Sufficiency Rating by Investment Opportunity

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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).

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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.

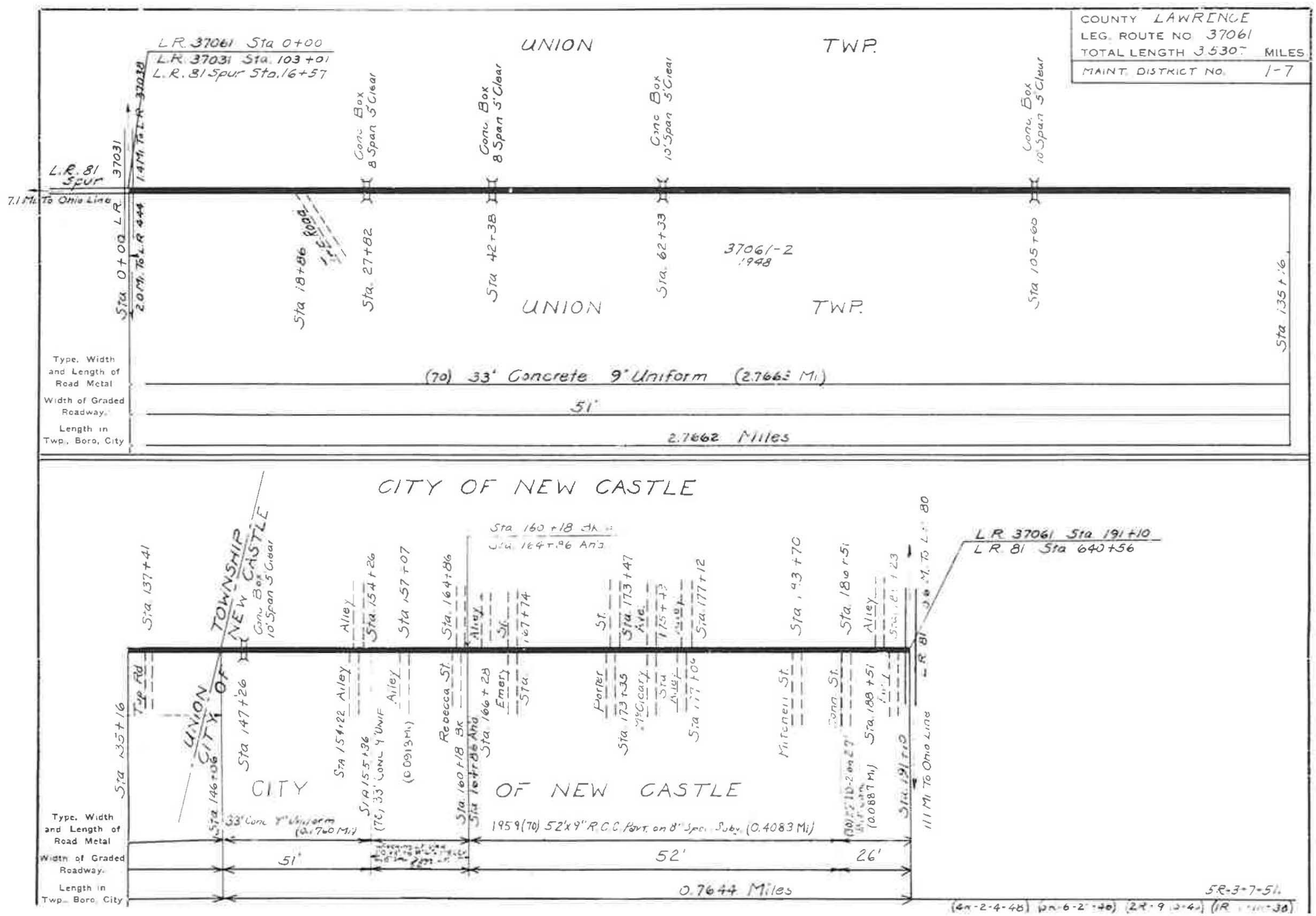

Figure 1. Original scale 1 inch = 1,000 ft (in boro or city 1 inch = 500 ft).

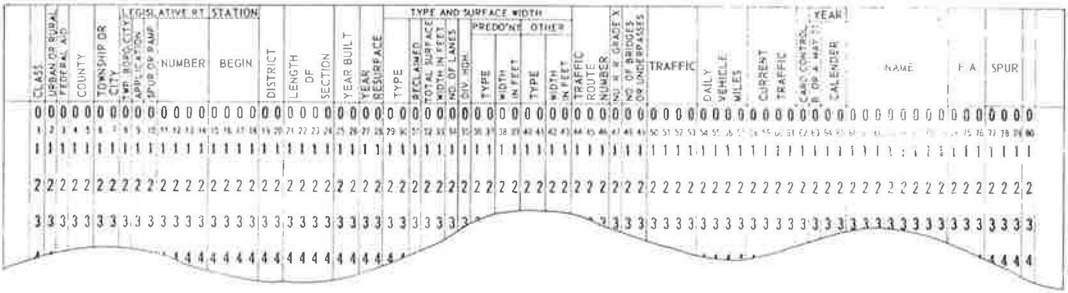

Figure 2. Road log.

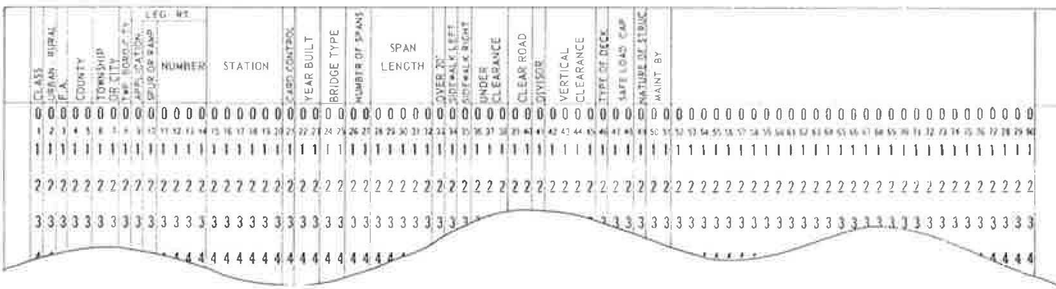

Figure 3. Bridge log.

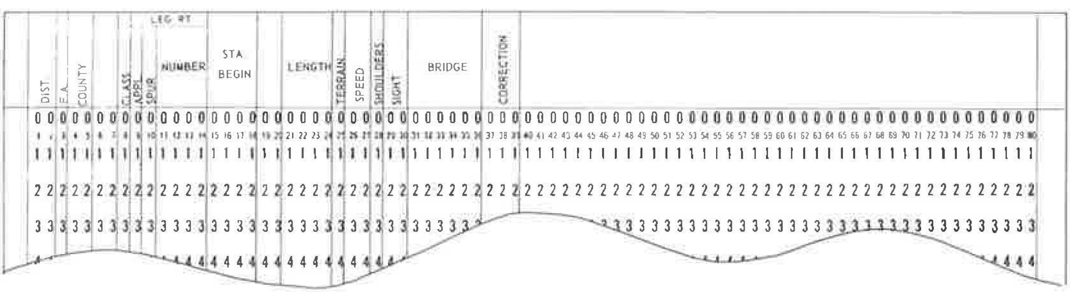

Figure 4. "210" Study.

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

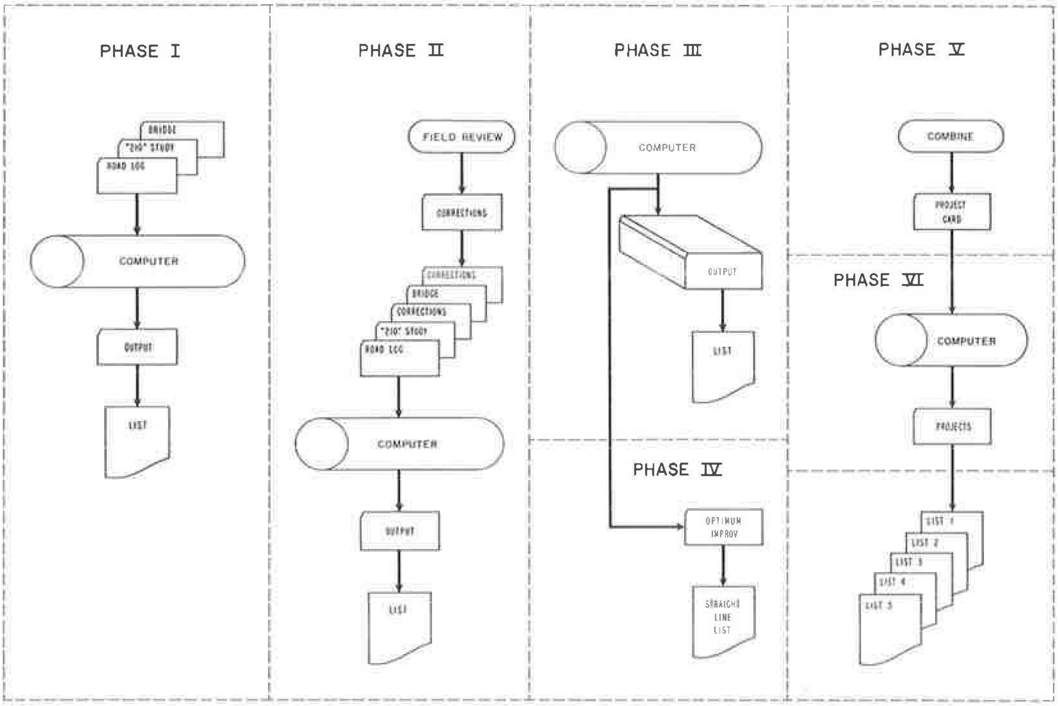

Figure 5.

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	Outlying Urban Park
79	315	.12	25	C	NEW CASTLE	07	61	30	60	2	D	7630	0	R	35	40	77	63	FAU	232	30	Outlying Urban Park
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	Outlying Urban Park
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	UNL	
	359	.90			BRIDGE			52					20								UNL	
79	372	2.03	25	S	SHENANGO	51	00	33	70	3	D	6430	8	F	60	60	74	98	FAP	739	UNL	
	381	.32			BRIDGE			53					20								UNL	

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

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

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.

[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).

[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

[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	NEW CASTLE	.77	B 24	63	1343	165.00	2380	181
	192		1.16	B 48					
	252		1.37	B 24					
79	146	NEW CASTLE	.27	R EXIST	70	20			
	187		.09						
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	USER BEFOR	ROAD COST	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.

REFERENCES

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3. Highway Sufficiency Ratings. HRB Bull. 53, 1952.