Statewide Transportation Analysis & Research

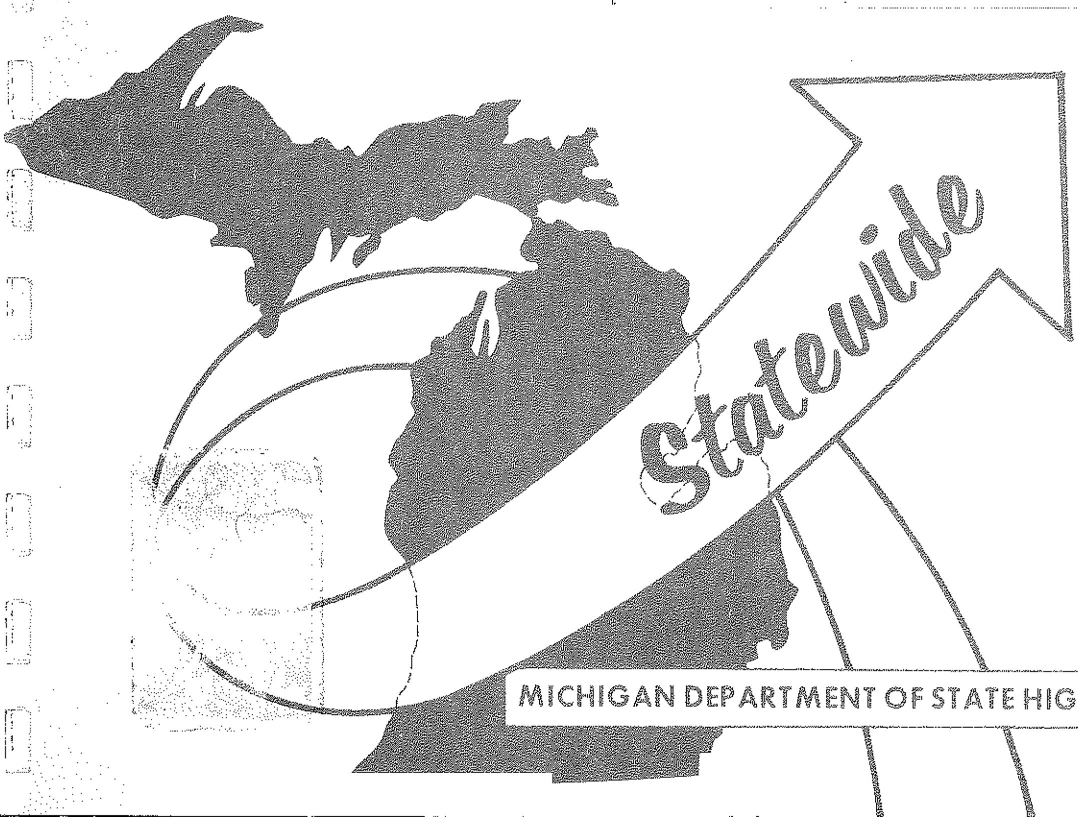
MICHIGAN'S STATEWIDE
TRANSPORTATION MODELING
SYSTEM

VOLUME I-E

**MODEL APPLICATIONS:
COST-BENEFIT ANALYSIS**

STATEWIDE RESEARCH AND DEVELOPMENT

REVISED NOVEMBER, 1974



MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

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STATE HIGHWAYS AND TRANSPORTATION

BUREAU OF TRANSPORTATION PLANNING

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STATE OF MICHIGAN

WILLIAM G. MILLIKEN, GOVERNOR

DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

STATE HIGHWAYS BUILDING - POST OFFICE DRAWER K - LANSING, MICHIGAN 48904

JOHN P. WOODFORD, DIRECTOR

November 5, 1974

Mr. Sam F. Cryderman
Deputy Director
Bureau of Transportation
Planning

Dear Mr. Cryderman:

The Highway Planning Division is pleased to present a revised version of Volume I-E in the Statewide Transportation Modeling System series. It describes the interfacing of a Cost-Benefit Analysis process with the Statewide Traffic Forecasting Model. This version contains an expanded section on running the model, plus an appendix devoted to the equations used within the program.

The cost-benefit process offers the capability of comparing user benefits and capital costs of alternative transportation plans quickly and efficiently and to calculate their net present worths at a variety of interest rates. Summaries can be generated at the county, regional, or statewide level. This may provide a means of addressing the dual issues of increased public involvement in the planning process and more rapid analysis of economic impacts of travel.

Sincerely,

Richard J. Lilly, Administrator
Highway Planning Division

MODEL APPLICATIONS: COST–BENEFIT ANALYSIS

by

Terry L. Gotts

Revised November, 1974

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PREFACE

PREFACE

Recent Federal legislation demands that Departments of Transportation must consider the public's need for "fast, safe, and efficient" transportation in evaluating alternative highway plans. At the same time, the increased stress on public involvement in the transportation planning process increases greatly the number of alternatives which must be considered in any given project. Finally, impacts are to be identified and measured early enough in the planning process so that they can influence the formulation of later alternates. It would appear that the only feasible means of satisfying all the requirements is an automated method of comparing the economic effects of travel on various plans, and of summarizing these effects at a variety of levels. The interface of a benefit-cost analysis model with the Statewide Transportation Modeling System is offered as a partial solution to this apparent dilemma.

This report updates Volume I-E in the Statewide Travel Modeling System series of reports. The complete series is as follows:

Volume	I	Objectives and Work Program
Volume	I-A	Region 4 Workshop Topic Summaries
Volume	I-B	Single and Multiple Corridor Analysis
Volume	I-C	Model Applications: Turnbacks
Volume	I-D	Proximity Analysis: Social Impacts of Alternate Highway Plans on Public Facilities
Volume	I-E	Model Applications: Turnbacks
Volume	I-F	Air and Noise Pollution System Analysis Model
Volume	I-G	Transportation Planning Psychological Impact Model
Volume	I-H	Level of Service Systems Analysis Model: A Public Interaction Application
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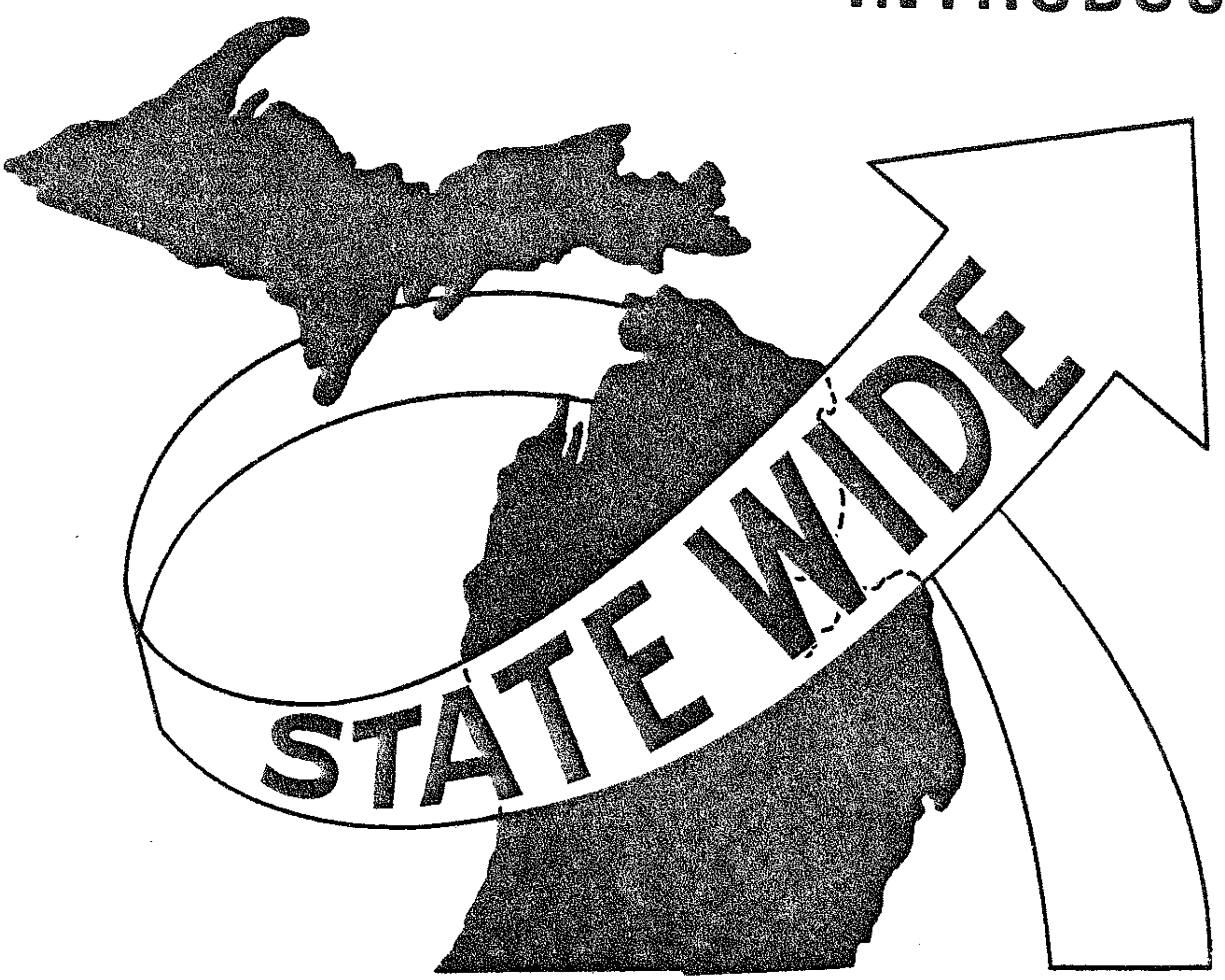
Volume	XI	Computer Run Times - An Aid in Selecting Statewide Travel Model System Size

INTRODUCTION



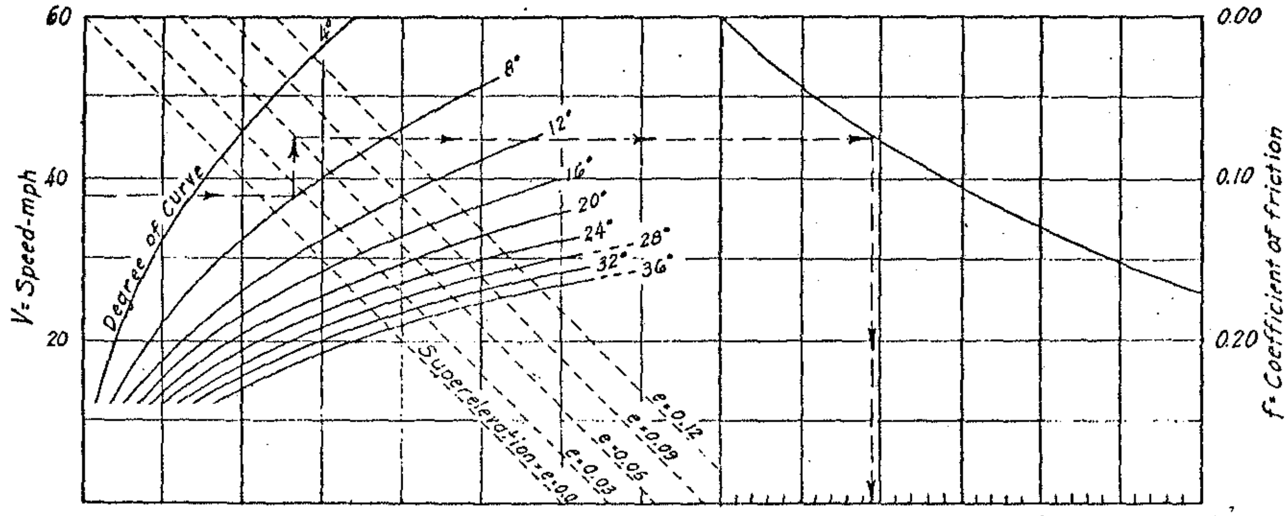
INTRODUCTION

For many years, cost-benefit analysis has been used in transportation planning as well as in business. Transportation management has soundly reasoned that a specific improvement in a highway network should not be made unless it could reasonably be expected to pay for itself in long-term benefits to the taxpayer. However, a single new freeway can produce monumental changes in existing travel patterns throughout a road network; it is therefore misleading to speak of benefits gained by a small part of that network to the exclusion of all other parts. Until now, the means have not been at hand to solve this dilemma and to make cost-benefit analysis a working tool of the transportation planning process. With this in mind, Statewide Studies began looking for an acceptable means of merging this economic analysis with the traffic forecasts of the Statewide Model.

In a review of existing literature and models, five basic sources should be discussed separately:

A. "Road User Benefit Analysis for Highway Improvements"; American Association of State Highway Officials (AASHO) part 1, 1960.

This is by far the oldest source consulted. It is mainly a pencil-and-paper oriented study method, whereby a highway engineer or analyst consults a series of curves like those in Figure 1 to convert road characteristics to user costs and benefits. In and of itself, this is not necessarily bad; however, the functional relationships given are old and not necessarily valid today. Also, the method depends upon the



Computed by Standard Curve Formula

$$e+f = \frac{V^2 D}{5730 \times 15}$$

Percent of operating cost on tangents

Example: Assume 38 mph operation on 8° curve, 0.06 superelevation. Follow arrows and read 109.50 % as the factor to apply to correct the tangent road user cost values.

RELATION BETWEEN OPERATING COSTS ON CURVES AND ON TANGENTS

Figure 5

assumption that the nature of traffic on the alternatives is basically similar; it would not permit, for example, the study of whether or not to build a truck route to divert slower vehicles from an overloaded main trunkline. The alternates must be similar in terrain and design conditions to be comparable by the AASHO method. Thus the method is "not suitable for priority determination of projects on an area or state-wide basis".

Finally, some of the economic principles are somewhat shaky, as past review by various economists has indicated. The writers note that there is some resistance to the use of interest rates in computing capital cost, since "some have found it possible to construct and operate their highways on a cash basis". Also, it is remarked that "road user benefit analysis might be made without inclusion of interest, with resultant higher benefit ratios". However, it is not economically sound to use a zero rate of interest, for this disregards completely the opportunity value of capital. The Red Book is now in the process of being updated by the Stanford Research Institute.

B. Robley Winfrey, Economic Analysis for Highways; International Textbook Company, 1969. (Note: Robley Winfrey is a Highway Engineering Consultant. He was formerly Professor of Civil Engineering at Iowa State University).

Professor Winfrey has devoted this excellent textbook to placing highway economic analysis on a firm footing. Beginning with basic concepts in principles of engineering economy, he proceeds to identify highway benefits and costs and to begin to analyze them within the framework of "consumer surplus", that is, amount of value in excess of cost. In order to evaluate this consumer surplus (which may, incidentally, be negative, indicating costs which surpass value accrued), the concepts of compound interest and discounting are introduced. Winfrey then goes into deeper detail in describing highway costs (including accident "costs") both those costs related specifically to the road itself and those related to the type of vehicle being driven. He concludes with tables of running costs of motor vehicles and standard compound interest, arithmetic gradient and exponential growth factors.

C. "Summary and Evaluation of Economic Consequences of Highway Improvements", HRB Report 122, 1971.

This source covers much of the same ground as the Winfrey book (since Winfrey was a principal investigator here also) but explores in more depth the concept of cost-effectiveness. Cost-effectiveness takes the position that since not all benefits and adverse consequences of proposed highway changes can be described only on a qualitative basis. The report also focuses on the decision-making process and the factors managers must weigh in approving one alternative transportation plan over another.

D. Highway User Investment Study; by the Statewide Highway Planning Division of the Office of Highway Planning, Federal Highway Administration.

In 1972, after the Federal Needs study, the FHA produced a benefit-cost and cost-effectiveness program as a part of their report to Congress on the highway needs of the nation. It takes in a list of deficiencies for each needs section, supplements it with such input as accident rates, vehicle speed change (as well as stop and delay) factors, and daily train frequencies, and produces for each section a benefit/cost ratio. the cost-effectiveness summaries are formed by simple accumulation on a section; benefit/cost ratios are generated by assigning dollar values and then discounting to net present worth, using a twenty-year study period. The program details the following:

(i) Benefits: accident reduction, operating cost savings, time savings maintenance and administrative savings, and total benefits

(ii) Net costs

(iii) Net present worth

(iv) Benefit-cost ratio

E. "Benefit-Cost analysis of the Proposed Post-1977 Highway Construction Program"; Stanford Research Institute, Menlo Park, California, 1971.

This report presents an analysis of the user effects of a set of highway projects proposed by the Michigan State Highway Commission. The analysis proceeds using a program, developed by SRI, called HiBenCo, which provides the same sort of benefit-cost summaries detailed above in the FHA program. In addition, HiBenCo has the additional advantage of being project-oriented: it has the capability of analyzing groups of improvements which are not only not a part of the same road section but may be separated by a large distance. In short, HiBenCo exhibits the potential for allowing a decision-maker to monitor the <u>entire system</u> which falls under his care. It allows him to document more fully the farsightedness of his decisions.

Whichever form of economic analysis was chosen, maximum efficiency demands that it be amenable to interfacing with the Statewide Transportation Modeling System. The present model uses 547 zones (See Figures 2 and 3) with the associated highway network depicted in Figure 4. It should also be able to be summarized by areas such as the county-level system generated by Segmental Model, which is shown in Figure 5. With these basic requirements in mind, the next step is the actual selection of analysis method.

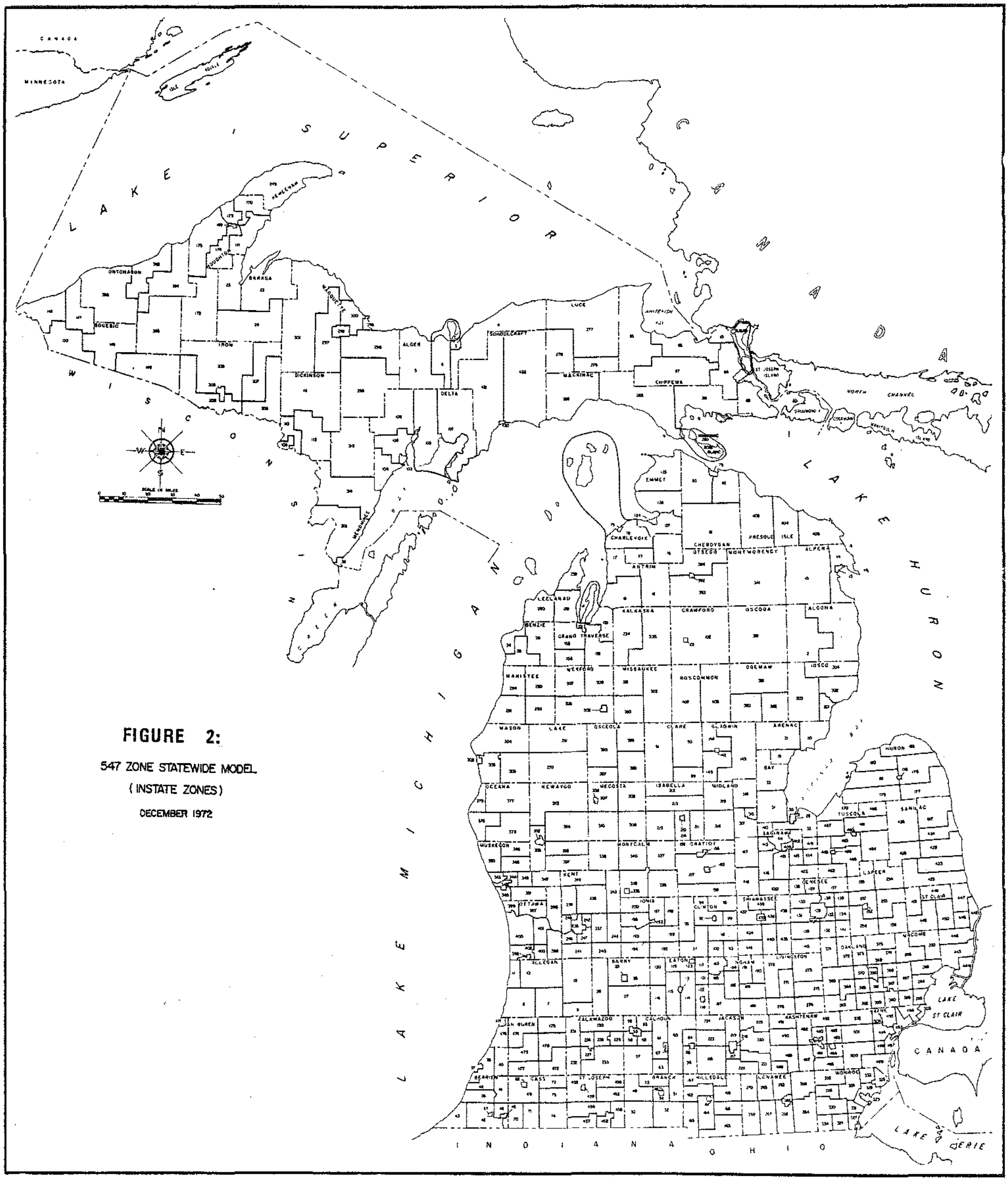


FIGURE 2:

547 ZONE STATEWIDE MODEL
(INSTATE ZONES)
DECEMBER 1972

FIGURE 3:

MICHIGAN'S TRANSPORTATION MODELING SYSTEM

547 ZONE
OUTSTATE ANALYSIS ZONES

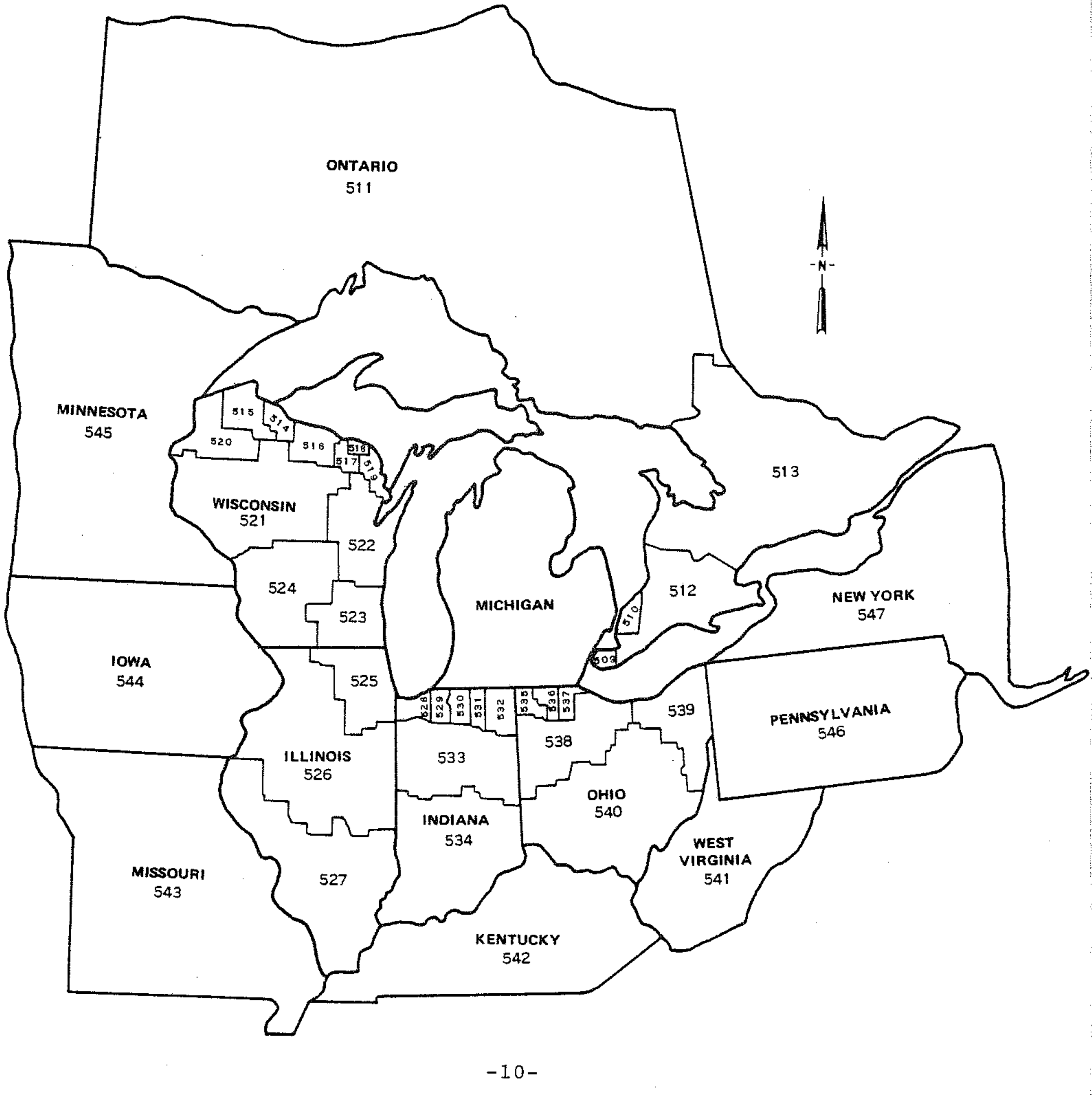


FIGURE 4:

MICHIGAN'S STATEWIDE TRANSPORTATION MODELING SYSTEM

1970 HIGHWAY NETWORK

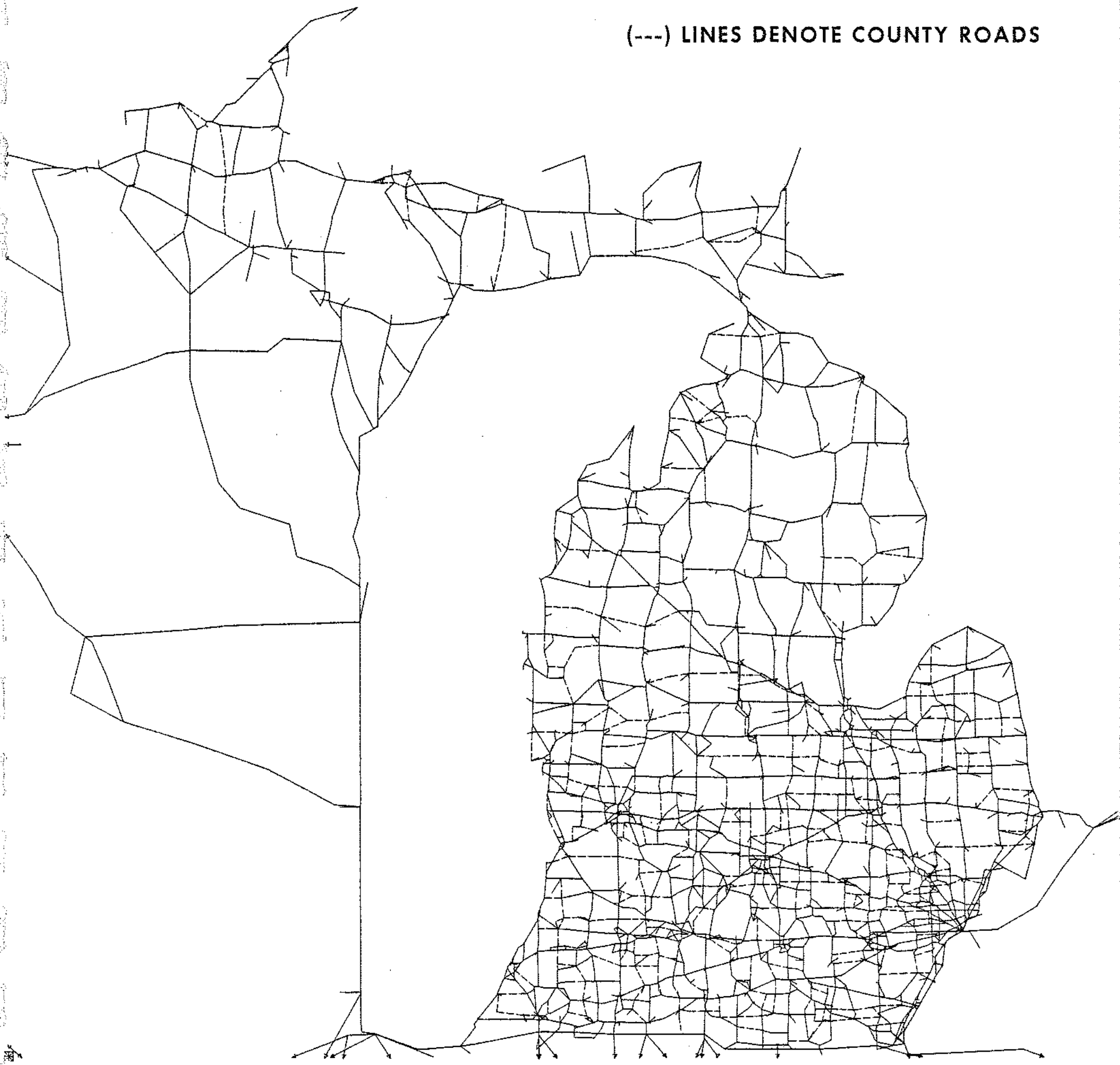


FIGURE 5: COUNTY-LEVEL ZONE SYSTEM

CHOICE OF ANALYSIS METHOD

CHOICE OF ANALYSIS METHOD

Cost-benefit analysis, by its very nature, aims at identifying "high payoff" projects whose benefits per unit cost are greatest. In highway terms, such projects are those that minimize total transportation cost, that is, both road and user costs. Therefore, it deals in general with consequences of road development to which it is possible to assign dollar values. Social and economic consequences of such developments are the province of cost-effectiveness analysis.

In order to use effectiveness analysis, the planner should have in mind an objective or goal which he wished his new development to achieve. The cost-effectiveness process then compares a series of alternative plans by contrasting, for each plan, the costs of gaining the objective with the extent to which the plan approaches the goal. A distinguishing feature of effectiveness analysis is that it does not lead to economic evaluation in the same sense as does engineering economy analysis. Neither is there a precise way to apply it to the project formulation of an engineering design. Because the items subject to a cost-effectiveness approach often cannot be priced either on the cost or the benefit side and sometimes even defy any quantification, they must often be evaluated largely on their own merits and in terms of the overall goals of the community and the public's preferences with respect to social and economic values.

Thus, cost-benefit analysis and cost-effectiveness analsis are not anthithetic. Rather, they should be used to complement one another in the decision-maker's economic analysis. The area of cost-effectiveness analysis is addressed by Proximity Analysis, which had been defined and implemented by Statewide previously. Therefore, the unit initially chose to direct its efforts to the development of a viable cost-benefit analysis system which may be easily integrated with the traffic forecasts of the Statewide Travel Modeling process.

Two basic criticisms of cost-benefit analysis are raised in several sources, most recently in Harvey (8). The first source of ambiguity is inherent in the name "benefit/cost ratio". One implicitly assumes that all costs should be in the denominator, and that is where they are placed in the AASHO "Red Book" version. However, the problem may be confused by combining a "one-time" cost like capital outlay with an ongoing cost like maintenance; maintenance costs more closely resemble other user costs, such as time and operating costs. Thus the increase in maintenance costs when a new expressway is to be built would represent a negative benefit, and should accordingly be included in the numerator, not the denominator. The cost-benefit routine described here follows Harvey's suggestion: only incremental capital costs appear in the denominator of our benefit/cost ratio.

The other criticism has more to do with how cost-benefit techniques are applied in many instances than with the underlying economic theory. Many users do not consider the fact that when more han one alternative is considered, the incremental benefits and costs used to calculate the benefit/

cost ratio for each alternative are the differences in benefit and cost between the alternative and the do-nothing, or neutral, alternative. Therefore, when the initial set of benefit/cost ratios have been computed, nothing has yet been done about comparing the alternatives among themselves. This may lead to an erroneous conclusion, since saying that A has a higher benefit/cost ratio than B or C is simply saying that A is preferred most strongly to the neutral alternative. In order to be sure that A is the correct choice, it is necessary to directly compare A to B and C and to ascertain that A actually is preferred to B and C. This is done by using A as the new alternative and calculating the benefit/cost ratios of B with respect to A and C with respect to A. Most writers refer to this as the "incremental approach"; it is a form of marginal analysis. Harvey (6), p. 83 states that "it appears that the use of the incremental approach resolves the ambiguities indicated by both of the major sources of confusion regarding the benefit/cost ratio."

One additional word on the decision-making process is also in order here. Cost-benefit analysis and cost-effectiveness, too, have at various times and by various people either been denounced as useless or hailed as the ultimate solution to the decision problem. They are neither. Both views arise from a less-than-thorough understanding of these management tools. When the procedures of cost-benefit analysis are correctly applied, the answer to the question of priorities is reliable. However, it must be understood by all concerned that one cannot substitute the results of the analysis for the decision itself; in order to arrive at an objective, rational decision, a manager is obligated to use all pertinent information at his disposal, including cost-benefit analysis.

If one were to categorize the areas in which a decision maker needs effective information, four might be listed: traffic, engineering, cost-effectiveness (including environmental factors), and cost-benefit analysis. All too often, decisions have had to be made using only the first two or possibly three. But without careful analysis of the fourth, how can a highway planner be sure that he is allocating his resources in the most efficient manner? The process presented here is offered as a means of closing this information gap.

PROGRAM DEVELOPMENT

PROGRAM DEVELOPMENT

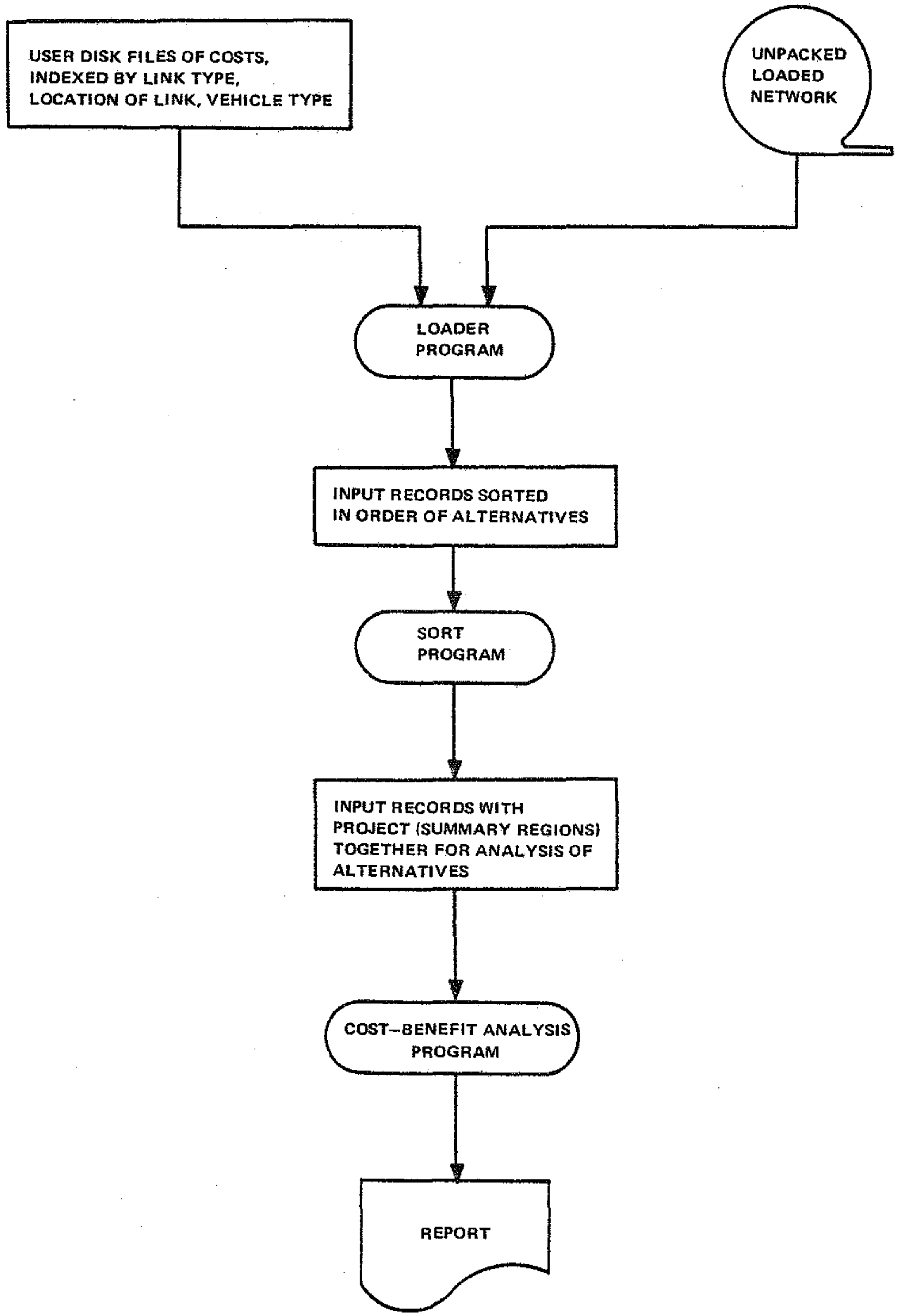
Faced with the need for an economic analysis program, only two courses of action were feasible. Either a new computer program depending upon the Statewide model could be developed, or an existing program could be adapted to, and interfaced with, the Statewide Transportation Modeling System. Since HiBenCo seemed to hold the potential for providing the sort of answers which were needed, it was decided to adopt the second alternative.

The adaptation process occurred in three phases. First, the program deck was obtained (it had originally been sent to the now-defunct Interagency Transportation Council, under whose auspices the SRI study had been done). It was then converted from the FORTRAN-IV language as used on the CDC-6400 computer to the type of FORTRAN-IV used on the MDSH Burroughs B-5500. In this version, provision had been made for a maximum of only ten segments (links) per segment group.

Phase two of the adaptation was to allow the program to provide cost-benefit summaries by summary regions, usually by county or group of counties. Thus a decision-maker would be able to review at a glance the effect of a proposed highway on the accumulated mileage of any county or region of the state. Of course, the user may again specify the time period he wishes to use in considering costs and benefits, and, as before, all figures are specified at three different interest rates (which may also be specified by the user, if he chooses). Details of the process appear in the section on program operation.

Finally, it was necessary to write two routines to create the files for the benefit-cost program to use. The loader program (see figure 6 for data flow detail) strips link-specific information and traffic off an unpacked, loaded Statewide model network and combines it with time and running costs for various vehicle types, accident rates, maintenance costs, etc., to form a basic file. An example of the input and output of the loader program is shown in Figure 6a. The records are then sorted by project number, where the summary region appears as the last two digits of the project number, to create a file which can be input to the benefit-cost program to generate alternative comparisons by summary region, up to ten alternatives per region.

FIGURE 6: DATA FLOW



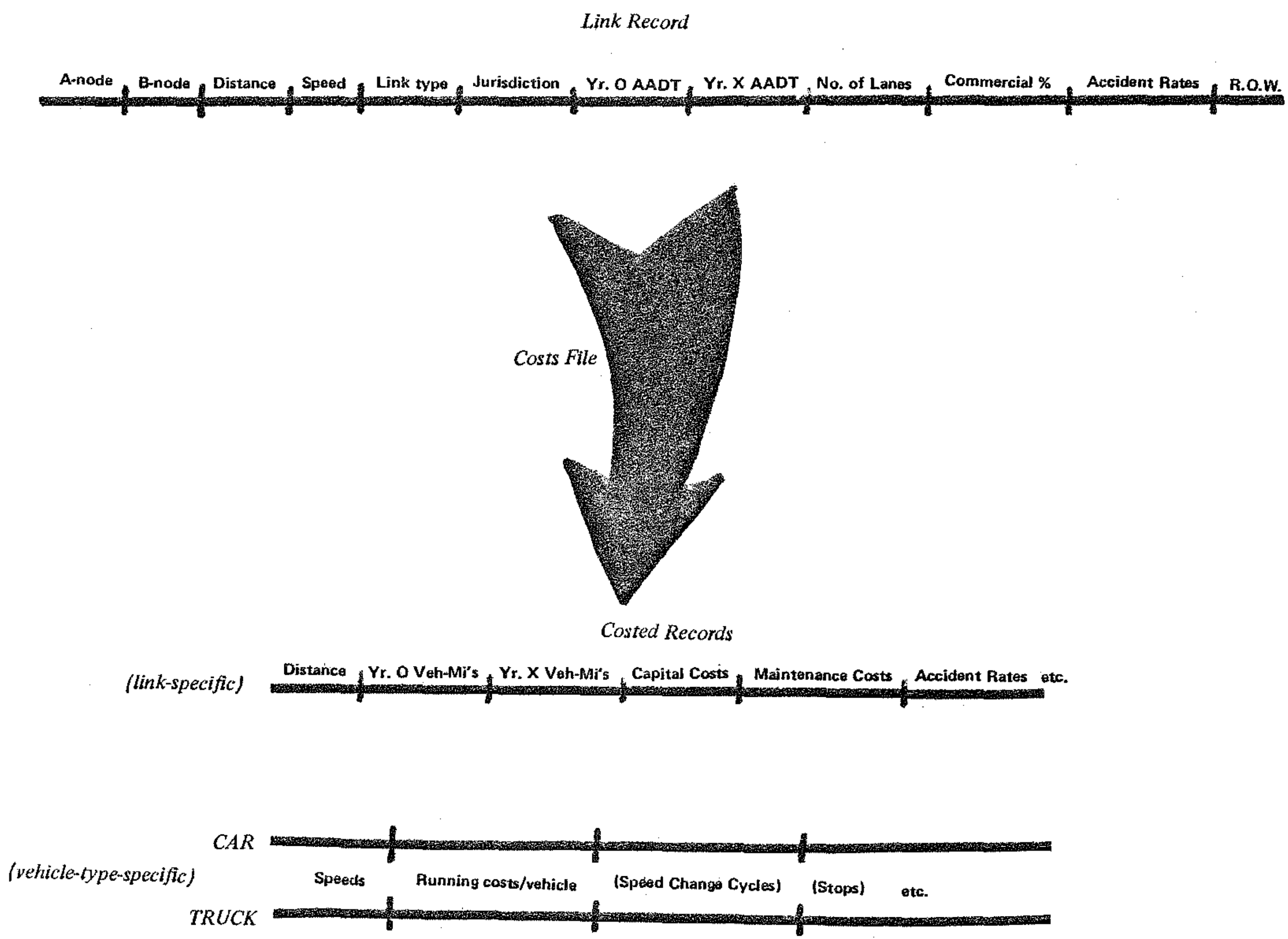
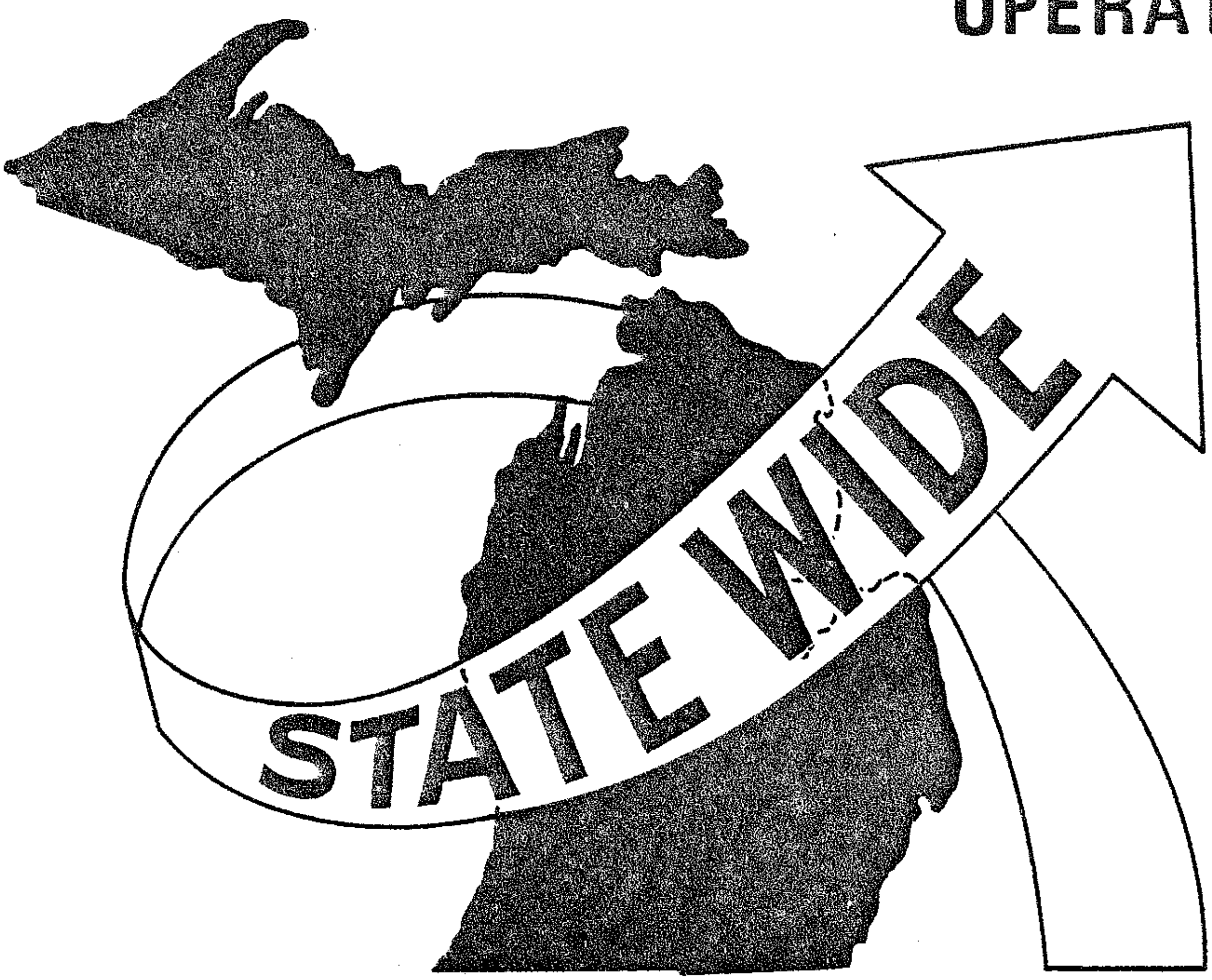


FIGURE 6a: FUNCTION OF LOADER PROGRAM

PROGRAM OPERATION



PROGRAM OPERATION

The basic method of obtaining economic input is to estimate costs and cost factor data for a period midway in the life of the project. This data is then applied to traffic levels over the entire project life. In general, the "life" of the project--that is, the period of time after the original construction that all segments of the proposed route can reasonably be expected to provide good service with no major maintenance--should be taken as no more than ten years more than the period of traffic estimation. For example, if the "study period" is taken to be 1975-1995, traffic forecasts should be made for 1985, ten years in the future. SRI recommends that the study period be taken as 20 years.

The program permits the user to specify three interest rates in order to compute compound interest factors. These factors recognize that money earns interest, and so a dollar put in the bank today will be worth more than a dollar put in the bank ten years from today, if both are allowed to accumulate compounded interest until twenty years from now. It is thus necessary to convert future costs, once calculated, into their present worth; it is on this present worth that the benefit/cost ratio and consumer-surplus summary are calculated. Details of the equations used in the process can be found in the Appendix to this report.

The choice of interest rates is a very controversial subject. Normally, an economic analyst chooses an interest rate and then "brackets" his choice with one higher rate and one lower rate; besides giving him the highest and lowest benefit/cost ratio he can reasonably expect, this "bracketing" also allows him to see how sensitive his project costs are to fluctuations in interest rates.

Finally, since for accuracy road user benefits should not be extrapolated past the study period, the SRI program makes the simplifying assumption that after the study period, the road has no residual value. Such things as right-of-way clearly continue to have value even after the road has disintegrated; however, other sensitivity analyses cited in the SRI manual above indicate that the residual value of an alternative plays a relatively minor role in its economic attractiveness. This is also apparent intuitively: given two sections of road of the same length in the same general area such that the wearing course of each has ceased to be functional, what is left should be of approximately equal value. Thus, comparing residual values should not have much effect. SRI comments that "nonzero assumptions (of residual costs) would increase the attractiveness of projects by minor amounts".

The following data must be input to the process:

A. For each link of each alternative:

(1) Project length

(2) Capital Cost

(3) Annual maintenance cost

(4) Base year ADT

(5) Number of years past base year of traffic forecast ("year X")

(6) Year X ADT

(7) Percent trucks

(8) Fatal, injury and property-damage accident rates

(9) Average costs per accident for each accident type

B. For each vehicle type of each link:

(1) Year X speed

(2) Speed change cycles and stops per vehicle-mile

(3) Tangent running cost

(4) Stopping cost*

(5) Speed change cost*

C. For the entire study, taken as a whole:

(1) Interest rates

(2) Values of time for up to 5 vehicle types

(3) Ideling time cost for up to 5 vehicle types*

(4) Life of study

A more detailed discussion of the various costs can be found in the SRI HiBenCo report (5). The starred costs are not presently used; however, the machinery exists to use them when data becomes available.

The details of the actual steps the program takes in calculating a benefit/cost ratio are found in the accompanying flow chart, Figure 7; discussion of the compound interest

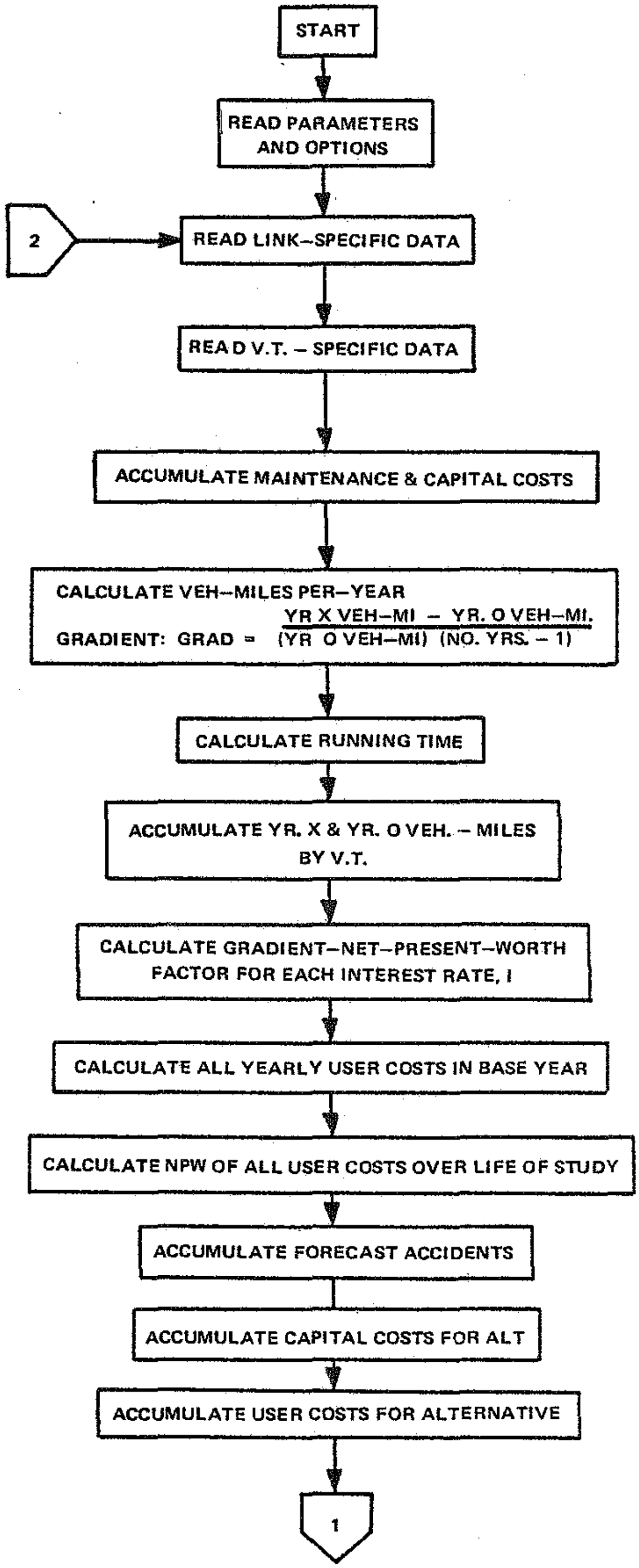
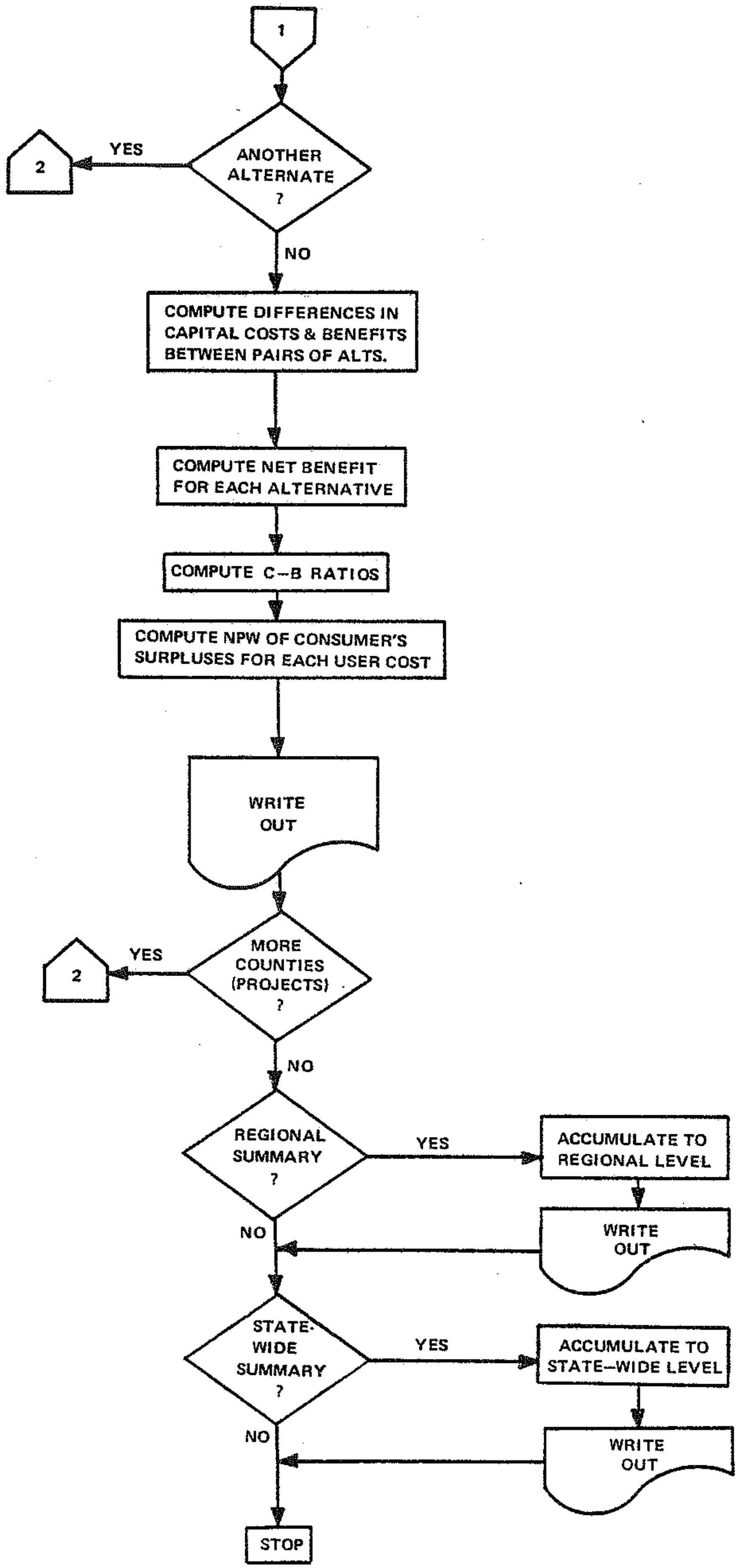


FIGURE 7: PROGRAM LOGIC


1
ANOTHER ALTERNATE ?
YES
2
NO
COMPUTE DIFFERENCES IN CAPITAL COSTS & BENEFITS BETWEEN PAIRS OF ALTS.
COMPUTE NET BENEFIT FOR EACH ALTERNATIVE
COMPUTE C–B RATIOS
COMPUTE NPW OF CONSUMER'S SURPLUSES FOR EACH USER COST
WRITE OUT
MORE COUNTIES (PROJECTS) ?
YES
2
NO
REGIONAL SUMMARY ?
YES
ACCUMULATE TO REGIONAL LEVEL
WRITE OUT
NO
STATE-WIDE SUMMARY ?
YES
ACCUMULATE TO STATE–WIDE LEVEL
WRITE OUT
NO
STOP

equations used in the program can be found in Winfrey (10), chapter 6 ("Compound Interest Equations"), pp. 82-93.

The program calculates, for each summary area (county, region, or state) and each interest rate, the net present worth of the following costs for each alternative:

(1) Auto running costs

(2) Auto time cost

(3) Truck running costs

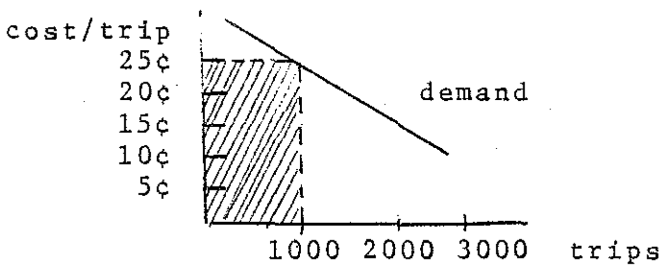
(4) Truck time costs

(5) Accident costs

(6) Capital costs

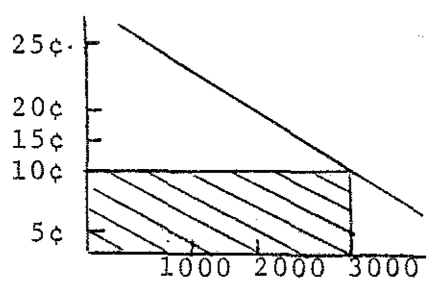
It then contrasts these costs for each alternative with those for the do-nothing alternative ("alternative 0").

If the user so requests, the program also outputs "consumer surplus" calculations. Consumer surplus refers to value received in excess of the price paid by consumers. As an example, suppose a two-lane road with frequent speed changes is replaced by a freeway; although the higher freeway speed means a higher tangent running cost in general, this is offset by shorter travel time and fewer accidents, so net user cost may decrease. Suppose the average price of a trip on the old road was \$.25, but is only \$.10 on the new. The utimate result is that the average trip through the link costs less, and so more people are willing to use the link: the demand on the link rises say from an ADT of 1000 trips/day on the old road to an ADT of 3000 trips/day of the new road. Now if those 1000 people who were willing to pay \$.25 to drive on road can now get where they are going for \$.10, they are getting a \$.25 value for a \$.10 price--their consumer surplus is \$.15 per trip. Suppose additionally that if the price on the old road had been \$.20 that 2000 trips would have used the road, an increase of the demand at \$.25 of 1000 trips. With the new road, some of those people are getting what they consider a \$.20 value for \$.10, and their consumer surplus is \$.10. The consumer surplus for the new road is most easily shown by a sequence of diagrams:



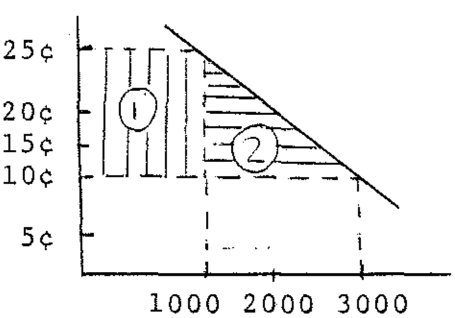
(1) User cost on old road

= (1000) (\$.25)=\$250



(2) User cost on new road

= (3000) (\$.10)-\$300



(3) Consumer Surplus= (1) & (2)

= (1000) (\$.15)+½(2000) (\$.15)

= \$150 + \$150 = \$300

FIGURE 8

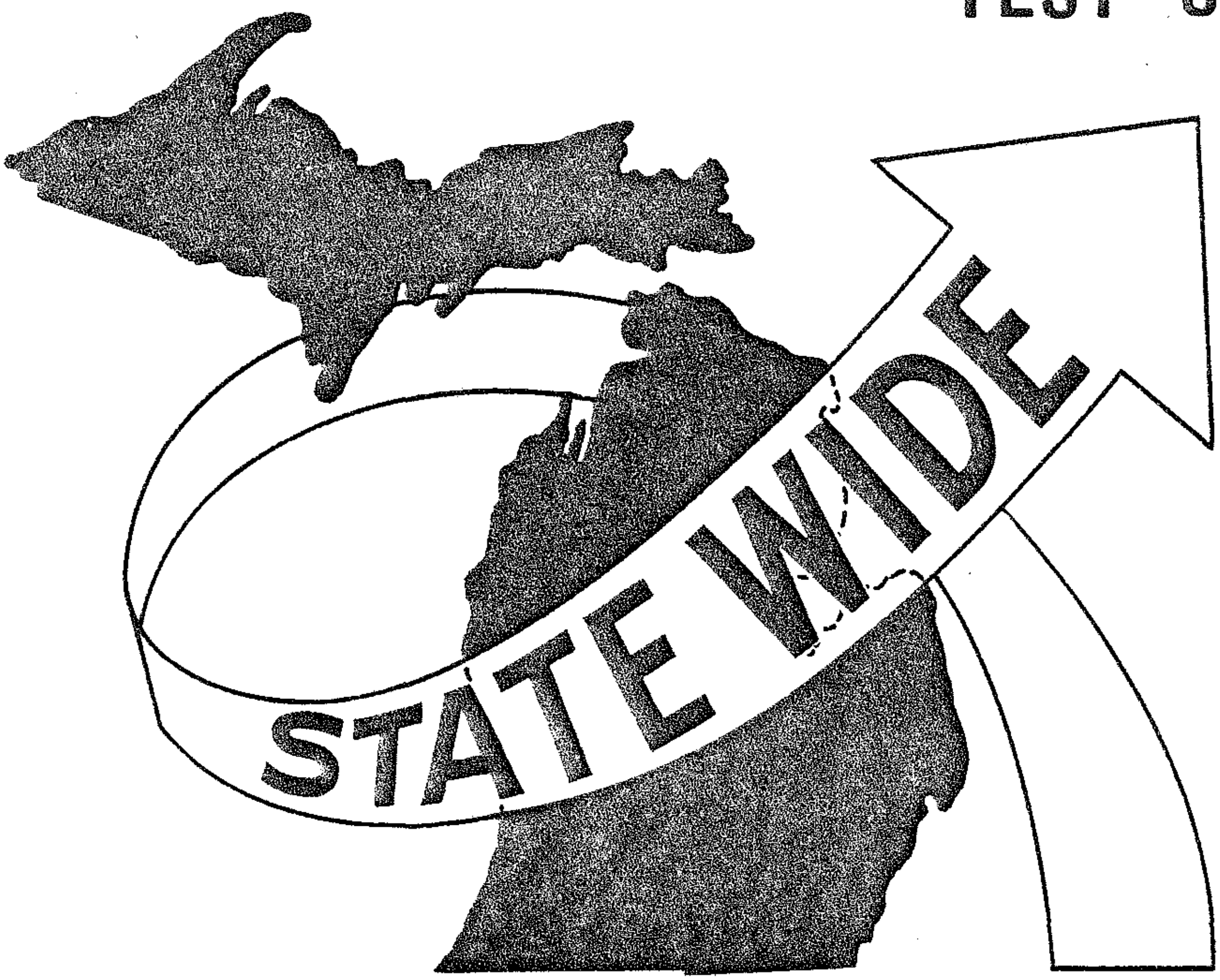
Consumer surplus is therefore a means of identifying and quantifying the additional benefits gained through induced traffic, that is, trips which would not have occurred at all had the new road not been built. Of course, the only way to know whether the increased flow comes from induced or diverted traffic is to estimate volumes and perform cost-benefit analysis for the entire network (or at least the network in the vicinity of the links) and for that we need the Statewide traffic forecasting model. If the reader wishes to pursue the subject of consumer surplus in more detail, he would be well-advised to consult Winfrey (10), chapter 4 (pp. 49-66).

There is an additional advantage to the inclusion of consumer-surplus calculations. The very existence of a benefit/cost ratio calculated for a summary region presupposes that there will be capital expenditure in that region for at least one alternative plan. If it becomes necessary to make cost-benefit comparisons at a very fine level, this procedure allows the comparisons to be made on a consumer surplus basis when benefit/cost ratios cannot be calculated for all summary regions. For more detailed information on consumer-surplus based inference, consult Harvey (6).

(A warning is in order here. Unless traffic is estimated on proposed links in the base year (before they have been built), it is possible to get a specious negative value for consumer's surplus, especially if the proposed alternative includes some abandonments. In such a situation, the use of consumer's surplus calculations is <u>not</u> recommended.)

Finally, the program estimates the number of accidents on each alternative in each project (summary area) in year X and summarizes these in a table by accident type and alternative.

TEST CASE



TEST CASE

The test case consists of comparing five preliminary alternative highway building plans with the "do-nothing" alternative, hereafter referred to as "alternative 0 (zero)". This technique of comparison with a do-nothing alternative follows the action plan guidelines set down by the Federal Highway Administration. Alternate 0 is just the basic highway network depicted in the network plot of Figure 4. For ease of reference, the base network as it would appear on a highway map is shown in Figure 9.


FIGURE 9: DO-NOTHING ALTERNATE
LAKE SUPERIOR
CANADA
WISCONSIN
LAKE MICHIGAN
LAKE HURON
INDIANA
OHIO
LAKE ERIE
DETROIT
ONTARIO
CANADA
DETROIT METROPOLITAN AREA

The five alternates differ only inside a ten-county region. Therefore, only that region will be shown. A detail of the region for the do-nothing is shown in Figure 10. Figures 11-a through 11-e depict the proposed configurations of alternates 1,2,3,4 and 5 in order of increasing capital cost. In these illustrations, new freeways are shown as solid, heavy lines; new two-lane roads are denoted by heavy dashed lines.

In considering the outputs, two levels of contrast will be given. First, the five plans will be compared on the basis of their impact on one county, Manistee County. Next, the impact on the region will be shown for each plan. The effect of each of the states as a whole could also be considered, if desired; it is not included here. For brevity, only a 7% rate of interest will be shown. Consumer's surplus calculations were not made for this example, because base-year observed traffic data was used for existing links in lieu of a base-year traffic assignment on each alternative.

Refer now to Figure 12a-b, the comparisons for Manistee County. The heading in Figure 12a states that for project 2122110051, the proposed improvement is "new construction" of Federal-Aid primary (FAP) roads other than Interstate. The next two lines of the heading refer only to alternative 0, the do-nothing; there are 80 miles of state trunkline ("length") in the county; the interest rate under consideration is 7%, and the value ascribed to passenger-car travel time is $2.50/hour. In the base year (1970) Manistee County had 200,000 vehicles-miles on trunkline on an average day, and thirty years later (1970 + 30 = 2000) there will probably be 300,000 vehicle-miles in

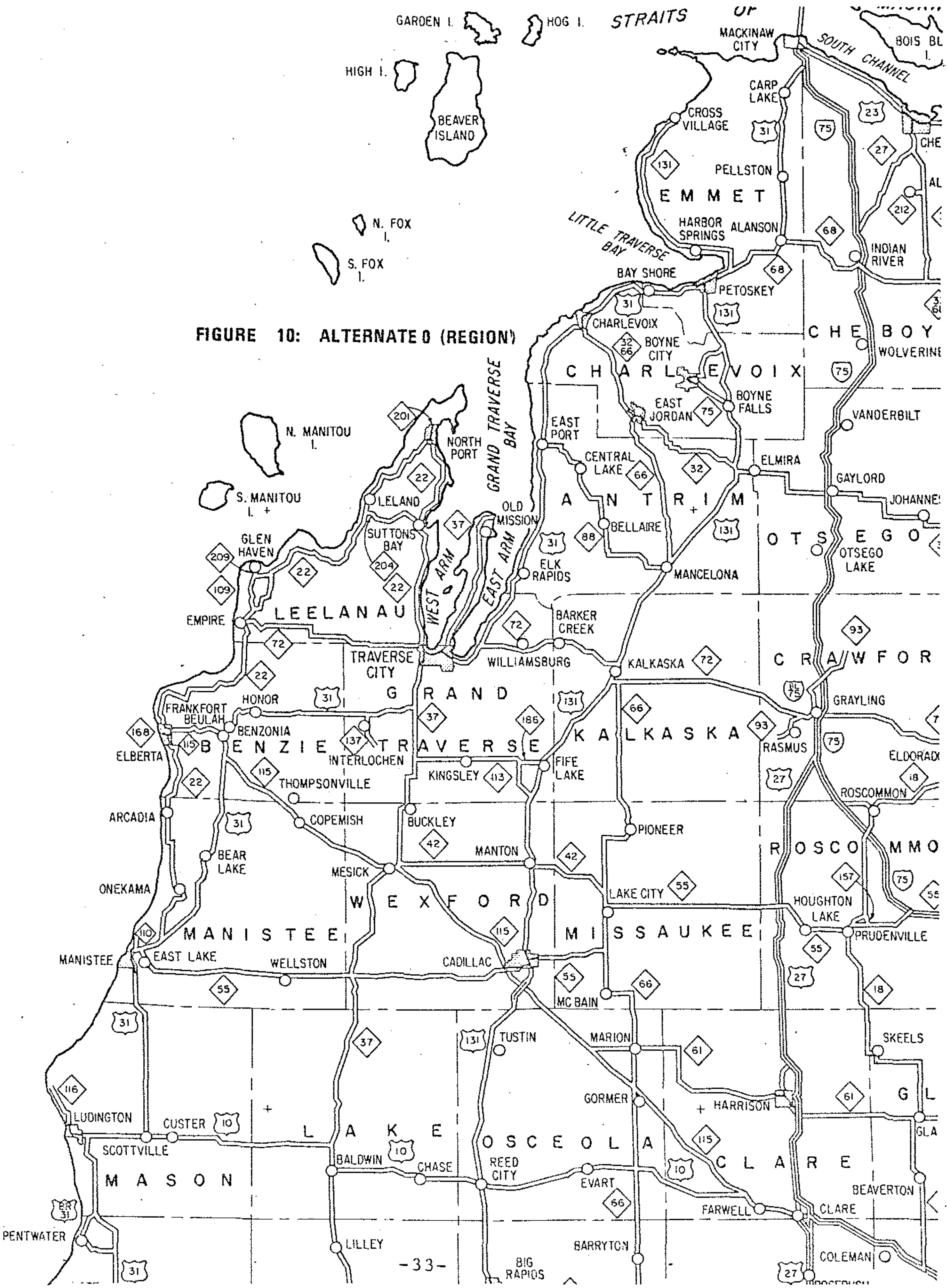


FIGURE 10: ALTERNATE D (REGION)

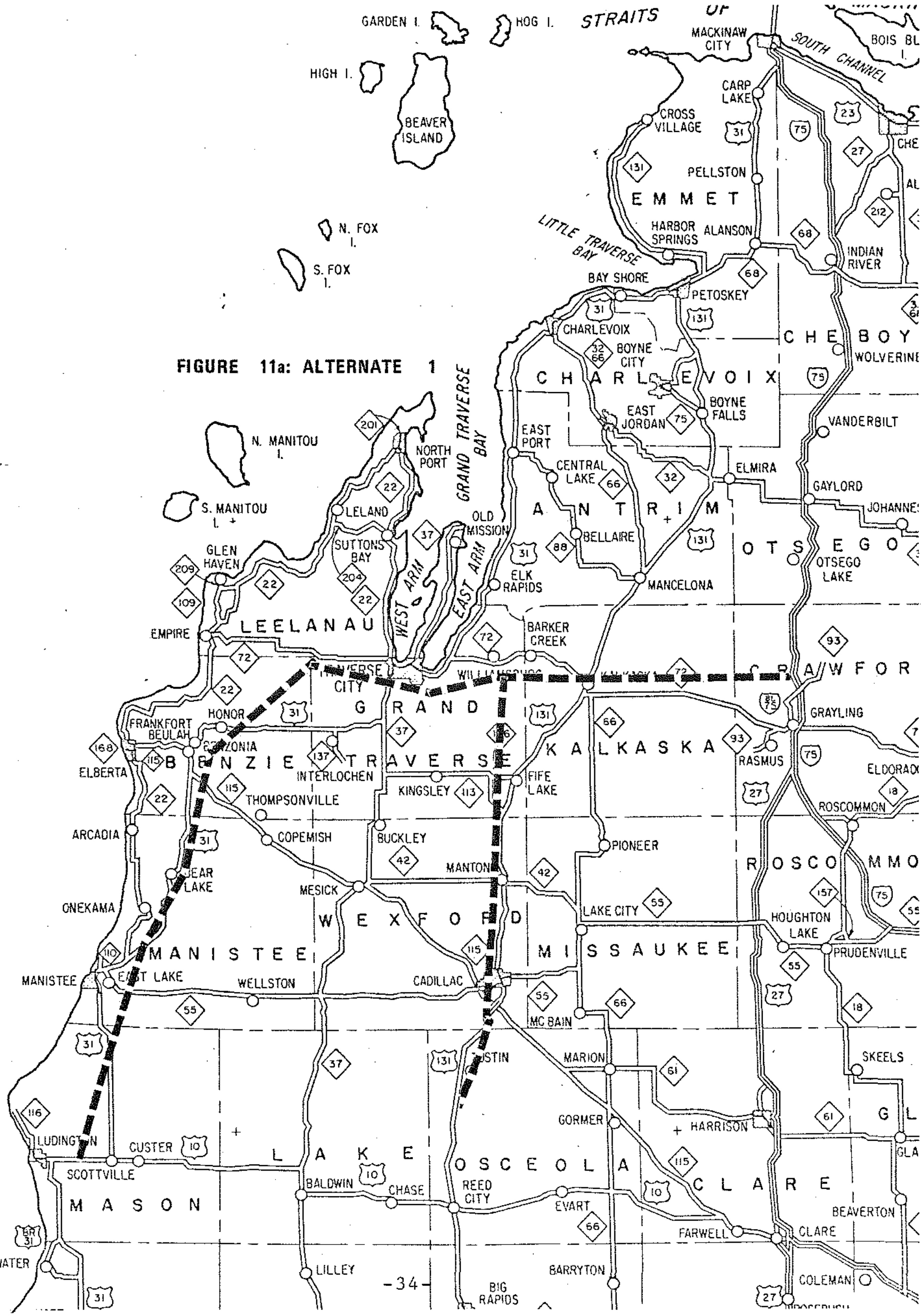


FIGURE 11a: ALTERNATE 1

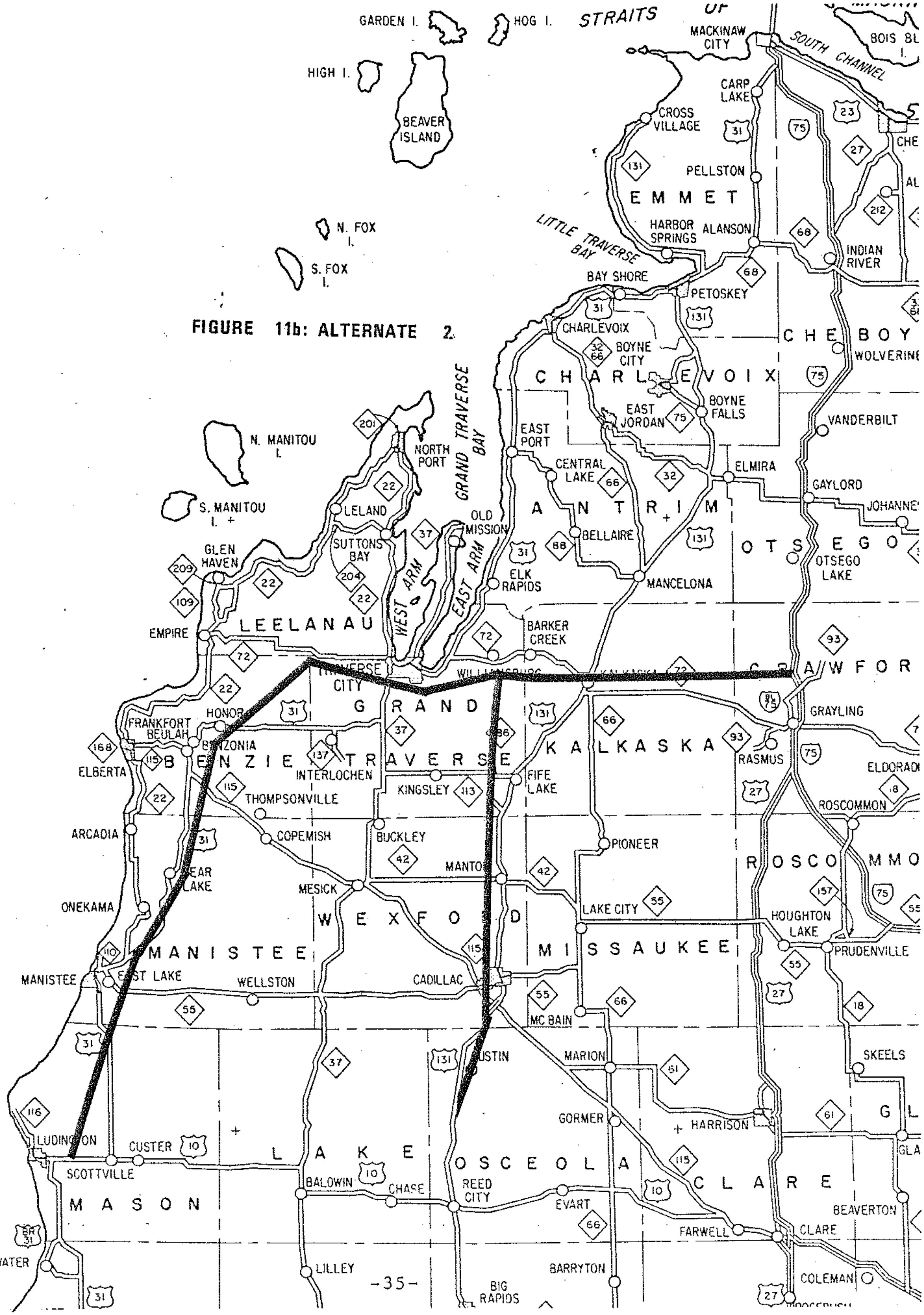


FIGURE 11b: ALTERNATE 2

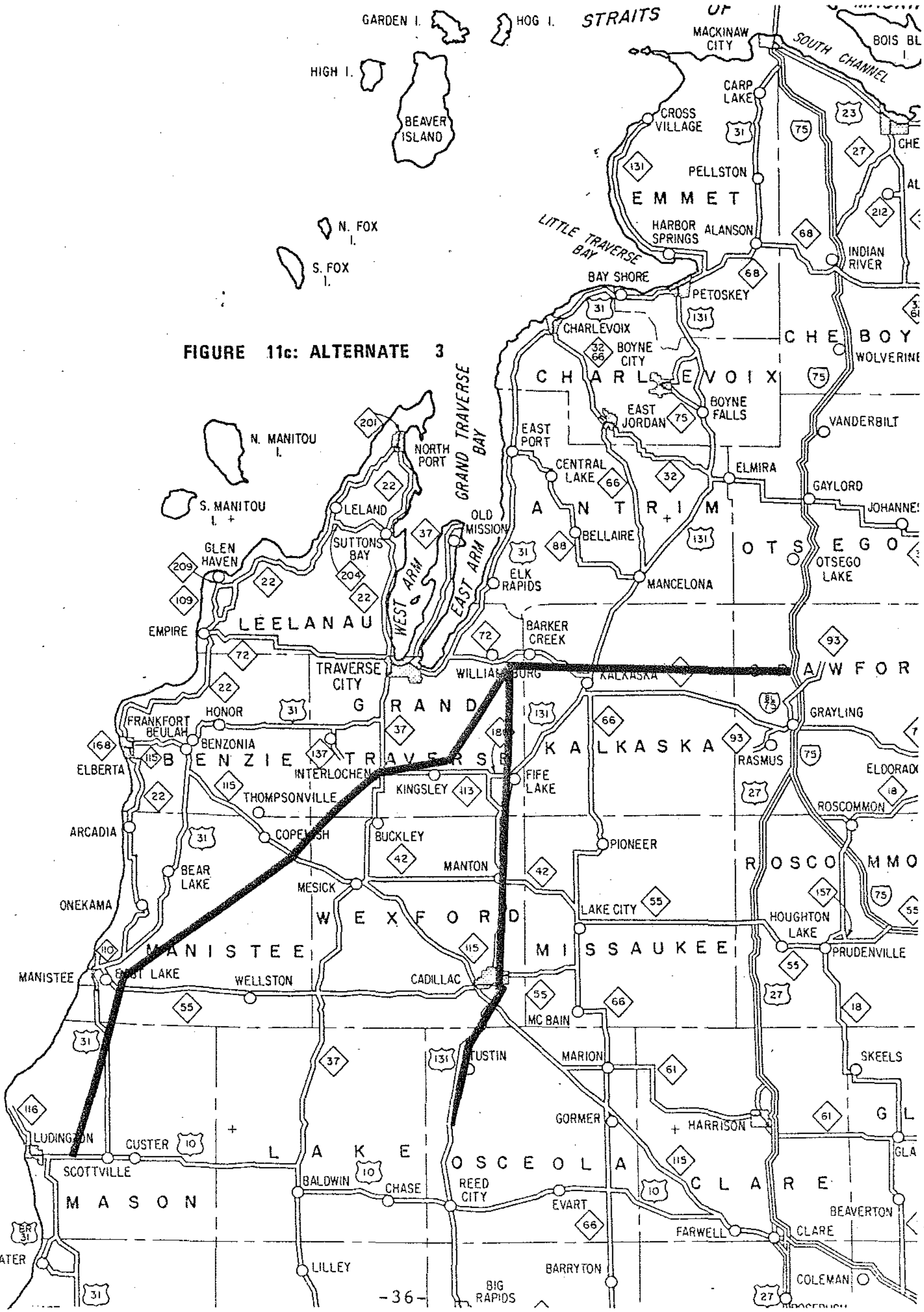
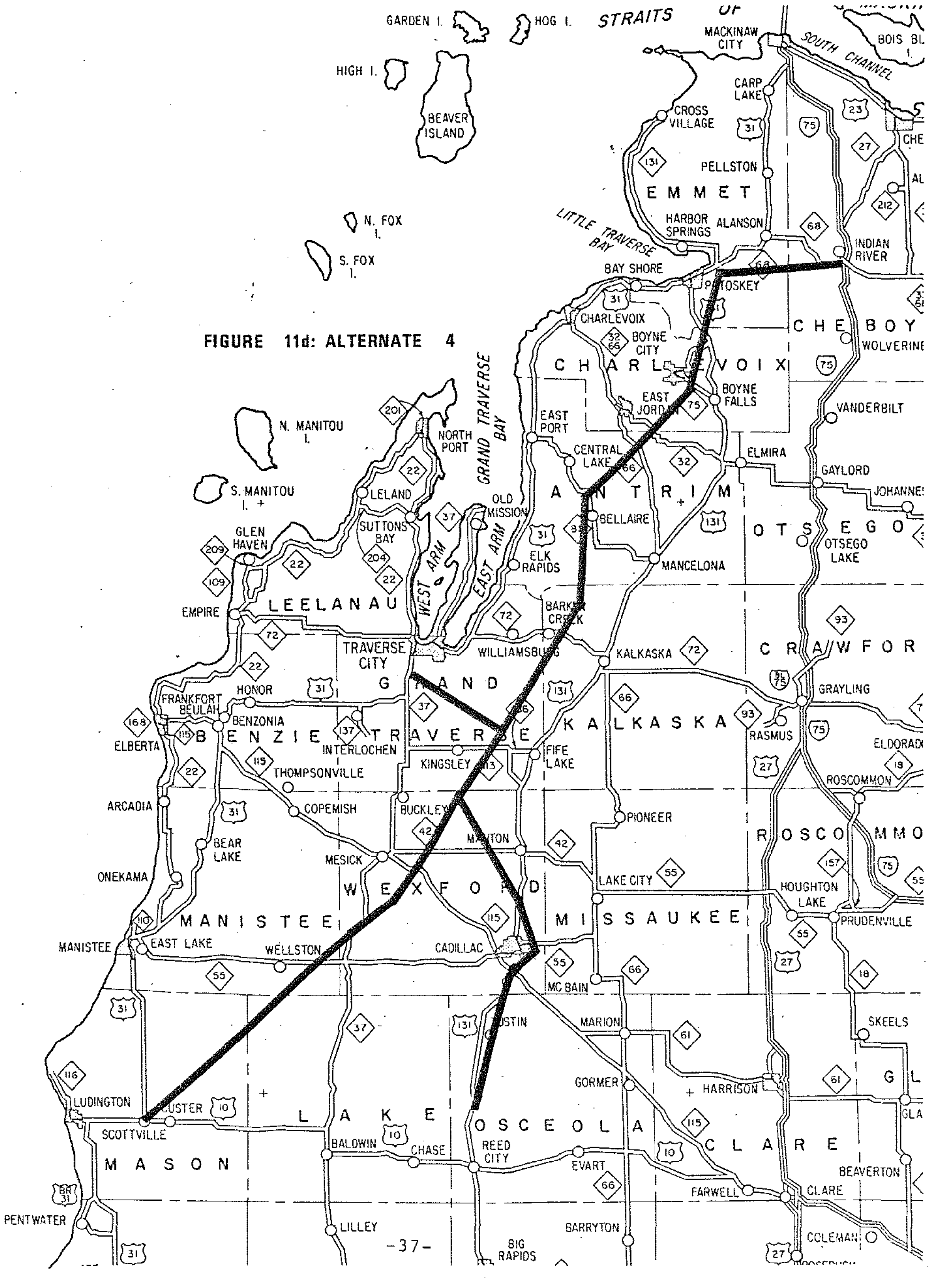


FIGURE 11c: ALTERNATE 3

FIGURE 11d: ALTERNATE 4



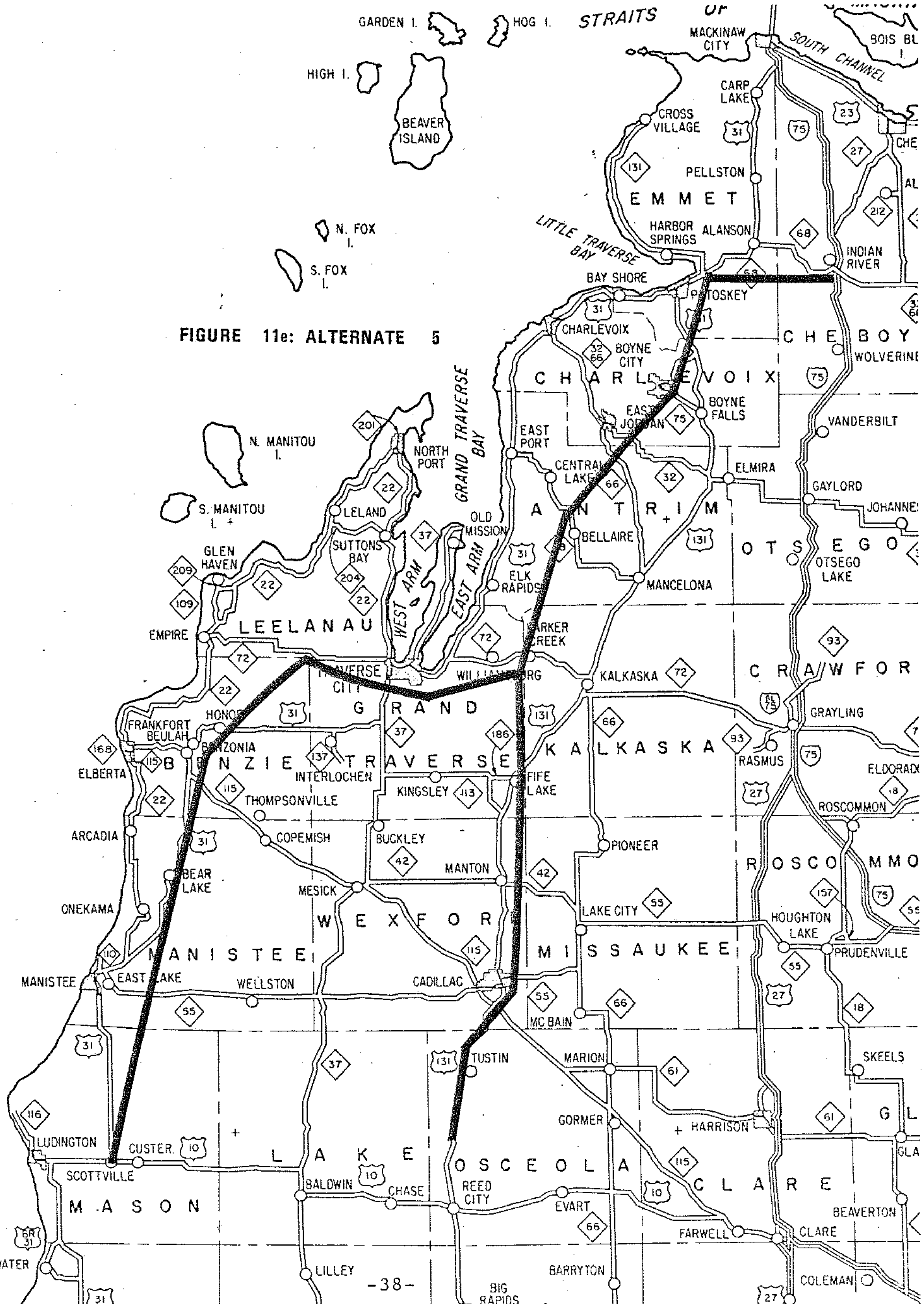


FIGURE 11e: ALTERNATE 5

Manistee County if no new construction takes place (the figure in the heading is expressed in thousands of vehicle miles, and ".2 E03" means ".2 x 10^3" or 200).

Next the alternates are compared according to the net present worth over the life of the study of six costs. As before, ".534 E05" means ".534 x 10^5" or 53400; since everything is expressed in thousands of dollars, the real dollar figure for the net present worth of auto running cost over thirty years is 53,400,000 in Manistee County, computed using an interest rate of 7%. For the display, these figures are rounded to three significant digits; of course, the exact figures are used in computation. "Total Present Worth of User Costs" (fifth line down) is a subtotal of the present worths previous four costs: Auto Running Cost, Truck Running Cost, Accident Costs, and Truck Time Costs. "Annual Maintenance Cost" is displayed for comparison only; the figure for the life of the study is given in "Present Worth of Annual Maintenance Cost". This and "Present Worth of Auto Time Costs" are then added to "Total Present Worth of User Costs" to give "Present Worth of User, Maintenance, and Auto Time Costs". Finally, capital costs for the construction in the county undereach alternative plan are given; these include construction costs, right-of-way costs where applicable, and the extra costs of interchanges and structures over and above the cost of the roadway. One might use all or any group of the measures in arriving at a preferred alternate. Which ones are used depends upon the goals and objectives of the decision-makers.

Figure 12b gives two possible measures of comparing alternatives, net benefits and benefit-cost ratios. Each has been used for decision-

PROJECT 2122110001 IMPROVEMENT TYPE: NEW CONST. SYSTEM: OTHER FAP

LENGTH = 80. INTEREST RATE = 7 PERCENT VALUE OF PASSENGER CAR TRAVEL TIME = $ 2.5 PER HR.

ALT. O VEH. - MILES = YEAR 1-- .2E 03 YEAR 30-- .3E 03

	ALTERNATIVE COST, THOUSANDS					
	0	1	2	3	4	5
PRESENT WORTH OF AUTO RUNNING COST	$ .534E 05	.391E 05	.370E 05	.310E 05	.509E 05	.370E 05
PRESENT WORTH OF TRUCK RUNNING COST	$ .210E 05	.152E 05	.145E 05	.118E 05	.200E 05	.145E 05
PRESENT WORTH OF ACCIDENT COSTS	$ .561E 04	.410E 04	.397E 04	.303E 04	.542E 04	.397E 04
PRESENT WORTH OF TRUCK TIME COSTS	$ .192E 05	.138E 05	.131E 05	.114E 05	.183E 05	.131E 05
TOTAL PRESENT WORTH OF USER COSTS	$ .992E 05	.721E 05	.686E 05	.572E 05	.947E 05	.686E 05
ANNUAL MAINTENANCE COST	$ 160.	179.	205.	259.	199.	205.
PRESENT WORTH OF ANNUAL MAINTENANCE COST	$ .199E 04	.222E 04	.255E 04	.322E 04	.247E 04	.255E 04
PRESENT WORTH OF AUTO TIME COSTS	$ .480E 05	.350E 05	.329E 05	.292E 05	.459E 05	.329E 05
PRESENT WORTH OF USER, MAINTENANCE, AND AUTO TIME COSTS	$ .149E 06	.109E 06	.104E 06	.896E 05	.143E 06	.104E 06
CAPITAL COSTS	$ .0	.164E 05	.327E 05	.428E 05	.156E 05	.327E 05

FIGURE 12a: COUNTY SUMMARY

COMPARISON OF ALTERNATIVES

NET PRESENT WORTHS (THOUSANDS)

	USER, MAINT., AUTO TIME COST	CAPITAL COST	NET BENEFIT
1 VS 0	.4E 05	.2E 05	.2E 05
2 VS 0	.5E 05	.3E 05	.1E 05
3 VS 0	.6E 05	.4E 05	.2E 05
4 VS 0	.6E 04	.2E 05	-.9E 04
5 VS 0	.5E 05	.3E 05	.1E 05

BENEFIT COST RATIOS

1 VS 0	2.43
2 VS 0	1.38
2 VS 1	0.330
3 VS 0	1.39
3 VS 1	0.748
3 VS 2	1.43
4 VS 0	0.392
4 VS 1	40.8
4 VS 2	2.28
4 VS 3	1.97
5 VS 0	1.38
5 VS 1	0.330
5 VS 2	.0
5 VS 3	1.43
5 VS 4	2.28

FIGURE 12b: COUNTY SUMMARY

making at various times in the past. If net benefit (= difference between alternates in benefits - difference in costs) is the decision criterion, either alternative 1 or alternative 3 would be preferred. In terms of benefit-cost ratios, alternate 1 is most strongly preferred to alternate 0, although alternates 2,3, and 5 are feasible (have benefit-cost ratio, relative to alternate 0, at least 1.00). Of the other feasible alternates, none has a benefit-cost ratio relative to alternate 1 of 1.00 or more. Therefore, if one only looked at Manistee County, alternate 1 would be the logical choice from a benefit-cost ratio viewpoint.

Figure 13a, the detail for the ten-county region, is organized exactly like Figure 12a. Again, a decision-maker might choose to consider only the first four cost categories for example, and to integrate these with other variables in a decision matrix. Or, if he chooses to use net benefit or benefit-cost ratio, he would look at a report like that in Fugure 13b. At a regional level, alternate 4 seems to be preferred from a net-benefit standpoint. Looking at the benefit-cost ratios, the ratios of each alternate relative to alternative 0 exceeds 1.00; therefore, all alternates are feasible. Comparing alternates 1-5 among themselves, alternate 4 is preferred with respect to each of the others (the ratio of "5 to 4" being less than 1.00 implies that 4 is preferred to 5). So the benefit-cost ratios yield the same result at the regional level as the net-benefits computations; build alternative 4.

In real life, representatives of the Department of Transportation

PROJECT 2122110001 IMPROVEMENT TYPE: NEW CONST. SYSTEM: OTHER FAP

LENGTH = .12E 03 INTEREST RATE = 7 PERCENT VALUE OF PASSENGER CAR TRAVEL TIME = $ 2.5 PER HR.

ALT. O VEH.-MILES: YEAR 1 – .2E 04 YEAR 30 – .4E 04

	ALTERNATIVE COST, THOUSANDS					
	0	1	2	3	4	5
PRESENT WORTH OF AUTO RUNNING COST	$ .544E 06	.457E 06	.431E 06	.447E 06	.421E 06	.416E 06
PRESENT WORTH OF TRUCK RUNNING COST	$ .210E 06	.175E 06	.165E 06	.171E 06	.162E 06	.159E 06
PRESENT WORHT OF ACCIDENT COSTS	$ .630E 05	.494E 05	.480E 05	.538E 05	.497E 05	.423E 05
TOTAL PRESENT WORTH OF USER COSTS	$ .193E 06	.161E 06	.151E 06	.157E 06	.149E 06	.146E 06
ANNUAL MAINTENANCE COST	$ .101E 07	.843E 06	.796E 06	.829E 06	.781E 06	.763E 06
PRESENT WORTH OF ANNUAL MANTENANCE COST	$ .155E 04	.170E 04	.184E 04	.193E 04	.201E 04	.199E 04
PRESENT WORTH OF AUTO TIME COSTS	$ .193E 05	.211E 05	.228E 05	.240E 05	.249E 05	.247E 05
PRESENT WORTH OF USER, MAINTENANCE, AND AUTO TIME COSTS	$ .151E 07	.127E 07	.120E 07	.125E 07	.118E 07	.116E 07
CAPITAL COSTS	$ 691.E 04	.102E 06	.179E 06	.170E 06	.186E 06	.223E 06

FIGURE 13a: REGIONAL SUMMARY

COMPARISON OF ALTERNATIVES

NET PRESENT WORTHS (THOUSANDS)

	USER, MAINT., AUTO TIME COST	CAPITAL COST	NET BENEFIT
1 VS 0	.2E 06	.1E 06	.1E 06
2 VS 0	.3E 06	.2E 06	.1E 06
3 VS 0	.3E 06	.2E 06	.1E 06
4 VS 0	.3E 06	.2E 06	.2E 06
5 VS 0	.4E 06	.2E 06	.1E 06

BENEFIT COST RATIOS

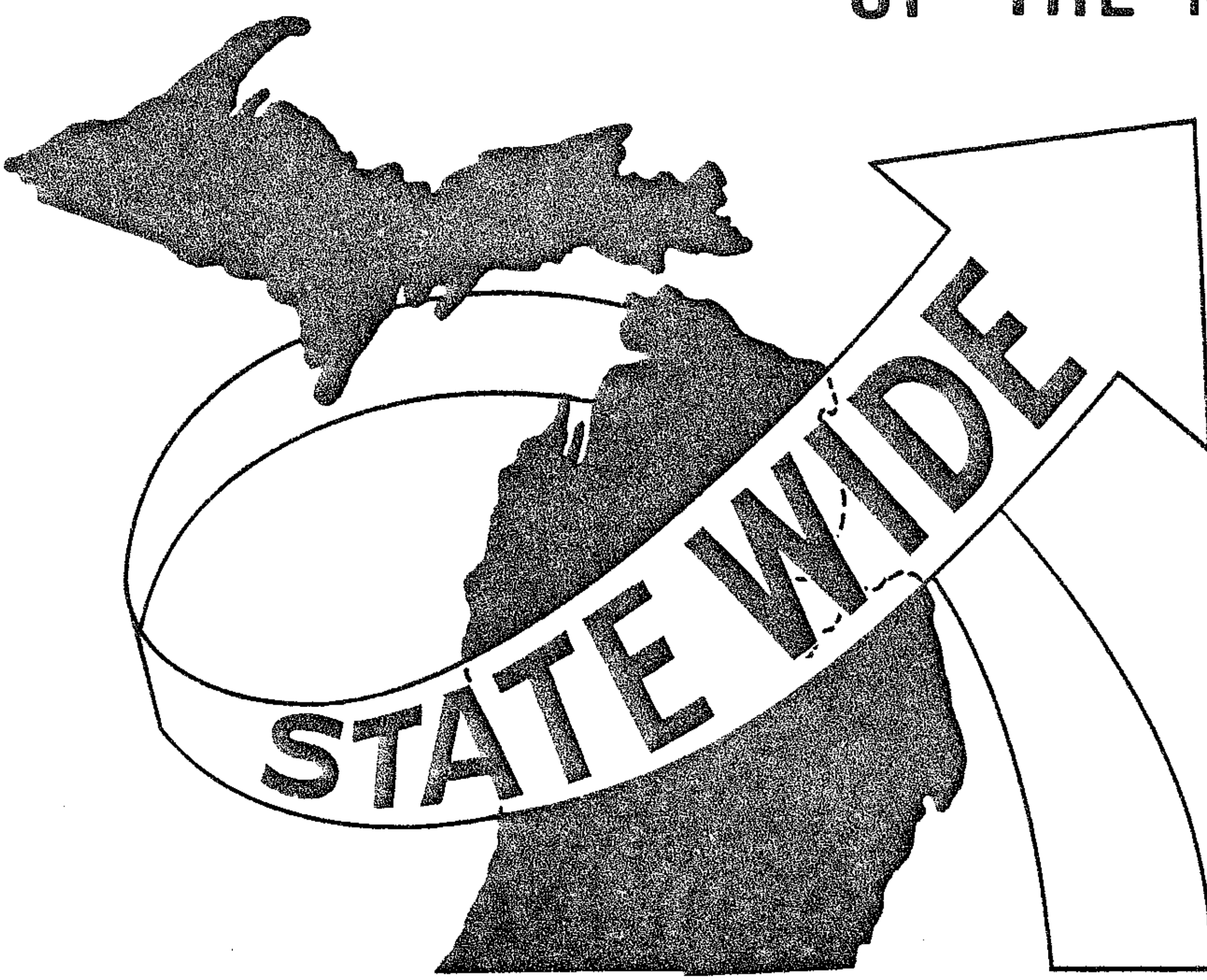
1 VS 0	2.53
2 VS 0	1.81
2 VS 1	0.914
3 VS 0	1.60
3 VS 1	0.294
3 VS 2	5.74
4 VS 0	1.85 ⇦
4 VS 1	1.08 ⇦
4 VS 2	2.70 ⇦
4 VS 3	4.31
5 VS 0	1.64
5 VS 1	0.943
5 VS 2	0.992
5 VS 3	1.77
5 VS 4	0.634 ⇦

ALTERNATIVE 4 MOST ECONOMICAL ALTERNATIVE

FIGURE 13b: REGIONAL SUMMARY

might sit down with representatives of each of the counties in the region and examine the tradeoffs between what seems to be best for each county and what seems to be best for the region. In this way, a compromise might be reached. Since the analogous program outputs are available at the statewide level, the same sort of tradeoff analysis could go on there.

SENSITIVITY OF THE MODEL



SENSITIVITY OF THE MODEL

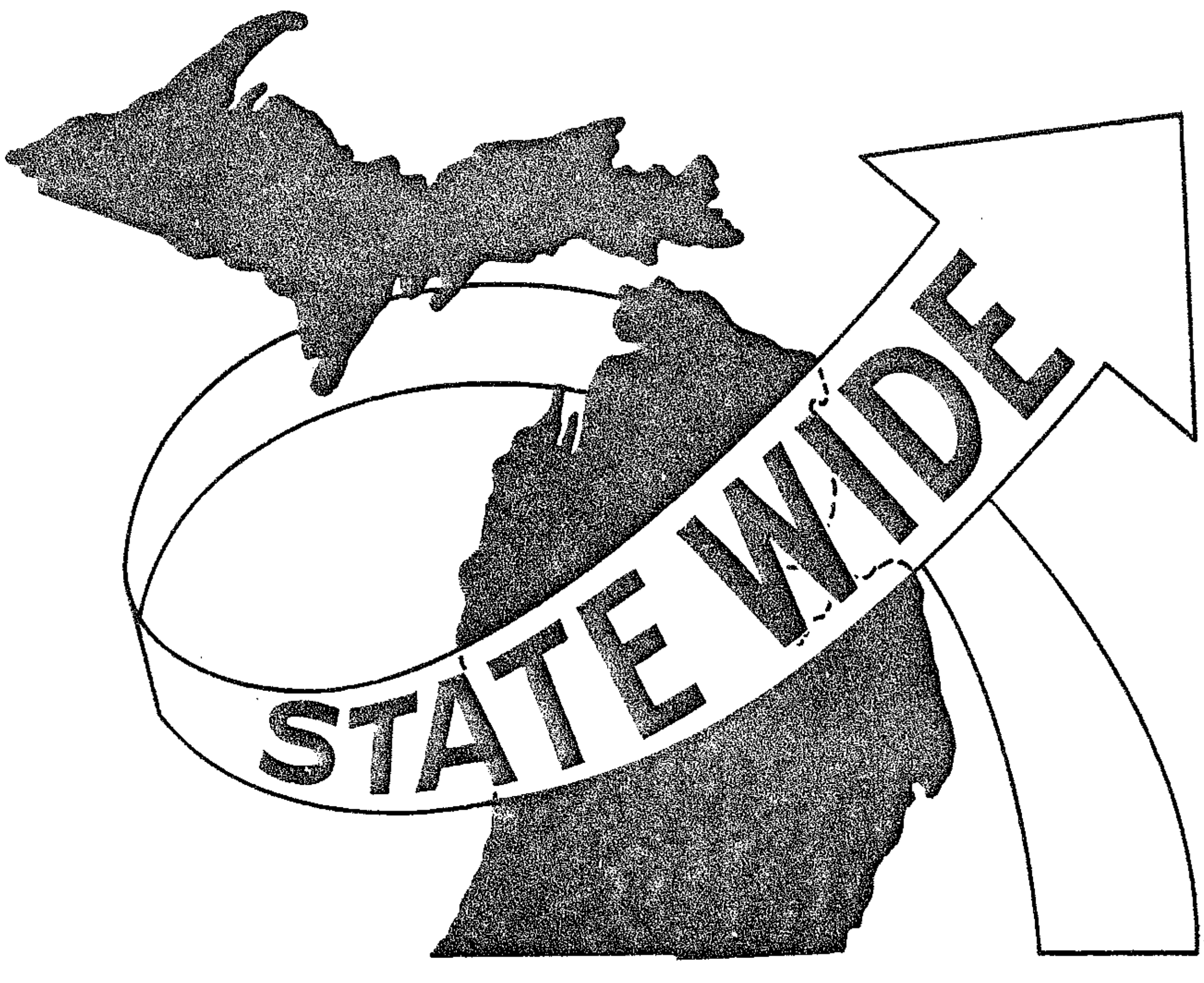
By the term "sensitivity" is meant by the degree to which the outputs vary in response to small changes in the inputs. In the area of cost-benefit analysis, sensitivity is very important. A model should respond to change, but not too violently: since most inputs to the model should be relatively insensitive to very small changes in estimated data but responsive to larger changes.

The equations which predict costs midway in the project life are bilinear in nature; we define a function of two variables as "bilinear" if, given a pair of variables in the equation, for a fixed value of one variable the equation is linear in the other variable. As an example, the equation $f(x,y) = xy$ is said to be bilinear: if $x = 3$, the equation becomes linear in y, namely $f(3,y) = 3y$. Such equations are, in general, quite insensitive to small changes in y for small x but very sensitive to small changes in y for large x. Therefore, to achieve the proper level of sensitivity as described above, traffic and costs are scaled to thousands of vehicles and thousands of dollars. Without this scaling, it would be possible for the model to behave very erratically. The scaling "brings things back into perspective", so to speak.

The discounting equations, in contrast to the prediction equations, contain compound-interest discounting factors. These factors contain such terms as $(1 + i)^n$, where i is an interest rate and n is the study life. In the most common instance n + 20 years, so (1 + interest rate) is being multiplied by itself 20 times. Consequently, a small change in the interest rate i could make a great deal of difference in computed net present worth of costs, and a correspondingly great difference in the benefit/cost ratio. For example, Curry and Haney (3) state that "a .5% change in the interest rate could easily cause changes of more than .17 in benefit/cost ratios". Similarly, they note that such a change could be caused by a change of only two years in the length of the study period. Lengthening the study period only increases the benefit/cost ratio, however, since we assume zero residual at the end of project life. Therefore, a twenty-year study period seems to place more of the "burden of proof" on the new alternate. Also, in comparing multiple alternatives, as long as the same study life is used for all alternatives the actual choice of study life should not materially affect the ranking of the alternates by benefit/cost ratio.

It would be beneficial at a future date to conduct a detailed sensitivity analysis on this program similar to the one made by Curry (2) on his version of the benefit/cost ratio in the 1965 Highway Research Record (p. 119).

APPLICATIONS



APPLICATIONS

Winfrey and Zellner (12) discuss in some detail the process of decision-making. They point out that a "decision", far from being a single determination of a course of action, actually involves five preliminary decisions which must be settled before the final "decision" can be announced:

A. What courses of action represent viable alternatives? Conversely, which actions should be dropped from consideration as totally unfeasible?

B. How can value be measured on each alternative? What quantities will be monitored during the execution of any of the alternatives to determine whether or not management's objectives are being met? What variables will show whether a project is "on" or "off" the track?

C. Having determined the variables to be used in measuring value, how does a decision-maker actually associate a value with each alternative? That is, how can be use these "value variables" to compare the alternative at hand?

D. What circumstances beyond the manager's control may influence his ability to carry out his decision? What external controls (for example, budgetary controls) may be imposed on him which limit his discretionary powers?

E. How should the answers to the first four questions be used to make the final decision?

Almost certainly, step (b) will include at least one of the following: running costs, time costs, and accidents (or accident costs). Up to this time, decision makers have not been able to call for fast, accurate, handy estimates of each type of cost: either analysis procedures were too slow or too costly or both, and by the time estimates were made they were already out of date. The combination of the Statewide Traffic Forecasting Model and the cost-benefit analysis package now provides a potent management tool, a means of providing fast, cheap, accurate cost estimates in each of the above areas.

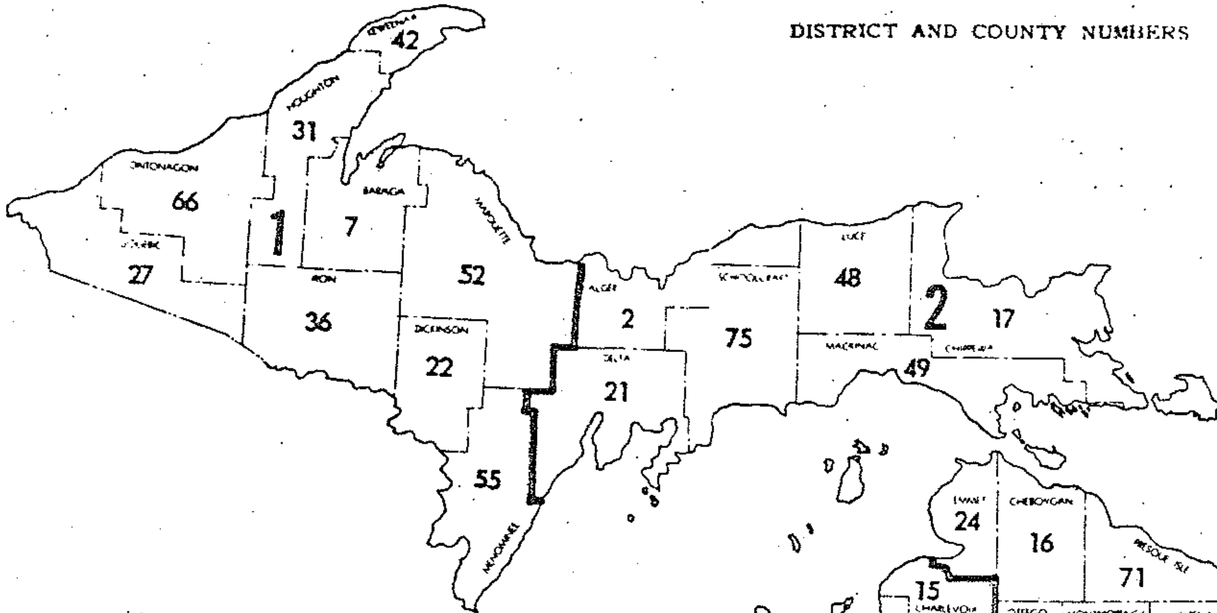
Moreover, the interface gives a system-level picture of costs. Classical cost-benefit analysis, such as the AASHO version, has traditionally dealt only with costs on and about the segments which are being considered for change. Although many authors (see Curry and Haney (3), p. 15, for example) have recommended that cost-benefit analysis be done on a network level, the task of estimating traffic on all links of a network for as many as ten alternates for five time periods from a base year seemed insurmountable. Consequently, management has run the risk of making a decision which is good for a particular segment but is incompatible with the total network; for instance, the "best" type of improvement for a segment may not be in keeping with the traffic it generates on the next segment, actually resulting in a higher cost on the whole system. These benefit-cost indicators can also be summarized by any summary region the manager desires. The program now outputs summaries by county or groups of counties, such as the State Planning Regions shown in Figure 14. Virtually any other types of geographical summaries are easily obtainable with a few minutes work on the loader program.

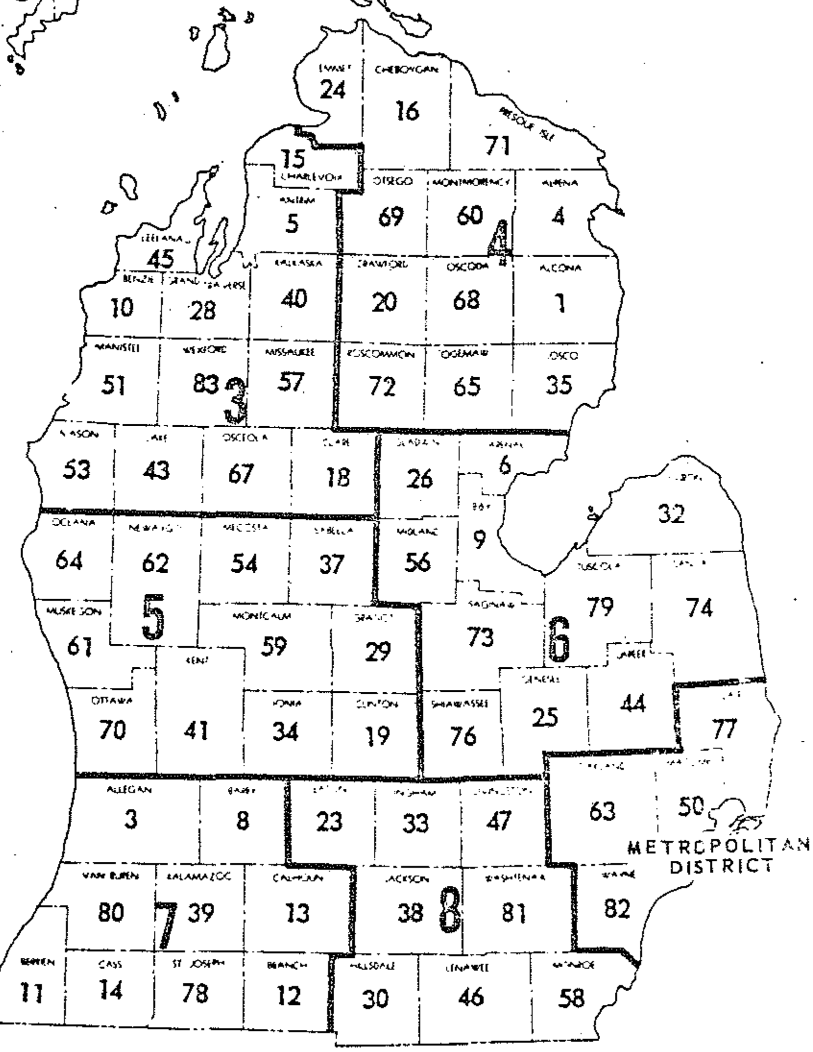
Summaries are not limited to geographical factors, either. It would be prefectly feasible to select only those trips in each network belonging to a given set of vehicle types or trip purposes and then to compare alternates by their effects on these trips. As an example, one might wish to find the effect of a freeway in heavily

FIGURE 14

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

DISTRICT AND COUNTY NUMBERS





COUNTIES

	DIST.		DIST.
1. ALCONA	4	43. LAKE	3
2. ALGER	2	44. LAPEER	6
3. ALLEGAN	7	45. LEELANAU	3
4. ALPENA	4	46. LENAWEE	8
5. ANTRIM	3	47. LIVINGSTON	8
6 ARENAC	6	48. LUCE	2
7. BARAGA	1	49. MACKINAC	2
8. BARRY	7	50. MACOMB	MET.
9. BAY	5	51. MANISTEE	3
10. BENZIE	3	52. MARQUETTE	1
11. BERRIEN	7	53. MASON	3
12. BRANCH	7	54. MECOSTA	5
13. CALHOUN	7	55. MENOMINEE	1
14. CASS	7	56. MIDLAND	6
15. CHARLEVOIX	3	57. MISSAUKEE	3
16. CHEBOYGAN	4	58. MONROE	8
17. CHIPPEWA	2	59. MONTCALM	5
18. CLARE	3	60. MONTMORENCY	4
19. CLINTON	5	61. MUSKEGON	5
20. CRAWFORD	4	62. NEWAYGO	5
21. DELTA	2	63. OAKLAND	MET.
22. DICKINSON	1	64. OCEANA	5
23. EATON	8	65. OGEMAW	4
24. EMMET	4	66. ONTONAGON	1
25. GENESEE	6	67. OSCEOLA	3
26. GLADWIN	6	68. OSCODA	4
27. GOGEBIC	1	69. OTSEGO	4
28. GD.TRAVERSE	3	70. OTTAWA	5
29. GRATIOT	5	71. PRESQUE ISLE	4
30. HILLSDALE	8	72. ROSCOMMON	4
31. HOUGHTON	1	73. SAGINAW	6
32. HURON	6	74. SANILAC	6
33. INGHAM	8	75. SCHOOLCRAFT	2
34. IONIA	5	76. SHIAWASSEE	6
35. IOSCO	4	77. ST. CLAIR	MET.
36. IRON	1	78. ST. JOSEPH	7
37. ISABELLA	5	79. TUSCOLA	6
38. JACKSON	8	80. VAN BUREN	7
39. KALAMAZOO	7	81. WASHTENAW	8
40. KALKASKA	3	82. WAYNE	MET.
41. KENT	5	83. WEXFORD	3
42. KEWEENAW	1		

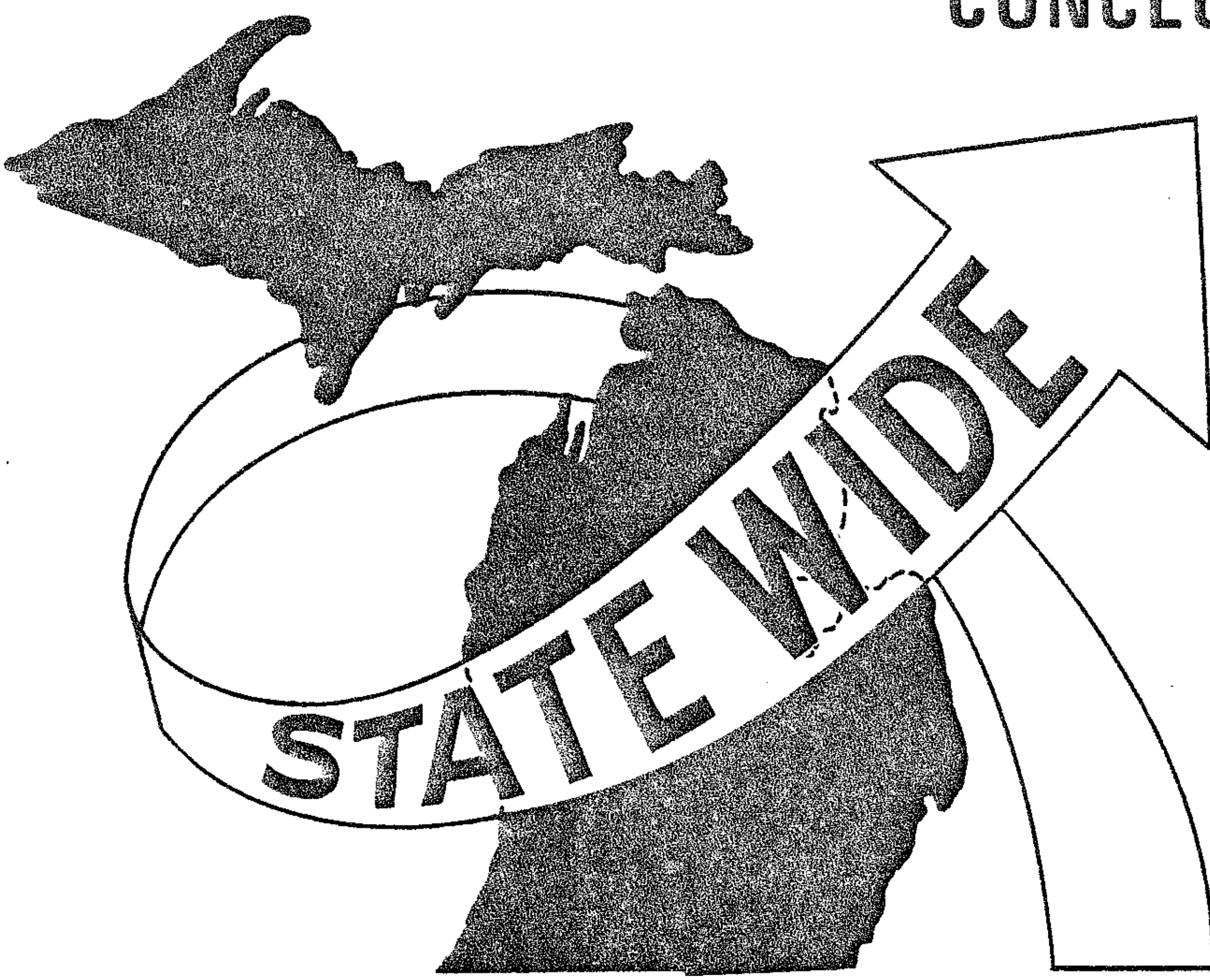
recreational areas on vacation traffic, all other traffic, and then all traffic combined. To the best of our knowledge, no other traffic forecasting and economic-analysis package now in existence gives the capability of making these comparisons quickly, cheaply, and accurately.

There is also nothing to stop the cost-benefit analysis from operating on an urban network, if that were desired. Some relatively minor modifications on the loader program would be called for in order to input data on number of railroad crossings, stop signs, stop signals and the percent green on each. Thus the combination of state trunkline network and the urban networks made the cost-benefit analysis a potentially powerful tool in the administration of the Program Budget Evaluation System (PBES). In some cases, of course, a re-evaluation of "impact indicators" (the value variables described in B) may be necessary to add, if need be, more easily quantifiable variables.

Finally, naivete about how tax revenue is derived prompts one deceptively simple comment. Suppose a road is built which, let us say, affords trucks 90% of the total consumer's surplus over the next ten years and autos only 10% of the total consumer's surplus. It then seems reasonable that commercial carriers pay a larger share of the cost of the road (through license plates and diesel fuel tax) than should passenger-car owners. Again, we would admittedly be out of our depth if we presumed to advise on the subject of tax responsibility. We offer this simply as an example of the type of deductions an expert analyst might be able to draw from the output of the cost-benefit analysis program.

In summary, then: the combination of the Statewide Traffic Forecasting Model and the cost-benefit analysis package gives a manager an effective, inexpensive solution to the problem of defining, and projecting target values for quantifiable measures of "how well an alternative is doing". We know of no other method which can do any equivalent job as quickly, as cheaply, and as thoroughly.

CONCLUSION



CONCLUSION

Many new challenges are posed by recent Federal guidelines for transportation planning, especially in the realm of economic impacts of highway travel. Transportation planners must analyze the economic impacts of alternative plans quickly and efficiently; yet a marked increase in public involvement decrees that many more alternatives be considered than ever before.

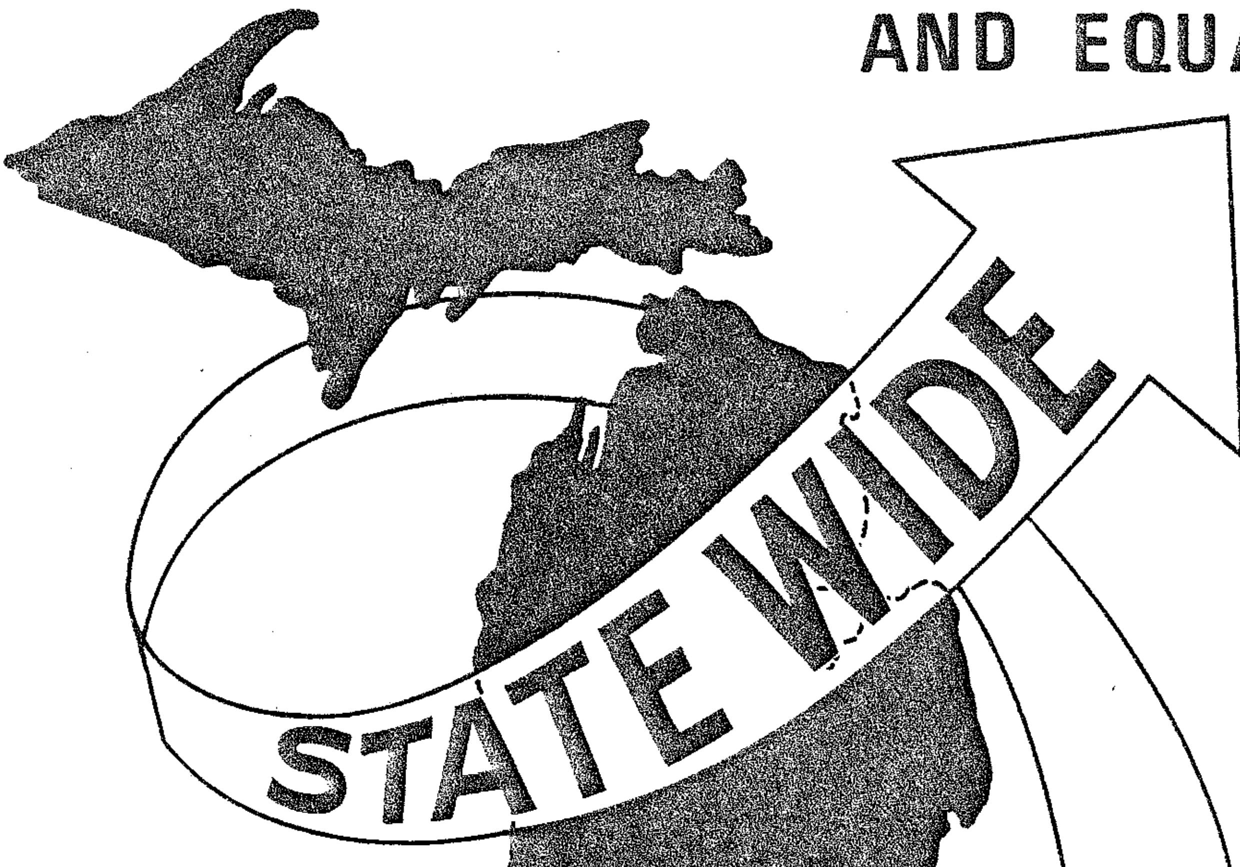
As a possible means of achieving these dual goals, a benefit-cost analysis process has been interfaced with the Statewide Traffic Forecasting Model. It offers the capability of comparing many user impacts and capital costs of alternate transportation plans quickly and efficiently and to calculate their net present worths at a variety of interest rates. Summaries can be calculated for counties, regions, and the state as a whole to facilitate many levels of transportation planning.

Statewide is always interested in comments or suggestions which will help the Statewide Transportation Modeling System address timely issues in transportation planning. Interested persons are invited to contact:

Mr. Richard E. Esch, Manager
Statewide Interagency Procedures
Research and Development Section
Highway Planning Division
Bureau of Transportation Planning
MDSH&T
P.O. Drawer K
Lansing, Michigan 48904

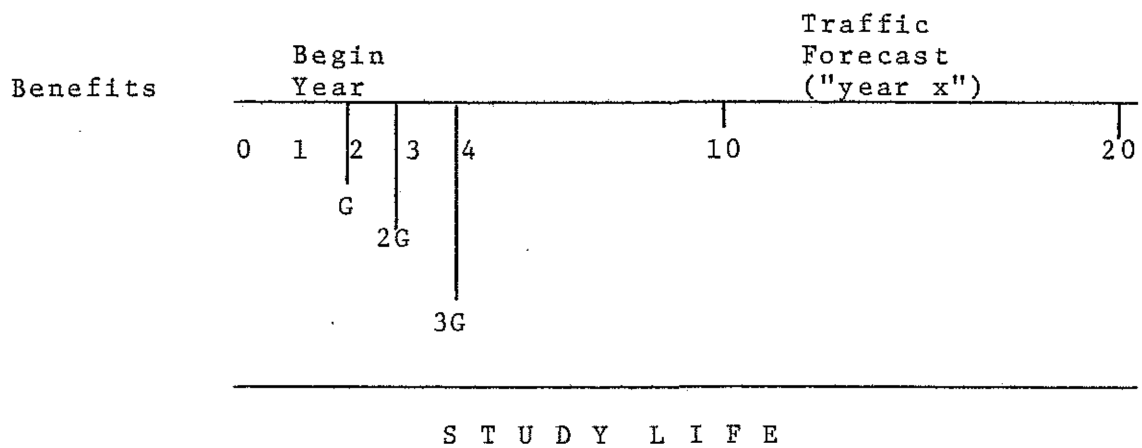
or contact him by telephone at (517)373-2663.

APPENDIX:
IMPORTANT FORMULAS AND EQUATIONS



APPENDIX: IMPORTANT FORMULAS AND EQUATIONS

The formulas used assume that the following type of situation holds: traffic can be calculated or observed for the first year of the study period and can be forecast at a point at least half the study life away. Thus the effect of an alternate on benefits begins to appear in year two. Graphically, it looks like this for a twenty-year study.



The vehicle-miles gradient can be visualized as the proportion which the average yearly increase in vehicle miles is of the total base-year vehicle miles for the county (or region). If vehicle-miles for each year in the study would be plotted, the gradient would be approximately the slope of that curve. It is calculated in the program by the formula

$$G = \frac{(\text{year X vehicles-miles}) - (\text{year 1 vehicle miles})}{(\text{year 1 vehicle miles})\ (X - 1)}$$

where X is the number of years past year 0 for which the future traffic forecast is made.

To calculate the net present worth of a benefit at a certain interest rate one then calculates the average yearly benefit and multiplies by a "gradient compound interest net present worth factor". The concept is quite straightforward: it is assumed that there are a fixed average dollar amount of new benefits every year; call it D. Then since the traffic forecast is for year 1, during year 2 there \$D worth of benefits are saved, during year 3 \$2D, and so on. If this money were deposited in the bank at interest rate "r" each year for the life of the study ("L" years) the first \$D would earn compound interest for L-1 years, the next year's \$2D would earn for L-2 years, and so on until the deposit of \$(L-1)D made at the end of the last year would earn no interest at all. The sum of these compounded amounts is called the "gradient compound amount" and is given by

$$GCA = \left[\frac{(1 + r)^L - 1 - L}{r}\right] \frac{D}{r}$$

The net present worth is obtained by dividing by $(1 + r)^L$, the compounded worth of a dollar invested at interest rate r for the life of the study. That is, the gradient net present worth is the amount which would have to be deposited at interest rate r at the beginning of the study period in order to accumulate an amount equal to the CGA by the end of the study. The gradient net present worth is given by

$$PWFG = \left[\frac{(1 + r)^L - 1 - L}{r}\right] \frac{D}{r\ (1+r)^L}$$

The reader is referred to a good discussion in Winfrey, Chapter 6. Winfrey's equations (6-7B) and (6-8B) can be obtained from the above formulas for GCA and PWFG by setting D=1.

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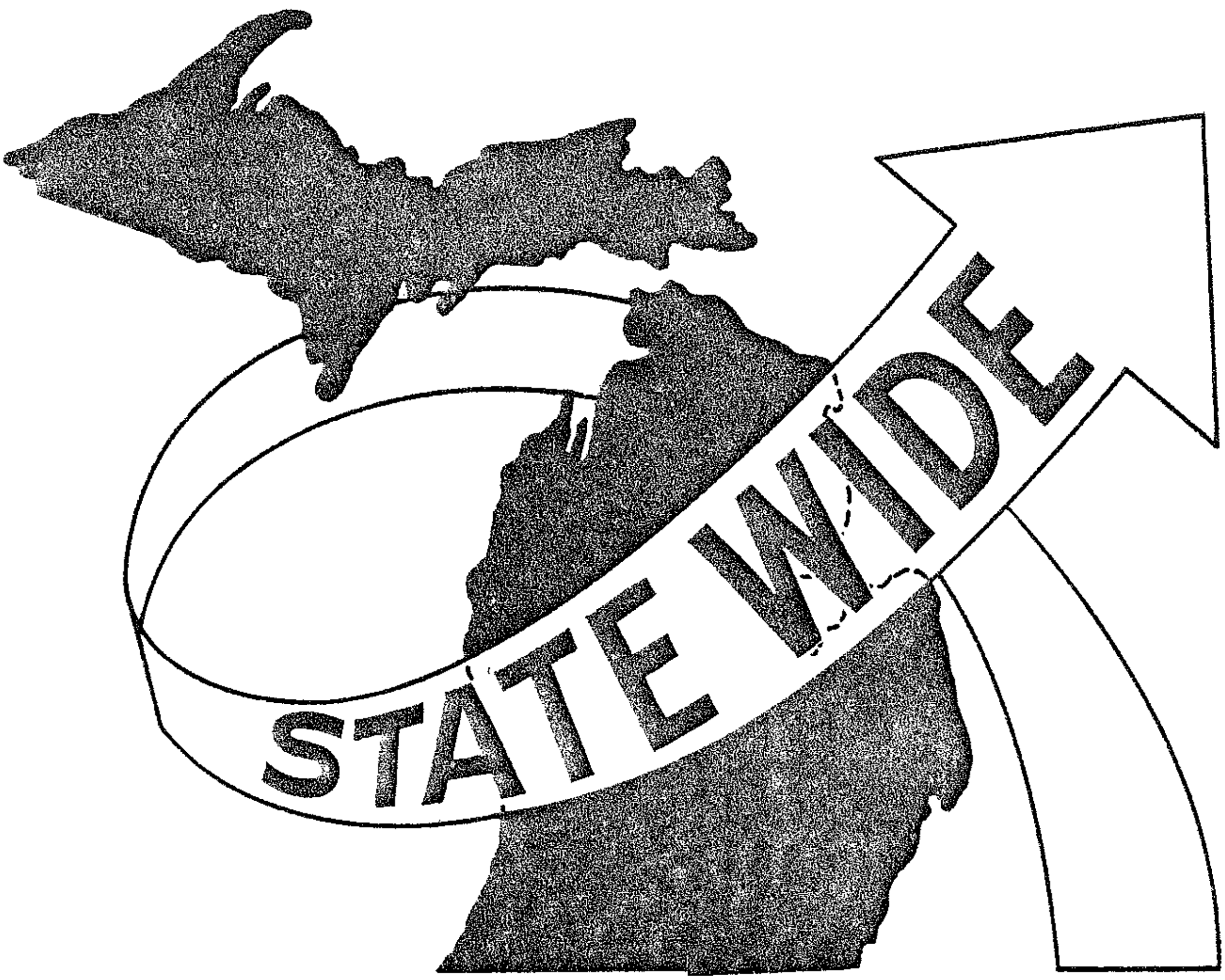

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