A General-Purpose Model for Motor Vehicle Operating Costs

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The costs of motor vehicle operation vary over time and from place to place. To deal with the temporal and geographical changes in the unit prices of the various factors that comprise motor vehicle operating costs, this paper discusses a method of estimating motor vehicle operating costs on the basis of physical parameters and quantities that can be related to vehicle characteristics, highway alignment, and traffic conditions. The method relies on a computer program that generates tables of operating costs that are applicable over a wide range of speed and gradient for a specified level of service, highway standard, and surface type. Calculations are carried through in terms of units of consumption, such as gallons of fuel, so that actual costs might be varied to reflect local conditions and changing prices. Each component of operating cost is output for the appropriate range of speed and grade. The program is designed primarily to be used as a substitute for continuously updating such operating cost sources as the AASHO Red Book. A sample output is presented illustrating the use of the model to generate data for a particular combination of vehicle type and level of service, along with summary data for a range of level of service. A series of nomographs that permit hand calculation of operating costs are also presented. The sample problem is then treated by comparing the results of using the computer-generated operating cost tables with hand calculation.

•ROAD USER COSTS are the most important element in total highway costs for almost any reasonable level of traffic volume and are therefore frequently critical in decision-making in highway planning. [No attempt is made here to discuss the use of user costs in highway economy studies of the benefit-cost variety, as numerous references on the subject already exist (1).] One of the major problems encountered in estimating motor vehicle operating costs for use in highway economy studies is to obtain data that are relevant to both the time period under consideration and the particular geographical location of the study. Most currently available operating cost sources suffer from one or more of the following shortcomings:

1. It is difficult to adjust prices to reflect changes over time, because increases in the various components that comprise total operating costs are not uniform. In other words, with fuel, oil, and tire costs combined in an aggregate cost, it is difficult to account for increases in the cost of fuel alone.
2. Similarly, extra-market values such as the value of travel time are often aggregated with market values such as fuel costs in a manner that makes it difficult to adjust total operating costs should some of the extra-market components change.
3. The factor prices that comprise total operating costs may vary significantly from one locale to another.

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4. Often, only automobile costs are treated in any detail, and costs of truck operation must be inferred from the automobile costs for similar operating conditions.

To deal with these problems, a method of estimating motor vehicle operating costs on the basis of physical parameters and quantities has been developed. [A more detailed discussion appears elsewhere (2).]

APPROACHES TO DETERMINING OPERATING COSTS

A variety of techniques can be used to estimate the physical units that determine motor vehicle operating costs. These techniques vary with respect to the level of detail desired and the nature of the data available to describe highway geometry, surface type, driver behavior, and the vehicle itself. In general, all methods attempt to relate consumption rates for such items as fuel and tires to various alignment, vehicle, and operating characteristics. However, considerable choice exists in the selection of the level of detail used to describe the alignment (for example, whether information is provided for 100-ft sections or 1-mile sections), as well as the degree of interaction among vehicles (for example, the choice of using detailed simulation techniques to describe the speed characteristics of a fleet of vehicles or using typical speed profiles).

Basically, four approaches can be used to determine the physical units necessary for estimating motor vehicle operating costs. The first involves hand calculation and the use of basic charts and tables that are available in the literature (3). Where user costs are required only infrequently or where the alignment under study is of uniform character, hand computation may prove satisfactory. The nomographs shown in Figures 1, 2, 3, and 4 have been prepared to facilitate such calculations for the automobile case. A sample calculation is shown on each chart. Similar charts are available for single-unit and combination trucks.

Where alignment is variable and a large number of volume and service conditions must be considered, lengthy hand calculations can be reduced by use of the computer. A simple computer program designed for this purpose is introduced later in the paper. This program generates tables of operating costs per unit of distance over a wide range of speed and gradient. In this case, total operating costs and final results for a particular project would still require some hand calculation.

A third approach makes use of detailed computer simulation programs that can accommodate a wide range of vehicle types, operating conditions, and alignments. An early approach, known as the Vehicle Simulation Program, was developed at the Massachusetts Institute of Technology (4). This method is analogous to the train performance calculators widely used in the railroad industry in that basic laws of physics are used to simulate the movement of a vehicle over a specified alignment in small increments of time, distance, or speed.

The MIT problem-oriented language ICES (Integrated Civil Engineering Systems) contains a subsystem ROAD that includes an updated Vehicle Simulation Program. A modified version of this approach is also reported by Clark (2).

Finally, attempts have been made to determine operating costs by reducing data arrays to a series of equations. These cost equations are useful for evaluating operating costs over a network of highways. They sacrifice accuracy in the interests of computational ease (5).

A GENERAL PURPOSE MODEL

In general, use of an up-to-date operating cost table is adequate for the level of detail used in most highway cost calculations. This is evident from the fact that early attempts to develop detailed vehicle simulation programs referred to in the preceding have never been widely used in highway practice. For this reason, although the background research for this paper dealt with each of the first three approaches, the remainder of this paper concerns the second approach, that is, a computer program that generates tables of operating costs applicable over a wide range of speed and gradient for the specified level of service (6), highway standard, and surface type.

This program is based largely on empirical information already available in tabular and graphical form and, as such, does not involve any simulation technique. For variable

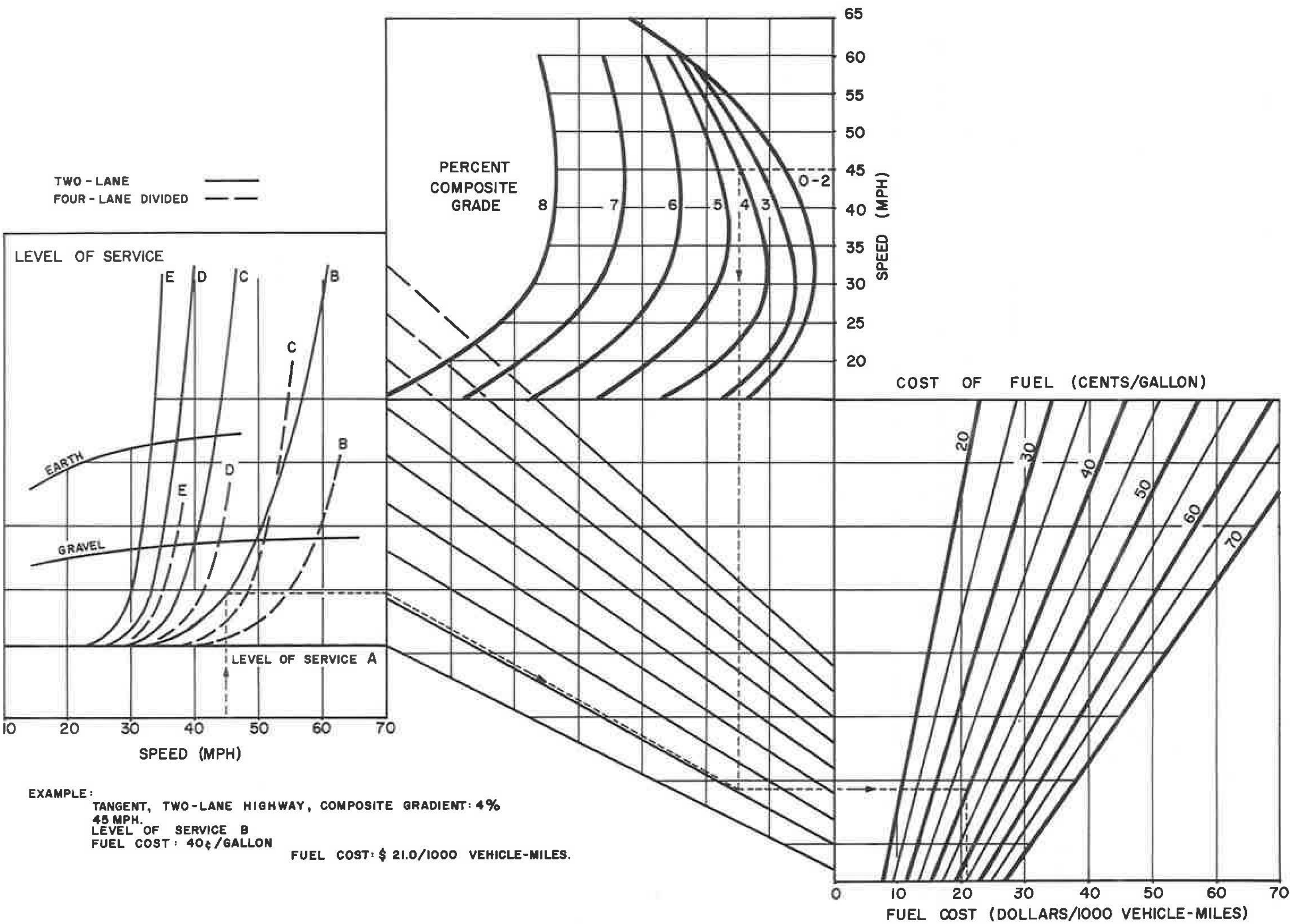

Figure 1. Passenger vehicle fuel costs, tangent rural highways.

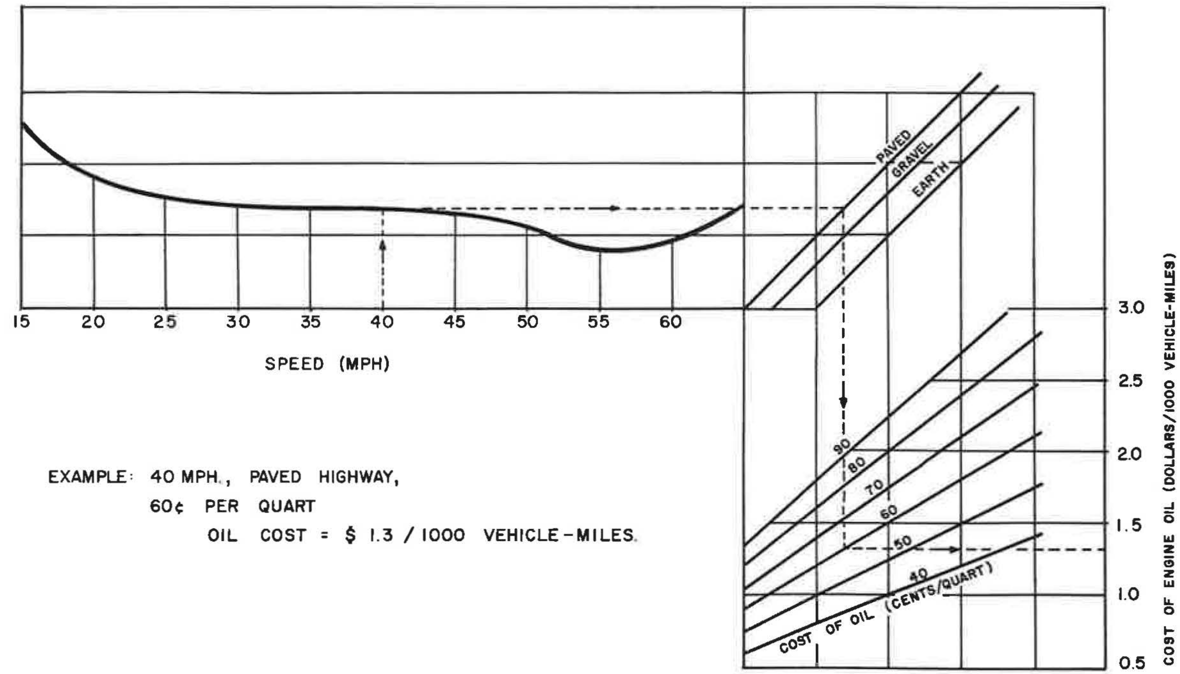

Figure 2. Passenger vehicle engine oil consumption, tangent rural highways.

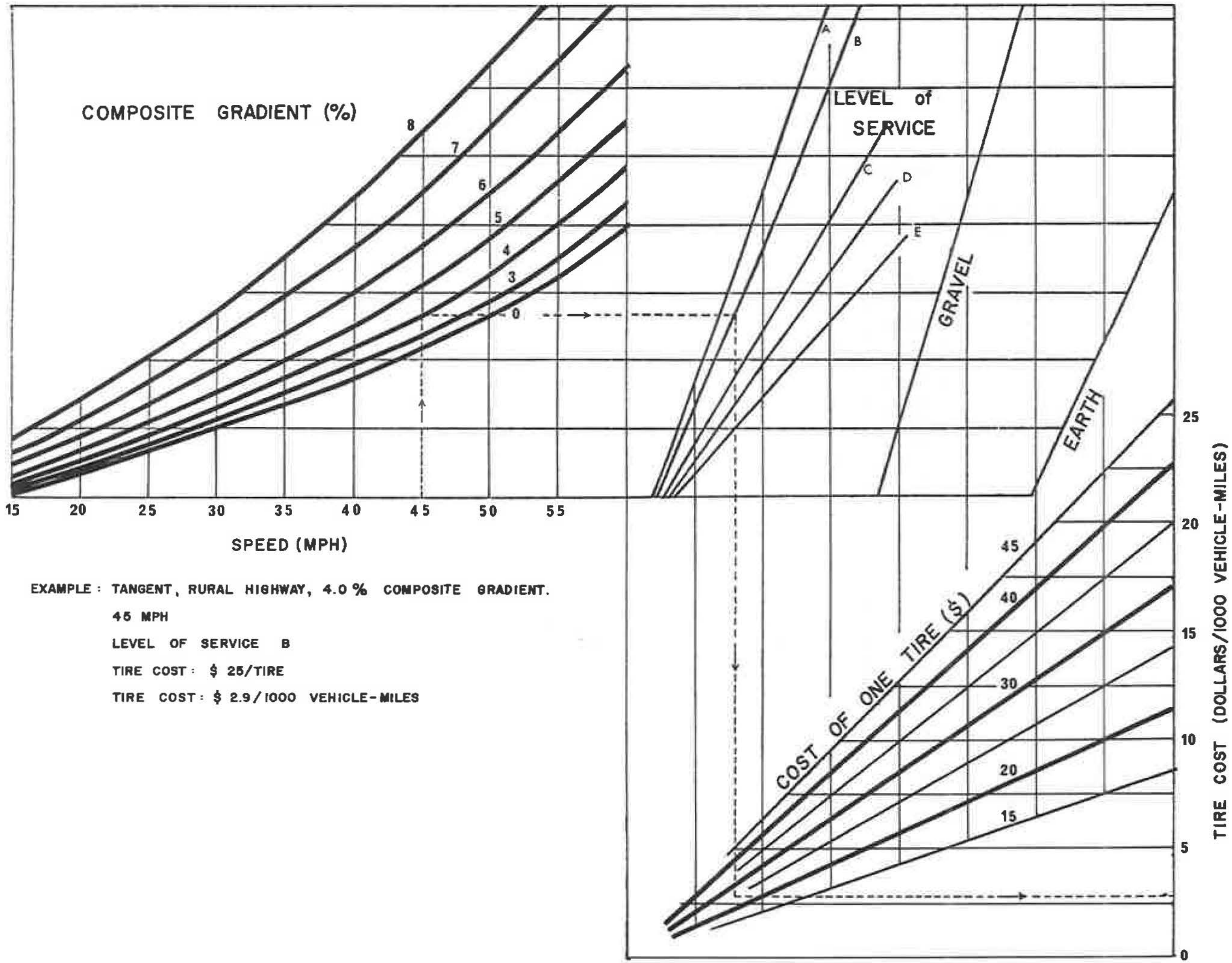

Figure 3. Passenger vehicle tire costs, tangent rural highways.

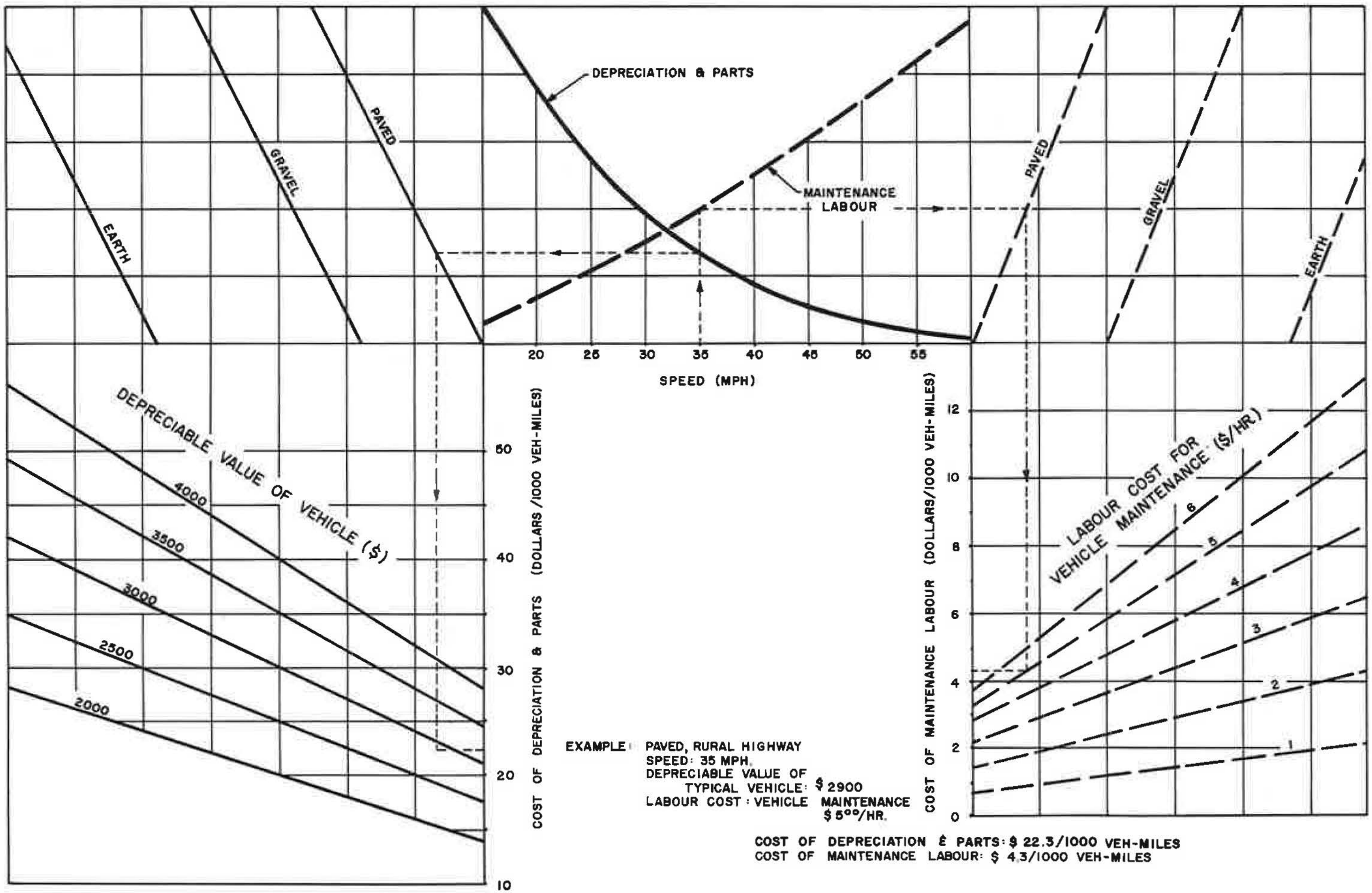

Figure 4. Passenger vehicle maintenance and depreciation costs, tangent rural highways.

volume and alignment conditions, calculation of operating costs for a given project is reduced to application of these table values to the alignment and traffic conditions at hand. The essence of this program is that calculations are carried through in terms of units of consumption (such as gallons of fuel), so that unit costs might be varied to reflect local conditions and changing prices. Although the actual tables generated by the computer program are presented in terms of cost, output can be regenerated easily by varying any or all of the input parameters. The program prepares tables of user costs when supplied with the following general data: vehicle type, surface type, roadway type, level of service, unit costs, range of speeds, and range of grades.

A flow chart for the computer program is shown in Figure 5. Table 1 is an example of the output obtained for a passenger vehicle operating on tangent two-lane highway with level of service B. The input parameters are indicated on the table. Similar tables may be generated for the remaining levels of service or, alternatively, the program may be used to produce a summary table showing the direct operating and time costs for a variety of levels of service, as given in Table 2. Similar tables for truck operation can also be generated. Although the units used in these sample tables are British units, the program accommodates British, U.S., or metric units. In preparing a manual

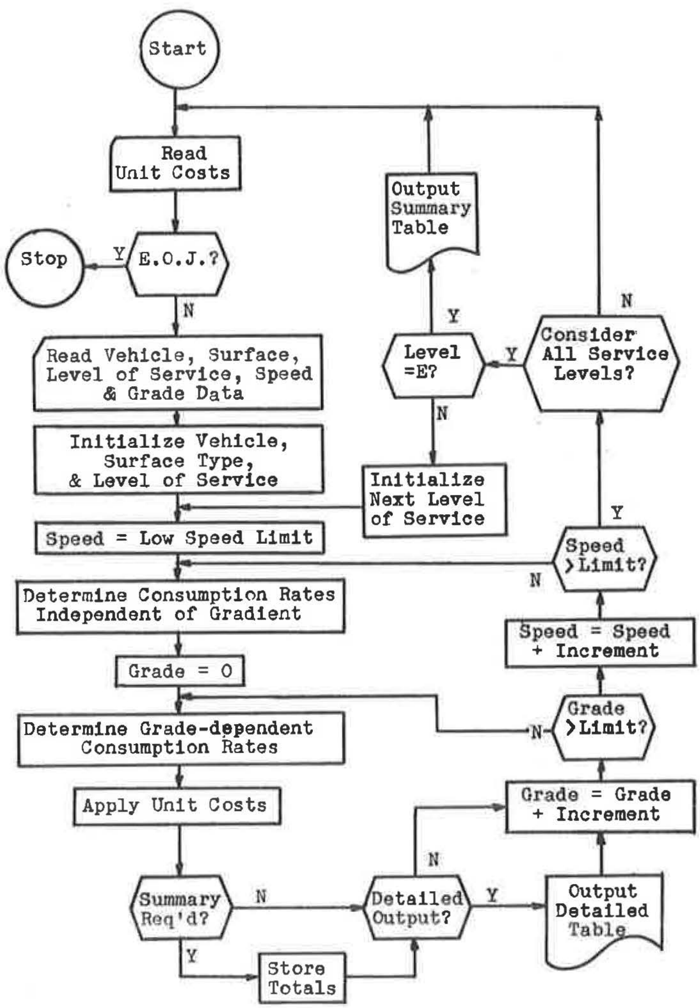

Figure 5. Generalized flow chart for table generation program.

TABLE 1

ROAD USER COSTS FOR PASSENGER VEHICLES IN RURAL AREAS

(Tangent 2-Lane Highways, Paved Surface, Level of Service B)

Speed (mph)	Grade (percent)	Operating Costs, Dollars per 1,000 Vehicle-Miles							
		Fuel[a]	Tires[b]	Oil[c]	Maintenance[d]	Depreciation[e]	Subtotal	Time Cost[f]	Total Cost
36	0	13.5	1.8	1.6	7.3	17.8	42.10	43.1	85.15
	2	13.7	1.8	1.6	7.3	17.8	42.23	43.1	85.29
	4	14.7	2.1	1.6	7.3	17.8	43.56	43.1	86.62
	6	16.8	2.7	1.6	7.3	17.8	46.28	43.1	89.34
40	0	14.0	2.1	1.6	7.4	17.1	42.30	38.7	81.05
	2	14.3	2.1	1.6	7.4	17.1	42.59	38.7	81.34
	4	15.3	2.4	1.6	7.4	17.1	43.83	38.7	82.58
	6	17.1	3.1	1.6	7.4	17.1	46.43	38.7	85.18
44	0	15.2	2.4	1.6	7.8	16.4	43.38	35.2	78.60
	2	15.6	2.4	1.6	7.8	16.4	43.77	35.2	79.00
	4	16.4	2.7	1.6	7.8	16.4	44.93	35.2	80.16
	6	18.1	3.5	1.6	7.8	16.4	47.46	35.2	82.69
48	0	17.2	2.7	1.6	8.2	15.9	45.51	32.3	77.80
	2	17.6	2.7	1.6	8.2	15.9	45.92	32.3	78.22
	4	18.3	3.1	1.6	8.2	15.9	47.05	32.3	79.34
	6	19.8	4.0	1.6	8.2	15.9	49.52	32.3	81.81
52	0	20.4	3.0	1.5	8.6	15.4	48.94	29.8	78.75
	2	20.7	3.0	1.5	8.6	15.4	49.27	29.8	79.08
	4	21.4	3.5	1.5	8.6	15.4	50.38	29.8	80.18
	6	22.9	4.5	1.5	8.6	15.4	52.89	29.8	82.70
56	0	25.1	3.4	1.4	9.0	15.0	53.91	27.7	81.59
	2	25.2	3.4	1.4	9.0	15.0	54.01	27.7	81.69
	4	25.7	3.9	1.4	9.0	15.0	55.07	27.7	82.75
	6	27.2	5.1	1.4	9.0	15.0	57.74	27.7	85.42

[a]Fuel cost = $0.32 per gallon.
[b]Tire cost = $25.00 per tire (plus retreads).
[c]Oil cost = $0.75 per quart.
[d]Labor cost = $3.25 per hour.
[e]Depreciable value = $2,900.00.
[f]Time cost = $1.55 per hour.

TABLE 2

ROAD USER COSTS FOR PASSENGER VEHICLES IN RURAL AREAS AT VARIOUS LEVELS OF SERVICE

(Tangent 2-Lane Highways, Paved Surface)

Speed (mph)	Grade (percent)	Time Costs	Operating Costs, Dollars per 1,000 Vehicle-Miles, for Level of Service							
			A		B		C		D	
			Operate	Total	Operate	Total	Operate	Total	Operate	Total
36	0	43.1	41.7	84.8	42.1	85.2	43.8	86.8	48.1	91.1
	2	43.1	41.9	84.9	42.2	85.3	43.9	87.0	48.2	91.3
	4	43.1	43.2	86.2	43.6	86.6	45.4	88.5	50.1	93.2
	6	43.1	45.8	88.8	46.3	89.3	48.5	91.6	54.0	97.0
40	0	38.7	41.6	80.3	42.3	81.0	45.7	84.5		
	2	38.7	41.9	80.6	42.6	81.3	46.1	84.8		
	4	38.7	43.0	81.8	43.8	82.6	47.6	86.3		
	6	38.7	45.5	84.2	46.4	85.2	50.8	89.6		
44	0	35.2	41.8	77.1	43.4	78.6	51.6	86.8		
	2	35.2	42.2	77.4	43.8	79.0	52.1	87.4		
	4	35.2	43.2	78.5	44.9	80.2	53.8	89.0		
	6	35.2	45.5	80.7	47.5	82.7	57.5	92.7		
48	0	32.3	42.4	74.7	45.5	77.8	58.3	90.6		
	2	32.3	42.7	75.0	45.9	78.2	59.0	91.3		
	4	32.3	43.7	76.0	47.0	79.3	60.7	93.0		
	6	32.3	45.8	78.0	49.5	81.8	64.6	96.9		
52	0	29.8	43.1	72.9	48.9	78.7				
	2	29.8	43.3	73.2	49.3	79.1				
	4	29.8	44.2	74.0	50.4	80.2				
	6	29.8	46.2	76.0	52.9	82.7				
56	0	27.7	44.1	71.8	53.9	81.6				
	2	27.7	44.2	71.8	54.0	81.7				
	4	27.7	44.9	72.6	55.1	82.8				
	6	27.7	46.9	74.6	57.7	85.4				
60	0	25.8	45.6	71.4						
	2	25.8	45.4	71.2						
	4	25.8	46.1	71.9						
	6	25.8	48.0	73.8						

Note: Fuel cost = $0.32 per gallon
Oil cost = $0.75 per quart
Depreciable value = $2,900.00
Labor cost = $3.25 per hour
Tire cost = $25.00 per tire
Time cost = $1.55 per hour

for use in a highway department, the program could be used to generate 40 to 50 tables similar to Table 1 for a number of surface types and vehicle types on two-lane and divided highways, and over the appropriate range of levels of service.

EXAMPLE OF COMPUTER PROGRAM

The use of the computer program can be demonstrated through a simple problem relating to the alignment shown in Figure 6. An alignment U-V-W is under study as a

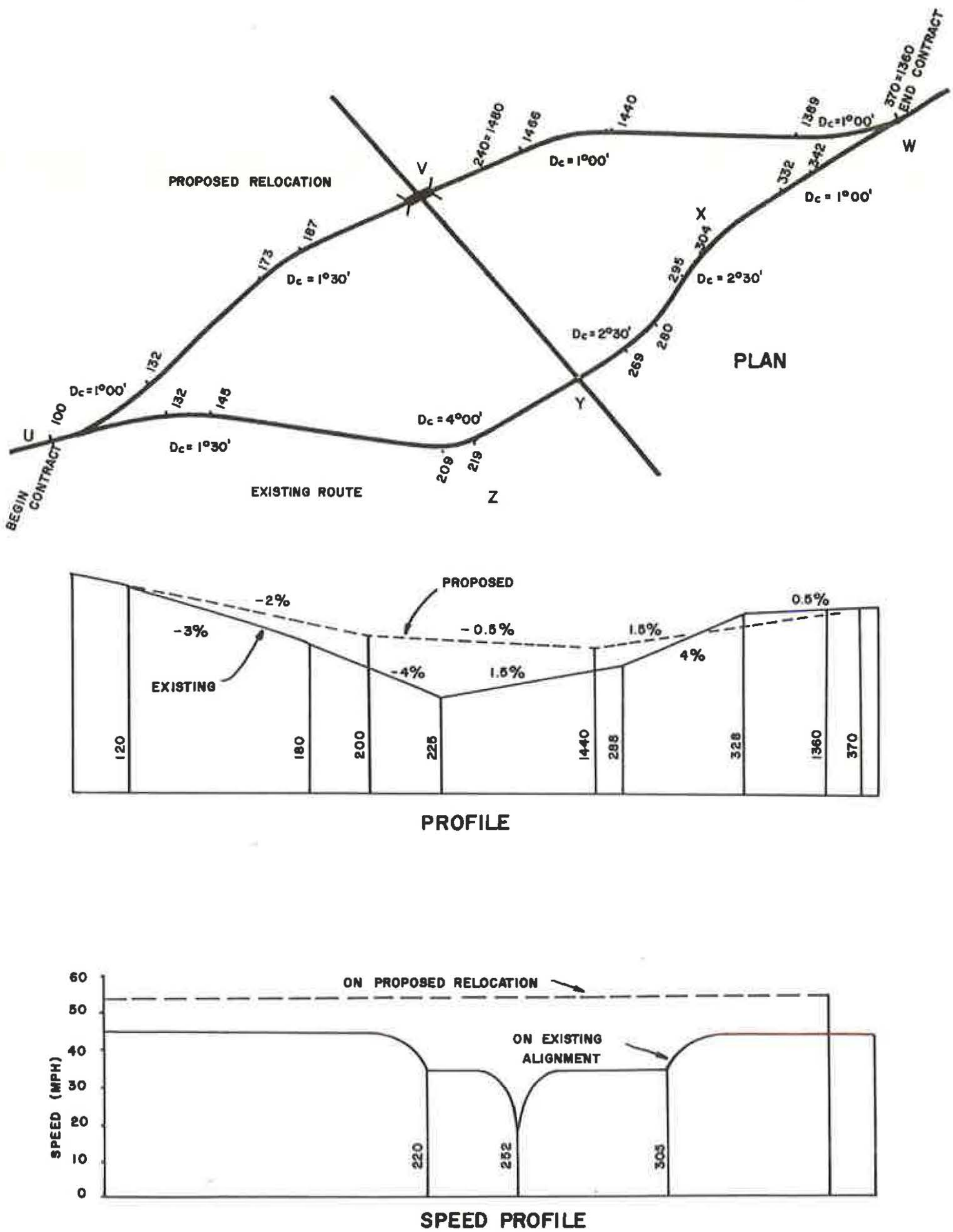

Figure 6. Sketch for example problem.

possible replacement to an existing route U-Y-W. Project life is taken as 20 years and a rate of interest of 5 percent is to be used for analysis. Both routes are two-lane highways with high standard surfacing in a rural area except for development in section X-Z. Five hundred vehicles per hour is taken as representative of the equivalent annual volume over the 20-year life of the project. [The term equivalent annual volume is commonly used to denote a weighted average volume where weighting factors are determined by the interest rate. Effectively, it is the present discounted value of all future volumes multiplied by the capital recovery factor.] The hourly volume is composed of 425 automobiles, 50 single-unit trucks, and 25 combination units. Level of service B is taken as representative of operation on proposed route U-V-W and average running speed is estimated at 53 mph. Sections U-Z and X-W on the existing facility are assumed to operate at level of service B and average running speed of 45 mph. Section X-Z provides level of service C at an average running speed of 35 mph (where flow is uninterrupted). The effect of conflict occurring in this section is to be estimated by one 10-mph speed change cycle per vehicle. That is, speed is assumed to be forced to 25 mph with immediate acceleration back to 35 mph. Stop control at intersection Y delays main-road vehicles for an average of 6 seconds.

Without attempting at this point to carry out the entire analysis, the use of the computer-generated tables can be illustrated for the case of alignment U-Y-W. Because three vehicle types and two levels of service are accounted for, a total of six operating cost tables must be consulted. Each of these tables is similar in form to Table 1. Alternatively, summary tables similar to Table 2 could be consulted.

As shown, each component of total operating costs is output for the appropriate range of speed and grade. Applying these results to the problem simply involves multiplication of computer-calculated costs by the lengths of segments of the project having uniform characteristics. The results obtained by using this procedure are given in Table 3. As indicated, all costs are shown per 1,000 vehicles using the route.

For purposes of comparison, the results of hand computation for the case of automobiles only are given in Table 4. The data necessary for these hand calculations can be obtained from a number of sources as previously mentioned or can be approximated from the series of nomographs shown in Figures 1 through 4 and similar nomographs for single-unit and combination trucks. The computer approach clearly allows for more detailed investigation of the problem by reducing both the time and tedium of calculations. If in the sample problem, for example, unit prices were expected to change over the period of analysis, Tables 1 and 2 could be regenerated by simply altering the input unit prices.

To complete the example, costs per 1,000 vehicles over both routes are given in Table 5 by consulting the appropriate operating cost tables. Costs resulting from curvature and speed changes are included (2). Multiplying these costs by the appropriate equivalent annual volumes for each vehicle type results in the total equivalent annual

TABLE 3

CALCULATION OF VEHICLE OPERATING COSTS USING COST TABULATIONS[a]

Section	Length (miles)	Percent Grade	Speed (mph)	Automobiles		Single-Unit Trucks		Combination Units	
				Cost per Mile	Cost	Cost per Mile	Cost	Cost per Mile	Cost
100-120	0.38	2.0	45	78.86	30.0	151.07	57.4	254.2	97
120-180	1.14	3.0	45	79.43	90.5	153.15	174.7	284.0	324
180-220	0.76	4.0	45	80.00	60.8	155.23	117.0	293.1	223
220-225	0.09	4.0	35	89.37	8.0	168.74	15.2	298.0	27
225-288	1.19	1.5	35	88.07	104.9	165.24	196.7	270.0	320
288-305	0.32	4.0	35	89.37	28.6	168.74	54.0	298.0	95
305-328	0.44	4.0	45	80.00	35.2	155.23	68.4	293.0	129
328-270	0.80	0.5	45	75.54	62.9	150.87	170.4	238.70	191
Subtotal					$421		$804		$1,406
Curve and speed change costs					42		106		370
Total operating cost					$463		$910		$1,776

[a]All costs are for 1,000 vehicles.

TABLE 4

HAND COMPUTATION OF AUTOMOBILE OPERATING COSTS ON TANGENT HIGHWAY, EXISTING ALIGNMENTS

Section	Length (miles)	Speed (mph)	Percent Gradient	Cost per 1,000 Vehicle-Miles (dollars)								
				Fuel	Oil	Depreciation and Parts	Labor	Tires	Travel	Total	Cost per 1,000 Vehicles ($)
1	2	3	4	5	6	7	8	9	10	11	2 x 11
100-120	0.38	45	2.0	15.80	1.65	21.10	3.28	2.50	34.40	78.73	29.95
120-180	1.14	45	3.0	16.10	1.65	21.10	3.28	2.55	34.40	79.08	90.10
180-220	0.76	45	4.0	16.62	1.65	21.10	3.28	3.05	34.40	80.10	60.90
220-225	0.09	35	4.0	15.20	1.65	22.20	2.92	2.78	44.40	89.15	8.03
225-228	1.19	35	1.5	13.90	1.65	22.20	2.92	2.50	44.40	87.57	104.20
228-305	0.32	35	4.0	15.20	1.65	22.20	2.92	2.78	44.40	89.15	28.55
305-328	0.44	45	4.0	16.62	1.65	21.10	3.28	3.05	34.40	80.10	35.20
328-370	0.80	45	0.5	15.50	1.65	21.10	3.28	2.37	34.40	78.30	62.60
Total cost per 1,000 vehicles											419.5

TABLE 5

SUMMARY OF ROAD USER COSTS

Vehicle	Equivalent Volume	Existing Route		Proposed Route	
		Dollars per 1,000 Vehicles	Total Cost (dollars)	Dollars per 1,000 Vehicles	Total Cost (dollars)
Passenger	425	463	1,720,000	372	1,385,000
Single-unit	50	910	400,000	743	325,000
Combination	25	1,776	390,000	1,320	290,000
Totals			2,510,000		2,000,000

operating costs. The annual operating cost savings for the proposed route ($510,000) can then be compared with the capital cost of the improvement. For a 20-year life and 5 percent rate of return these savings would justify a capital improvement of approximately $6.3 million.

CONCLUDING REMARKS

The purpose of introducing the example has been to illustrate application of the tables generated by the computer. However, it is important to note that this is not intended to be a computer model that is run every time a problem is encountered that requires the use of operating cost data. Basically, this program is intended to be used as a substitute for continuously updating such operating cost sources as the AASHO Red Book. In other words, it should be used to generate a series of tables covering a wide range of operating conditions (speed, grade, level of service) for a vehicle fleet that is typical for a particular region. Periodically, as either prices or composition of the vehicle fleet change, new sets of tables could be regenerated and used to assist in what would otherwise be a hand calculation of operating costs.

REFERENCES

1. Wohl, M., and Martin, B. V. Evaluation of Mutually Exclusive Design Projects. HRB Spec. Rept. 92, 1967.
2. Clark, G. A. A System for Computation of Motor Vehicle Operating Costs. Dept. of Civil Engineering, Univ. of Toronto, Master's thesis, 1968.

3. de Weille, Jan. Quantification of Road User Savings. World Bank Staff Occasional Papers, No. 2, Johns Hopkins Press, Baltimore, 1967.
4. Lang, A. S., and Robbins, D. H. A New Technique for Predicting Vehicle Operating Costs. HRB Bull. 308, 1962, pp. 19-35.
5. Roberts, P. O., and Soberman, R. M. A Vehicle Performance Model for Highways in Developing Countries. Traffic Quarterly, Vol. 21, No. 3, July 1967, pp. 443-462.
6. Highway Capacity Manual—1965. HRB Spec. Rept. 87, 1965.