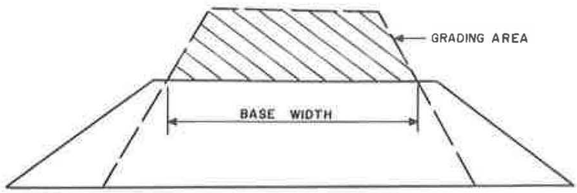
While that was suitable for Manitoba situations, elsewhere this could be modified, for example according to observed pavement condition or width.

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

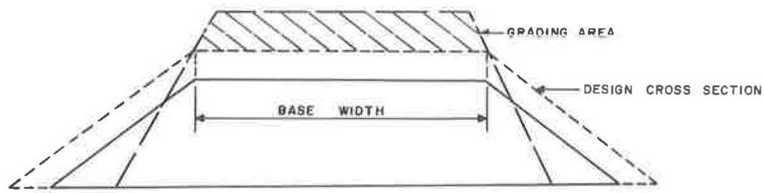
GREATER THAN STANDARD



CASE B1

EXISTING AREA SLOPES INTERSECT

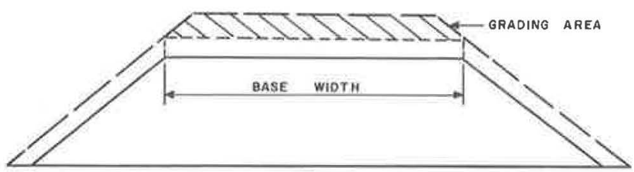
TOP OF STANDARD AREA



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

Height (width + slope × height) × 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.

Appraisal of Needs and Cost Estimating Procedures

Minnesota Trunk Highway Needs Study

R. O. KIPP and W. T. LUSSKY, Respectively, Highway Needs Engineer and Data Processing Program Supervisor, Minnesota Department of Highways

Minnesota's Trunk Highway Needs Study, which was started in 1961, is designed to utilize insofar as possible the speed and efficiency of electronic data processing equipment to compute, list, and summarize the cost of needed construction on the State Highway System. The computer procedures are programmed for the IBM 1410 computer and are so arranged that various parts of the basic input data may be revised periodically as changes occur in the factors which influence the end result of cost computations.

The results of this study and related computer programs have been very satisfactory. The updating features of the programs have been utilized and found to work as expected.

The output data are being used for construction programming, informational releases to the general public, and in conjunction with legislative inquiries and presentations.

•PERIODICALLY every state has made studies of its highway systems to determine their adequacy and the estimated costs involved in correcting deficient sections. The degree of accuracy has run from a rough appraisal based on general averages to fairly concise estimates based on quantities of work and realistic unit prices for the types of work involved. The states have seldom been able to keep the studies current because of varying cost increases of the various items, changes in design and construction standards, and revisions in traffic projections. These varying components require a multitude of computations to maintain such a study in current status. Without the use of modern electronic computers, the task of maintaining these studies would be a tedious and prohibitive process.

As in other states, Minnesota's highway systems have been the subject of needs studies in the past. Due to legislative action, the 30,000-mile County State-Aid Highway and 1,200-mile Municipal State-Aid Street Systems have had continuing needs studies since 1957. Work on the continuing Trunk Highway Needs Study was started in mid-1961 with the first six to nine months spent reviewing needs study procedures used previously in Minnesota and several other states, designing the data collection sheets, writing the manual of instructions, and having preliminary conferences with the programmer for the computer operations.

The Trunk Highway Needs Study computer procedures have been programmed for the IBM Model 1410 computer and related equipment. These procedures have been organized to utilize, wherever possible, the speed and efficiency of electronic data processing. The computer program is so arranged that the various phases may be revised periodically as changes occur in design criteria, traffic data, or cost factors without disrupting the balance of the basic information.

Paper sponsored by Committee on Highway Needs and presented at the 43rd Annual Meeting.

Form No. 2972
12-61
(Rev. 4-62)

MINNESOTA HIGHWAY DEPARTMENT - U.S. BUREAU OF PUBLIC ROADS
TRUNK HIGHWAY NEEDS STUDY - ROADWAY DATA SHEET

IDENTIFICATION

1. Control Section ______ 2. Segment ______ 3. District ______ 4. T. H. ______ 5. Length ______
6. Municipality ______ 7. Termini ______
8. Federal Designation: Interstate: Rural (1) Urban (2); Primary: Rural (3) Urban (4); Secondary: Rural (5) Urban (6); Non-Federal: Rural (7) Urban (8)
9. Urban Classification: Non-Municipal: Non-Urban (1) Urban (2) Municipal: Non-Urban (3) Urban (4)
10. Service Level of Facility: Freeway (1) Expressway (2) Trunk Route (3) Collector (4)
For Office Use (5) (6)
11. Proposed Springtime Restriction: Plan "A" ______ Plan "B" ______ Final ______
12. Legal Designation: Constitutional Route (1) Legislative (2)
Cost Range (1) (2) (3)

TRAFFIC DATA

13. Est. Present Traffic (Average Daily Traffic) ______ 14. Year ______
15. Est. Future Traffic (Average Daily Traffic) ______ 16. Year ______
17. Percent Commercial ______ 18. Commercial ______
19. Percent for 30th Peak Hr. ______ 20. 30th PH ( ) / ( ) = 22. Vol. /Cap Ratio ______
21. Practical Capacity (No Parking) ....
23. Estimated Classification of Trucks:
(a) Percent 2 axle single ______
(b) Percent 3 axle single ______
(c) Percent 3 axle TT-ST ______
(d) Percent 4 axle TT-ST ______
(e) Percent 5 axle TT-ST ______
(f) Total Percent (b) + (d) + (e) = ______

ROAD DATA (Existing or under Contract)

I. Thru Roadway:

24. Left Roadway (Or Non-Divided Facility)

	Type	Thickness	Width
A. Surface	______	B. ______	C. ______
D. Shoulder	______	....	E. ______
F. Base	______	G. ______	....
H. Latest Grading Year	______		
I. Latest Surfacing Year	______		

25. Right Roadway (Divided Highway Only)

	Type	Thickness	Width
A. Surface	______	B. ______	C. ______
D. Shoulder	______	....	E. ______
F. Base	______	G. ______	....
H. Latest Grading Year	______		
I. Latest Surfacing Year	______		

26. Design Speed MPH ______ 27. No. of Traffic Lanes (2) (3) (4) (6) 28. Not Divided (1) Divided (2)
29. Median: None (0) Raised (1) Depressed (2) 30. Median Width (Ft.) ______
31. Percent of Passing Sight Distance Less Than 1500 Ft. ______ 32. Geometric Design: Rural (1) Urban (2)
33. Maintenance Rating: Non-Excessive (1) Excessive (2)
34. Terrain: Swampy (1) Flat (2) Rolling (3) Rugged (4)
35. Construction Status: Not Under Construction (0) Surface Remaining (1) Base & Surface Remaining (2) Complete Construction (3)
36. Present Springtime Load Capacity (Tons). (3) (4) (5) (6) (7) (8) (9)
37. No. of Bridges (Report on Form #2973) ______ 38. No. of R. R. X-ings (Report on Form #2974) ______

II. Interchanges (Ramps Only)

	Type	Thickness	Width
39. Surface	______	40. ______	41. ______
42. Shoulder	______	....	43. ______
44. Base	______	45. ______	....

46. Total Length (Miles) ______
47. Year of Construction ______

III. Frontage Roads:

48. Left Side Length (Miles) ______

	Type	Thickness	Width
A. Surface	______	B. ______	C. ______
D. Shoulder	______	....	E. ______
F. Base	______	G. ______	....
H. Year of Construction	______		

49. Right Side Length (Miles) ______

	Type	Thickness	Width
A. Surface	______	B. ______	C. ______
D. Shoulder	______	....	E. ______
F. Base	______	G. ______	....
H. Year of Construction	______		

IV. Climbing Lanes:

	Type	Thickness	Width	Length (Feet)
50. Surface:	______	51. ______	52. ______	53. ______
54. Base	______	55. ______	56. Year of Construction	______

Figure 1.

V. Urban Information:

57. Right of Way Width ____________ Ft. 58. Building Line to Building Line Width ____________

59. Parking: None (0) Off Peak Only: One Side (1) Both Sides (2) Center (3)
Continuous: One Side (4) Both Sides (5) Center (6)

60. Traffic Flow: One Way (1) Two Way (2)

61. Curbs: None (0) One Side (1) Both Sides (2) 62. Boulevard Width ____________

63. Sidewalks: None (0) One Side (1) Both Sides (2) 64. Sidewalk Width ____________

65. Illumination None (0) Intersections Only (1) Continuous (2)

66. Access Control: None (0) Partial (1) Full (2)

67. Type of Drainage (Describe) ____________

68. Type of Area: Residential % ____________ Commercial % ____________ Industrial % ____________

VI. Condition Ratings & Recommended Construction Period:

69. Conformance to Minimum Standards:
A. Presently Adequate (1) Presently Deficient (2)
B. Future Deficiency: 1-5 Yrs. (1) 6-10 Yrs. (2) 11-15 Yrs. (3) 16-20 Yrs. (4) None (0)
C. Features Deficient: None (0) Geometric (1) Structure (2) Other (3) Combination (4)

70. Recommended Construction Period:
First 5-Yr. Period (1) Second 5-Yr. Period (2) Third 5-Yr. Period (3) After Third 5-Yr. Period (4)

71. Rating Factors:
A. Foundation ________ B. Surface ________ C. Load Carrying Capacity ________ D. Safety ________
E. Traffic Capacity ________ F. Total Rating ________ G. Adjusted Rating ________

72. Hazard Conditions:
A. No. of Stopping Sight Distance Restrictions ________ B. No. of Deficient Horizontal Curves ________
C. No. of Narrow Bridges ________ D. No. of Intersections at Grade ________

ROAD DATA PROPOSED

73. Estimated Length ____________ Mi. 74. Proposed Width ____________ Ft.

75. Alignment: Same (1) New (2) 76. Not Divided (1) Divided (2)

77. Traffic Lanes: (2) (4) (6) Other ________ 78. Design Load (Tons) (7-9) (9)

79. Terrain (New Alignment): Swampy (1) Flat (2) Rolling (3) Rugged (4)

80. Predominant Soil Class of Proposed Subgrade:
A3 (50%) (1) A2 (75%) (2) A6 (100%) (3) A7 (125%) (4)

81. Surface Type: Rigid (1) Flexible (2) 82. Design: Rural (1) Urban (2)

83. Number of Traffic Separations Required: (Report on Form #2973) ____________

84. Ramp Lengths (Total ________ Mi.) 85. Climbing Lanes (Total ________ Ft.)

86. Frontage Roads (Total ________ Mi.) 87. Frontage Road Load Design (Tons) (5) (7) (9)

88. Number of Cross Roads Affected (Report on Form #2975) ____________

89. Utility Adjustments: Not Required (1) Required (2)

RIGHT OF WAY NEEDS (Estimated Cost - Item 91 Will Be Provided By R/W Section)

90. R/W Not Needed (1) R/W Needed* (2)

91. Estimated Cost ____________ (Thousands of Dollars)
* If R/W is Needed, Complete Separate Form #2976.

CONSTRUCTION ITEMS

I. Grading

92. Clearing & Grubbing: None (0) Light (1) Average (2) Heavy (3)

93. Demolition: None (0) Industrial (1) Urban (2) Suburban (3) Rural (4)

94. Removal Items: Concrete Pavement (S. Y.) ________ Concrete or Masonry Structures (C. Y.) ________
Portable Culverts (L. F.) ________ Curb & Gutter (L. F.) ________ Sidewalk (S. F.) ________

95. Type of Grading: None (0) Reshape Only (Minor) (1) Widen Only (No Grade Change) (2)
Regrade & Widen (3) Regrade (Complete) (4) Complete (New Alignment) (5)

96. Class of Excavation: (C. Y. Per Mile):
Class "A" ________ Class "B" ________ Class "A" Borrow ________ Class "B" Borrow ________

97. Swamp Excavation: Estimate Total C. Y. ____________

98. Swamp Backfill: Estimate Total C. Y.: Adjacent Cuts ____________ Borrow ____________

99. Rock Excavation: Estimate Total C. Y.:
Class "ASR" ________ Class "ALR" ________ Class "AIR" ________

100. Minor Drainage Structures: Number Under 10 Feet ____________
Number 10-20 Feet ____________

Figure 1. Continued.

II. Base

101. Left Roadway: (Or Non-Divided Facility)

					Partial Base Only
None	(0)	Gravel	(1)		T/M ______
Complete Base	(1)	Bituminous	(2)		T/M ______
Widening	(2)	Soil Cement	(3)	Inches____	SY/M ______
Strengthening	(3)	Slip Form Concrete	(4)	Inches____	SY/M ______
		Formed Concrete	(5)	Inches____	SY/M ______

102. Right Roadway: (Divided Highway Only)

					Partial Base Only
None	(0)	Gravel	(1)		T/M ______
Complete Base	(1)	Bituminous	(2)		T/M ______
Widening	(2)	Soil Cement	(3)	Inches____	SY/M ______
Strengthening	(3)	Slip Form Concrete	(4)	Inches____	SY/M ______
		Formed Concrete	(5)	Inches____	SY/M ______

III. Surfacing

103. Left Roadway: (Or Non-Divided Facility)

None (0)

Additional Bituminous (1) Inches ______ T/M ______ 2321 (2) 2331 (3) 2341 (4) 2351 (5)

Complete Bituminous (2)

Slip Form Concrete (3) Inches ______ SY/M ______ Non-Reinforced (1) Reinforced (2)

Formed Concrete (4) Inches ______

104. Right Roadway: (Divided Highway Only)

None (0)

Additional Bituminous (1) Inches ______ T/M ______ 2321 (2) 2331 (3) 2341 (4) 2351 (5)

Complete Bituminous (2)

Slip Form Concrete (3) Inches ______ SY/M ______ Non-Reinforced (1) Reinforced (2)

Formed Concrete (4) Inches ______

IV. Shouldering:

105. None (0) Complete Shoulder (1)

Reshouldering (2) Quantity T/M ______

V. **Miscellaneous Items:** (Do Not Include Items To Be Done By Maintenance Forces)

106. Fencing (Hundredths of Miles): Rural ______ Urban ______

107. Storm or Sanitary Sewers (L. F.) ______ Approximate Size (Inches) ______

108. No. of Lighting Installations: Partial (Interchanges or Intersections Only) ______
Continuous (Maybe a Portion of the Segment) ______

109. No. of Traffic Signal Installations: Flashing Beacons ______ Isolated Pretimed ______
Interconnected Pretimed ______ Full Traffic Actuated or Pedestrian Signals ______
Traffic Adjusted (3 to 5 Intersections) ______ Traffic Adjusted (5 or More Intersections) ______

110. Signing: No (1) Yes (2) 111. Curb (L. F.) ______ 112. Curb & Gutter (L. F.) ______

113. Sidewalk (S. F.) ______ 114. Guard Rail: Double Cable (L. F.) ______ Structural Plate (L. F.) ______

115. Roadside Development: (Estimated Cost) ______

116. Other (Specify) ______

REMARKS

Figure 1. Continued.

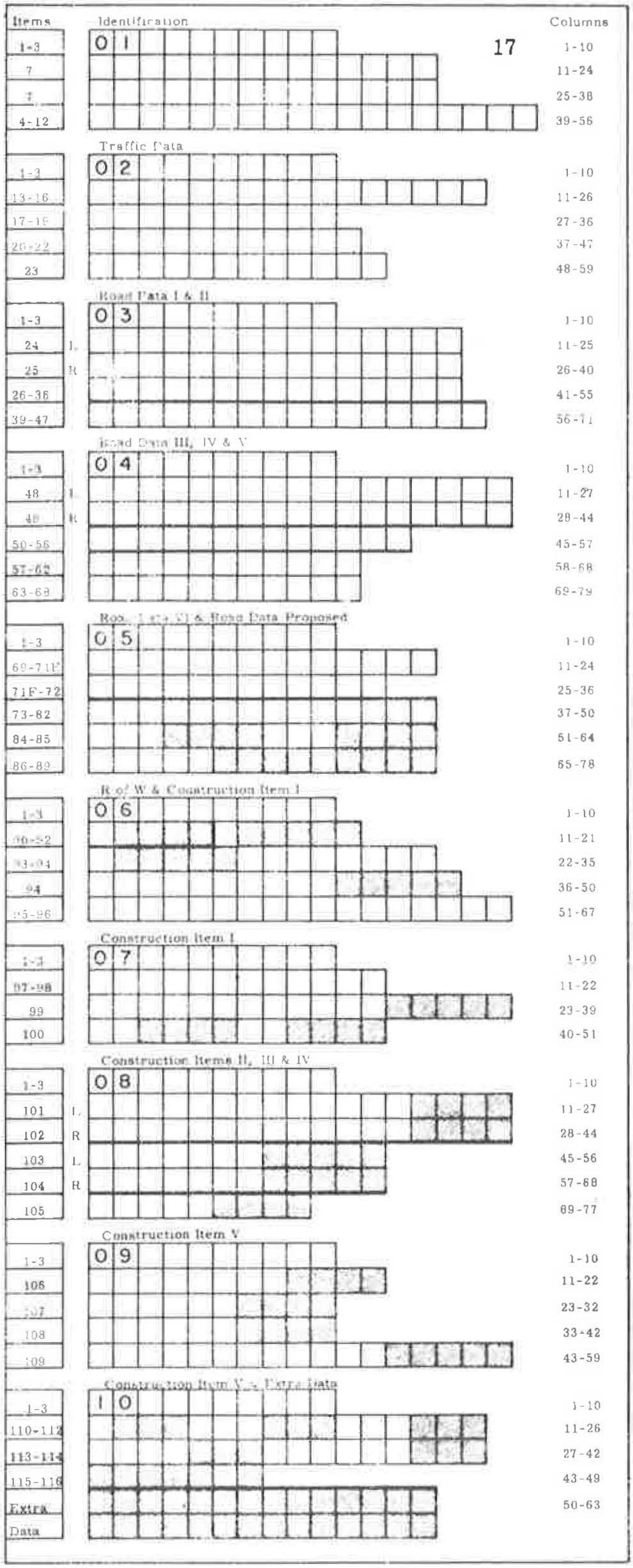


Figure 1. Continued.

Form No. 2973
1-62

MINNESOTA HIGHWAY DEPARTMENT - U.S. BUREAU OF PUBLIC ROADS
TRUNK HIGHWAY NEEDS STUDY - STRUCTURE DATA SHEET

IDENTIFICATION

1. Control Section ______ 2. Segment ______ 3. District ______
4. Located on T.H. ______ , ______ Miles ______ of ______
5. M.H.D. Bridge No. ______ 6. Bridge Sequence No. ______

EXISTING CONDITIONS (Or Under Contract)

7. Type of Service: Stream X-ing (1) Hwy./R.R. (2) R.R./Hwy. (3)
Highway Separation (4) Highway Interchange (5)
R.R. Grade X-ing (6) Local Road Crossing At Grade (7)
8. Type of Structure ______ 9. Year Built ______
10. Structure Length ______ Ft. 11. No. of Spans ______
12. Roadway Width ______ Ft. 13. Sidewalk Width: Left ______ Right ______
14. Vertical Clearance ______ (To Tenths) 15. Safe Loading ______ Tons
16. Substructure: Steel (1) Concrete (2) Timber (3) Other (4)
17. Superstructure: Steel (1) Concrete or Masonry (2) Timber (3) Other (4)
18. Type of Floor: Steel (1) Concrete (2) Wood (3) Other (4)
19. Placement: Skew (1) Square (2) 20. Projected A.D.T. ______

ADEQUACY & RECOMMENDED CONSTRUCTION PERIOD

21. Conformance To Minimum Standards
A. Presently Adequate (1) Presently Deficient (2)
B. Future Deficiency:
1-5 Yrs. (1) 6-10 Yrs. (2) 11-15 Yrs. (3) 16-20 Yrs. (4) None (0)
C. Features Deficient: None (0) Capacity (1) Structure (2) Other (3)
22. Recommended Construction Period
1st 5-Yrs. (1) 2nd 5-Yrs. (2) 3rd 5-Yrs. (3) After 3rd 5-Yrs. (4)

PROPOSED IMPROVEMENT

23. Type of Service: Stream X-ing (1) Hwy./R.R. (2)
R.R./Hwy. (3) Hwy./Hwy. (4)
24. Type of Work: Redeck (1) Recondition (2) Replace - Same Site (3)
Replace - New Site (4) New Structure (5)
25. Type of Structure ______ 26. Structure Length ______
27. Design Load: H15-S12 (1) H20-S16 (2) Other (3) ______
28. Roadway Width ______ 29. Sidewalk Width: Left ______ Right ______
30. Substructure Material:
Steel (1) Concrete (2) Tr. Timber (3) Other (4) ______
31. Superstructure Material:
Steel (1) Concrete (2) Tr. Timber (3) Other (4) ______

COST ESTIMATE (Thousands of Dollars)

32. Right of Way (See Instructions) $ ______
33. Approaches (See Instructions) $ ______
34. Structure Cost $ ______
35. Total Cost $ ______

Items		Columns
Card	1 1	1 - 2
1		3 - 6
2		7 - 9
3		10
4		11 - 13
4		14 - 17
4		18 - 24
5		25 - 29
6		30 - 32
7		33 - 35
8		36 - 42
8		43 - 49
9		50 - 51
10		52 - 55
11		56 - 57
12		58 - 60
13		61 - 64
14		65 - 67
15		68 - 69
16-19		70 - 76

Items		Columns
Card	1 2	1 - 2
1		3 - 6
2		7 - 9
3		10
21		11 - 13
22		14
23		15
24		16
25		17 - 23
25		24 - 30
26		31 - 34
27		35
28		36 - 38
29		39 - 42
30		43
31		44
32		45 - 48
33		49 - 52
34		53 - 56
35		57 - 63
Extra		64 - 70

DESCRIPTION OF IMPROVEMENT & REMARKS: ______

Figure 2.

Form No. 2974
1-62

MINNESOTA HIGHWAY DEPARTMENT - U.S. BUREAU OF PUBLIC ROADS
TRUNK HIGHWAY NEEDS STUDY - RAILROAD CROSSING DATA SHEET

IDENTIFICATION

1. Control Section ______ 2. Segment ______ 3. District ______
4. Name of Railroad ______ 5. X-ing No. ______
6. Location: Section ______ Township ______ Range ______
7. Located ______ Miles (E) (W) (N) (S) Of Depot At ______

EXISTING CONDITIONS

8. No. of Tracks: Mainline ______ Passing ______ Other ______
9. Daily Train Movements: Scheduled ______ Irregular ______
10: Approximate Speed ______ 11: Alignment: Tangent (1) Curve (2)
12. No. of Accidents (1930 To Present) ______ Injured ______ Killed ______
13: Type of Protection: None (0) Signs Only (1) Signals Only (2) Signals & Gates (3)
14. Presently Adequate (1) Presently Deficient (2)

Sketch of Location

Indicate North Arrow in Box

T. H. ______

Proj. A. D. T. ______

Note: Distances and grade shown are from Intersection of Road and R. R.

15. Clear Vision at 300 Feet (All Quadrants) Yes (1) No (2)

PROPOSED IMPROVEMENTS

16. Proposed Protection: None (0) Signs Only (1) Signals Only (2) Signals & Gates (3) Separation (4)

Describe: ______

NOTE: If a Separation is Proposed, Complete Form #2973

17. Recommended Construction Period:
1-5 Yrs. (1) 6-10 (2) 11-15 (3) 16-20 (4) None (0)

COST ESTIMATE

18. Proposed Protection Estimated Cost $ ______

Items	Identification	Columns
Card	1 3	1 - 2
1		3 - 6
2		7 - 9
3		10
4		11 - 17
5		18 - 21
6		22 - 23
6		24 - 26
6		27 - 28
7		29 - 32
7		33
7		34 - 40
	Existing Conditions	
8		41 - 44
9		45 - 48
10		49 - 50
11		51
12		52 - 57
13		58
14		59
15		60
	Proposed Improvements	
16		61
17		62
	Cost Estimate	
18		63 - 68
	Extra Data	
Extra Data		

REMARKS: ______

Figure 3.

Form No. 2975
2-62

MINNESOTA HIGHWAY DEPARTMENT - U.S. BUREAU OF PUBLIC ROADS
TRUNK HIGHWAY NEEDS STUDY - LOCAL ROAD CROSSING DATA SHEET

IDENTIFICATION

1. Control Section ________ 2. Segment ________ 3. District ________
4. Name of Crossroad or Street ________ 5. X-ing No. ________
6. Located on T. H. ______, ________ Miles ______ of ________

EXISTING CONDITIONS

7. Local Road Crossing Effected Length (Miles) ________

	Type		Thickness		Width
A. Surface	________	B.	________	C.	________
D. Shoulder	________		....	E.	________
F. Base	________	G.	________		....

H. Latest Grading Year ________ I. Latest Surfacing Year ________

8. No. of Traffic Lanes ________ 9. No. of Parking Lanes ________
10. Divided (1) Not Divided (2) 11. Design Speed MPH ________
12. Present Crossroad Traffic (A.D.T.) ________ 13. Year ________
14. Projected Crossroad Traffic (A.D.T.) ________ 15. Year ________
16. Projected T.H. Traffic (A.D.T.) ________ 17. Year ________

PROPOSED CONSTRUCTION

18. Local Road Crossing Proposed Length (Miles) ________

	Type		Thickness		Width
A. Surface	________	B.	________	C.	________
D. Shoulder	________		....	E.	________
F. Base	________	G.	________		....

CONSTRUCTION ITEMS

	UNIT COST	COST
19. Right of Way (Complete Form #2976)		$
20. Grading		
________ CY. Class: (A) (B) Borrow: (Yes) (No)		
________ CY. Swamp Excavation		
________ CY. Swamp Backfill: Borrow (1) Cuts (2)		
________ CY. Rock Class: (ASR) (ALR) (AIR)		
21. Base		$
________ T/M Gravel		
________ T/M Bituminous		
________ SY/M ______ Inches ________ (Concrete Design)		
22. Surface		$
________ T/M Bituminous		
________ SY/M ______ Inches ________ (Concrete Design)		
23. Shoulders		$
________ T/M Gravel		
________ T/M Bituminous		
24. Utilities		$
Total of Items 20, 21, 22 & 23 ________ X ____ Percent		$

25. Total Cost Estimate .... $

Remarks: ____

Items	Identification	Columns
Card	1 4	1 - 2
1		3 - 6
2		7 - 9
3		10
4		11 - 17
5		18 - 20
6		21 - 23
6		24 - 27
6		28
6		29 - 35

Items	Existing Conditions	Columns
7		36 - 39
A-C		40 - 44
D-E		45 - 47
F-G		48 - 50
H-I		51 - 54
8-11		55 - 59
12-13		60 - 66
14-15		67 - 73
Extra		74 - 80

Items	Proposed Construction	Columns
Card	1 5	1 - 2
1		3 - 6
2		7 - 9
3		10
18		11 - 14
A-C		15 - 19
D-E		20 - 22
F-G		23 - 25
H		26 - 29

Items	Cost Estimate	Columns
19		30 - 33
20		34 - 37
21		38 - 41
22		42 - 45
23		46 - 49
24		50 - 53
25		54 - 57

Items	Extra Data	Columns
Extra		58 - 64
Data		65 - 71
		72 - 78

Figure 4.

Form No. 2976
11-61

(Front)

TRUNK HIGHWAY NEEDS STUDY - HIGHWAY NEEDS UNIT
RIGHT-OF-WAY COST DETERMINATION

Control Section ________ Segment ________

T. H. No. ________ Segment Length ____ Mi.

Termini: ____________________

Location From Present Route (Describe or Use Space for Sketch on Back) ____

____

____

1. New Location ☐ Single Roadways ☐ 4 Lane Divided ☐

   Access Control Full ☐ Partial ☐ None ☐

   Length ________ Mi. $ ________

2. Old Location

   Additional Width ________ ft.

   Taking on Both Sides ☐ or ________ Side Only

Access Control Required: Full ☐ Partial ☐ None ☐

Access Previously Taken: Full ☐ Partial ☐ None ☐

   Length ________ Mi. $ ________

3. Additional R/W at Interchanges

Type	Location	
________	________	$ ________
________	________	$ ________
________	________	$ ________
________	________	$ ________
	Total Items 1 and 2	$ ________
	Total Item 3	$ ________

Sketch of Location of Proposed Improvement

(Back)

Scale

1" = approx. ________ Feet / Mile

(Strike out unit not applicable)

N

INSTRUCTIONS

1) Enter approximate distance scale used in space provided.
2) New Alignment - show approximate general location in relation to existing highway (s), county roads, towns, etc.
3) Existing Alignment - indicate locations and which side of present highway additional R/W should be acquired.
4) This sketch may be used to indicate location of R/W Needs on adjacent segments providing the affected segments are so noted on the sketch and sheets for affected segments are attached.

Figure 5.

TABLE 1

MINIMUM CONDITIONS CONSIDERED ADEQUATE FOR EXISTING TRAFFIC ON RURAL TRUNK HIGHWAYS

SERVICE LEVEL OF FACILITY		FREEWAY EXPRESSWAY	TRUNK ROUTES		FEEDER OR COLLECTOR ROUTES	
1960 ADT (DAILY HEAVY COMMERCIAL)		OVER 5,000 (OVER 600)	2,000-5,000 (300-600)	1,000-2,000 (150 - 300)	400-1,000 (UNDER 150)	UNDER 400 (UNDER 150)
OPERATING SPEED, M.P.H.		50-55	45-50	40-45	AVERAGE 40	AVERAGE 40
SURFACE TYPE[4]		HIGH	HIGH INTERMEDIATE	LOW INTERMEDIATE	LOW	LOW
NUMBER OF LANES		4	2[1]	2	2	2
LANE WIDTH, FEET		12	12	11	10	10
SHOULDER WIDTH, FEET		8	6	6	4	3
MAXIMUM GRADIENT, PERCENT[2]		5-7	5-7	5-7	7-10	8-12
MAXIMUM CURVATURE, DEGREES[2]		5-9	6-14	6-14	9-14	11-25
STOPPING SIGHT DISTANCE		600	475	475	350	350
POSTED SPRINGTIME AXLE LOAD TONS		9	9	9	7 ULTIMATE 9 TON[3]	7 ULTIMATE 9 TON[3]
BRIDGES	SAFE LOADING	H 20	H 15	H 15	H 10	H 10
	WIDTH	MINIMUM PAVEMENT WIDTH + 2 FEET				MINIMUM SURFACE WIDTH
	VERTICAL CLEARANCE	14 FEET				
RAILROAD PROTECTION		GRADE SEPARATION	ALL CROSSINGS OF MAIN LINE TRACKS TO HAVE FLASHING LIGHTS. ALL OTHER CROSSINGS TO HAVE FLASHING LIGHTS WHEN EXISTING AVERAGE DAILY TRAFFIC X TRAINS PER DAY = 3,500.			

1. FOUR LANE DIVIDED WHEN OVER 8,000 AVERAGE DAILY TRAFFIC.
2. LOWER FIGURE FOR FLAT TERRAIN, HIGHER FIGURE FOR RUGGED OR HILLY TERRAIN.
3. UNLESS NECESSARY TO PROVIDE UNRESTRICTED OUTLET TO MUNICIPALITY OVER 1,000 POPULATION.
4. GOOD SURFACE CONDITION REQUIRED.

TABLE 2

MINIMUM CONDITIONS CONSIDERED ADEQUATE FOR EXISTING TRAFFIC ON URBAN TRUNK HIGHWAYS

SERVICE LEVEL OF FACILITY		FREEWAY	EXPRESSWAY	TRUNK ROUTES	TRUNK ROUTES	FEEDER OR COLLECTOR ROUTES
1960 ADT		OVER 25,000	10,000 - 30,000	3,000-10,000	1,000-3,000	UNDER 1,000
DESIGN SPEED, M.P.H.		50	35	30	30	30
DESIGN AXLE LOAD, TONS		9	9	9	9	9
SURFACE TYPE[1]		HIGH	HIGH	HIGH	INTERMEDIATE	
NUMBER OF LANES[2]		MINIMUM 4 DIVIDED	4 OCCASIONALLY DIVIDED	2 - 4	2	2
LANE WIDTH, FEET		11 PREFERABLY 12	11	10 - 10.5	10	10
ILLUMINATION		PREFERABLY CONTINUOUS	CONTINUOUS IN HIGHLY DEVELOPED AREAS	INTERSECTIONS		
PARKING		NONE	OCCASIONALLY	OCCASIONALLY RESTRICTED	NORMALLY PERMITTED	
CONTROL OF ACCESS		FULL	PARTIAL	OCCASIONALLY CONTROLLED	USUALLY NONE	
MINOR CROSS STREETS		TERMINATED	USUALLY TERMINATED	AT GRADE		
MAJOR CROSS STREETS		SEPARATED	OCCASIONALLY SEPARATED	NORMALLY AT GRADE		
CONTROL OF CROSS OR TURNING TRAFFIC AT GRADE		ALL SEPARATED	SIGNALS OR STOP SIGNS	SIGNALS OR STOP SIGNS		
PRIVATE DRIVEWAYS		NONE	CONTROLLED	SOME CONTROLLED	YES	YES
BRIDGES	WIDTH	PAVEMENT 4'	WIDTH OF THROUGH LANES			
	LOADING	H-20			H-15	
	VERTICAL CLEARANCE	14 FEET				
RAILROAD PROTECTION		ALL SEPARATED	ELIMINATE WHERE POSSIBLE FOR 2 OR MORE TRACKS OR FOR ONE TRACK WITH 6 OR MORE TRAINS. AUTOMATIC SIGNALS ON ALL OTHERS.		AUTOMATIC SIGNALS	

1. GOOD SURFACE AND CONDITION REQUIRED.
2. NUMBER OF THROUGH TRAFFIC LANES.

TABLE 3

NEW CONSTRUCTION DESIGN STANDARDS FOR RURAL TRUNK HIGHWAYS

SERVICE LEVEL OF FACILITY	INTERSTATE & FREEWAYS	EXPRESSWAYS	TRUNK ROUTES		FEEDER OR COLLECTOR ROUTES		
1981 ADT (DAILY HEAVY COMMERCIAL)	OVER 10,000 (OVER 1,100)	5000-10,000 (600-1,100)	2,000-5,000 (300-600)	1,000-2,000 (150-300)	400-1,000 (LESS	200-400 THAN 150)	UNDER 200
DESIGN SPEED, M.P.H.	70	70	70	70	60	50	50
OPERATING SPEED, M.P.H.	POSTED LIMIT	POSTED LIMIT	40-60[1]	40-60[1]	AVG. 45[1]	AVG. 45[1]	AVG. 45[1]
SURFACE TYPE	HIGH	HIGH	HIGH	HIGH INTERMEDIATE	LOW INTERMEDIATE	LOW	LOW
DESIGN AXLE LOAD, TONS	9	9	9	9	7 ULTIMATE 9[2]	7 ULTIMATE 9[2]	7 ULTIMATE 9[2]
NUMBER OF LANES	MIN-4 DIVIDED	4 DIVIDED	2 (MIN.)	2 (MIN.)	2	2	2
LANE WIDTH, FEET	12	12	12	12	12	12	12
SHOULDER TYPE	BITUMINOUS	BITUMINOUS	BITUMINOUS	GRAVEL	GRAVEL	GRAVEL	GRAVEL
SHOULDER WIDTH, FEET	10	8	8	8	6	4	4
MAXIMUM CURVATURE, DEGREES	3[3]	3[3]	3[3]	4[3]	5[3]	6[3]	8[3]
MAXIMUM GRADIENT, PERCENT	3[3]	3[3]	4[3]	5[3]	5[3]	6[3]	6[3]
CONTROL OF ACCESS	FULL	FULL OR PARTIAL	PARTIAL	ACCESS BY PERMIT	ACCESS BY PERMIT	ACCESS BY PERMIT	NOT REQ'D
R/W WIDTH, FEET	200'+ DISTANCE BETW. C/L		200' MINIMUM 4 LANES 150' MINIMUM 2 LANES		120	100	100
STOPPING SIGHT DISTANCE, FEET	600	600	600	600	475	350	350
PASSING OPPORTUNITIES[4]	NOT APPLICABLE		4 LANE-NOT APPLICABLE 2 LANE - ONE PER MILE		ONE PER MILE	AS AVAILABLE	
BRIDGES — WIDTH — UNDER 80' LONG	(FAI 150') PAVEMENT PLUS EFFECTIVE SHOULDER WIDTH				PAVEMENT PLUS 6 FEET		
BRIDGES — WIDTH — OVER 80' LONG	(FAI 150') PAVEMENT PLUS 6 FEET						
BRIDGES — LOADING	H 20 S16			H 20 S16		H 15 S12	
VERTICAL CLEARANCE, FEET[5]	16' 4"	16'	16'	16'	16'	16'	16'
RAILROAD PROTECTION	GRADE SEPARATIONS		GRADE SEPARATIONS ON 4 LANE DIVIDED ROADS AND ON 2 LANE ROADS WHERE NO. OF TRAINS EXCEEDS 6 PER DAY. FLASHING LIGHT SIGNALS ON ALL MAIN LINE CROSSINGS, ALL OTHERS FLASHING LIGHTS WHEN AVERAGE DAILY TRAFFIC X TRAINS PER DAY = 3,000. REFLECTORIZED WARNING SIGNS ON ALL OTHERS.				

1 WITH LOCAL RESTRICTIONS.
2 UNLESS NECESSARY TO PROVIDE UNRESTRICTED OUTLET TO MUNICIPALITY OVER 1,000 POPULATION.
3 MAY BE INCREASED BY 2/3 IN RUGGED OR HILLY TERRAIN.
4 A CLIMBING LANE SHALL BE PROVIDED FOR TRUCKS ON 2 LANE ROADS WHERE THE TRAFFIC IS OVER 2,000 AVERAGE DAILY TRAFFIC (12% HEAVY COMMERCIAL) AND THE PRODUCT OF THE PERCENT OF GRADE X THE LENGTH OF GRADE EXCEEDS 5,000.
5 VERTICAL CLEARANCES OF 15' ARE ALLOWABLE IN THE TWIN CITY METROPOLITAN AREA WITHIN THE F.A.I. BELTLINE, EXCEPT ON RAILROAD SEPARATIONS.

TABLE 4

NEW CONSTRUCTION DESIGN STANDARDS FOR URBAN TRUNK HIGHWAYS

SERVICE LEVEL OF FACILITY	INTERSTATE & FREEWAYS	EXPRESSWAYS	TRUNK ROUTES		FEEDER OR COLLECTOR ROUTES[2]	
1981 ADT	25,000 + HIGH LEVEL OF SERVICE	10,000-30,000 LOW LEVEL OF SERVICE	3,000-10,000	1,000-3,000	400-1,000	UNDER 400
DESIGN SPEED LIMIT, M.P.H.	MINIMUM 50	40	40	30	30	30
DESIGN AXLE LOAD, TONS	9	9	9	9	9	9
SURFACE TYPE	HIGH	HIGH	HIGH	HIGH	HIGH INTERMEDIATE	HIGH INTERMEDIATE
NUMBER OF LANES[1]	MIN. 4 DIVIDED	4 DIVIDED	4 DIVIDED OCCASIONALLY	2 OCCASIONALLY 4	2	2
LANE WIDTH, FEET	12	12	12	12	12	12
ILLUMINATION	CONTINUOUS	CONTINUOUS	[4]	INTERSECTIONS		
PARKING[3]	NO	NO	RESTRICTED OR ELIMINATED	OCCASIONALLY RESTRICTED	YES	YES
CONTROL OF ACCESS	FULL	FULL OR PART.	PARTIAL	USUALLY NONE		
MINOR CROSS STREET	TERMINATED	TERMINATED	USUALLY TERMINATED	AT GRADE		
MAJOR CROSS STREET	SEPARATED	PREFERABLY SEPARATED	AT GRADE			
CONTROL OF CROSS OR TURNING TRAFFIC AT GRADE	ALL SEPARATED	PREFERABLY SEPARATED OR STOP SIGNS	PREFERABLY STOP SIGNS - SOME TRAFFIC SIGNALS	STOP SIGNS OR TRAFFIC SIGNALS		
PRIVATE DRIVEWAYS	NONE	NONE OR FEW	RESTRICTED SOME RIGHT TURNS ONLY		YES	YES
BRIDGES — WIDTH	PAVEMENT AND MINIMUM 4'		TRAFFIC LANES + 4' + SIDEWALKS			
BRIDGES — LOADING	H-20 S-16					
BRIDGES — VERTICAL CLEARANCE	16' 4"[5]	16'[5]				16'[6]
FRONTAGE ROADS PEDESTRIAN CROSSINGS	WHERE NEEDED ELIMINATED OR SEPARATED		USUALLY NONE CROSSWALKS			
RAILROAD PROTECTION	GRADE SEPARATIONS		ELIMINATE WHERE FEASIBLE FOR 2 OR MORE TRACKS OR FOR 1 TRACK WITH 6 OR MORE TRAINS PER DAY. AUTOMATIC SIGNALS AT ALL OTHERS.		AUTOMATIC SIGNALS SPUR TRACKS MAY HAVE REFLECTORIZED CROSSBUCKS.	

1. THROUGH TRAFFIC LANES
2. THE MAJOR PORTION OF THIS CLASSIFICATION WOULD BE MADE UP OF CITY STREETS NOT ON THE TRUNK HIGHWAY SYSTEM AND THEREFORE NOT INCLUDED IN THIS STUDY.
3. PARALLEL PARKING IN LANES (8-10 FEET IN WIDTH) PROVIDED IN ADDITION TO THROUGH TRAFFIC LANES.
4. CONTINUOUS IN BUSINESS, COMMERCIAL, AND DENSE RESIDENTIAL AREAS; INTERSECTIONS IN INDUSTRIAL AND OUTLYING RESIDENTIAL AREAS.
5. VERTICAL CLEARANCE OF 15' ARE ALLOWABLE IN THE TWIN CITY METROPOLITAN AREA WITHIN THE F.A.I. BELTLINE, EXCEPT ON RAILROAD SEPARATIONS.

COLLECTION OF DATA

Five separate forms are used in the collection of data. The forms are as follows:

Form No. 2972—Roadway Data Sheet (Fig. 1).—This form contains the full identification and classification for each segment, present and future traffic data, existing and proposed road data, urban information, condition ratings and recommended construction period, space for the estimated right-of-way cost, and estimated construction involved in fulfilling the needs.

Form No. 2973—Structure Data Sheet (Fig. 2).—This form contains an abbreviated identification section for each bridge, the existing conditions, a section to indicate the adequacy of the existing structure and the recommended period of construction for the proposed improvement, the proposed improvement, and the estimated cost of the improvement.

Form No. 2974—Railroad Crossing Data Sheet (Fig. 3).—This form contains information regarding railroad crossings and is similar in nature to that in Form No. 2973.

Form No. 2975—Local Road Crossing Data Sheet (Fig. 4).—This form is used in those instances where it was necessary to do considerable work on a local road (city, county or township) in order to meet the proposed grade line or structure involved in the state highway improvement.

Form No. 2976—Right-of-Way Cost Determination Work Sheet (Fig. 5).—This form is for the use of the district engineer and the lands and right-of-way division in determining the location and estimating the cost of the right-of-way needed for the proposed improvement.

Because of the continuing nature of the study, these forms were designed to provide for the collection of information which is pertinent now or is expected to be so in the future. Because the approaching construction season produced a lack of time, the urban information section of Form No. 2972 was not used for the initial study. The spaces provided for a breakdown of the heavy commercial vehicles were not used because this information is not available on a statewide basis. However, it is expected that the balance of the information will become available over the next several years.

APPRAISAL PROCEDURES

The appraisal of the Trunk Highway System required an inspection and evaluation of each road section, bridge, and railroad grade crossing to determine: (a) which sections are presently inadequate to handle present traffic when compared to assumed minimum conditions which are considered as adequate to handle present traffic, (b) which sections are inadequate to handle the anticipated traffic 20 years hence when compared to the current construction design standards, and (c) the nature and the amount of construction required to bring each section up to these design standards. Also considered were future structural, geometric, and other inadequacies which may reasonably be anticipated to occur within the next two decades. Tables 1 through 4 give the minimum conditions and the construction design standards.

This appraisal of the Trunk Highways was made by the district engineers and their staffs. For the purpose of this study, the district engineers have indicated in which quarter of the 20-yr period such improvements should be made if funds were available at that time. Factors in this determination would be the degree of adequacy of the existing facility, and the relative urgency of the improvements.

DESIGN CRITERIA

The design criteria used throughout this study are based on the current construction designs in use in Minnesota. Typical standard designs are included as part of the cost computations. As changes in the standard designs occur, they may affect the estimated cost, and the affected quantities in the computer program may be revised to reflect this.

The standards to which each section of roadway and its related facilities are compared for adequacy are governed by the proposed service level of the facility, projected traffic estimates, and rural or urban classification. The data supplied by the district engineers is reviewed by the Highway Needs Unit for conformance to standards, completeness, and consistency between districts prior to machine processing.

After this preliminary checking is completed, the needs study data are coded on the data sheets and then punched on tabulating cards to make up an input deck for the computer.

Traffic Data

The traffic data, both present and projected, were obtained from the Traffic Analysis Unit. The projections of the traffic volumes anticipated in 1981 are based on the trend of the traffic growth during the last ten years. The majority of these projections are the result of a computer program designed for the Traffic Analysis Unit; however, each projection is reviewed and the stations which appear to have irregular or decreasing growth rates are studied and a projection determined for each one. The needs study procedure is designed to provide for revisions of the projected traffic estimates should the growth rate vary considerably from the present projections. These projections are used by the computer in selecting the proper typical design for the cost computations where complete base, surface or shoulders are specified.

Cost Data

The major difference between this and other studies of its type is that the majority of its cost computations are performed by computer processes using: (a) a unit cost table which is programmed into the computer separately, and (b) the reported or required quantities of the various work items necessary to fulfill the construction needs on each segment of trunk highway. To develop the unit cost data, the Department's Estimating Section divided the state into twelve cost areas (Fig. 6), based on general topography, availability of construction material and labor rates. The unit costs for the work items included in the computer program are estimated for each of the twelve cost areas. These estimated unit costs are determined from recent construction contracts on the items included in the Needs Study Work Items. All bridge costs were computed by the Highway Needs Unit using average costs per sq ft of deck area. These costs, recommended by the Bridge Section, were varied by the type of service, skew, and bridge width; in the case of concrete box culverts, the cost per foot was estimated for each of the several types in use. Railroad protection costs were estimated by the district engineers from a range of costs furnished for each type of protection. Roadside development costs were estimated by the district engineers since this item varies considerably within each cost area. Right-of-way costs, though not currently available, are being estimated by the Lands and Right-of-Way Section.

Computer Programs

The needs study involves a series of computer programs which perform several functions. The five functions are (a) to edit the input data for invalid coding or conditions wherever possible, (b) to assemble a magnetic tape file containing the input data, (c) to update the input data tape to reflect the current conditions and proposed improvements on each highway segment, (d) to compute the estimated costs of construction, and (e) to print a variety of listings and reports showing the mileage and cost of the proposed construction by various breakdowns.

The initial computer program (Program A) is designed to perform the first two of these. This program is written so that the edit function is always performed, while the tape assembly may or may not be performed. The input to this program is a deck of punched tabulating cards containing the information from the data sheets. The program performs approximately 150 edits on each segment for which there is a set of data cards, resulting in a printed list of the errors which were detected. These errors are invalid cards due to faulty reporting, coding, keypunching, errors in card sequence, or incomplete sets of cards. In assembling the tape, tabulating cards numbered 1 through 10 which contain the data from the Roadway Data Sheet—Form No. 2972 must be present. The limit on the number of bridges, railroad crossings, and local road

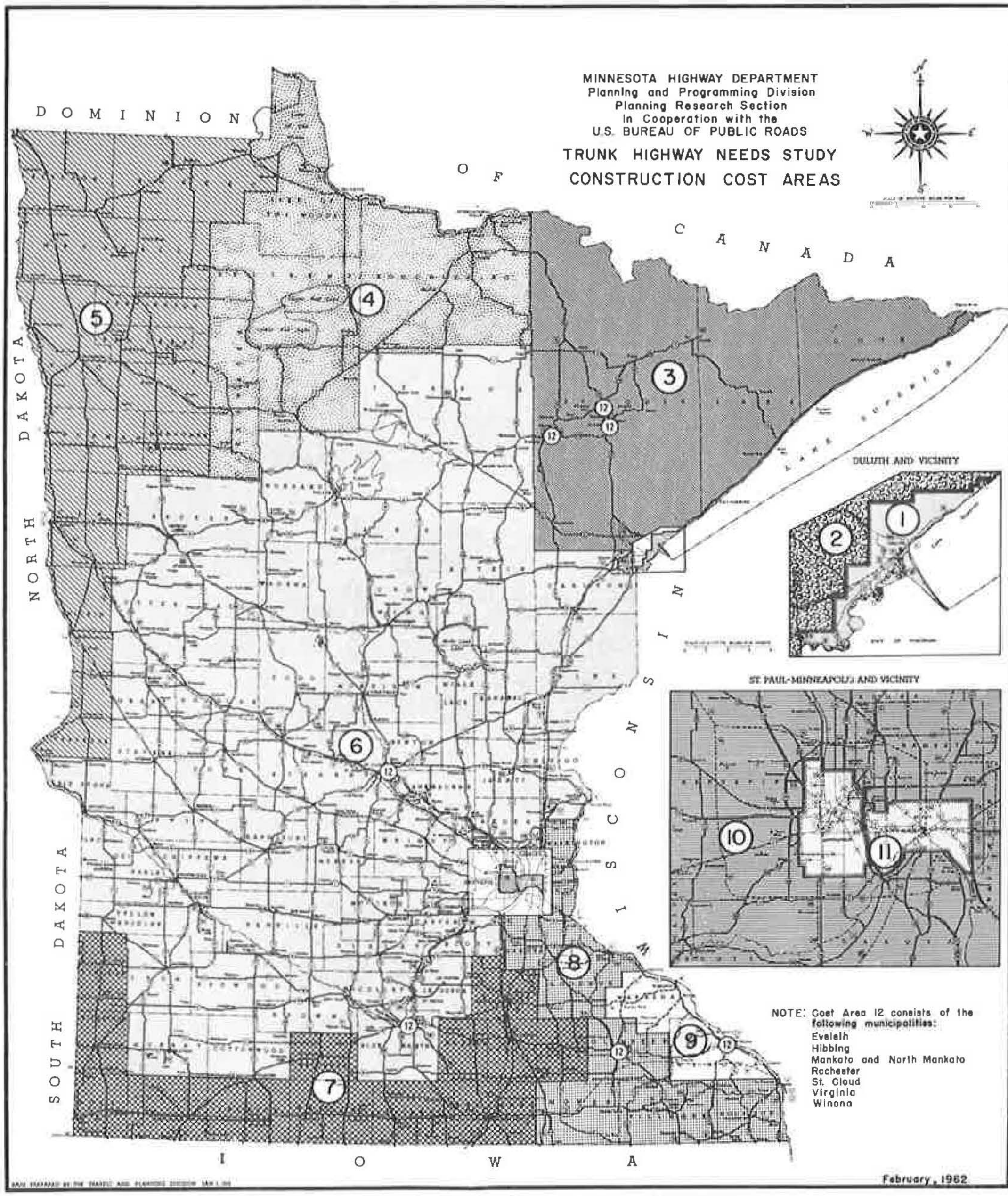


Figure 6.

crossings which can be included with each section is determined by the total number of positions allotted for this supplementary data. The available space provides for a maximum of 15 bridges per segment; however, this number would be reduced if railroad or local road crossings are also required in the segment. Figure 7 shows the flow of the various operations involved in Program A and Program B.

If an existing tape is to be updated, Program A may be used to perform the edits on the corrected data cards prior to the updating. When used in this manner, the instructions must state that the production on this program is for edit only. In this case, a

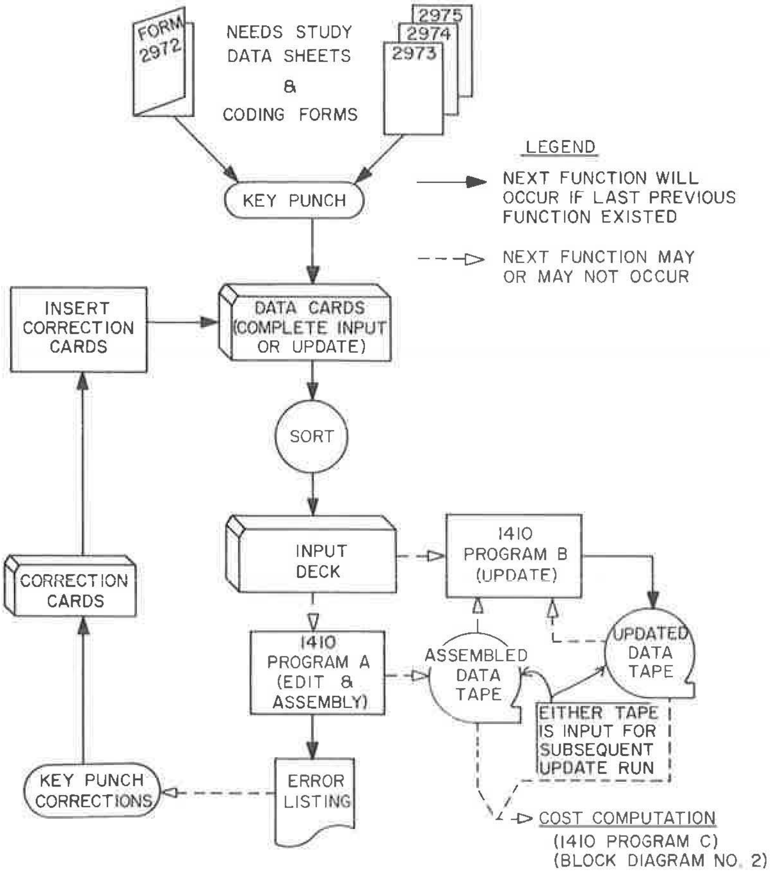


Figure 7. Data tape assembly and update.

data tape will not be assembled, although a listing of the edit errors will be printed. The input deck to Program A may represent the entire Trunk Highway System or any part of it, as long as the proper sequencing of cards entered as input is maintained; thus, each time Program A is run for editing purposes and the corrections for errors noted in the listing are made, only those sections which had errors need to be re-edited.

Computer Program B is designed to update an existing Trunk Highway Needs Study data tape; this is the third function of the computer program. A segment which is on the existing tape may be corrected, deleted, or left undisturbed; a new segment may also be added to those already on the tape. In this program, the existing data for a segment to be corrected is completely removed from the tape and a new set of data is inserted. Thus, for segments to be corrected as well as for the new segments, the entire set of data cards for the segment (10 roadway data cards plus any bridge, railroad or local road crossing cards for the segment) must be included with the input. The limitations on the positions available for supplementary data are the same as for Program A. To delete a segment from the tape, a delete card is used which removes all the data for the segment to be eliminated from the tape.

The fourth computer function is carried out by Program C (Fig. 8). This program computes for each segment the costs of all the various work items that comprise the proposed construction on the segment. This is accomplished by using the data tape assembled by either Program A or Program B and a deck of cost cards containing unit prices for each item by cost area. Program C is split into two phases; the first produces a printed image of the unit cost table as it appears within the program, and the

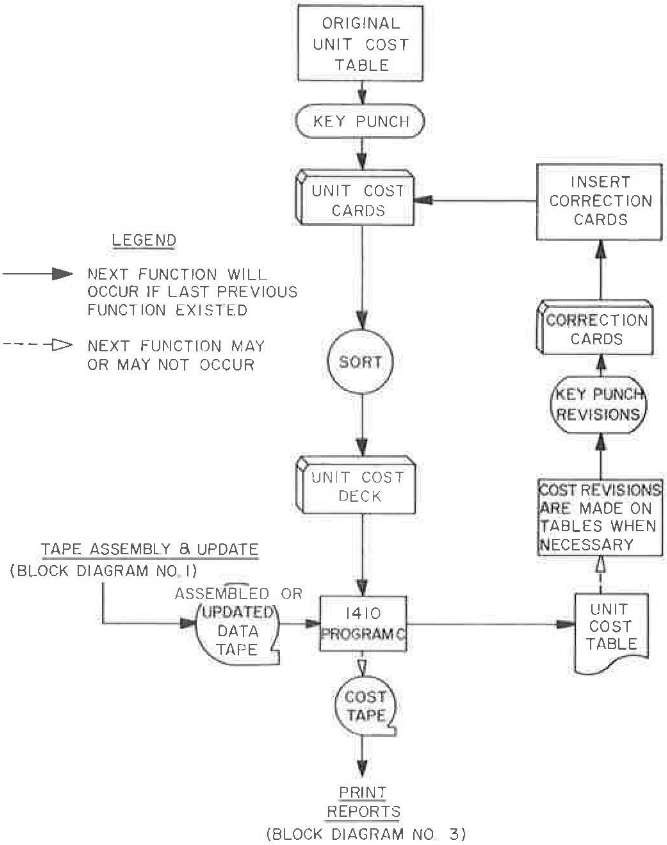


Figure 8. Cost computation.

second performs the cost computations. The first phase serves as a check to make sure that the proper unit costs are being used in the cost computations. After completion of the first phase of the program, the use of the second phase is optional; thus, the program may be used only for the purpose of updating and checking the unit costs. When it is necessary to revise any of the unit costs, the revisions are marked on the cost table produced from the last cost deck and the new unit costs cards are keypunched directly from this.

Included in the cost computation program itself are tables of precalculated quantities used for the complete construction items as related to the various design specifications and the numerous cost computation formulas for each cost item. As changes in the standard designs occur, the affected quantities in the computer program may be revised to reflect the effect of change in design on the estimated cost.

The input data on base, surface, and shoulder specify whether partial or complete construction of these items is required. If partial construction is shown, the quantities of materials to be used in the cost formulas are also specified as part of the input. If complete construction is indicated, the program determines the exact design to be used from the traffic volume and type of construction. After determining the proper design, it refers to the quantity tables to obtain the quantities associated with that design for use in the cost formulas. The end result of Program C, phase 2, is a cost tape. This tape contains the identification and classification, traffic volumes, as well as the costs for each item of work required within each segment. It is from this tape that the various summaries and listings are obtained, either directly or indirectly.

The production of the various reports (listings and summaries) from the cost tape is shown schematically in Figure 9. The majority of the needs study reports come directly

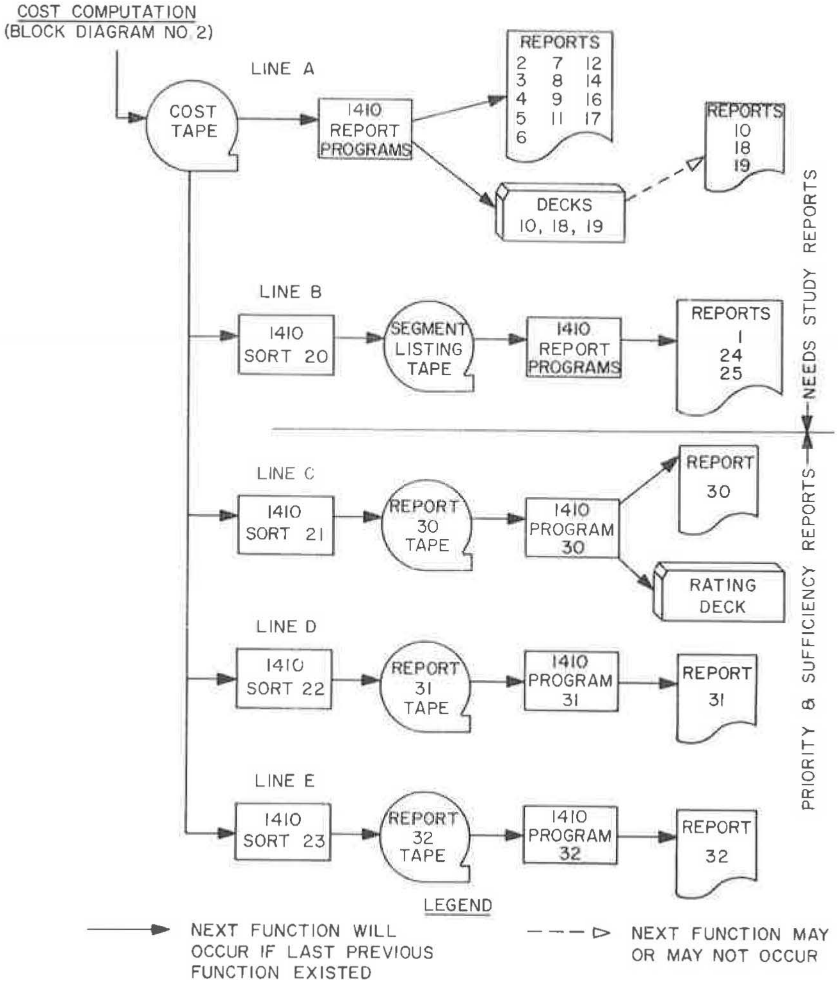


Figure 9. Print reports.

from the cost tape (line A); three are derived from output decks (line A); and three are obtained from a segment listing tape derived from the cost tape (line B). The balance of the programs (lines C, D, and E) enable the Data Correlation Unit to utilize the condition ratings contained in the needs study for developing sufficiency ratings. These ratings and the needs study estimates are being used by the Construction Program Unit in establishing construction programs. A list of the programmed reports is included in the Appendix.

The date of production is inserted in the tape label to differentiate between tapes made at different times. This date will be carried forward to the "cost tape" (see Program C). The "year" portion of this date will automatically be printed on all reports subsequently printed directly from this cost tape. On reports which are printed from sorted tapes, the year must be inserted by the computer console operator using the date on the label of the Trunk Highway Needs Study update tape.

CONCLUSION

To date, the results obtained from this study and the related computer programs have been satisfactory. The many edits contained in the program help considerably to reduce the clerical errors which appear in any large volume of work such as this study entails. The original assembled tape was updated three times within the 6-month period following its production: the first made minor corrections to the original data; the second update removed the needs covered by contracts awarded during the first half of calendar year 1962 and reflected the changes in corporate limits, Federal designation and load-carrying capacity which had occurred since January 1962; the third update reflected the results of the rearrangement of the area covered by two districts and contracts awarded through the first quarter of the 1963 calendar year. Listings of the cost of the proposed improvements on each highway segment and bridge and tabulated summaries of costs furnished to the district engineers and Program Development Section have been well received. Based on experience so far, the needs study is easily maintained; therefore, it can be used for a number of years. We feel that the features designed into the Minnesota Trunk Highway Needs Study allow for enough flexibility for the study to be maintained on a continuing basis.

Many of the tabulated reports are produced by the computer in a format suitable for inclusion in reports furnished to the legislature and highway-related organizations. Reproductions of portions of several of the listings and tabulations are included in the Appendix.

The computer programs (IBM Model 1410) are documented and copies will be made available on request to the authors.

Appendix

TRUNK HIGHWAY NEEDS STUDY REPORTS

Report

1. Segment Listing of Estimated Costs for Major Work Items with Control Section and District Totals.
2. Tabulation of Estimated Costs and Proposed Miles for Individual Work Items, by County, District, and Statewide.
3. County Tabulation of Proposed Miles and Estimated Costs for Plan B and Plan A by Variance in Design with District and State Totals.
4. Tabulation of Miles and Estimated Costs by Legal Designation, by County, District, and Statewide.
5. Tabulation of Miles and Estimated Costs by Service: Level of Facility and Urban Classification, by District and Statewide.
6. Tabulation of Miles and Estimated Costs by Federal Designation and Urban Classification, by County, District, and Statewide.
7. Tabulation of Miles and Estimated Costs by Urban and Municipal Classifications, by County, District, and Statewide.
8. Tabulation of Miles and Estimated Costs by Type of Project, by County, District, and Statewide, with District and State Project Type Summaries.
9. Tabulation of Estimated Costs and Proposed Miles by Present and Proposed Load Restriction, by County, District, and Statewide.
10. Segment Listing of Estimated Costs and Existing Miles of Potential Trunk Highway Turnbacks by Service Level of Facility with Totals by Legal Designation.
11. Tabulation of Estimated Costs and Existing Miles by Type of Project by Period of Deficiency, by County, District, and Statewide.
12. Segment Listing of 20-to-22 Foot Wide Concrete Pavement by Trunk Highway Number.
13. Canceled.
14. Tabulation of Estimated Costs and Proposed Miles by Type of Project and Recommended Construction Period, by District and Statewide.
15. Canceled.
16. Tabulation of Estimated Costs and Existing and Proposed Miles by Federal Designation by Rural/Urban Classification by Present ADT, by District and Statewide.
17. Tabulation of Estimated Costs and Existing and Proposed Miles by Federal Designation by Rural/Urban Classification by Projected ADT, by District and Statewide.
18. Card Output for Trunk Highway Needs and County State Aid Needs Comparison.
19. Card Output for Miscellaneous Tabulated Summaries.
24. Listing of Existing and Proposed Bridges with Estimated Cost of Construction or Reconstruction, by District.
25. Tabulation of the Number of Existing and Proposed Bridges and Estimated Costs by Type of Service, by Type of Work, by County Within District, by District, and Statewide, with District and State Totals by Federal Designation and Service Level.
30. A. Statewide Rural Condition Rating Listing by Adjusted Rating, Control Section, and Segment.
    B. Rural Condition Rating Output Deck.
31. Rural Condition Rating Listing by District by Adjusted Rating, Control Section, and Segment.
32. Rural Condition Rating Listing by District by Trunk Highway, Control Section, and Segment.

MINNESOTA HIGHWAY DEPARTMENT
PLANNING AND PROGRAMMING DIVISION
PLANNING RESEARCH SECTION
IN COOPERATION WITH THE
U.S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS
1963 TRUNK HIGHWAY NEEDS STUDY

TABULATION OF MILES AND ESTIMATED COSTS
BY URBAN AND MURICIPAL CLASSIFICATIONS
BY COUNTY, DISTRICT, AND STATEWIDE

TYPICAL TITLE SHEET

REPORT NO. 1
SEGMENT LISTING
(1963 Data)

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T H 274     0.46 M S TO N L WOOD LAKE        CONT SECT 8714     SEG 010     DIST 8     EXISTING MILES    .46     PROPOSED MILES    .46
WOOD LAKE             EXISTING NOT DIVIDED        BIT SURFACE  24 FT  26 FT      YR GRADE 48      YR SURFACE 50      SECONDARY RURAL
PROJECT TYPE - GRADE, BASE, AND BITUMINOUS               PROPOSED DESIGN RURAL          9 TON      PROJECTED ADT  1727     COLLECTOR
   PRELIMINARY ENGINEERING   $                   BASE                           $    10,900     RETAINING WALLS               $
   RIGHT OF WAY                                  SURFACE AND SHOULDERS                5,600     RAILROAD PROTECTION                 7,000
   CLEARING AND GRUBBING               300       RAILROAD GRADE SEPARATIONS                     HIGHWAY PROTECTION
   DEMOLITION                          300       HIGHWAY GRADE SEPARATIONS                      ROADSIDE DEVELOPMENT
   UTILITY ADJUSTMENT                  500       INTERCHANGLS                                   MISCELLANEOUS ITEMS
   GRADING + MINOR STRUCTURES        6,700       OTHER BRIDGES AND TUNNELS                      ENGINEERING + CONTINGENCIES         3,130
                                                                                                           TOTAL COST        $     34,400

T H 274     N L WOOD LAKE TO TH 67           CONT SECT 8714     SEG 020     DIST 8     EXISTING MILES  8.51     PROPOSED MILES  8.37
RURAL                 EXISTING NOT DIVIDED        BIT SURFACE  24 FT  26 FT      YR GRADE 48      YR SURFACE 50      SECONDARY RURAL
PROJECT TYPE - GRADE, BASE, AND BITUMINOUS               PROPOSED DESIGN RURAL          9 TON      PROJECTED ADT   936     COLLECTOR
   PRELIMINARY ENGINEERING   $                   BASE                           $   162,900     RETAINING WALLS               $
   RIGHT OF WAY                                  SURFACE AND SHOULDERS               80,700     RAILROAD PROTECTION
   CLEARING AND GRUBBING            14,600       RAILROAD GRADE SEPARATIONS                     HIGHWAY PROTECTION                  2,400
   DEMOLITION                        5,400       HIGHWAY GRADE SEPARATIONS                      ROADSIDE DEVELOPMENT
   UTILITY ADJUSTMENT                8,900       INTERCHANGES                                   MISCELLANEOUS ITEMS
   GRADING + MINOR STRUCTURES      211,600       OTHER BRIDGES AND TUNNELS          133,000     ENGINEERING + CONTINGENCIES        59,95C
                                                                                                           TOTAL COST        $    659,500

   BRIDGES     MHD BR NO 04608     8.10 NWOOD L   YR 26    EXIST STREAM X-ING    PROP STREAM X-ING    NEW STRUCTURE     COST $    47,000
               MHD BR NO 04584     4.70 NWOOD L   YR       EXIST STREAM X-ING    PROP STREAM X-ING    NEW STRUCTURE     COST $    86,000

TOTAL CONTROL SECTION 8714   EXISTING MILES    8.97       MILES OF PROPOSED CONSTRUCTION    8.83
   PRELIMINARY ENGINEERING   $                   BASE                           $   173,800     RETAINING WALLS               $
   RIGHT OF WAY                                  SURFACE AND SHOULDERS               66,300     RAILROAD PROTECTION                 7,000
   CLEARING AND GRUBBING            14,900       RAILROAD GRADE SEPARATIONS                     HIGHWAY PROTECTION                  2,400
   DEMOLITION                        5,700       HIGHWAY GRADE SEPARATIONS                      ROADSIDE DEVELOPMENT
   UTILITY ADJUSTMENT                9,400       INTERCHANGES                                   MISCELLANEOUS ITEMS
   GRADING + MINOR STRUCTURES      218,300       OTHER BRIDGES AND TUNNELS          133,000     ENGINEERING + CONTINGENCIES        63,080
                                                                                                           TOTAL COST        $    693,900

TOTAL COUNTY 87 DISTRICT 8   EXISTING MILES  133.55       MILES OF PROPOSED CONSTRUCTION  133.41
   PRELIMINARY ENGINEERING   $                   BASE                           $ 1,824,800     RETAINING WALLS               $
   RIGHT OF WAY                                  SURFACE AND SHOULDERS            2,190,200     RAILROAD PROTECTION                17,000
   CLEARING AND GRUBBING            90,300       RAILROAD GRADE SEPARATIONS         308,000     HIGHWAY PROTECTION                 74,900
   DEMOLITION                       32,500       HIGHWAY GRADE SEPARATIONS                      ROADSIDE DEVELOPMENT
   UTILITY ADJUSTMENT               60,900       INTERCHANGES                                   MISCELLANEOUS ITEMS               162,500
   GRADING + MINOR STRUCTURES    2,544,700       OTHER BRIDGES AND TUNNELS        1,966,000     ENGINEERING + CONTINGENCIES       927,180
                                                                                                           TOTAL COST        $ 10,199,200

TOTAL DISTRICT 8             EXISTING MILES 1457.62       MILES OF PROPOSED CONSTRUCTION 1431.08
   PRELIMINARY ENGINEERING   $                   BASE                           $15,492,700     RETAINING WALLS               $
   RIGHT OF WAY                                  SURFACE AND SHOULDERS           14,260,900     RAILROAD PROTECTION               221,400
   CLEARING AND GRUBBING           600,800       RAILROAD GRADE SEPARATIONS       2,699,000     HIGHWAY PROTECTION                835,200
   DEMOLITION                      265,600       HIGHWAY GRADE SEPARATIONS           73,000     ROADSIDE DEVELOPMENT
   UTILITY ADJUSTMENT              609,600       INTERCHANGES                       539,000     MISCELLANEOUS ITEMS               764,000
   GRADING + MINOR STRUCTURES   25,498,100       OTHER BRIDGES AND TUNNELS        8,049,000     ENGINEERING + CONTINGENCIES     8,990,830
                                                                                                           TOTAL COST        $ 90,903,000
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REPORT NO. 2
TABULATION OF INDIVIDUAL WORK ITEMS
(1962 Data)

STATEWIDE TOTAL

GRADING	RESHAPE ONLY MILES	RESHAPE ONLY COST	WIDEN ONLY MILES	WIDEN ONLY COST	REGRADE + WIDEN MILES	REGRADE + WIDEN COST	REGRADE COMPLETE MILES	REGRADE COMPLETE COST	NEW ALIGNMENT MILES	NEW ALIGNMENT COST
RIGHT OF WAY		$		$		$		$		$
CLEAR AND GRUB	12.52	5,700	1216.80	1,584,700	1272.75	2,228,100	2189.33	3,610,000	1325.36	2,324,700
DEMOLITION	5.93	20,100	108.59	205,300	465.46	600,400	1043.79	1,053,800	889.33	2,157,400
REMOVAL ITEMS										
CLASS A		1,343,600		28,147,600		31,096,100		75,493,100		58,499,100
B				3,501,700		2,546,300		15,228,300		10,743,300
A BORROW				5,665,900		1,111,100		1,955,600		3,660,200
B BORROW				3,600				375,000		40,800
SWAMP EXCAV	38.65	319,500	236.74	944,500	416.36	2,348,800	1316.28	6,267,400	608.47	4,968,000
SWAMP BACKFILL	28.16	552,300	229.18	1,881,700	468.24	5,134,200	1195.02	13,537,400	575.01	11,250,700
ROCK EXCAV ASR			12.86	22,000			.12	45,000	.05	4,500
ALR										
AIR			63.62	77,100	156.69	274,500	113.95	484,800	99.95	404,400
MINOR STR U10 NO.	16	90,700	98	6,323,800	414	2,420,800	415	2,409,500	228	1,333,300
O10 NO.	18	197,400	247	2,665,000	65	734,300	109	1,244,000	112	1,272,800
LOCAL RD CROSS NO.			1	113,000					2	79,000

NO GRADING 2129.39 MILES

BASE	COMPLETE BASE MILES	COMPLETE BASE COST	WIDENING MILES	WIDENING COST	STRENGTHENING MILES	STRENGTHENING COST
GRAVEL	2953.72	$42,466,100	1851.75	$14,691,600	252.62	$ 1,970,900
BITUMINOUS	2624.26	67,185,500	770.12	9,341,200	846.14	9,163,900
SOIL CEMENT	18.50	462,700				
SF CONCRETE			116.17	1,141,500		
FORMED CONC	34.57	4,553,800	595.46	8,235,400	21.88	336,500

NO BASE 3249.44 MILES

SURFACING	MAIN ROADWAY MILES	MAIN ROADWAY COST	ACCESSORY ROADS	MILES	COST*
NONE	1542.32	$	RAMPS	184.43	$17,985,500
ADDITIONAL BITUMINOUS	5044.86	67,647,500	CLIMBING LANES	16.80	625,400
COMPLETE BITUMINOUS	4700.90	54,907,400	FRONTAGE ROADS	132.74	4,269,800
SLIP FORM CONCRETE	383.42	20,922,700			
FORMED CONCRETE NON-REINF	550.76	29,613,100			
FORMED CONCRETE REINFORCED	1392.83	84,240,500			

* INCLUDES BASE AND SURFACE COSTS

SHOULDERING	MILES	COST
COMPLETE	9367.14	$41,019,500
RESHOULDERING	1201.01	2,889,000

MISCELLANEOUS ITEMS

	MILES	COST		LIN FT	COST		NO.	COST
FENCING	229.25	$ 4,876,700	STORM SEWERS	173,400	$14,976,300	LIGHTING PARTIAL	1,861	$ 1,861,000
SIGNING	485.77	9,834,000	CURB	722,600	1,443,600	CONTINUOUS	2,435	1,924,000
			CURB + GUTTER	302,200	10,000,400	TRF SGNLS FLASHING BEACONS	34	23,000
			GUARD RAIL	251,900	5,179,200	ISOLATED PRETIMED	135	810,000
						INTERCON PRETIMED	45	405,000
		COST				TRAFFIC ACTUATED	179	2,143,000
ROADSIDE DEVELOP		$ 70,000		SQ FT	COST	TRAFFIC ADJ 3 TO 5	22	525,000
OTHER COSTS		$ 2,451,700	SIDEWALK	785,200	$ 733,000	TRAFFIC ADJ OVER 5	6	85,000

	NUMBER ADEQUATE	NUMBER DEFICIENT	COST
RAILROAD GRADE SEPARATIONS	215	280	$63,045,000
HIGHWAY GRADE SEPARATIONS	27	137	16,181,000
HIGHWAY INTERCHANGES	92	287	43,730,000
OTHER BRIDGES AND TUNNELS	721	166	8,503,000
RAILROAD PROTECTION SIGNS	73	9	10,800
SIGNALS	168	222	1,706,000
SIG + GATES	11	35	572,000
UTILITY ADJUSTMENT			11,794,200
ENGINEERING AND CONTINGENCIES			10,763,000

TOTAL COST	$1,218,077,300
TOTAL EXISTING MILEAGE	11,817.16
TOTAL PROPOSED MILEAGE	12,232.44

REPORT NO. 5
TABULATION OF MILES AND ESTIMATED COSTS BY SERVICE LEVEL
(1963 Data)

DISTRICT 9

SERVICE LEVEL	RURAL			URBAN			TOTAL		
	EXISTING MILES	PROPOSED MILES	COST	EXISTING MILES	PROPOSED MILES	COST	EXISTING MILES	PROPOSED MILES	COST
FREEWAY	.00	11.50	$ 5,307,200	5.67	7.59	$ 13,980,300	5.67	19.09	$ 19,287,500
EXPRESSWAY	97.29	101.07	$ 21,320,800	72.18	64.16	$ 32,105,100	169.47	165.23	$ 53,425,900
TRUNK ROUTE	182.08	169.93	$ 13,911,400	71.65	64.10	$ 16,779,700	253.73	234.03	$ 30,691,100
SUB-TOTAL 1-3	279.37	282.50	$ 40,539,400	149.50	135.85	$ 62,865,100	428.87	418.35	$ 103,404,500
COLLECTOR 4	72.96	28.36	$ 1,536,900	34.81	18.98	$ 2,622,900	107.77	47.34	$ 4,159,800
COLLECTOR 5	15.58	14.09	$ 682,500	6.38	5.84	$ 965,700	21.96	19.93	$ 1,648,200
COLLECTOR 6	.00	.00	$ 0	.00	.00	$ 0	.00	.00	$ 0
SUB-TOTAL 4-6	88.54	42.45	$ 2,219,400	41.19	24.82	$ 3,588,600	129.73	67.27	$ 5,808,000
TOTAL	367.91	324.95	$ 42,758,800	190.69	160.67	$ 66,453,700	558.60	485.62	$ 109,212,500

STATE TOTALS

SERVICE LEVEL	RURAL			URBAN			TOTAL		
	EXISTING MILES	PROPOSED MILES	COST	EXISTING MILES	PROPOSED MILES	COST	EXISTING MILES	PROPOSED MILES	COST
FREEWAY	121.71	118.19	$ 19,443,600	118.38	130.03	$ 149,309,700	240.09	248.22	$ 168,753,300
EXPRESSWAY	1,213.66	1,219.76	$ 250,832,100	249.58	222.73	$ 98,952,600	1,463.24	1,442.49	$ 349,784,700
TRUNK ROUTE	5,505.96	5,130.95	$ 355,406,100	179.97	160.21	$ 40,926,200	5,685.93	5,291.16	$ 396,332,300
SUB-TOTAL 1-3	6,841.33	6,468.90	$ 625,681,800	547.93	512.97	$ 289,188,500	7,389.26	6,981.87	$ 914,870,300
COLLECTOR 4	1,908.60	1,637.47	$ 96,533,000	129.69	75.40	$ 17,877,900	2,038.29	1,712.87	$ 114,410,900
COLLECTOR 5	1,353.77	1,325.36	$ 85,797,600	40.51	34.12	$ 9,432,600	1,394.28	1,359.48	$ 95,230,200
COLLECTOR 6	1,001.12	1,008.77	$ 64,527,900	4.91	4.81	$ 1,296,700	1,006.03	1,013.58	$ 65,824,600
SUB-TOTAL 4-6	4,263.49	3,971.60	$ 246,858,500	175.11	114.33	$ 28,607,200	4,438.60	4,085.93	$ 275,465,700
TOTAL	11,104.82	10,440.50	$ 872,540,300	723.04	627.30	$ 317,795,700	11,827.86	11,067.80	$1,190,336,000

REPORT NO. 6
TABULATION OF MILES AND ESTIMATED COSTS BY FEDERAL DESIGNATION
(1963 Data)

DISTRICT	RURAL			URBAN			TOTAL		
FEDERAL DESIGNATION	EXISTING MILES	PROPOSED MILES	COST	EXISTING MILES	PROPOSED MILES	COST	EXISTING MILES	PROPOSED MILES	COST
DISTRICT 6									
INTERSTATE			$			$			$
PRIMARY	876.76	789.41	108,900,600	65.01	45.41	12,381,100	941.77	834.82	121,281,700
SECONDARY	424.81	414.84	44,295,100	5.97	4.72	2,065,300	430.78	419.56	46,360,400
NON-FEDERAL				4.09	2.93	299,500	4.09	2.93	299,500
TOTAL	1,301.57	1,204.25	$ 153,195,700	75.07	53.06	$ 14,745,900	1,376.64	1,257.31	$ 167,941,600
DISTRICT 7									
INTERSTATE			$			$			$
PRIMARY	870.49	816.24	67,173,900	35.44	27.16	9,873,400	905.93	843.40	77,047,300
SECONDARY	423.46	422.86	28,780,000	3.61	1.27	87,000	427.07	424.13	28,867,000
NON-FEDERAL	1.46	.86	693,900	1.18	1.18	178,500	2.64	2.04	872,400
TOTAL	1,295.41	1,239.96	$ 96,647,800	40.23	29.61	$ 10,138,900	1,335.64	1,269.57	$ 106,786,700
DISTRICT 8									
INTERSTATE			$			$			$
PRIMARY	988.31	966.39	70,727,900	25.14	21.84	1,201,300	1,013.45	988.23	71,929,200
SECONDARY	442.19	441.67	26,926,500	1.48	1.48	43,000	443.67	443.15	26,969,500
NON-FEDERAL	.50	.50	4,300				.50	.50	4,300
TOTAL	1,431.00	1,408.56	$ 97,658,700	26.62	23.32	$ 1,244,300	1,457.62	1,431.88	$ 98,903,000
DISTRICT 9									
INTERSTATE			$			$			$
PRIMARY	311.01	270.29	38,467,700	169.78	143.29	61,022,300	480.79	413.58	99,490,000
SECONDARY	56.90	54.66	4,291,100	6.47	6.23	1,127,100	63.37	60.89	5,418,200
NON-FEDERAL				14.44	11.15	4,304,300	14.44	11.15	4,304,300
TOTAL	367.91	324.95	$ 42,758,800	190.69	160.67	$ 66,453,700	558.60	485.62	$ 109,212,500
STATE TOTALS									
INTERSTATE			$			$			$
PRIMARY	6,987.82	6,386.29	585,496,700	635.62	556.71	287,880,700	7,623.44	6,943.00	873,377,400
SECONDARY	4,092.76	4,039.68	283,496,700	40.56	26.03	8,299,600	4,133.32	4,065.71	291,796,300
NON-FEDERAL	24.24	14.53	3,546,900	46.86	44.56	21,615,400	71.10	59.09	25,162,300
TOTAL	11,104.82	10,440.50	$ 872,540,300	723.04	627.30	$ 317,795,700	11,827.86	11,067.80	$1,190,336,000

REPORT NO. 8
TABULATION OF MILES AND ESTIMATED COSTS BY PROJECT TYPE
(1963 Data)

DISTRICT	PROJECT CODES	TYPE OF PROJECT	EXISTING MILES	PROPOSED MILES	COST
DISTRICT 7	00	NO CONSTRUCTION	121.08		$
	01,02,03	SURFACING	7.03	7.03	258,000
	04,05,06,07	BASE + SURFACE	23.58	23.58	1,194,800
	08,09	COMPLETE	244.17	288.75	58,973,300
	10,11,12,13	REGRADE, WIDEN, AND RESURFACE	820.79	831.22	43,677,000
	14	MISCELLANEOUS	118.99	118.99	2,683,600
	TOTAL		1,335.64	1,269.57	$ 106,786,700
DISTRICT 8	00	NO CONSTRUCTION	45.29		$
	01,02,03	SURFACING	104.79	104.79	3,238,000
	04,05,06,07	BASE + SURFACE	11.99	12.01	502,600
	08,09	COMPLETE	189.12	205.46	26,088,400
	10,11,12,13	REGRADE, WIDEN, AND RESURFACE	1,045.18	1,048.37	67,668,200
	14	MISCELLANEOUS	61.25	61.25	1,405,800
	TOTAL		1,457.62	1,431.88	$ 98,903,000
STATEWIDE TOTALS	00	NO CONSTRUCTION	1,165.13		$
	01,02,03	SURFACING	822.86	919.69	30,979,100
	04,05,06,07	BASE + SURFACE	130.41	130.34	7,111,700
	08,09	COMPLETE	3,328.33	3,728.72	705,987,300
	10,11,12,13	REGRADE, WIDEN, AND RESURFACE	5,801.36	5,810.35	399,715,800
	14	MISCELLANEOUS	579.77	578.70	46,542,100
	TOTAL		11,827.86	11,067.80	$1,190,336,000

REPORT NO. 9
TABULATION OF MILES AND ESTIMATED COSTS
BY
PRESENT AND PROPOSED SPRINGTIME LOAD RESTRICTION
(1963 Data)

DISTRICT PRESENT LOAD RESTRICTION	PROPOSED 7-TON ULT 9-TON MILES		PROPOSED 7-TON ULT 9-TON COST	PROPOSED 9-TON MILES		PROPOSED 9-TON COST	TOTAL MILES		TOTAL COST
DISTRICT 1									
NON-EXIST	.12	$	6,500	59.33	$	23,605,400	59.45	$	23,611,900
3-TON									
4-TON	162.11		15,341,700	62.23		8,219,400	224.34		23,561,100
5-TON	240.96		11,978,800	107.19		7,970,900	348.15		19,949,700
6-TON	53.34		2,596,000	38.59		3,047,800	91.93		5,643,800
7-TON	82.62		3,390,300	213.23		22,584,000	295.85		25,974,300
8-TON									
9-TON	3.37		167,000	492.39		78,308,600	495.76		78,475,600
TOTAL	542.52	$	33,480,300	972.96	$	143,736,100	1,515.48	$	177,216,400
DISTRICT 2									
NON-EXIST	18.21	$	1,713,300	4.55	$	2,615,500	22.76	$	4,328,800
3-TON									
4-TON	172.85		9,494,800	42.56		4,284,600	215.41		13,779,400
5-TON	195.95		10,916,100	146.99		9,837,200	342.94		20,753,300
6-TON	119.84		4,737,300	166.23		8,994,400	286.07		13,731,700
7-TON	120.64		3,287,300	279.66		10,788,700	400.30		14,076,000
8-TON									
9-TON	1.49		15,400	445.45		35,167,200	446.94		35,182,600
TOTAL	628.98	$	30,164,200	1,085.44	$	71,687,600	1,714.42	$	101,851,800
STATEWIDE TOTALS									
NON-EXIST	67.26	$	5,819,700	341.86	$	154,274,000	409.12	$	160,093,700
3-TON									
4-TON	814.67		77,753,400	220.70		29,203,300	1,035.37		106,956,700
5-TON	1,231.58		71,187,500	1,142.46		87,713,000	2,374.04		158,900,500
6-TON	469.52		22,905,100	718.81		54,776,500	1,188.33		77,681,900
7-TON	388.50		16,607,800	1,400.11		102,085,700	1,788.61		118,693,500
8-TON									
9-TON	36.55		1,890,600	4,235.78		566,119,100	4,272.33		568,009,700
TOTAL	3,008.08	$	196,164,100	8,059.72	$	994,171,900	11,067.80		$1,190,336,000

REPORT NO. 24
LISTING OF EXISTING AND PROPOSED BRIDGES
(1963 Data)

```
DIST 1  TH 169  MHD BR NO  2112  2.70 EKEWATN  EXISTING STREAM     24 FT W106D              BUILT 32  COSTS- R/W        $       0
  CONT SEC 6934  SEGMENT 010   FAP  EXPRESSWAY   RDWAY  49 FT, SDWKS NONE                     LOAD 20T          APPROACH                0
    PROJ ADT   8,312      PLACEMENT-SQUARE     PROPOSED STREAM    RECONSTR       24 FT C106D                    STRUCTURE          20,000
    PRESENT STRUCTURE DEFICIENT - GEOMETRICS     RDWAY 130 FT, SDWKS NONE    DESIGN H20-S16                    TOTAL      $   20,000
                                               RECOMMENDED CONSTRUCTION WITHIN  5 YRS.

DIST 1  TH 169  MHD BR NO  5207  3.30 EKEWATN  EXISTING HWY/RR     170 FT D P G             BUILT 34  COSTS- R/W        $       0
  CONT SEC 6934  SEGMENT 010   FAP  EXPRESSWAY   RDWAY  27 FT, SDWKS NONE                     LOAD 20T          APPROACH            2,000
    PROJ ADT   8,312      PLACEMENT-SQUARE     PROPOSED HWY/RR    REPL-SAME      170 FT                         STRUCTURE          90,000
    PRESENT STRUCTURE ADEQUATE                   RDWAY  30 FT, SDWKS NONE    DESIGN H20-S16                    TOTAL      $   92,000
    DEFICIENT WITHIN 15 YRS. - GEOMETRICS      RECOMMENDED CONSTRUCTION WITHIN 20 YRS.

DIST 1  TH 169  MHD BR NO        3.30 EKEWATN  EXISTING NONE                                          COSTS- R/W        $       0
  CONT SEC 6934  SEGMENT 010   FAP  EXPRESSWAY                                                                  APPROACH            2,000
    PROJ ADT   8,312      PLACEMENT-           PROPOSED HWY/RR    NEW BRIDGE     170 FT                         STRUCTURE          90,000
                                                 RDWAY  30 FT, SDWKS NONE    DESIGN H20-S16                    TOTAL      $   92,000
                                               RECOMMENDED CONSTRUCTION WITHIN  5 YRS.

DIST 1  TH  73  MHD BR NO  6234     AT HIBBING  EXISTING HWY/RR     115 FT C S               BUILT NR  COSTS- R/W        $       0
  CONT SEC 6934  SEGMENT 040        TRUNK         RDWAY  23 FT, SDWKS NONE                     LOAD 20T          APPROACH                0
    PROJ ADT   8,312      PLACEMENT-SKEW       PROPOSED HWY/RR    REPL-SAME      144 FT                         STRUCTURE          78,000
    PRESENT STRUCTURE DEFICIENT - GEOMETRICS     RDWAY  30 FT, SDWKS NONE    DESIGN H20-S16                    TOTAL      $   78,000
                                               RECOMMENDED CONSTRUCTION WITHIN    YRS.

DIST 1  TH 169  MHD BR NO 69002  2.00 NE TH73  EXISTING HWY/RR     148 FT 0 S               BUILT 61
  CONT SEC 6934  SEGMENT 130   FAP  EXPRESSWAY   RDWAY  62 FT, SDWKS NONE                     LOAD 20T
    PROJ ADT  10,400      PLACEMENT-SKEW
    PRESENT STRUCTURE ADEQUATE

DIST 1  TH 169  MHD BR NO 69003  2.00 NESTH73  EXISTING HWY/RR     196 FT 0 S               BUILT 61
  CONT SEC 6934  SEGMENT 130   FAP  EXPRESSWAY   RDWAY  62 FT, SDWKS NONE                     LOAD 20T
    PROJ ADT  10,400      PLACEMENT-SKEW
    PRESENT STRUCTURE ADEQUATE

DIST 1  TH 169  MHD BR NO 69014     AT HIBBING  EXISTING HWY SEP    200 FT                   BUILT 61
  CONT SEC 6934  SEGMENT 130   FAP  EXPRESSWAY   RDWAY  60 FT, SDWKS NONE   20.0 VERT CLR  LOAD   T
    PROJ ADT  10,400      PLACEMENT-SQUARE
    PRESENT STRUCTURE ADEQUATE
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Development of an Integrated Highway Management System

D. G. MALCOLM and D. R. EARICH
Management Technology Inc., Los Angeles, Calif., and Washington, D. C.

The West Virginia Highway Department has developed a management system designed to improve the planning, scheduling, and control of operations in the fields of engineering, right-of-way acquisition, and construction. The program of development includes three major phases: (a) highway program definition-management system feasibility study; (b) system design and initial operation capability; and (c) full-scale system implementation and personnel training. The paper concentrates primarily on the second phase, describing the system and the results of its application to Interstate System work during 1963. The new system was productive of marked progress in work achievement over the year 1962.

•THE STATE Road Commission of West Virginia began a program to improve its planning, programming, scheduling and control of operations in engineering, right-of-way, and construction in August 1962. The program recognized the need for new and pervasive approaches and consequently, was conceived as research and development work in the field of highway management. The objective of the program was to design, install and test an integrated management information system which would supply on-line, updated information to functional, program and top management in regard to time, cost and physical performance of its program in Interstate, ABC, and secondary roads.

The program has been conducted in three major phases: Phase I, Highway Program Definition—Management System Feasibility, August 1962 to February 1963; Phase II, System Design and Initial Operational Capability, February 1963 to January 1964; Phase III, Full-Scale Implementation and Training, continuing from January 1964.

This paper is directed primarily to a description of the results of the Phase II effort, describing the system and the initial results achieved in its applications to the Interstate program. The Phase II activity was supported as a Federal-Aid Research Project under contract HPS-HPR1(24).

PHASE I: HIGHWAY PROGRAM DEFINITION—MANAGEMENT SYSTEM FEASIBILITY

In early 1962, State Road Commissioner Burl A. Sawyers recognized that the West Virginia program in roads was falling farther behind in both its Interstate and Federal-assistance programs. The Interstate program, for example, was on a performance trend line such that only slightly over 50 percent would be completed in 1972—the target year for completion. Although many efforts were under way to improve the situation, and a major portion of the problem could be explained by the fact that nearly 30 percent of West Virginia's 520 miles of Interstate had been added to the program as recently as the previous two years, the Commissioner was not satisfied. He and his top management staff were determined to see that all possible steps were taken to achieve full completion by the target date.

As a first step, it was recognized that the overall program needed better and more detailed definition in terms of the manpower required, the funding required from the state legislature, the facilities required, etc., to meet specific completion schedules involved. It was also recognized that an improved organization and attendant procedures were needed and that supporting management information and control systems were required to establish targets

Paper sponsored by Committee on Highway Organization and Administration and by Committee on Highway Programming.

and to update and control the plan. In July 1962, the Commission was convinced that networking technology—the critical path method (CPM or PERT)—could be used as the core for developing an "integrated management system" which would establish targets of performance for each operating organizational element, spell out the required manpower and financial resources, and would provide a dynamic means of "statusing" the plan, monitoring accomplishments and identifying potential problem areas before occurrence.

At that time, CPM had been used on various construction and planning projects in West Virginia and many other states, but had not been used in any highway department as the means for planning and controlling the internal operations of its large multi-project engineering organization. The Phase I effort was therefore directed toward two principal objectives: (a) the immediate need was to bring the overall program into sharp definition, hence the term "program definition"; and (b) the effort was considered a research effort to determine the feasibility and practicality of utilizing CPM as the basis for an integrated highway management system.

Accomplishments

During the period August 1962 through February 1963, study effort was directed to the following accomplishments:

Overall highway program definition was achieved.
- Performance objectives, policies, priority rules were explicitly stated.
- Integrated master schedules for both department and projects were developed.
- Funds and manpower required to meet schedules were developed.
- A comprehensive report to the legislature on the programs at present and a plan for the future was developed.

Feasibility of applying CPM to internal management of commission.
- Preliminary networks for engineering, right-of-way and construction were developed and analyzed for improvement and proper control points.
- Standard CPM modules (networks) were deemed feasible.

Preliminary system description of proposed management information system was developed.
- Design concept for integrated management system was developed and approved.
- Initial training and indoctrination of Commission personnel in system concept was achieved.

Necessary organization for implementation of management system was established.
- Management scheduling and control division established on a level with operating (often called functional) divisions.

Design Concept for Integrated Highway Management System

In developing the design concept, the following general guidelines were laid down at the outset:

- The system should provide the common language and basis for all management communication in the Commission.
- The system should be rapidly responsive to requests for information concerning: status of schedule, costs and manpower, potential slippages and progress outlook, simulated effects of proposed changes.
- The system should make most efficient use of existing procedures and data sources.
- The system should be simple and flexible.
- The implementation should be approached in an evolutionary manner, yet obtaining management control at an early date.

From these guidelines, the following design criteria were established:

- Management performance objectives, policies and priorities shall form the basis for planning and scheduling activities.

Information generated must serve both functional (i.e., divisional) and program management needs—both functional and program cuts of information are required.

Functional and program goals must be consistent at all times. All internal and external milestones showing responsibilities should be identified. BPR events are to be included.

The three classes of information (schedule, cost, manpower) shall be consistent and from a common source.

Plans must be updated and obtained weekly from actual experiences, to provide realistic control information.

Planning and actuals information shall be in the same format.

Information generated should be designed to serve all levels of management from the same source data and file.

Contractor proposals and reporting should be in a format directly usable in the management system.

In developing a realistic design concept to meet these criteria, it was found necessary to treat explicitly four major management tasks:

Establishment of performance objectives.

Development of a specific plan to attain objectives.

A means for execution and updating of the specific plan.

Specification of an organization for implementation and operation of the management system.

In discussing each of these tasks, it is helpful to examine the information structure and flow pattern of management decision and data involved. Figure 1 shows the information structure—a hierarchy of reports from the task level up to the total state program. Figure 2 shows the data flow and the dynamic nature of management decision. The arrows, or feedback loops, describe the continuing nature of the management process. These two illustrations describe the principal features of the design concept.

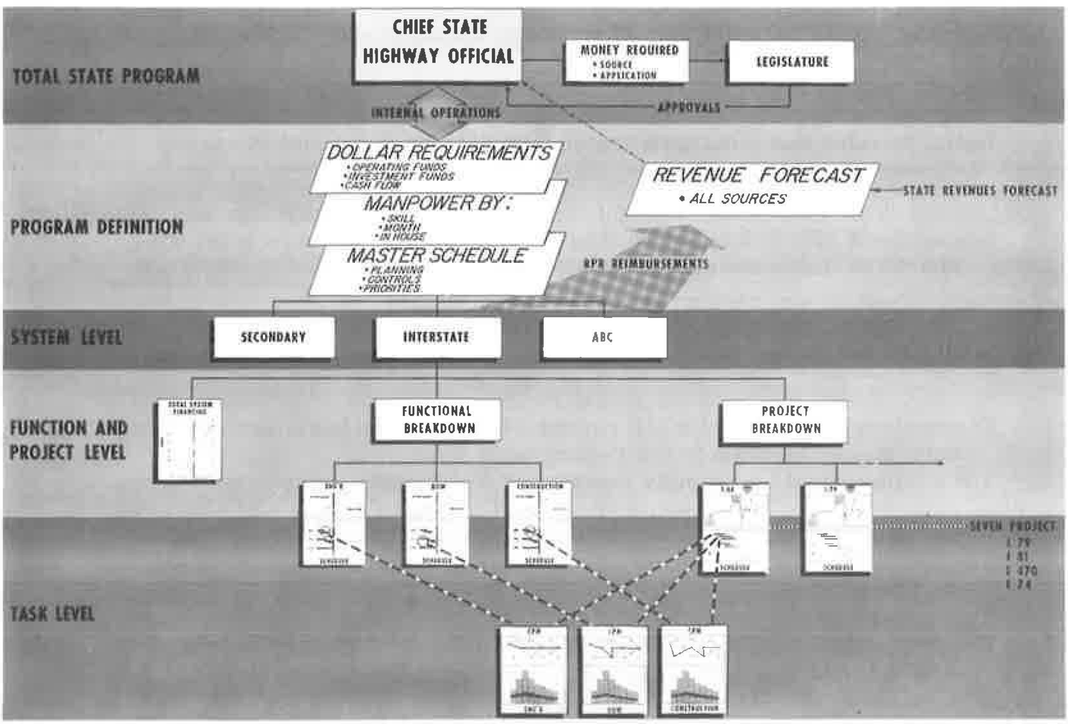

Figure 1. Information structure—integrated management system.

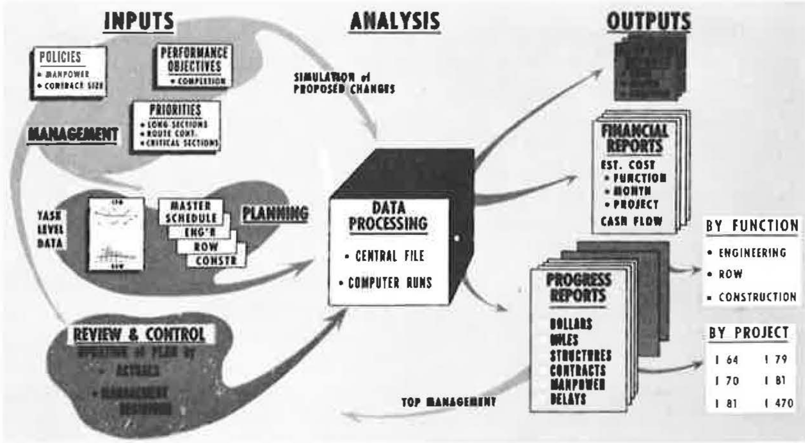

Figure 2. Management decision and data flow.

Establishment of Performance Objectives

Management must first establish its overall goals in a manner which provides criteria for the planners. In the Phase I effort, the goals were stated as a commitment to complete the Interstate System by June 1972, and to attain the maximum level of effort possible with the resources available in the ABC and 100 percent state-funded programs.

Following this, important policies and priorities were set down as guidelines in planning. Typical policy statements were the uniform employment policy and the maximum size of construction contract desired. Priorities to be followed in planning were also stated. In Interstate, for example, these included a planning directive to develop continuous long sections of highway, to work on hazardous areas, and to emphasize connections with adjacent states or major metropolitan areas within the state as a first priority consideration. Armed with these specific guidelines, the task of developing a specific plan is undertaken.

Development of a Specific Plan

The total state program should be defined internally in three ways, each of which is consistent with achieving the same overall goal (Fig. 1). First, a master schedule is

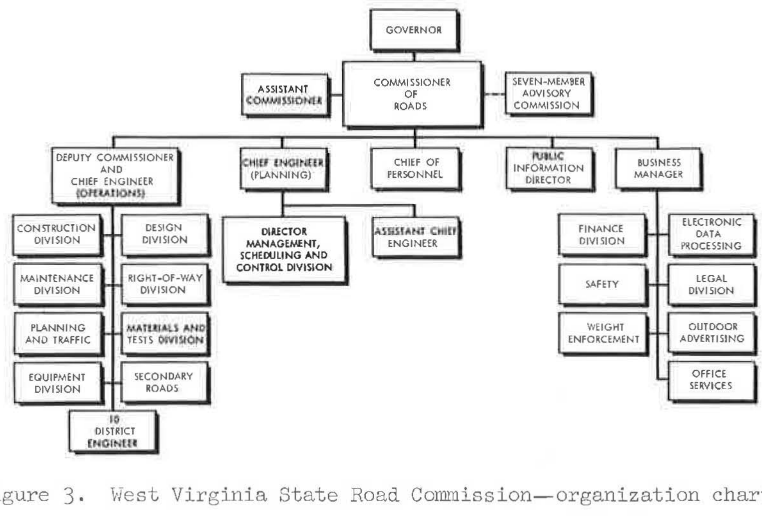

Figure 3. West Virginia State Road Commission—organization chart.

required which shows what projects are to be performed and at what time. These are overall inclusive schedules for each engineering, right-of-way and construction project involved in a section. Second, the dollar requirements to support each project should be laid out by time interval. Third, the manpower requirements for each project should be developed by skill category and by time interval for the total program. These three control concepts, when consistent, provide the necessary program definition. This was accomplished in Phase I in a gross way based on broad planning standards. The Phase II effort was directed to integrating the task level CPM data into the planning and reporting structure.

As a second level of information, the three "systems" comprising the total program: Interstate, ABC and 100 percent state highway programs, are broken out separately. This breakout is necessary to insure managerial attention to the competing nature of these various systems for available resources in the overall program and to provide data for decisions covering allocation of resources. Decisions which lead to on-again, off-again attention to the various programs do not produce the best morale or results.

Below the system level, it is necessary to develop information to support two different management looks at the same job of work. These are the functional division and the route manager (or project level) responsibilities. The engineering, right-of-way and construction divisions need clearly established goals showing what specific projects are to be accomplished, at what time and cost and with what resources. Then, since the work flow is roughly through the divisions, it is desirable to have a route manager concentrating on orderly, timely completion of total projects which generally cross back and forth between the functional divisions several times before completion.

A detailed "task level" type of information that shows individual project schedules and resources is required by each of these managers. These detailed plans and schedules must be consistent with the overall master schedule. As indicated in Figure 1, task level information will be based on a CPM network for the particular project in question. Standard networks or "modules" were developed which eliminate the need for constructing initial networks for each project.

Execution and Updating of Specific Plan

When a feasible plan has been developed and authenticated by management, the total process of work is set in motion. At this time, reports on actual accomplishments to the date of the report are needed which show compliance with the schedule, cost and manpower targets, and which clearly identify the physical accomplishments.

Management also needs a class of information in the form of reports that provide early identification of potential problem areas before they occur. Reports that predict the amount and cause of program slippage, identify administrative bottlenecks, and that point up required decisions concerning long lead time actions are needed in order to obtain and maintain managerial initiative. Management also needs the capability to determine the effects of proposed policy changes. In a properly designed computer-assisted management system, it is possible to perform quickly required replanning to determine the effects of proposed policy changes. This feature is called the capability to "simulate" the effect of a proposed policy change.

Finally, management requires a series of data that shows the present as well as the projected fiscal status of the program and the resulting financial requirements and implications. Financial status information includes the monthly reports of apportionments available, programmed obligations, obligations, expenditures and reimbursements. These should be updated to include transactions made. Periodically, top management must make a realistic forecast of financial requirements. Data required will show the planned source and application of funds. Estimates of funds to be derived from all sources, e.g., reimbursements and taxes, must be available and consistent with the official master program plan. The application of these funds must consider the Commission's operating costs, the program costs and cash flow requirements to support the reimbursement cycle and must also be consistent with the official update program plan.

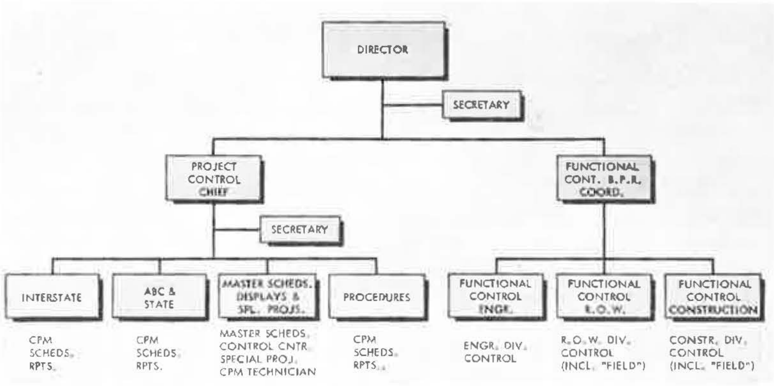

Figure 4. Management scheduling and control division—organizational structure.

Organization for Implementation and Operation of Management System

It was recognized early that effective cross-functional control could be obtained only by developing a group which had the responsibility and authority to acquire the necessary data and update the master schedule in a reliable manner and in the common format as designed. Therefore, a management scheduling and control division (Fig. 4) was created and was made responsible to the chief engineer, planning (Figs. 3 and 4). The new division has organizational status equivalent to the operating divisions and it permits the development of the necessary checks and balances over the flow of work between the operating (functional) divisions. The division has no authority to direct the work of the operating divisions. Rather, it acts in an advisory capacity concerning priorities, the predicting of slippages and their impact, and is custodian of the schedule.

PHASE II: SYSTEM DESIGN AND INITIAL OPERATIONAL CAPABILITY

Results of the Phase I effort led to the conclusion that detailed design test and implementation of the design concept should be undertaken immediately. Five principal objectives were established for this phase of the work:

1. Design and develop a CPM system capable of providing administrative information vital to highway department management, utilizing a Univac SS90 computer for data processing and integration.
2. Development of operating procedures that will permit successful operation of the CPM system. These procedures will be designed to promote accuracy, completeness and uniformity of system input and output data.
3. Development of project planning and scheduling methods and data that will establish realistic plans for the timely completion of all highway projects, with primary emphasis on completion of the Interstate System.
4. Development of a highway status reporting system that satisfies internal administrative needs as well as those of "external" agencies. Emphasis will be primarily on devising meaningful and useful management reports concerned with schedule achievement. Methods of reporting and forecasting manpower and funding information will also be developed.
5. Development of the most practical organization and staffing concept that permits the CPM-based highway management system to function in the most efficient manner.

In Phase II, three main tasks were accomplished: the detailed design of the operating integrated management information system, the programming of the computer, and the implementation and test of the system, including training.

Initial CPM Data Acquisition

The conference method was judged to be the most effective way to develop the detailed CPM networks. The conferences also provided a means of training appropriate division personnel in the CPM method, permitting all personnel "to grasp the big picture," preventing important steps being overlooked, providing an awareness of the interrelationships between personnel within a specific division as well as with other divisions or agencies, arbitrating terminology differences, and stimulating thinking in devising new and more efficient methods of accomplishing the tasks. This last point, termed "procedure purification," proved to be one of the most rewarding aspects of the study and resulted in eliminating, resequencing and combining many activities in the preliminary networks.

Several conferences were held with each of the three major divisions. At each of these meetings, there were generally 15 to 25 individuals present, including representatives of the Bureau of Public Roads and other divisions that might play an important role in developing the networks.

The ground rules established for developing the networks during these meetings were basic, yet extremely important to the overall system. These were as follows:

Module Concept.—The networks would be developed based on a typical situation in engineering, right-of-way and construction. The networks, when developed, were to provide control from the point in time when the advance planning division completed required studies until the project was open to traffic. These modules would attempt to accommodate 85 to 90 percent of the situations that might arise. The same networks would be used to monitor every project.

Desired Sequence.—The networks would reflect the sequence of operations that was desired for use with every project.

Problem Areas.—Known problem areas would be treated with particular care; emphasis would be placed on these areas through the definition of these problems in detail.

Interstate Oriented.—The networks would be oriented around the Interstate problems, with careful attention to providing enough steps to cover any particular problem that might arise when using the "modules" to control projects on the Primary and Secondary Highway Systems within the State.

After a brief explanation of CPM and the establishment of the basic ground rules, all personnel were aware of what was needed and the network development began. The development of the modules generally took three conferences with each division. The first conference began with the establishment of a "job list." The purpose of the job list was to provide a check list to be used while developing the networks. It helped to remind the attendees of the major steps involved in the overall operation and reduced the possibility of overlooking tasks. It also served as an "icebreaker"; for the development of the job list encouraged personnel in attendance to participate fully in discussions and to arbitrate any problem areas that might arise.

The job list prepared for engineering was particularly helpful in establishing the stages of a project as it progressed through design. The first phase was termed the "reconnaissance phase" and included design from advanced planning until a corridor was established. The second phase was termed the "design report phase" and included design from establishment of a corridor until a line had been defined. The third phase is the "contract plans phase" which covers the detailed design of the construction section.

After the job list was completed, networking was started. Having established the parameters of each network, the task was to "fill in the blanks" so as to provide a continuous chain of activities that linked the two end points—start of the project and completion of the project. In developing the networks, each activity was tested by the following questions:

> What task(s) must be accomplished before the activity in question can begin?

What task(s) cannot proceed until the activity in question has been accomplished?
What task(s) can or should be accomplished concurrent with this activity?

The objective was to show the earliest possible start and the latest possible completion date for each task, even though it is customary to accomplish the job at some specific point between these two extremes.

The network took shape until a complete arrow diagram was constructed, connecting the beginning and end of the module in question and showing all the activities with proper interrelationships and interdependencies. A master plan, in the form of a network, was now available which would provide all personnel with a step-by-step "road map" through the project. This completed the first conference.

The next step was to draw the network in a "smooth-rough" form so that it could be properly reviewed by the conference attendees. While redrawing the network, the planner examined it carefully in order to insure that good networking techniques had been utilized.

Once the network was drawn in a "smooth-rough" form, it was distributed to the attendees for review. The review provided the attendees with an opportunity to look objectively at the network, in their own offices, so as to insure that it accurately portrayed the plan. When all the attendees at the second conference were satisfied that the network reflected the plan, the final step was ready to be accomplished.

The planner next redrew the network in smooth form, representing the work of the two previous conferences. Again, networks were distributed to the attendees for their review. At this third meeting, little additional sequence information was obtained from the attendees. Those present were asked to examine each activity on the network under review and to determine the length of time necessary to accomplish each task. This action started the scheduling phase. The same approach was utilized in the obtaining of time estimates, for it is extremely important that the person responsible for the task estimate the time required to perform it. In this way the validity of the estimates are improved and an effective "commitment" is obtained.

When considering times for an activity, the estimator must remember and record those factors that control the length of time necessary for each activity's completion. Such items as type of manpower skills required, number of men available, the number of hours per day and shifts per day should be recorded. By analyzing an activity in this manner, the estimator was able to give a time estimate that reflects the expected elapsed time expressed in working days. If the estimator determines that performance of the task requires six consecutive days of work, he gives a time estimate of six working days.

The third conference had as its specific purpose the application of time estimates to each activity, as well as the suggestion of any final changes that might be required in the network. Once this purpose had been accomplished, the planner made these minor changes and applied the time estimates to the smooth network. Thus, for each activity on each network module, there was associated the following data elements: responsible division; elapsed time for the activity; manpower required (number of men, skill category, and percent of time required); direct costs incurred as a result of the activity.

When the networks had been approved, they were ready for use in conjunction with the Commissioner's computer. Figures 5, 6, 7 and 8 represent network developed in conferences with the right-of-way and engineering divisions.

Use of Standard Networks for Specific Projects

These networks are referred to as "standard modules" and have been found directly applicable to about 85 percent of all projects. For these cases, there is no need to draw networks for each project. Rather, the tabular listing of the module, such as shown in Figure 9 for right-of-way, is used as the basis for project estimation and as the input form to the computing center. Variations in the elapsed time, manpower or direct costs are simply made on this tabular listing, authenticated by the appropriate management and then entered into the active project file.

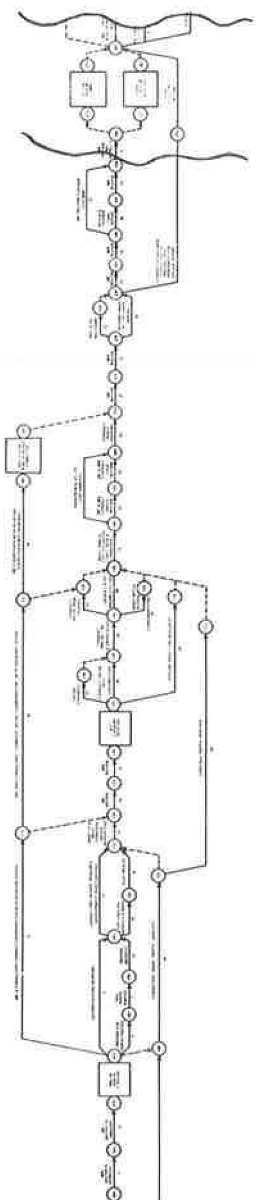

Figure 5. CPM module reconnaissance and design report phase—Part 1: reconnaissance.

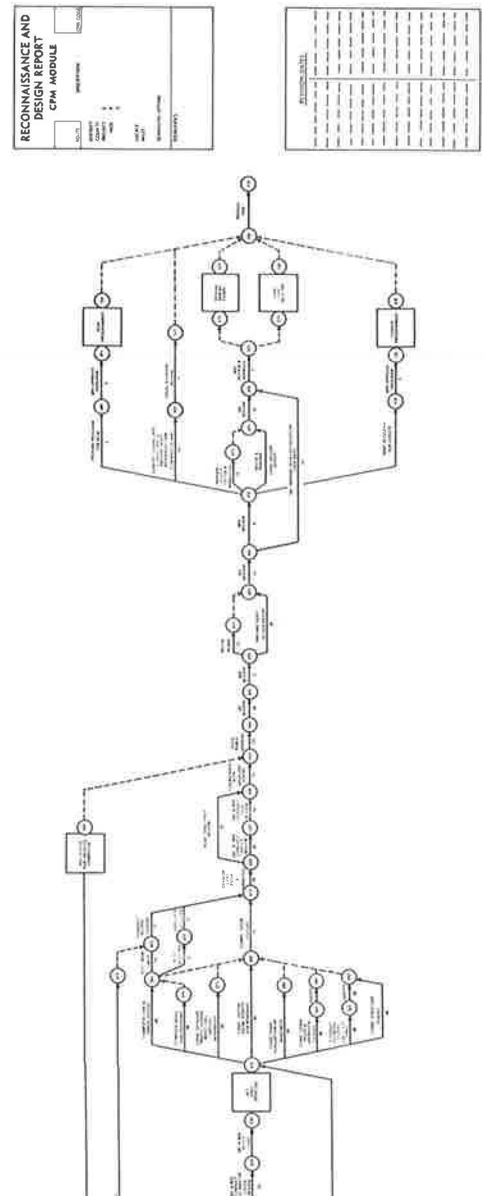

Figure 6. CPM module reconnaissance and design report phase—Part 2: design report phase.

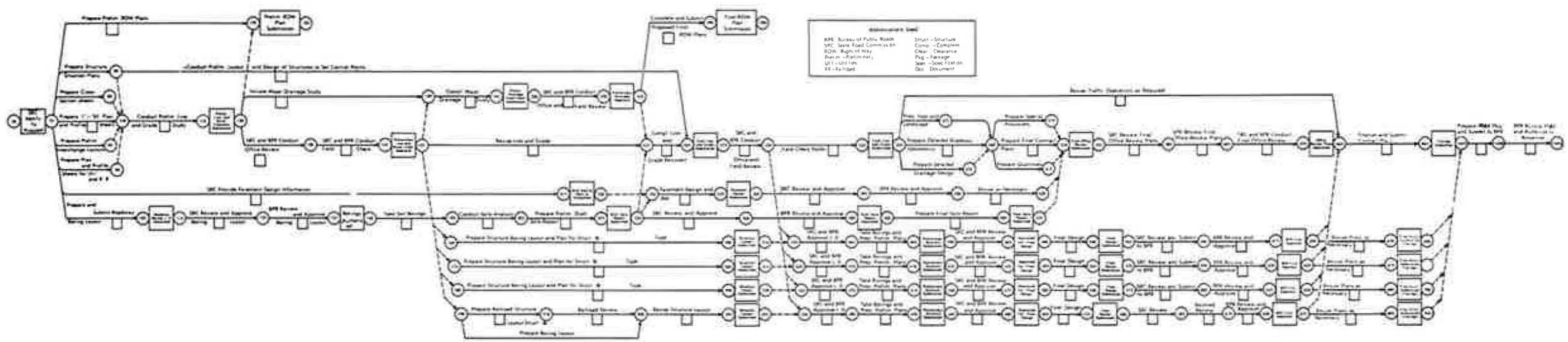

Figure 7. Contract plans CPM module.

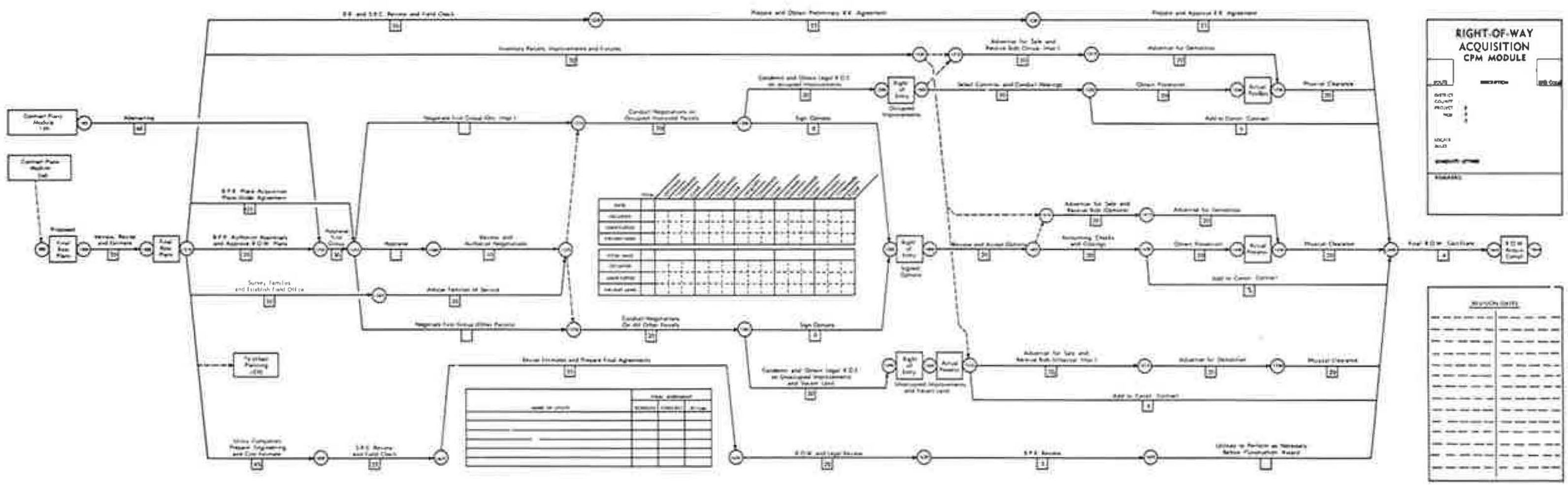

Figure 8. Right-of-way acquisition CPM module.

STANDARD MODULE
RIGHT-OF-WAY ACQUISITION

PREDECESSOR	SUCCESSOR	ACTIVITY	ELAPSED TIME	RESP. ORG.	MANPOWER SKILL & % TIME		DIRECT COST
	1210	Final R/W Plans	-				
1210	1220	R.R. & S.R.C. Field Check	20	R	115		
1210	1240	Inventory Parcels, Improvements & Fixtures	30	R	110	110	
1210	1270	B.P.R. Place Acquisition Plans Under Agreement	25	B	990		
1210	1250	B.P.R. Auth. Appraisals & Appr. R/W Plans	20	B	990	990	
1210	1285	Survey Families & Estab. Field Office	20	R	140	140	
1210	1600	Util. Co's Prepare Eng. & Cost Estimate	45	U	830	830	
1220	1230	Prepare & Obtain R.R. Agreement	25	R	120		
1230	1640	Prepare & Approve R.R. Agreement	25	R			
1250	1260	Appraise R/W Plans	30-100	R			
1260	1270	Review & Auth. Nego.	10				
1600	1610	S.R.C. Review & F'ld Check	25				
1610	1620	Revise Estim. & Prepare					
1270	1280	Conduct Nego					
1270	1285	Conduct Ne					
1280	1290	Condemn					
1280							

Figure 9. Tabular listing of module.

For some projects, activities in addition to the standard module are deemed desirable. Such net activities are added simply by modifying the tabular listing with the following: defining the activity predecessor and successor events, estimating direct cost and manpower, writing the activity name.

In this way, the labor of network construction and updating is avoided, while at the same time, there is the benefit of reference standard networks to visualize the flow and status. The data from the tabular listing for each project are entered on a CPM input sheet (Fig. 10). Next, the desired completion date from the master schedule is entered into columns 13-16, and the input cards are punched. When all projects are similarly entered, all the necessary data for processing have been "inputted."

Computer Program

A standard CPM computer program for the SS90 was redesigned and modified to obtain the following capabilities: relate working days to specific calendar dates, insert scheduled starting day and scheduled completion day, determine positive, negative or zero slack for each activity, and handle cost and manpower inputs for each activity. The revised computer program was used to provide the outputs at the project and program levels.

Data Outputs at Project Level

The output printout for each project contains the following information for each activity in the project:

Column Heading	Data Description
PREDECESSOR EVENT	- 4 digit number
SUCCESSOR EVENT	- 4 digit number
ACTIVITY DESCRIPTION	- Word description
ACTIVITY COST	- Direct costs
ACTIVITY DURATION	- Working days
EARLY FINISH DATE	- Work days from project start
LATEST ALLOWABLE FINISH DATE	- Date
ACTUAL COMPLETION DATE	- Date (when completed)
SLACK	- Working days
MANPOWER	- By Division, skill and percent of time

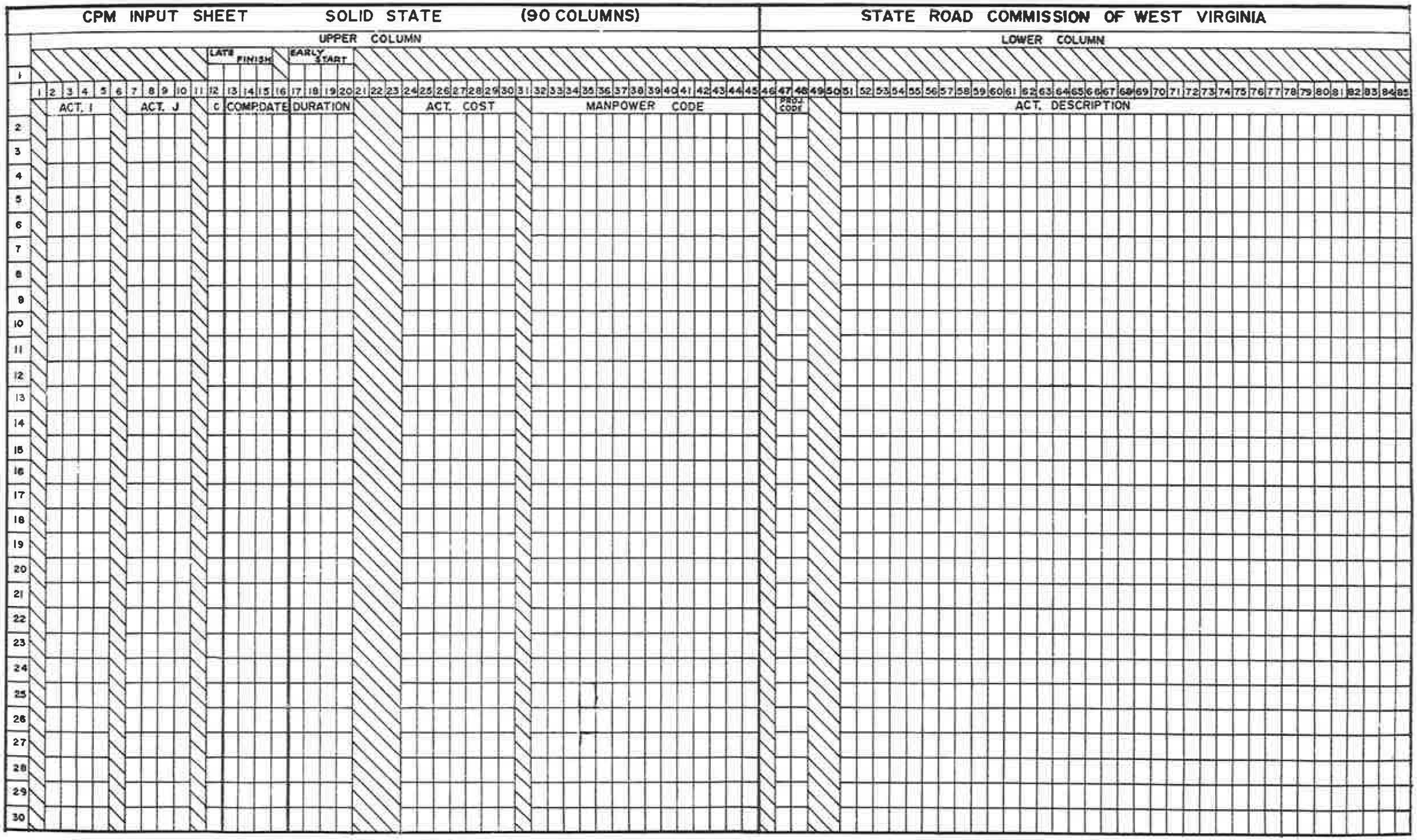

Figure 10. CPM input sheet.

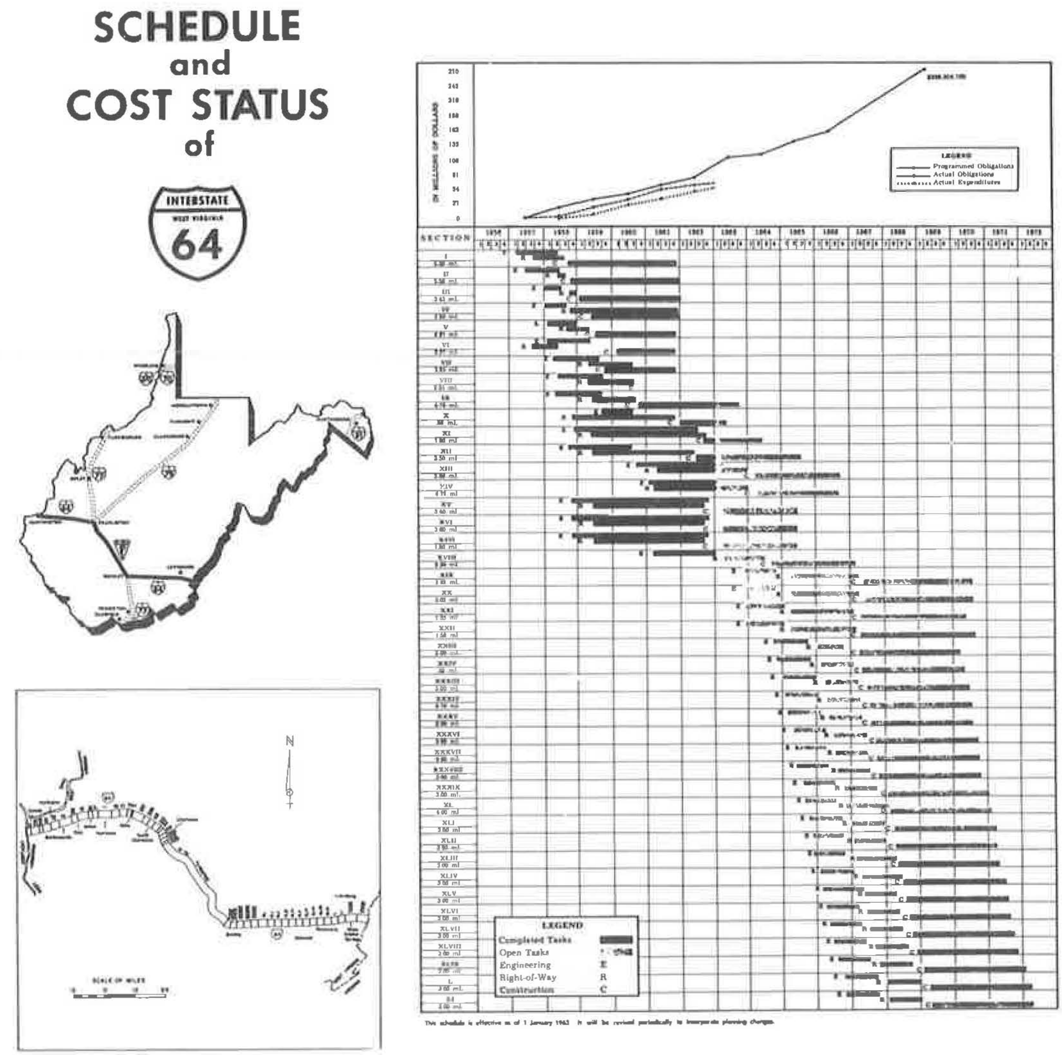

Figure 11.

Each output sheet has the project name and appropriate word description of the project printed out at the top of the sheet. These data are used in monitoring and managing the work within the project and permit "statusing" and rescheduling of internal project tasks to meet established due dates. These reports, produced at regular intervals, give each project manager the status of his project, a prediction of activities that may slip schedule date, and the manpower requirements expected.

Data Outputs at the Program Level

Revised master schedules and progress reports are prepared for both functional division and route manager uses. The functional manager concentrates on quality of work, assignment and development of personnel and meeting specific project dates; the route manager concentrates on program goals, priorities and work flow. Figure 11 is a typical route program master schedule. This chart, along with functional master schedules (Fig. 12), is on display in the management center. Several other short-range charts and progress reports not shown in this paper are made from the same data sources and show milestones completed and those in jeopardy.

RIGHT-OF-WAY MASTER SCHEDULE FOR INTERSTATE SYSTEM
(1957-1972)

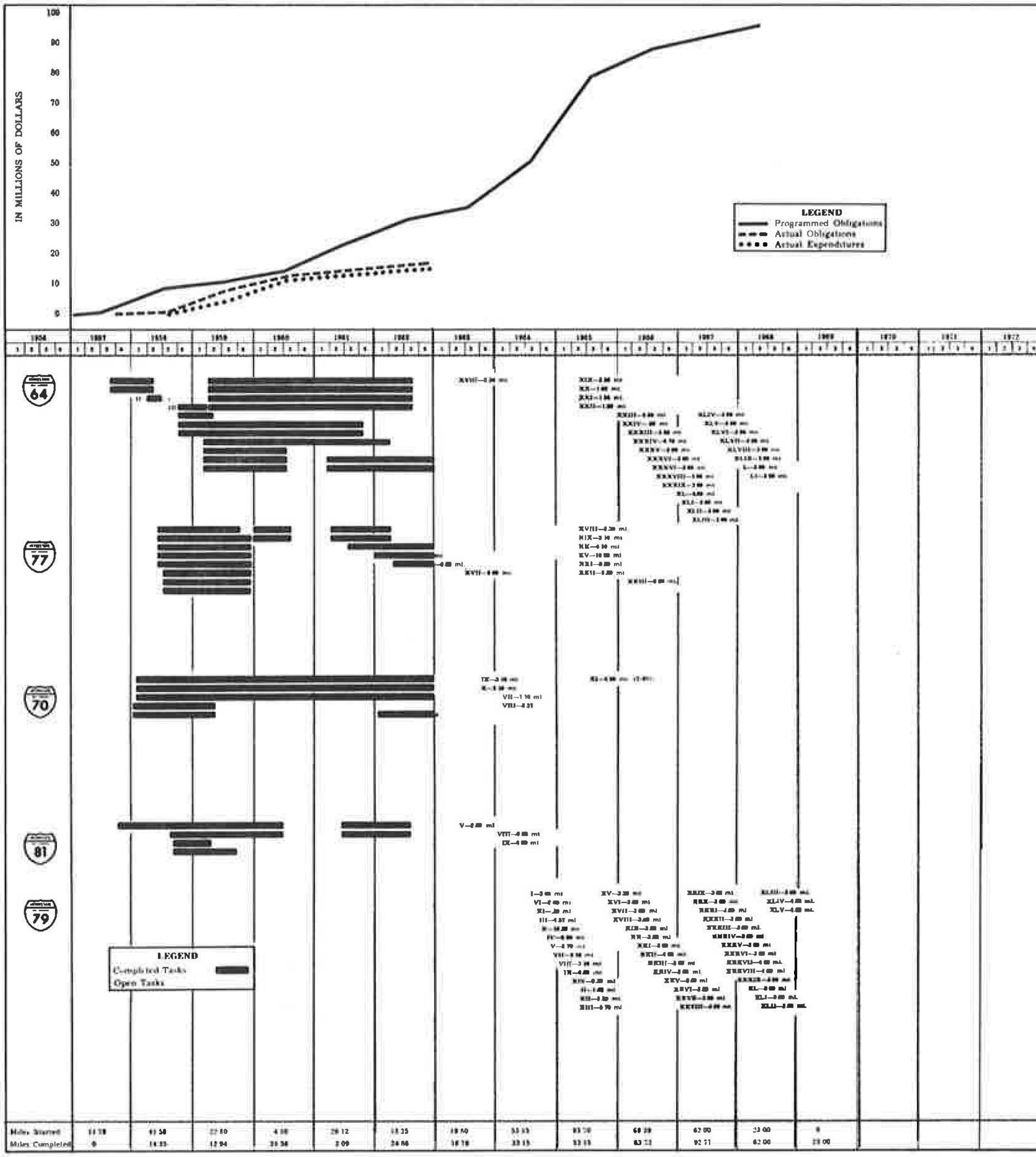

Figure 12.

It should be pointed out that with the more refined data now available at the project level, it is necessary to rework the master schedules. There are two main reasons for this required reworking: (a) the original estimates used in developing the master schedules were based on broad planning factors due to the lack of any detailed work standards, and (b) the question of available manpower in the various skill categories to meet the "desired" schedule had not been evaluated. It is thus necessary to re-examine the proposed schedule to determine whether it is feasible from a manpower-workload point of view in each component of each division.

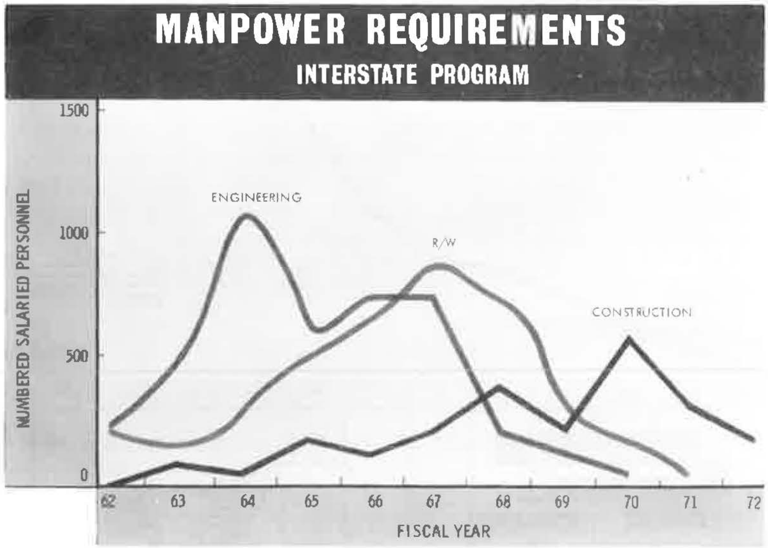

Figure 13.

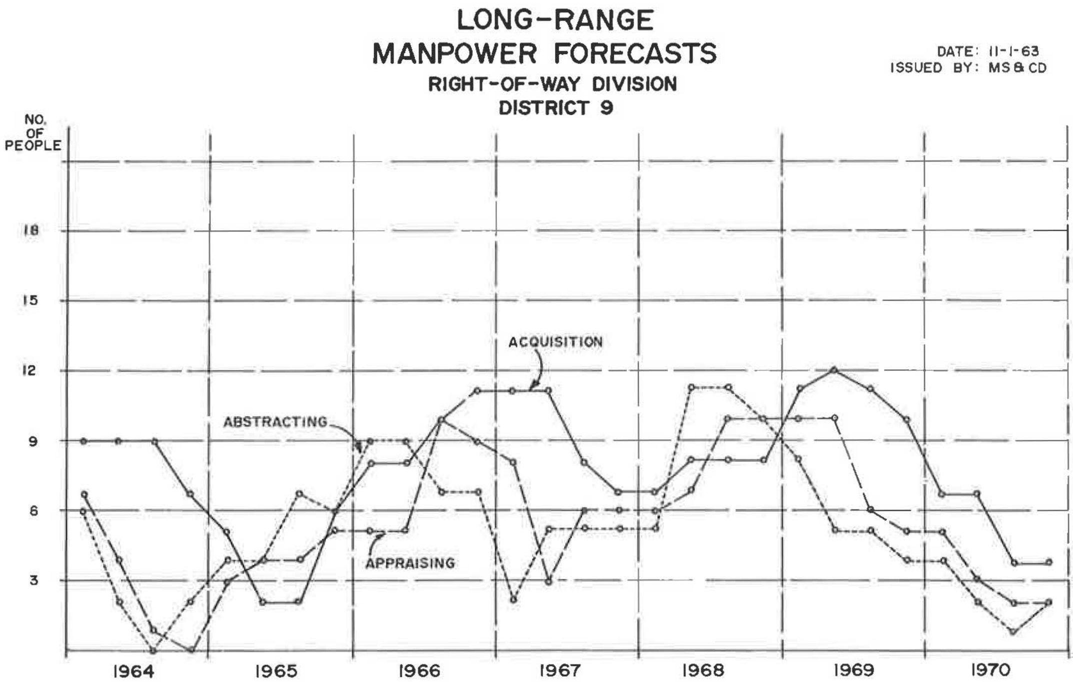

Figure 14.

Multi-Project Scheduling and Manpower Balancing

With all projects scheduled using the refined project data, the total manpower requirements are easily computed by skill, division and time frame. A graph of overall requirements according to initial master scheduling is shown in Figure 13. Divisional managers and the personnel function participated in assessing whether these requirements were attainable. When agreement was reached, a commitment was made by the functional manager in relation to the program goals. Manpower acquisition and training is continuously approached on a planned, reviewable basis. In the setting of any schedule, the manpower feasibility check is made to see whether the skills are available at the right time. If not, the detailed schedule is adjusted until a schedule compatible with the availability of personnel is achieved. The responsible manager always participates in this analysis and commitment. Figure 14 shows the manpower requirement for District 9 of the right-of-way division derived from computer outputs.

Automatic computer allocation and assignment of resources, while an attractive concept, was deemed infeasible due to human factors involved and the high variability of input data. Rather, by this iterative approach, all elements of the organization have participated in the planning and have committed themselves to the goals established. This has been found by many researchers in the defense establishment to be the most realistic approach to multi-project scheduling. For one thing, it rec-

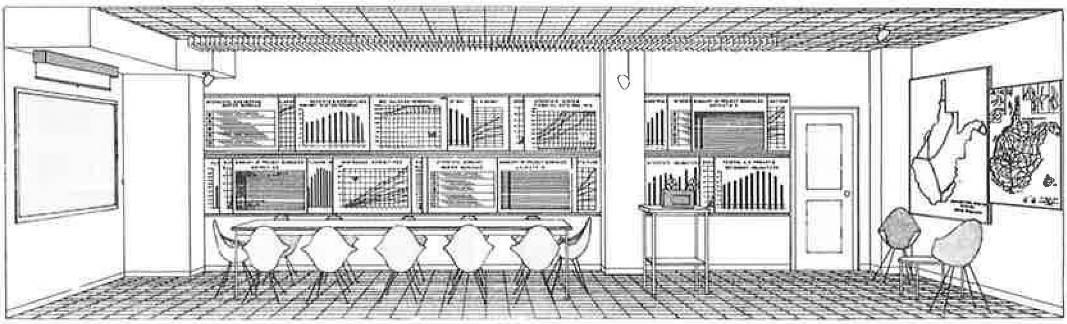

Figure 15. Management center.

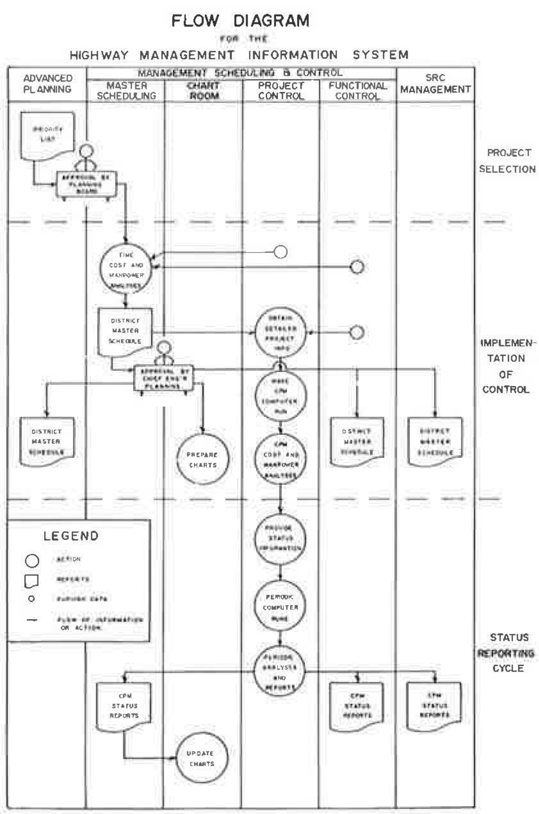

Figure 16. Flow diagram for the highway management information system.

ognizes the role and function of management at all levels in carrying out the plan and schedule. Furthermore, the approach is designed to face up to the fact that a project may change considerably from the planning phase to the execution phase, and that input planning data are in reality estimates having a significant probable error. The principle of participation and commitment is a very important one to observe in the design and implementation of management systems.

Total System Reports

In addition to the manpower report described in the previous section, several reports and displays are made, showing goals and progress at the total system level. Typical reports are summary schedule—miles completed by years, status of Interstate System, Interstate System total cost and mileage, Interstate System total expenditures, Federal-aid primary and secondary obligations, expenditures and receipts, SRC salaried personnel plan, and summary of project schedules by district. The data for each of these reports is based on updated project planning. Other reports deal with actual and potential slippages in projects. These reports and others form the setting for the management center.

Management Centers

The previously indicated charts are displayed in a management center which provides a common format for biweekly management review. Slippages and potential slippages are reviewed. The center has been called "arena for decision" (Fig. 15). Functional managers and route managers review the status and progress of their program against a common format and corrective action can often be taken on the spot. Revised schedules are developed following management meetings. In this way, management action is formed more in the future, rather than discussions centering on reasons and responsibility for current problems.

Management control centers are also being established in functional divisions of the Commission. In particular, the real time control center in the right-of-way division has proven most effective. Plans are currently under way to create appropriate management subcenters in each of the Commission's ten district offices managing operations throughout the state. The need for common format and source data is now well recognized in designing the reporting system. Also under consideration is the concept of a mobile management center, utilizing many of the program displays developed in this project, which will communicate the nature and progress in the road program to the citizens of West Virginia.

Operation of the System

Operating procedures were established in order to insure complete understanding of the system. A typical flow diagram of the system in operation is shown in Figure 16. A final report on the Phase II effort has been submitted. This report, for use by the various organizational elements of the Road Commission, is in the following twelve volumes:

Vol. 1	System Definition
Vol. 2	Organization and Staffing
Vol. 3	Personnel Information
Vol. 4	The Critical Path Method
Vol. 5	Scheduling
Vol. 6	Reporting
Vol. 7	Chart Room
Vol. 8	Procedures
Vol. 9	Engineering Consultant Specification
Vol. 10	Construction Contractor Specification
Vol. 11	Application of Statistics to Highway Forecasting
Vol. 12	Glossary

Portions of the report were used early in Phase II efforts to effect on-job training, a major requirement in the correct use and acceptance of a new system. One of the criteria in system development stated that "Contractor proposals and reporting should be in a format directly usable in the management system." Volumes 9 and 10 contain the specifications for such compliance. It is expected that this requirement, nearly identical to that employed by the Corps of Engineers, the Bureau of Yards and Docks, and the General Services Administration, will encourage better managerial practices at the controller level and will improve the quality of reporting. In this way, the current amount of time spent in interpreting contractor status will be reduced through the "common language" provided.

PHASE III: FULL-SCALE IMPLEMENTATION AND TRAINING

Full-scale implementation of the automated system has been under way over all road programs of the state since late 1963. Concentration in Phase II gave priority to the Interstate portion of the program, and the system was operated manually until computer programming was completed. Thus, the Interstate program has been under CPM control since early 1963, with extension to ABC and secondary programs proceeding in a time-phased manner, with full coverage planned for early 1965.

Results to Date

Calendar year 1963 was the peak year in terms of the total dollar volume of work let to contract in the history of the state road commission. Broad measures of improved performance are found in the fact that the Commission has been able to let to contract approximately 5 times the dollar volume of Interstate construction in 1963 as in 1962 ($65.9 million in 1963; $13.2 million in 1962). Also, about 5 times the dollar value of Interstate right-of-way was acquired in 1963 as compared with 1962 ($14.5 million in 1963; 2.8 million in 1962). In addition, over 3 times the dollar volume of Federal-aid primary and secondary construction work was let to contract in 1963 as was in 1962 ($17.1 million in 1963; $5.2 million in 1962). Further, the program for 1964 provides for approximately the same dollar volume in contract lettings. West Virginia has also moved some thirteen positions upward in the ranking of states in regard to the obligation of funds in the Interstate program. The CPM-based management system has been credited by West Virginia Road Commission management with a major assist in the improved performance shown in Figures 17 and 18.

Perhaps the most important result has been the clearly-evident renewed purpose and direction given to the organizational elements through the improved definition of the program, its statement of goals, and progress and exception reporting. In summary, the system provides the information means to:

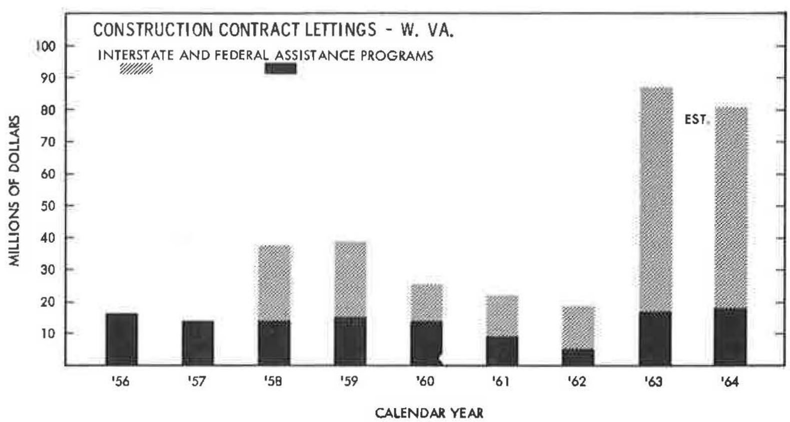

Figure 17.

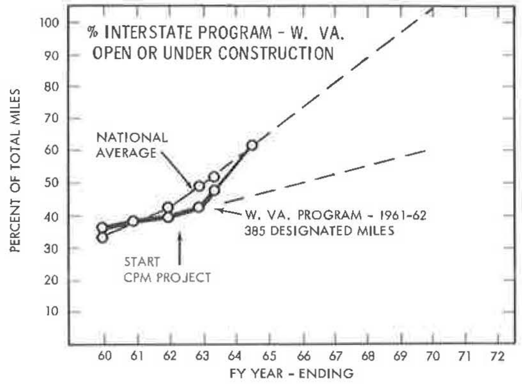

Figure 18.

1. Define the total road program by dollars, physical projects and functional tasks;
2. Integrate financial, engineering, right-of-way and construction planning;
3. Link long-range planning and operations management;
4. Predict likely problem areas before they occur, on an "exception" basis;
5. Illustrate or simulate the effects of work accomplishments and planning changes;
6. Improve schedules to meet deadlines and/or reduce cost;
7. Reduce the probability of overlooking important jobs and decisions;
8. Call out quarterly manpower and dollar requirements by function, project and system;
9. Establish performance targets for each organizational unit within the Road Commission;
10. Provide the yardstick for measuring performance of divisions and sections; and
11. Communicate better with the Bureau of Public Roads, the legislature and the public.

Training

Training has been accomplished on the job through use of a joint consultant-Road Commission implementation team. Frequent discussion and lecture sessions have been held to bring awareness and understanding of the management's objectives in the program to divisional personnel. Use of the materials in the final report proved useful in communicating the logic of the system and the new procedures required.

Systems Research in Management

There are unique problems facing a research and development effort in the management domain. Such research cannot be conducted in a laboratory or under the experimental conditions usually employed in physical and engineering research. The test laboratory for management research, or operations research, is necessarily the real world with the real people and their objectives, which are only partially polarized with those of the organization. This poses very special and difficult measurement problems.

There is difficulty in measuring, except in the broadest of terms, the cost and effectiveness of proposed management innovations such as, for example, the development of better, more integrated management information. Generally such measurements must be at the level of the total organization, since there are many interdepartmental interactions and a long time is required for significant data to be derived. During this time, external conditions may change and individual motives may change. If the results are adverse to certain individuals, they may take actions to compromise the "system" and its predictions. This added human factor makes it virtually impossible to measure accurately results of an operations research or management study in the real-world environment, where the desire for freedom from control is such an important factor.

Changes in an organization's performance can be ascribed to many coincidental forces. Thus, with the inadequacy of the experimental method in management and operations research projects recognized, a more direct comprehensive approach has been found necessary. This approach recognizes the following as requirements for successful management research:

1. Top management must be convinced of the need for the recommended improvement and give active direction to the program.
2. The design team must be made responsible for being intimately involved in the implementation of the research.

3. A development plan showing measurable milestones of accomplishment, assignment of responsibilities, resources required in both the design and implementation phase.
4. Critical and frequent top management review of the developmental plan.

In the final analysis, improved performance can be made only by a dedicated management. An improved management system is only a means to the desired end, a totally inadequate means if the information is not used wisely and continuously. The evaluation of the effect of a given system resides mainly in management's judgment concerning how much better it has been able to discharge its responsibilities with the new tools provided.

ACKNOWLEDGMENT

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