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Foreword

Three papers are included in this RECORD dealing with various aspects of engineering economy. A fourth paper is presented in summary form as it is published elsewhere.

J. W. Spencer points out that efforts in applying concepts of engineering economy have tended to ignore realities of road interdependencies. Transportation planners who have recognized these interdependencies have tended to be concerned more with physical flows of traffic than with measurement of economic consequences. The author states that there are a number of shortcomings in trying to allocate resources by various methods of priority rating systems. The paper suggests that an optimum approach would be based on a network-wide assessment of economic consequences. A procedure is outlined which makes use of traffic assignment and related computer programs for use in model testing of alternate sets of improvements.

J. H. Shortreed and Donald S. Berry propose methods for economic analysis to determine the need for grade separations on new freeways. Three hypothetical situations were investigated, with estimates made of reorganization of travel, and changes in travel costs, using net present worth in economic analysis. Results indicate that presently used methods tend to overestimate travel benefits from grade separations.

Salvatore J. Bellomo and Steven C. Provost discussed two procedures to improve the method of economic evaluation generally in use today. The first considers peak and off-peak travel to obtain improved system measures for the user cost quantification. The second considers a range of unit time values and interest rates in the economic evaluation. The paper suggests that improvements are needed in system measures to reflect true intersection delays and the value of time in real costs to the traveler.

The paper by C. H. Oglesby and M. J. Altenhofen is presented here as an abridgment since it is scheduled for publication in full in the NCHRP series. The paper examines current standards for roadbed width and rational underlying these standards. It presents a set of cost benefit measurements for different roadbed widths which indicate that there is little justification for wide roadbeds or for shoulders. Accident costs are examined and it was found that wider roadbeds do not improve accident experience of low-volume rural roads and even if all accidents could be eliminated, the savings would be nominal.

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An Approach to Planning and Programming Local Road Improvements Based on a Network-Wide Assessment of Economic Consequences

J. W. SPENCER, Department of Agricultural Engineering, Cornell University

Primary shortcomings of an informal approach to road-improvement decisions are that it offers (a) little factual basis for value judgments and (b) little guidance as to what should be the level of spending for roads. Priority ratings based on relative road importance and/or condition promote consistency in the decision process but they do not erase these shortcomings. The designation of "critical deficiencies" offers an answer to what should be spent for roads but depends on rather arbitrary definitions of adequacy. Functional classification tempers concepts of adequacy with concepts of economy but, as it has been used, requires arbitrariness in selection of standards and allocation of funds for the various classes.

Efforts to date in applying the concepts of engineering economy have tended to ignore the realities of road interdependencies. Transportation planners, in using the tools of traffic assignment, have recognized interdependencies—but their attention to economic consequences has provided little guidance for project timing and has tended to ignore that total use of the network may vary with alternatives for road improvement.

This paper suggests that an optimum approach would be based on a network-wide assessment of economic consequences, including consequences on the trips induced by road improvement. Such an approach ideally would converge efficiently on an economically optimum program of road expenditures. Although the evolution of an optimum set of improvements is not presently feasible, an approach is outlined by which alternative sets of improvements may be compared using the concept and tools of systems planning in a manner consistent with concepts in engineering economy. The procedure described makes use of the Bureau of Public Roads battery of traffic-assignment and related computer programs. An example suggests that the procedure is technically feasible, but falls short of the type of trial in the real world which would be necessary for a satisfactory evaluation.

•THE most common approach to decisions concerning what improvements should be made on which local roads, and when might best be described as "informal." Efforts toward more formal approaches have been focused on (a) measures of the importance and/or physical condition of roads, (b) the economic consequences of road improvements, and (c) systems planning.

The primary shortcoming of the informal approach is that it is likely to be lacking in that type of fact or estimate from road department leadership which can provide a

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most constructive basis for value judgments by elected officials. It offers little factual support of a manager's recommendations to an elected board as to what should be done on particular roads and what should be the level of spending for roads. It tends to accept the funds presently available as given.

Priority ratings of various sorts can bring the satisfaction of consistency and can serve as a protective device for a road-department manager and an elected board. They do not, however, erase the primary shortcoming of the informal approach. The concept of critical deficiencies, based on measuring physical conditions of roads against standards of tolerability or adequacy, takes planning off the defensive by offering an answer to what should be spent for roads. It is dependent, however, on rather arbitrary definitions of adequacy. Adequacy is tempered by attention to economy in the concept of functional classification. Despite its real contributions to efficiency, functional classification requires arbitrariness in selection of standards for the various classes and allocation of funds to the various classes.

The concepts of engineering economy have not been applied in a fully satisfying manner to the planning and programming of local road improvements. A particular shortcoming is that a project-by-project approach has neglected the reality of interdependencies of the elements in a road network.

The concepts and tools of systems planning, used primarily to date by transportation planners in urban areas, offer a convenient means for recognizing network interdependencies. Attention has been given to economic consequences in addition to physical flows but there has been little attention to alternatives in the timing of network improvements. Transportation planners, in using a least-cost approach, have tended to ignore that the total use of a network may vary with alternatives for road improvement.

In view of these shortcomings, this paper proposes some characteristics of an optimum approach to planning and programming. Although several features of the optimum approach cannot presently be achieved, a "feasible beginning" which incorporates most of the characteristics is offered. This feasible beginning makes use of the tools of traffic assignment and is consistent with concepts in engineering economy. Its focus on users in the measurement of consequences is claimed to be valid only in situations where reasonably complete access now exists.

SOME CHARACTERISTICS OF AN OPTIMUM APPROACH

Taking a network-wide viewpoint, it is suggested that an optimum approach would have the following characteristics:

1. Provides focus on economic efficiency

Although economic efficiency is not a total or absolute criterion, it is claimed that it is a more constructive criterion for central focus than such criteria as service, road sufficiency, safety, or preserving past investments. It is more constructive, first, in that by considering quantifiable gains and costs in money units, it provides some guidance, even leverage, as to how much should be spent for road network improvements. Secondly, but no less important, the economic-efficiency criterion provides a datum against which the important but not quantifiable "other-than-economic" consequences may be weighed; in short, it sharpens the "value" in value judgments.

2. Provides a format for weighing the economic consequences of social and political judgments

The advantage of an economic-efficiency focus in providing a datum for value judgments was suggested in the previous paragraph. The point to be added is that the criterion or format for analysis should express the quantifiable differences between alternatives in such a manner that disciplined attention to the differences not expressible in money terms is not only possible but encouraged.

3. Considers interdependencies of elements in the road network

An optimum approach would recognize that an improvement to road A followed by an improvement to road B may bring a combined effect considerably different than would be suggested by the addition of consequences of the projects considered independently.

4. Provides a point of communication between the road department and land-use planners

The possibilities in land-use prediction and control, and in the increasing knowledge of trip generating characteristics of various land uses, suggest that the involvement of planners should provide more realistic patterns of likely travel demand than road-by-road extrapolation of present traffic volumes. An optimum approach would keep distinctly separate those changes expected to occur without road network improvements and those changes in road use dependent upon or induced by improvements in the network.

5. Is without arbitrary geometric standards in design or definition of need

It is expected that local experience, apparent public expectation, practices on adjacent local road networks, and published standards may often provide a rather firm idea as to what the quality or level of improvements should be if these improvements are undertaken at all. An optimum approach would, however, place heavy emphasis on the recognition and definition of possible alternatives. If a road department has not defined alternatives which range from leaving roads "as is" to spot improvements to improvements matching highest aspirations, then these alternatives cannot be considered in any framework of analysis. A search for alternatives should not be viewed as an abandonment of engineering judgment and experience.

6. Can consider economic consequences of deletion or addition of road network elements

The changing patterns of agriculture and other uses of rural land may suggest that seasonal or complete abandonment should be present among alternatives considered for some roads. The present density of local road networks in the United States suggests that roads on entirely new locations may seldom be among the alternatives, but an optimum approach should be equipped to include this possibility.

7. Can consider economic consequences of stage construction

The alternatives for improvement of a particular road may include accomplishing the final result in stages. For example, the placement of a bituminous mat might be delayed for several years after placement of the base, with initially light traffic volumes being served by a dust palliative or bituminous surface treatment. An optimum approach would permit assessment of the economic consequences of such delays.

8. Provides a means for assessing alternatives in functional classification

In a mesh or grid-like network of local roads, there may well be several possible alternative patterns for selective collector-type improvements. An optimum approach would indicate which pattern of higher-quality collector roads and lower-quality access roads is likely to be economically preferable.

9. Considers consequences to users diverted from a former route to an improved route as well as the new use induced by network improvements

Characteristic 4 suggested that an optimum approach would keep a separate tally of those new trips that are expected to develop with (but not without) particular network improvements. Such induced traffic is likely to be only a portion of the increase in road use following an improvement. Another portion, perhaps the major portion of a typical increase, would be diverted traffic—traffic originally moving and which would continue to move between particular origins and destinations but which, with the improvement, would be persuaded to alter its route. An optimum approach would include a valid prediction of the most likely routes with and without a particular improvement or set of improvements, thereby permitting an accounting of consequences to diverted traffic. (On a heavily traveled road network where capacity or congestion problems exist, an optimum approach would consider also the consequences to traffic remaining on a link from which other traffic has been diverted; it is assumed in this study that congestion problems on a typical local rural road network are sufficiently slight that these consequences to remaining traffic may be ignored.)

10. Recognizes the reality of budget constraints but provides a guide to the desirability of relaxing these constraints

Characteristic 1 suggested that an advantage of focusing on economic efficiency was its guidance as to how much should be spent for road network improvements. More specifically, an optimum approach to planning and programming local rural road improvements would suggest an optimum pattern in the light of expected budget constraints and then furnish some index of the probable productivity of additional funds, should it be possible to relax these expected constraints.

11. Constraints cover both construction and maintenance

It is common practice for capital improvements to be considered separately from maintenance and repair. Maintenance tends to have a first call on available funds, with spending for improvements constrained by the expected remainder. Because of the interdependence of construction and maintenance efforts, and the frequent possibility of trade-offs, it appears that an optimum approach should constrain them jointly. It is possible, for example, that some planned neglect of a few selected roads might release funds for the earlier improvement of another. This improvement, in turn, could bring a subsequent reduction in maintenance demand for funds on that particular link.

12. Indicates optimum timing of various network improvements

As well as suggesting what improvements should be made on which roads, an optimum approach would indicate the optimum timing for each improvement. The desirable output would be a designation by specific year and not merely a rank ordering. This comment concerning specific year refers only to projects optimally introduced within, say, the first five years. For projects likely to be inserted in the network later, placement in perhaps five-year groupings might be all that is justified since it is assumed that analysis would be repeated at intervals so that sharpened estimates of future demand and consequences may be considered.

13. Converges efficiently on an economically optimum set

From among the several alternatives for each link in a road network—actually many alternatives considering alternatives in timing—an optimum approach would converge on that set of improvements, over the network and over time, which would maximize economic efficiency within the constraints imposed. Such a set would not be a final recommendation to decision makers but, rather, a basis for assessing the economic cost of departing from this set in the interest of consequences which had not been quantified in money terms.

A FEASIBLE BEGINNING

Several among the characteristics claimed for an optimum approach in road improvement planning and programming may appear idealistic. It is true that a scarcity of data could present problems in applying an approach which would meet these characteristics, but such problems are not insurmountable. The primary problem is not a lack of input data but, rather, the lack of ready mathematical programming tools which would permit efficient convergence on an economically optimum pattern of road investment.

Advances in mathematical programming, or perhaps even intensive attention by persons equipped at the present level of knowledge, may lead to means for handling this problem of optimization. It is suggested that, in the interim, some beginning can be made in meeting most of the suggested characteristics of an optimum approach.

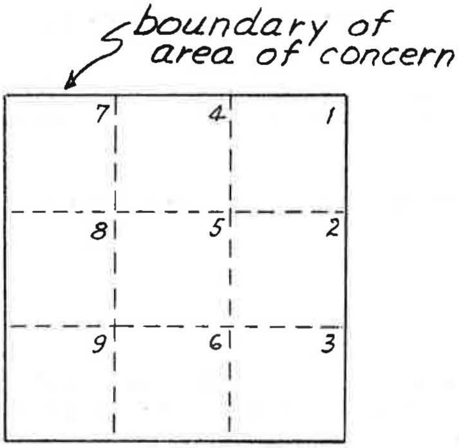
Such a feasible beginning is based on a deliberate comparison of sets of possible changes to the road network rather than on the evolution of an economically optimum set from among many alternatives on various links of the network. The approach is as follows:

1. Select a planning horizon

The analysis period consists of the time span between the present and some planning horizon in the future. This planning horizon is generally as far ahead as one can see with acceptable assurance that estimates of transportation demand are reasonable and that the network being considered will not become functionally obsolete.

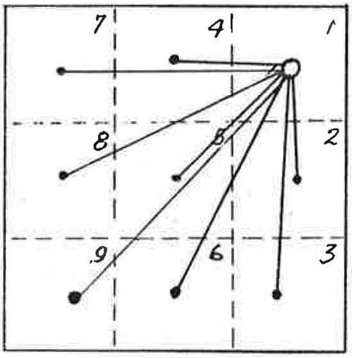
2. Subdivide the area into zones

An accounting of the consequences, to users, of changes in the road network is made on a trip basis rather than on a basis of road-by-road traffic volumes. Consequences are summed over all zone-to-zone movements. Although zones need not necessarily be uniform in size and shape, a grid-type zoning



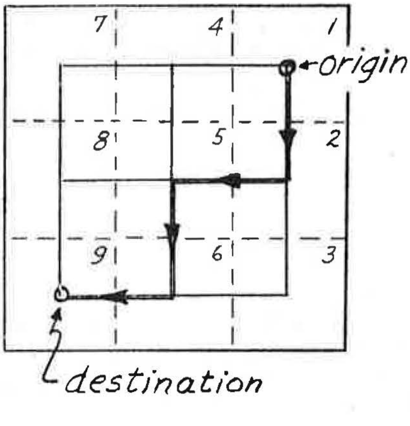
may be useful. A grid offers advantages in the possible aggregation of zones for planning on a larger, perhaps regional basis, as well as in a ready disaggregation for considering road improvement alternatives of more local interest. There is no firm answer as to desirable grid size. Zones should be small enough that intrazonal movements are of minor significance in the road network being analyzed. To use zones so small as an acre or two, however, would quickly tax the limited storage capacity of the computer and probably increase the cost of analysis more than the increased usefulness of results could justify. Where aggregation of zones in more than one county is a possibility, it should be advantageous to relate the grid to some standard coordinate system.

3. Define or estimate the present trip desire lines



Conventional origin-denstination survey techniques offer one method of establishing the approximate number of trips per unit of time between zones in the area of analysis. Less costly techniques may include, for a relatively small area, a property-by-property rundown by local persons well acquainted with individual travel patterns related to work or business, school, recreation, pickups and delivery, etc. For larger areas, and as the state of the art advances, it may be possible to develop synthetic patterns of trip desire based on land use.

4. Assign present trips to the existing road network



Trips are assigned to most likely paths through the road network. Assignment is perhaps most often made on the assumption that trip makers use the minimum-time paths. More sophisticated approximations have included some combination of time and distance in simulating the factors that underlie the choice of route.

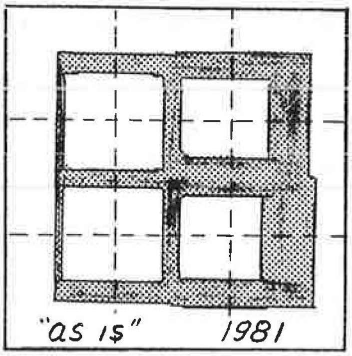
5. Assess accuracy of trip assignment

Some check on the validity of an initial trip assignment may be made by comparing actual traffic counts on links in the road network with link volumes developed in the assignment of trips to paths through the road network.

6. Estimate future zone-to-zone trip desire independent of any improvements in the road network

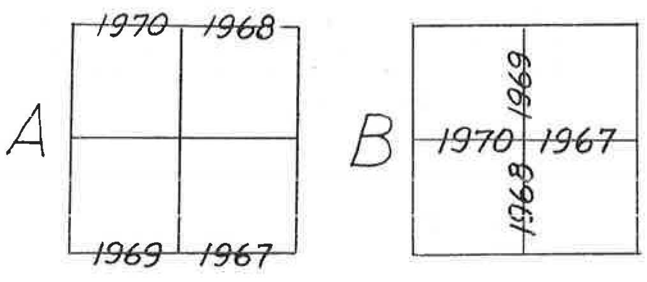
This estimate of year-by-year increases or decreases of trips between all pairs of zones is specifically concerned with changes which are expected to develop without any alterations to the "as is" condition of the road network.

7. Load the "as is" network with the estimated future trips in order to estimate the changing traffic volumes on network links



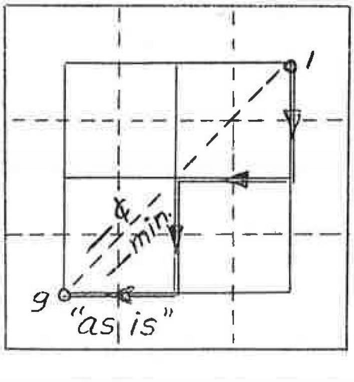
This pattern of predicted changes in traffic volumes should be a helpful guide for estimating the road maintenance costs if the "as is" level of service is continued. It also indicates where capacity problems may develop, and aids in defining alternative patterns of road network improvement.

8. Define the alternative sets of road network improvements



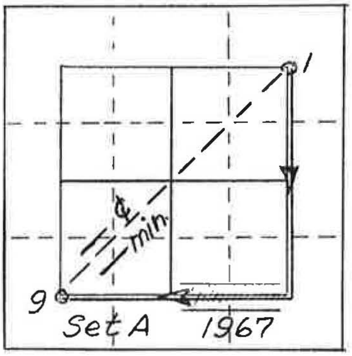
Alternative sets of network improvements, defined over the individual network elements and also over time, will reflect the possible alternatives in structuring a collector-access pattern (this refers to the application of the concepts of functional classification). The time dimension, as well as the level or quality of improvement represented in alternate sets, reflects a realistic attention to probable budget constraints.

9. Compute the interzonal unit travel times and vehicle operating costs for the "as is" network



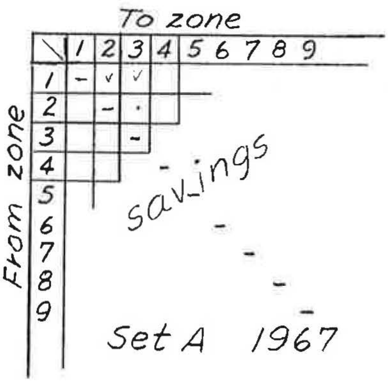
Having previously (in step 4) defined the minimum time paths between all pairs of zones, the interzonal travel time and vehicle operating cost are summed from the links constituting each of the minimum time paths.

10. Compute the interzonal unit travel times and vehicle operating costs for each yearly stage in the development of each alternative set of network changes



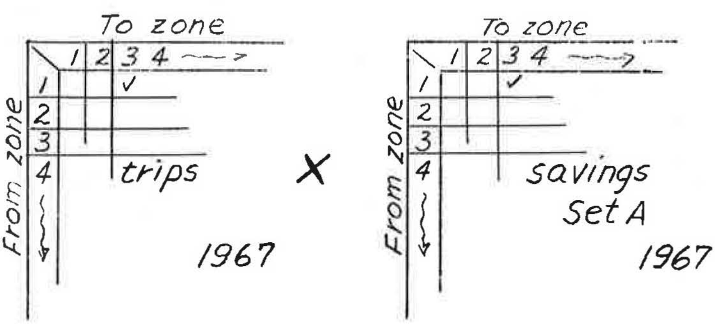
This follows the same procedure as noted in step 9. Minimum time paths may well be changed by progressive alterations in the road network.

11. Compute the unit savings in interzonal travel time and vehicle operating cost for each year (for each set) of the analysis period



This computation is merely a subtraction, over all pairs of zones, of the data assembled in step 10 from those assembled in step 9.

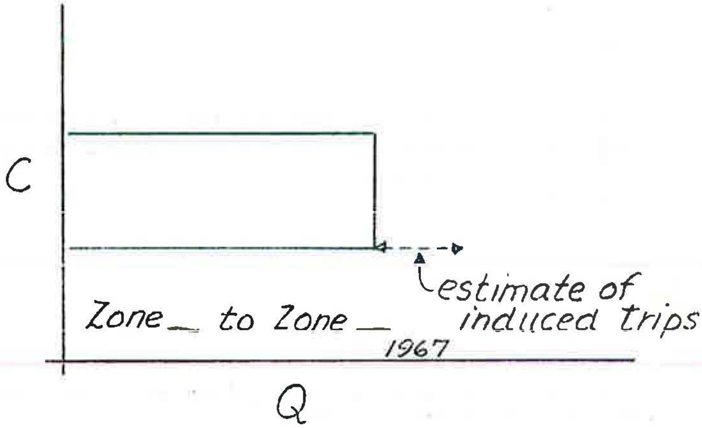
12. Sum over all pairs of interzonal movements, for each year, the product of "without improvement" trips and unit savings in travel time and vehicle operating cost related to alternative sets of improvements



This sum represents the benefits on existing trips and on the exogenous increase. It represents what makers of these trips, collectively, should be willing to pay, in a particular year, for the improved state of the road network.

$$\sum_{1967} = \_\_\_\_$$

13. Develop an estimate of the trips likely to be induced each year as network improvements in each set are progressively inserted

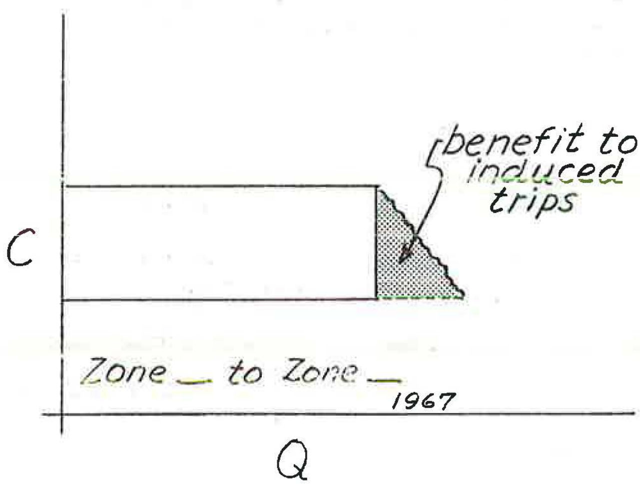


Estimating such trips is not an exact science. One approach is to assume that the increase in interzonal trips which is induced by road improvements is proportional to the percent decrease in travel time; that is

$$\frac{Q \text{ induced}}{Q \text{ original}} = n\left(\frac{T \text{ original} - T \text{ improved}}{T \text{ original}}\right)$$

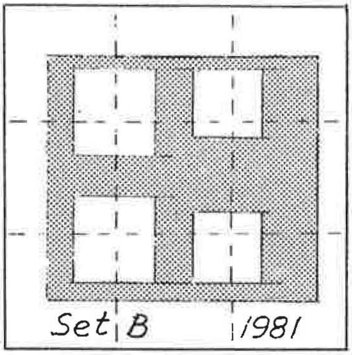
where n is an estimate of the inducing tendency of network improvements.

14. Compute the benefit to induced trips for each year of the analysis period



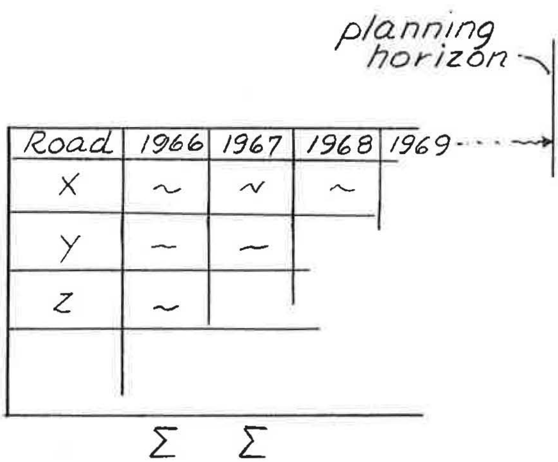
Computing the benefits on induced trips is not an exact science either. One approach is to assume (a) that the first induced trip is almost made without the improvement (and hence its "willingness to pay" for the improvement is equivalent to that of an existing trip), (b) that the last induced trip is almost not made with the improvement (and hence its willingness to pay is zero), and (c) that willingness to pay is evenly distributed between these extremes. With such assumptions, the triangular area beneath the "demand curve" may be used as an approximation of benefit to induced trips.

15. Load the future traffic on the network with the alternative sets of improvements inserted to produce the expected future traffic volumes



This loading of the revised network can guide the estimates of yearly road maintenance costs related to the alternative sets. It can also provide a warning as to where future capacity problems may develop.

16. Develop a road-by-year table of the estimated highway department expenditures related to each alternative set of improvements and for continuing the "as is" level of service on the network



The objective here is to yield an estimate, by year, of additional or reduced highway expenditures required for the alternative sets of improvements in comparison to continuing the "as is" level of service.

17. Discount the yearly benefits and costs of each alternative set to the present and sum them for comparison with other alternatives

Given a confidence that the particular discount rate used is appropriate, that a dollar value may unequivocably be assigned to the hours saved, that induced trips related to improvements have been estimated realistically, and that consequences not included in the analysis are either negligible or offsetting, then that set of improvements which produces the maximum present value of benefits minus costs is preferred. It is more realistic to recognize that unquantified consequences are not usually negligible or offsetting and that the differences in net present values provide a means for weighing these consequences.

It is yet more realistic to recognize that the other confidences that were treated as givens in the previous paragraph may often be rather shaky. This approach provides for a check of the sensitivity of the results to a range in values for the variables. If one variable is considerably less reliable than the others, for example the dollar value of savings in passenger car time, the approach permits a check of what the value assigned to this variable must be if alternative A is to be preferred to the "as is" alternative, or if the alternative B is to be preferred to alternative A.

It is expected that the analysis may suggest new sets or modifications of the first sets which should be assessed. One type of modification would consider the possible advantage of postponement. A related modification would consider the gain from earlier attention to some elements in an attractive set. In the case of the latter, the approach would indicate the economic gain that should be possible if certain budget constraints were relaxed.

A PROCEDURE—AND AN EXAMPLE

This section offers a procedure for implementing the "feasible beginning" approach. It indicates how one set of computer programs already available to highway engineers may be adapted, and illustrates the procedure by means of an example.

The Procedure

The procedure is based on the Bureau of Public Roads battery of traffic assignment programs (1, 2) prepared for the IBM 7090/94. In presenting a procedure based on these programs, it should be acknowledged that they will soon be out of date. The Bureau has been developing a new generation of transportation planning programs for use with the IBM 360. The IBM 360 equivalents of 7 of the 13 programs used in this procedure were to have been completed by February 1968; development of the equivalents of the remaining programs has not yet been firmly scheduled. The rationale for presenting in some detail the use of a generation of traffic assignment programs soon to be outdated is the expectation that its successor, despite the improvements, will have very similar functional components.

The 13 phases of the procedure described here do not parallel exactly the items in the approach described in the previous section. The groupings of various operations into phases have been guided primarily by apparent efficiencies in computer operations. The network description used with this BPR battery of programs does not include a field for the inclusion of vehicle operating costs on network links. These costs were coded in the distance field for the purposes of this study.

The Example

The example used to illustrate the procedure is admittedly oversimplified and small scale. The small scale was selected to permit manual spot checks on the accuracy of the computer output. The fictional Simpleisle, an island three miles square, is connected to the outside world only by its pier. Its road network, on a mile-square grid, is shown in Figure 1, which also indicates the average daily traffic counts (1966) and the locations of existing stop signs. The "business district" is located near the intersection of Davis, Lewis, Pier and King Roads.

Lewis and King Roads, reconstructed in 1964 and 1965, respectively, have a roadbed (shoulder break to shoulder break) width of 26 ft; a double bituminous surface treatment 18 ft wide is bordered by 4-ft shoulders. All other roads have a roadbed width of 16 ft and a surface of loose gravel.

The local board is pleased with the type of improvement made on King and Lewis Roads. It decides tentatively that the island can undertake the reconstruction of up to four more of its roads in the years 1967 through 1970. Stemming from conversation with the island engineer about the concepts of functional classification, two notions as to a possible collector structure emerge. Some board members tend to prefer a "ring plan"—the reconstruction of Adams, Brown, Evans and Fuller Roads—so that these, together with King and Lewis Roads, form a "reverse C" pattern of collectors. Other board members, concerned about probable heavy future traffic on Davis Road, suggest a "cross plan." This latter plan would call for the reconstruction of Davis, Ivy, Cass and Jones Roads, leaving the exterior roads to function as feeders. The engineer mentions the possibility that the cost of a fourth mile of reconstruction might be saved and road users served just as well by improving only Brown, Davis and Fuller Roads; this would provide a "reverse E" pattern of collectors.

The island engineer is charged with the responsibility of building a "factual" basis for the board choice from among these alternatives.

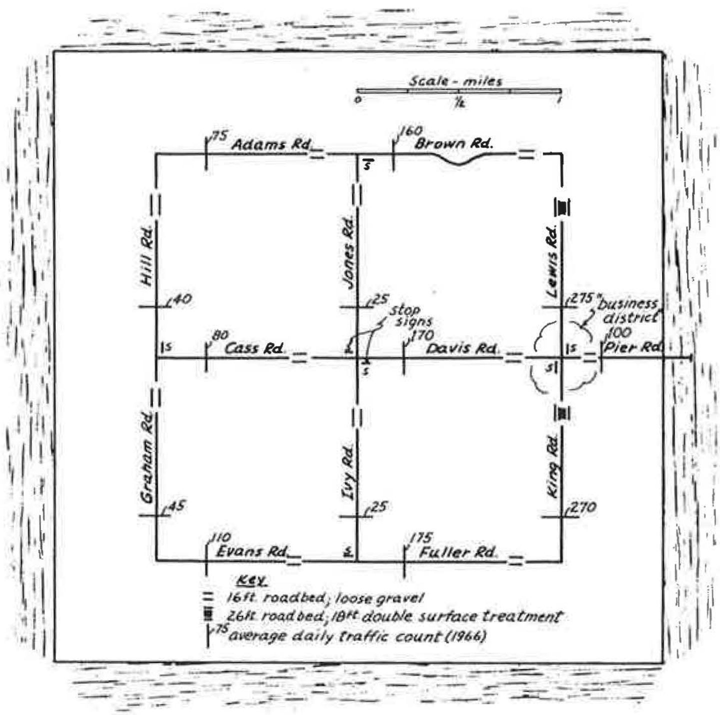


Figure 1. Simpleisle and its road network.

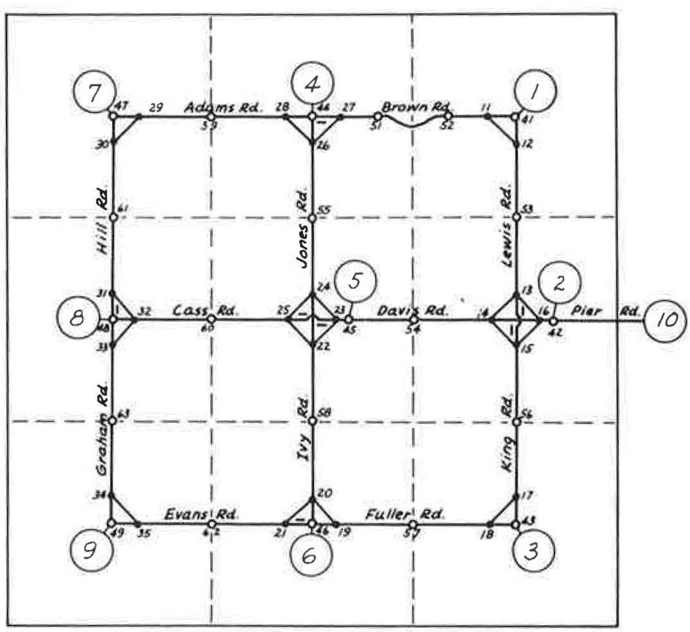


Figure 2. Zoning of Simpleisle and designation of road network links and nodes.

TABLE 1

PATTERN OF WEEKLY INTERZONAL TRIPS BY CARS AND TRUCKS IN 1966

from zone \ to zone	1	2	3	4	5	6	7	8	9	10
1		245 / 56	49 / 14	35 / 14	56 / 21	21 / 7	35 / 7	21 / 7	28 / 14	21 / 1
2	252 / 70		175 / 56	161 / 63	140 / 56	154 / 49	84 / 14	84 / 14	140 / 28	35 / 105
3	42 / 14	175 / 49		28 / 28	35 / 14	28 / 7	35 / 6	7 / 4	35 / 18	14 / 1
4	49 / 21	126 / 63	35 / 14		49 / 14	14 / 14	14 / 3	7 / 4	21 / 7	21 / 1
5	56 / 14	196 / 45	28 / 9	21 / 14		28 / 14	14 / 14	14 / 2	28 / 28	28 / 35
6	14 / 6	112 / 42	35 / 16	14 / 14	42 / 14		21 / 5	14 / 1	28 / 7	14 / 1
7	21 / 7	84 / 21	21 / 11	21 / 3	28 / 7	14 / 4		21 / 2	14 / 1	14 / 1
8	14 / 1	84 / 23	7 / 1	14 / 1	21 / 5	7 / 1	7 / 1		21 / 2	14 / 1
9	42 / 7	168 / 51	35 / 19	21 / 3	14 / 9	14 / 9	14 / 6	7 / 1		14 / 1
10	21 / 1	35 / 105	14 / 1	21 / 1	28 / 35	14 / 1	14 / 1	14 / 1	14 / 1	

Phase I—Preliminaries

Before the computer phases are undertaken it is necessary to (a) select a planning horizon, (b) subdivide the area into zones, (c) define the present pattern of interzonal trip desire for the types of vehicles to be included in the analysis, and (d) define relevant characteristics of the existing road network.

The planning horizon in the Simpleisle example is 15 years. The convenient assumption that the population is clustered near intersections and corners of the road network, together with the convenient dimensions of Simpleisle, make it possible to divide the area into the nine one-mile-square zones shown in Figure 2. The estimate of weekly trips between all pairs of zones in 1966 is shown in Table 1; for each interzonal movement, the top figure represents weekly movements by car (including pickup trucks) and the bottom figure the trips by heavier trucks or buses.

Figure 2 illustrates the conversion of the Simpleisle network and the zone centroids into a framework of links and nodes. An explanation is in order for what may seem to be a surplus of nodes. The additional nodes at intersections and corners were inserted so that costs related to stopping and turning movements could be attached. The nodes at intermediate locations along legs in the network are essentially dummy nodes, inserted to minimize scaling errors by the computer which were otherwise unavoidable in the use of the BPR battery of programs for the IBM 7090/94.

Travel times and vehicle operating costs for passenger cars and for a 12-kip truck were assigned for each link. It is assumed that all heavier vehicles are the 12-kip truck for which data are available (3).

Phase IIA—Build Present Trip Tables

This portion of Phase II converts interzonal trip data to binary trip tables on tape and, if desired, produces printouts of the trip tables for checking and reference. The basic elements of the program sequence are as follows:

PR133—Build binary trip table(s) for base year (trip tables for more than one class of vehicle can be built in one run of this program)
PR113—Print base-year trip table(s)

The trip-table printout, for cars, in the Simpleisle example is shown in Figure 3. The data correspond to the input data given in Table 1.

Phase IIB—Build Network Description and Trees, and Sum Link Volumes

This program sequence produces a binary network description, defines the trees, or minimum-time paths between all zones, and loads the trip table produced in Phase IIA on these minimum-time paths. The program sequence is as follows:

PR6—Build binary network description
PR12—Print link data (optional, but useful as a check)
PR1—Build trees
PR50—Format trip trace (useful for sketching and checking trees)
PROG. 2A—Load minimum-time paths
PROG. 4A—Sum link volumes

Figure 4 shows, for the Simpleisle example, the trace of minimum-time paths for cars from zone 2 to all other zones. The minimum-time path from zone 2 to zone 6 on the present network is via nodes 42, 16, 15, 56, 17, 18, 57, 19 and 46 with a total time of 3.63 minutes. A sketch of the trees, similar to that developed from the computer output in Figure 4, can be a useful guide to judgments as to how realistically the minimum-time paths represent the routes commonly taken.

Figure 5 is a map of total assigned daily traffic volumes on network links for the base year. In this example, assigned volumes are sufficiently (and conveniently) close to field counts so that adjustments need not be considered.

Phase III—Predict Future Demand for Interzonal Movement

Given reliable data on present interzonal movement of vehicles, the planning and programming of road improvements requires some prediction of future demand. The objective of this phase is to translate expected future growth or decline in the various zones, independent of any road network improvements, into expected interzonal movements at the planning horizon.

The best estimates of future land use in the various zones of Simpleisle are given in Table 2. These estimates and related estimates of expansion (or decline) in general activity are translated into growth factors for trips by cars and trucks. These growth factors are estimates of the ratios of trips to and from each zone at the planning horizon to the trips now existing, assuming the present level of road service is continued.

PRINT BASEYEAR WEEKLY TRIP TABLE-CARS SIMPLEISLE JWS

TRIPS FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	245	49	35	56	21	35	21	28
10	21									

511 TRIPS FROM THIS ZONE

TRIPS FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	252	--	175	161	140	154	84	84	140
10	35									

1225 TRIPS FROM THIS ZONE

Figure 3. Portion of printout of base-year trip table for cars (from PR113).

TREE NO. 2 FORMAT TRIP TRACE(TREES)-BASEYR NETWORK-CARS SIMPLEISLE

NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME
1	1.47	41	1.47	12	1.47	53	.80	13	.13	16	.00	42	.00
2	.00												
2	.00												
3	1.47	43	1.47	17	1.47	56	.80	15	.13	16	.00	42	.00
2	.00												
4	4.00	44	4.00	27	4.00	51	3.17	52	2.33	11	1.50	12	1.47
53	.80	13	.13	16	.00	42	.00	2	.00				
5	2.27	45	2.27	54	1.20	14	.13	16	.00	42	.00	2	.00
6	3.63	46	3.63	19	3.63	57	2.57	18	1.50	17	1.47	56	.80
15	.13	16	.00	42	.00	2	.00						
7	6.20	47	6.20	29	6.20	59	5.10	28	4.00	44	4.00	27	4.00
51	3.17	52	2.33	11	1.50	12	1.47	53	.80	13	.13	16	.00
42	.00	2	.00										
8	4.40	48	4.40	32	4.40	60	3.33	25	2.27	23	2.27	45	2.27
54	1.20	14	.13	16	.00	42	.00	2	.00				
9	5.83	49	5.83	35	5.83	62	4.73	21	3.63	46	3.63	19	3.63
57	2.57	18	1.50	17	1.47	56	.80	15	.13	16	.00	42	.00
2	.00												
10	1.07	42	.00	2	.00								

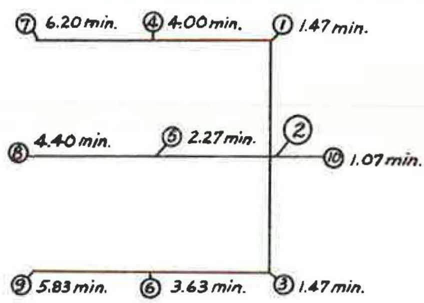


Figure 4. Format of trip trace showing minimum-time paths (for cars) from zone 2 to all other zones on basic network (from PR50).

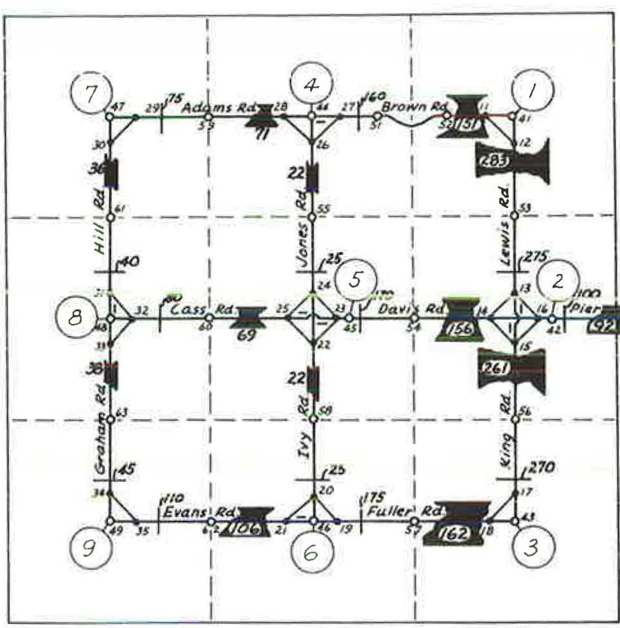


Figure 5. Map of assigned two-way volumes for comparison with actual counts (developed from output of PROG. 4A).

TABLE 2

EXPECTED CHANGES IN LAND USE, AND GROWTH FACTORS FOR TRIPS BY CAR AND TRUCK

Zone	Present Use	Potential in Agriculture	Probable Direction of Future Use	Expected Growth Factors for General Activity (15 years)	Estimated Growth Factors for Trips (15 years)	
					cars	Trucks
1	agriculture & residential	good	residential	1.6	1.8	1.5
2	commercial, industry, agriculture	good	commercial & industry	2.5	2.5	2.5
3	agriculture	fair	residential	2.0	2.5	1.2
4	agriculture	good	agriculture	1.4	1.3	1.5
5	agriculture & industry	good	industry & agriculture	2.0	1.8	2.4
6	agriculture	excellent	agriculture	1.6	1.4	1.8
7	forestry	poor	recreation	1.3	1.6	1.2
8	agriculture	fair	agriculture	0.8	1.0	0.7
9	agriculture	good	agriculture	1.5	1.3	1.8
10	external	--	--	2.5	1.0	2.5

The development of a trip table for the horizon year is accomplished with the following program sequence:

> PR14—Fratar expansion from base-year trip table to horizon-year trip table
> PR113—Print horizon-year trip table

The horizon-year trip table for the Simpleisle example is shown in Figure 6.

Phase IV—Load Future Trips on "As Is" Network for Estimate of Future Traffic Volumes

The estimated future volumes on network links can serve as a guide to (a) estimating future maintenance costs for the "remain as is" alternative, and (b) defining possible alternative sets of improvements. The following is the sequence of computer programs used in Phase IV:

```
    1981(HORIZON) WEEKLY TRIP TABLE-CARS        SIMPLEISLE

                            TRIPS FROM ZONE      1   TO ALL ZONES
ZONE             0      1      2      3      4      5      6      7      8      9

 00             --     --    637     81     29     67     19     38     14     22
 10             17
      924 TRIPS FROM THIS ZONE

                            TRIPS FROM ZONE      2   TO ALL ZONES
ZONE             0      1      2      3      4      5      6      7      8      9

 00             --    655     --    678    313    397    315    216    125    263
 10             66
     3028 TRIPS FROM THIS ZONE
```

Figure 6. Portion of printout of horizon-year trip table for cars (from PR113).

PROG. GENPUR—Interpolate between base- and horizon-year trip tables for intermediate-year trip table
PROG. 2A—Load intermediate-year trip table on minimum-time paths
PROG. 4A—Sum intermediate-year link volumes
PROG. 2A—Load horizon-year trip table on minimum-time paths
PROG. 4A—Sum horizon-year link volumes

The first three programs in this sequence are not absolutely necessary. The traffic volumes for the base year (from Phase IIB) and for the horizon year would permit ready graphical interpolation, on a straight-line basis, of the volumes in intermediate years. These first three programs serve only as a check that mistakes have not been made in totaling link volumes for the base and horizon years. The estimated traffic volumes at the planning horizon in the Simpleisle example are shown in Figure 7.

Phase V—Build Tables of Interzonal Travel Times and Vehicle Operating Costs for "As Is" Network

The tables produced in this phase are used as a datum for the subsequent assessments of consequences, to users, related to alternative sets of network improvements. The sequence of computer programs in Phase V follows:

PR130—Build binary table of interzonal travel times
PR113—Print table of interzonal travel times
PR19—Build binary table of interzonal vehicle operating costs
PR113—Print table of interzonal vehicle operating costs

Figure 8 is an example of the printout of interzonal travel times and vehicle operating costs for cars traveling the minimum-time paths in the existing Simpleisle network. Times and costs are shown only for trips from zones 1 and 2.

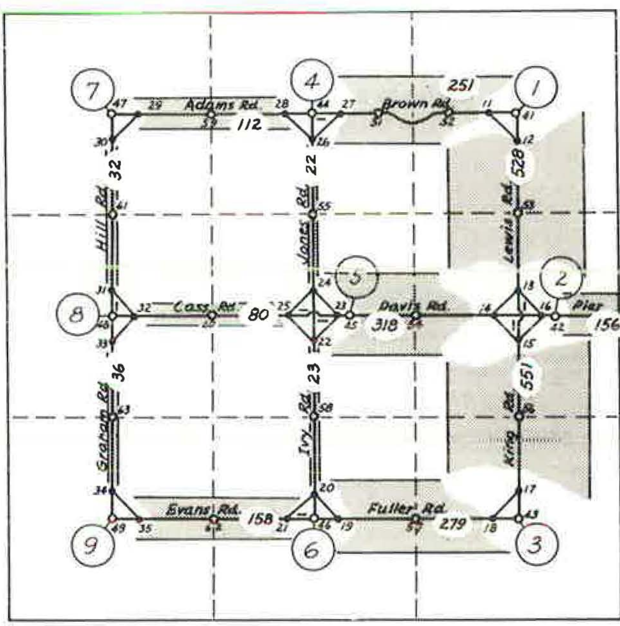


Figure 7. Estimated traffic volumes at planning horizon (1981) for "as is" network.

PRINT INTERZONAL TRAVELTIMES-BASIC-CARS SIMPLEISLE

TIMES FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	143	267	250	357	483	470	570	703
10	250									

TIMES FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	147	--	147	400	227	363	620	440	583 (5.83 min.)
10	107									

PRINT INTERZONAL VEHOPERCOSTS-BASIC-CARS SIMPLEISLE

COSTS ~~TIMES~~ FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	46	74	96	96	130	150	149	184
10	68									

COSTS ~~TIMES~~ FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	65	--	62	170	60	118	224	113	172 ($.172)
10	22									

Figure 8. Examples of printout of interzonal travel times and vehicle operating costs for cars on "as is" network (from PR113).

Phase VI—Develop Alternative Sets of Possible Network Changes

The timing of this phase is not critical except that the firming of alternatives should follow a study of the estimated future volumes on network links as developed in Phase IV. In reality, preliminary ideas surely would have developed even before Phase I.

Where the present network is basically a grid-like pattern with a general evenness in road quality, it should be especially desirable for the alternative sets to represent the various possibilities for collector-type improvements. Once the general structure of a particular alternative set is decided, the timing of link improvements is selected; this is a firm selection in the definition of a particular set, but may well be varied later in modifications of that set. In addition to sets varying as to the pattern of improvements over the network, an analysis should include sets varying as to the quality or level of service provided. Sets reflecting variation in both distribution and quality of improvements could be considered concurrently. Where a range in possible patterns of collectors exists, however, it may be advantageous to focus first on this decision, perhaps using some average level of improvement in the analysis. Subsequent sets, then, could assess the consequences of alternative levels of improvement.

Figure 9 sketches the three basic sets of road improvements compared in the Simpleisle example. Each set represents an alternative plan for developing a pattern of improved collectors. The level of improvement for each element in each set is assumed to be the same as that already provided in the reconstruction of Lewis and King

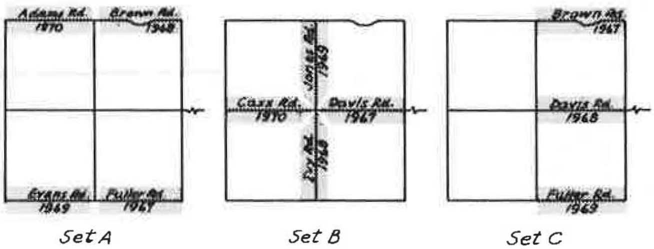


Figure 9. Alternative sets of improvements to road network.

TREE NO. 2 VII-3 FORMAT TRIP TRACE(TREES)-SET A,PROJ FB CARS

NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME	NODE	TIME
1	1.47	41	1.47	12	1.47	53	.80	13	.13	16	.00	42	.00
2	.00												
2	.00												
3	1.47	43	1.47	17	1.47	56	.80	15	.13	16	.00	42	.00
2	.00												
4	2.83	44	2.83	27	2.83	51	2.40	52	1.97	11	1.53	12	1.47
53	.80	13	.13	16	.00	42	.00	2	.00				
5	2.27	45	2.27	54	1.20	14	.13	16	.00	42	.00	2	.00
6	2.87	46	2.87	19	2.87	57	2.20	18	1.53	17	1.47	56	.80
15	.13	16	.00	42	.00	2	.00						
7	5.03	47	5.03	29	5.03	59	3.93	28	2.83	44	2.83	27	2.83
51	2.40	52	1.97	11	1.53	12	1.47	53	.80	13	.13	16	.00
42	.00	2	.00										
8	4.40	48	4.40	32	4.40	60	3.33	25	2.27	23	2.27	45	2.27
54	1.20	14	.13	16	.00	42	.00	2	.00				
9	5.07	49	5.07	35	5.07	62	3.97	21	2.87	46	2.87	19	2.87
57	2.20	18	1.53	17	1.47	56	.80	15	.13	16	.00	42	.00
2	.00												
10	1.07	42	.00	2	.00								

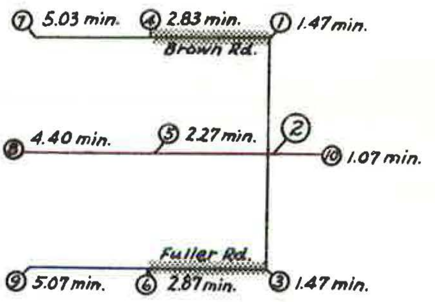


Figure 10. Format of trip trace showing minimum-time paths, for cars, from zone 2 to all other zones after improvements to Fuller and Brown Roads are completed (from PR50).

Roads—a raised grade line with 26-ft roadbed and 18-ft double bituminous-surface treatment.

Phase VII—Develop Revised Interzonal Travel Times and Vehicle Operating Costs Related to a Yearly Increment in Development of an Alternative Set

It should be noted that Phases VII through IX are repeated for each year that any alteration in the road network is made. The sequence of computer programs used in Phase VII follows:

PR6—Update binary network description
PR1—Rebuild trees for revised network
PR50—Format trip trace
PR130—Build table of revised interzonal travel times
PR113—Print table of revised interzonal travel times
PR19—Build table of revised interzonal vehicle operating costs
PR113—Print table of revised interzonal vehicle operating costs

Set A in the Simpleisle example, at the stage when improvements to Fuller and Brown Roads have been completed, is used for the illustration of computer output in Phases VII through IX. The trace of minimum-time paths at this stage is shown in Figure 10.

The "skim," by the computer, of the revised trees yields new tables of interzonal travel times and vehicle operating costs. A portion of the printout is shown in Figure 11; as in Figure 8, only data for trips from zones 1 and 2 are shown.

VII-5 PRINT INTERZONAL TRAVTIME-SET A,PROJ FB CARS

TIMES FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	143	267	130	357	407	350	567	627
10	250									

TIMES FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	147	--	147	283	227	287	503	440	507 (5.07 min.)
10	107									

VII-7 PRINT INTERZONAL VEHOPCOSTS-SET A,PROJ FB CARS

COSTS ~~TIMES~~ FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	46	74	42	96	130	96	140	184
10	68									

COSTS ~~TIMES~~ FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	65	--	62	125	60	118	179	113	172 ($.172)
10	22									

Figure 11. Examples of printout of interzonal travel times and vehicle operating costs for cars after improvement of Fuller and Brown Roads (from PR113).

Phase VIII—Compute Travel Time Benefits on Existing Trips (including exogenous change) and on Induced Trips for the Year in Which an Increment of an Alternative Set Is Inserted

The sequence of computer programs in Phase VIII follows:

PROG. GENPUR—Interpolate between base year and horizon year for year n trip table
PR113—Print year n trip table
PROG. GENPUR—Subtract interzonal travel times for network after year n change from travel time for "as is" network
PR113—Print table of unit interzonal travel time savings
PROG. GENPUR—Multiply year n trip table by unit interzonal travel time savings; print sum
PROG. GENPUR—Produce table of induced trips based on percentage reductions in interzonal travel time
PROG. GENPUR—Multiply table of induced trips by table of interzonal travel time savings by one-half; print sum

For the Simpleisle example, Figure 12 shows a portion of the weekly trip table for cars in 1968, the year when improvements to Fuller and Brown Roads (in Set A) would have been completed. This trip table, developed by straight-line interpolation, contains trips that will develop independent of road network improvements; induced traffic is not included.

Figure 13 is a printout of a portion of the table of unit savings in interzonal travel time for cars, with improvements to Fuller and Brown Roads complete. This table is the result of subtracting the travel times in Figure 11 from the "as is" travel times in Figure 8.

The products of unit savings in Figure 13 and numbers of trips in Figure 12, summed over all interzonal movements and converted to an annual basis, yield the benefit in time savings to existing trips and exogenous increase in trips by cars in 1968. It is assumed here that 1968 refers to a year beginning on July 1, 1968. It is assumed, for convenience, that construction for that year is accomplished instantaneously on July 1st

VIII-2 PRINT WEEKLY TRIP TABLE-1968-CARS

TRIPS FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	297	53	35	57	21	35	21	28
10	21									

568 TRIPS FROM THIS ZONE

TRIPS FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	305	--	242	181	174	175	101	89	156
10	39									

1462 TRIPS FROM THIS ZONE

Figure 12. Portion of 1968 trip table, for cars, built by interpolating between 1966 trip table (Figure 3) and 1981 trip table (Figure 6) (from PR113).

VIII-4 INTERZONAL UNIT TRAVTIME SAVING FOR SET A(F8) CARS

TIMES FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	--	--	120	--	76	120	3	76

TIMES FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	--	--	117	--	76	117	--	76 (0.76 min)

Figure 13. Portion of table of unit savings in interzonal travel time, for cars, resulting from improvements to Fuller and Brown Roads (from PR113).

VIII-5 MULTIPLY 1968 TRIPTAB BY UNIT TRAVTIME SAVING-A(F3) CARS

~~SUMMARY OF TRIP ENDS FROM TOTAL OUTPUT TAPE AS A RESULT OF GENPUR~~

ZONE	TRIPS FROM OTHER ZONES	TIME SAVINGS IN A TRIPS TO OTHER ZONES	INTRAZONAL TRIPS	TOTAL TRIPS RECEIVED	TOTAL TRIPS SENT	TOTAL TRIP ENDS
1	10,909	10,566	0	10,909	10,566	21,475
2	45,349	50,416	0	45,349	50,416	95,765
3	10,748	11,033	0	10,748	11,033	21,781
4	26,869	24,859	0	26,869	24,859	51,728
5	0	0	0	0	0	0
6	15,861	12,832	0	15,861	12,832	28,693
7	19,060	16,063	0	19,060	16,063	35,123
8	55	134	0	55	134	189
9	15,488	18,421	0	15,488	18,421	33,909
10	5,303	5,318	0	5,303	5,318	10,621
TOTAL	149,642	149,642 = 1496 hours	0	149,642	149,642	299,284

Figure 14. Savings in travel time on existing use (including exogenous change) by cars, in 1968, with improvements to Fuller and Brown Roads in place (from PROG. GENPUR).

VIII-10 INTERZONAL INDUCED TRIPS-1968-SET A(F8) CARS

TRIPS FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	--	--	16	--	3	8	--	4

31 TRIPS FROM THIS ZONE

TRIPS FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	--	--	52	--	36	19	--	21

128 TRIPS FROM THIS ZONE

Figure 15. Portion of table of weekly interzonal car trips induced, in 1968, by improvement of Fuller and Brown Roads (from PR113).

VIII-11 MULTIPLY INDUCED TRIPTAB BY UNIT INTERZONAL SAVING IN TRAVTIME *(by one-half)*

~~SUMMARY OF TRIP ENDS FROM TOTAL OUTPUT TAPE AS A RESULT OF GENPUR~~

ZONE	TRIPS FROM OTHER ZONES	TIME "SAVINGS" IN TRIPS TO OTHER ZONES	INTRAZONAL TRIPS	TOTAL TRIPS RECEIVED	TOTAL TRIPS SENT	TOTAL TRIP ENDS
1	1,652	1,477	0	1,652	1,477	3,129
2	4,914	5,473	0	4,914	5,473	10,387
3	1,249	1,181	0	1,249	1,181	2,430
4	3,920	3,978	0	3,920	3,978	7,898
5	0	0	0	0	0	0
6	1,764	1,516	0	1,764	1,516	3,280
7	1,784	1,628	0	1,784	1,628	3,412
8	0	0	0	0	0	0
9	1,134	1,265	0	1,134	1,265	2,399
10	572	471	0	572	471	1,043
TOTAL	16,989	16,989 = 170 hours	0	16,989	16,989	33,978

Figure 16. Time "savings" benefit, in 1968, on car trips induced by improvement of Fuller and Brown Roads (from PROG. GENPUR).

so that benefits to users begin to accrue immediately and extend over a full year. This result is shown in Figure 14, in which the shading is to delete those sections of this standard "summary of trip ends" table which are not relevant to this analysis. Although the total time saving of 1,496 hours is the figure which is used in subsequent analysis, this table permits the analyst to see how the total time saving is distributed among trips to or from various zones.

Figure 15 shows a portion of the table of weekly interzonal trips, by car, that are induced in 1968 with improvements to Fuller and Brown Roads in place. The product of these induced trips and the unit "savings" resulting from these improvements (Fig. 13), with this result then multipled by one-half, converted to an annual basis and summed over all interzonal movements, is shown in Figure 16. This 170 hours is an approximation of the time "savings" benefit, in 1968, on car trips which would not have developed without improvement of Fuller and Brown Roads.

Phase IX—Compute Vehicle-Operating-Cost Benefits on Existing Trips (including exogenous change) and on Induced Trips for the Year in Which an Increment of an Alternative Set Is Inserted

Phase IX is generally parallel to the sequence of operations in Phase VIII. A primary difference is that trip tables produced in Phase VIII are used as input here. The sequence of computer programs used in this phase follows:

PROG.GENPUR—Subtract interzonal vehicle operating costs for network after year n change from vehicle operating costs for "as is" network

PR113—Print table of unit savings in interzonal vehicle operating cost

IX-2 INTERZONAL UNIT VEHOPCOST SAVING FOR SET A(FB) CARS

TIMES FROM ZONE 1 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	--	--	54	--	--	54	9	--

TIMES FROM ZONE 2 TO ALL ZONES

ZONE	0	1	2	3	4	5	6	7	8	9
00	--	--	--	--	45	--	--	45 ($.045)	--	--

Figure 17. Portion of table of unit savings in interzonal vehicle operating cost for cars resulting from improvements to Fuller and Brown Roads (from PR113).

IX-5 NETWORK VEHOPCOST SAVING-TOTAL WEEKLY SET A(FB) 1968 CARS

COST SAVINGS IN

ZONE	TRIPS FROM OTHER ZONES	TRIPS TO OTHER ZONES	INTRAZONAL TRIPS	TOTAL TRIPS RECEIVED	TOTAL TRIPS SENT	TOTAL TRIP ENDS
1	3948	3969	0	3948	3969	7917
2	12630	12690	0	12630	12690	25320
3	3338	3500	0	3338	3500	6838
4	12195	11708	0	12195	11708	23903
5	0	0	0	0	0	0
6	232	908	0	232	908	1140
7	8730	7531	0	8730	7531	16261
8	252	231	0	252	231	483
9	280	1248	0	280	1248	1528
10	1710	1530	0	1710	1530	3240
TOTAL	43315	43315	0	43315	43315	86630

$43.315 per week x 52 = $2253

Figure 18. Savings in vehicle operating cost on existing use (including exogenous change) by cars, in 1968, with improvements to Fuller and Brown Roads in place (from PR116).

PROG.GENPUR—Multiply year n trip table by unit savings in interzonal vehicle operating cost

PR116—Print network-wide vehicle-operating-cost savings on existing use and exogenous increase

PROG.GENPUR—Multiply table of induced trips by unit savings in interzonal vehicle operating cost

PR116—Print double the sum of vehicle-operating-cost benefits to induced trips

For the Simpleisle example, Figure 17 shows a portion of a table of unit savings in interzonal vehicle operating costs for cars resulting from reconstruction of Fuller and Brown Roads. The output from multiplying these unit savings by the 1968 trip table (Fig. 12) and summing over all interzonal movements, is shown in Figure 18. The computer output furnishes weekly savings which are converted manually to the yearly savings used in subsequent analysis.

The product of the table of weekly induced trips by cars (Fig. 15) and the table of unit "savings" in vehicle operating cost (Fig. 17), summed over all zones, is shown in Figure 19. Conversion of the computer output to an annual figure for benefit on induced trips was performed manually as shown.

IX-8 SUM DOUBLE WEEKLY'VEHOPCOSTSAV'BENEFITS TO INDUCED 68C-A(FB)

COST "SAVINGS" IN

ZONE	TRIPS FROM OTHER ZONES	TRIPS TO OTHER ZONES	INTRAZONAL TRIPS	TOTAL TRIPS RECEIVED	TOTAL TRIPS SENT	TOTAL TRIP ENDS
1	1480	1296	0	1480	1296	2776
2	3169	3195	0	3169	3195	6364
3	677	639	0	677	639	1316
4	3609	3776	0	3609	3776	7385
5	0	0	0	0	0	0
6	88	232	0	88	232	320
7	1647	1534	0	1647	1534	3181
8	0	0	0	0	0	0
9	56	180	0	56	180	236
10	396	270	0	396	270	666
TOTAL	11122	11122	0	11122	11122	22244

$11.122 per week x 52 x $\frac{1}{2}$ = $289

Figure 19. Vehicle-operating-cost "savings" benefit, in 1968, on car trips induced by improvement of Fuller and Brown Roads (from PR116).

TABLE 3

USER CONSEQUENCES RELATED TO THE SET A (FBEA) IMPROVEMENTS AS COMPARED TO CONTINUING THE "AS IS" LEVEL OF SERVICE

Year (the present ↓)	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980 (planning horizon ↓)
Projects In		F	F, B	F, B, E	F, B, E, A										
Benefits on Existing Use and Exogenous Increase in Use															
Time savings - passenger cars (hours)		601	1496	2071	2511	2596	2681	2766	2851	2937	3022	3107	3192	3277	3362
Time savings - trucks (hours)		188	517	711	818	849	880	912	944	976	1007	1038	1070	1102	1134
Vehicle operating cost savings - passenger cars		$ 142	$2253	$2539	$2825	$2931	$3037	$3143	$3249	$3356	$3460	$3564	$3669	$3774	$3879
Vehicle operating cost savings - trucks		$ -54	$ 947	$ 911	$ 906	$ 930	$ 954	$ 978	$1002	$1027	$1050	$1073	$1096	$1119	$1143
Benefits on Induced Use															
Time "savings" - passenger cars (hours)		53	170	269	362	374	386	399	412	425	437	449	461	473	485
Time "savings" - trucks (hours)		16	60	92	109	113	117	121	125	130	134	138	143	148	153
Vehicle operating cost "savings" - passenger cars		$ 14	$ 289	$ 339	$ 446	$ 461	$ 477	$ 493	$ 509	$ 525	$ 541	$ 557	$ 573	$ 590	$ 607
Vehicle operating cost "savings" - trucks		$ -3	$ 133	$ 135	$ 151	$ 155	$ 159	$ 163	$ 167	$ 172	$ 177	$ 182	$ 188	$ 194	$ 200

(Shaded cells:) The development of these data is illustrated by samples of computer output.

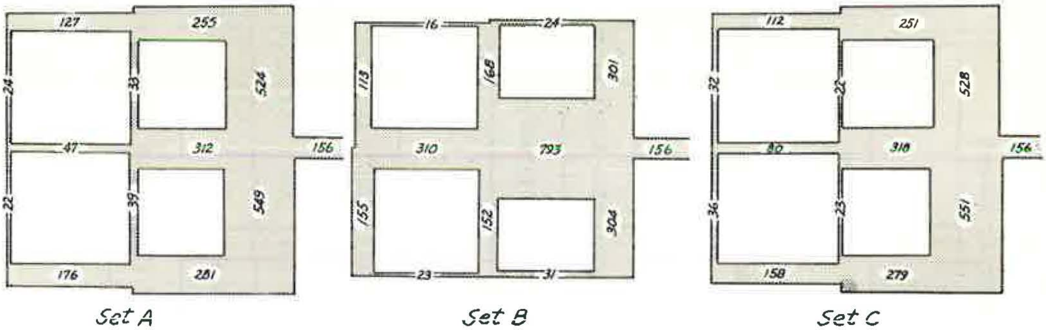


Figure 20. Estimated average daily traffic volumes (not including induced traffic) at planning horizon (1981) with alternative sets of improvements.

Phase X—Assess Consequences to Users for the Years Between the Completion of a Set of Improvements and the End of the Period of Analysis

The sequence of programs in Phase X, a composite of the sequences used in Phases VIII and IX, could, in a single computer run, provide data directly for each of the remaining years in the analysis period. However, with an assumed straight-line change in trips, it is possible to perform the Phase X sequence of programs for only the final year of the analysis period and then fill in the remaining years by interpolation.

The samples of computer output for Phases VII through IX have demonstrated the development of the data in the shaded cells of Table 3. Seven additional runs of the sequences of computer programs in these phases were required to produce the remaining data for the years 1967 through 1970 given in Table 3. Once the set of network improvements was completed in 1970, only two additional runs with the Phase X sequence, one for cars and another for trucks, were required to develop the data for the years 1971 through 1980.

Phase XI—Load Future Trips Onto the Improved Network

The program sequence here is similar to that in Phase IV; the Phase IV sequence is preceded by the use of PR6 to update the binary network description and PR1 to rebuild trees for the updated network. This phase does not include induced trips in the loading of the network and, hence, underestimates the traffic volumes to be expected. These volumes are probably close enough for estimating maintenance costs. Should it appear, however, that capacity problems are a real possibility, it would probably be worthwhile to include an estimate of induced traffic in this loading.

Figure 20 indicates how horizon-year traffic volumes on legs in the road network may be expected to vary with the alternative sets of improvements. These volumes do not include estimates of induced trips. Horizon-year volumes with set C are identical to volumes if the "as is" network is continued (Fig. 7); this is to say that set C results in no alteration of the minimum-time paths. Set A results in very little change in these paths whereas set B could be expected to result in a rather profound change in the distribution of traffic volumes on legs of the network.

Phase XII—Develop Estimates of Highway Costs Related to Various Alternatives

Phase XII develops a road-by-year table of estimated highway costs related to (a) continuing the "as is" level of service on the network, and (b) each of the alternative sets of network changes being considered in the analysis. The objective is to develop the year-by-year differences in costs related to each of the alternative sets as compared to the "as is" alternative.

TABLE 4

ESTIMATED ANNUAL HIGHWAY DEPARTMENT EXPENDITURES FOR VARIOUS ALTERNATIVES, SHOWING ADDITIONAL COSTS OF THE SEVERAL ALTERNATIVE SETS IN COMPARISON TO CONTINUING THE "AS IS" LEVEL OF SERVICE

Expenditure for Alternative: \ Year	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Continue "as is" level of service	$ 7,745	$ 6,765	$ 8,915	$ 7,655	$11,205	$ 8,955	$8,095	$8,035	$8,865	$10,530	$ 8,170	$8,200	$13,360	$ 9,615	$10,165
Set A (FBEA)	7,745	21,485	23,435	22,235	23,595	6,535	8,375	8,425	8,275	8,840	7,790	7,640	8,710	9,065	10,645
A (BFEA)	7,745	23,435	21,425	22,235	23,595	6,535	8,375	8,425	8,275	8,840	7,790	7,640	8,710	9,065	10,645
B (DIJC)	6,745	21,435	22,750	23,340	22,750	6,720	9,550	8,610	8,460	9,035	6,975	8,845	8,905	9,290	9,870
C (BDF)	6,745	23,435	21,425	22,225	10,035	7,785	7,625	7,685	8,525	9,300	7,050	7,900	11,970	10,345	8,115
C (DBF)	6,745	21,495	23,445	22,235	10,035	7,785	7,625	7,685	8,525	9,300	7,050	7,900	11,970	10,345	8,115
C (BFD)	7,745	23,435	21,425	22,215	10,035	7,785	7,625	7,685	8,525	9,300	7,050	7,900	11,970	10,345	8,115
C (FBD)	7,745	21,485	23,435	22,225	10,035	7,785	7,625	7,685	8,525	9,300	7,050	7,900	11,970	10,345	8,115
Additional Costs of Alternative Sets Over Continuing "As Is"															
Set A (FBEA) - "as is"	0	14,720	14,520	14,580	12,390	-2,420	280	390	-590	-1,690	-380	-560	-4,650	-550	480
A (BFEA)	0	16,670	12,510	14,580	12,390	-2,420	280	390	-590	-1,690	-380	-560	-4,650	-550	480
B (DIJC)	-1,000	14,670	13,835	15,685	11,545	-2,235	1,455	575	-405	-1,495	-1,195	645	-4,455	-325	-295
C (BDF)	-1,000	16,670	12,510	14,570	-1,170	-1,170	-470	-350	-340	-1,230	-1,120	-300	-1,390	730	-2,050
C (DBF)	-1,000	14,730	14,530	14,580	-1,170	-1,170	-470	-350	-340	-1,230	-1,120	-300	-1,390	730	-2,050
C (BFD)	0	16,670	12,510	14,560	-1,170	-1,170	-470	-350	-340	-1,230	-1,120	-300	-1,390	730	-2,050
C (FBD)	0	14,720	14,520	14,570	-1,170	-1,170	-470	-350	-340	-1,230	-1,120	-300	-1,390	730	-2,050

$$(B\text{-}C)_{pv} = \sum_{n=1}^{h} \frac{1}{(1+i)^n} \times$$

[

time savings (hours) to cars in year n x **value of car time**
+
time savings (hours) to trucks in year n x **value of truck time**
+
vehicle operating cost savings to cars in year n
+
vehicle operating cost savings to trucks in year n

} consequences on existing use and use developing without any network changes

+

inducing tendency for cars x [time "savings" benefit (hours) to induced car trips in year n x **value of car time** + vehicle operating cost "savings" benefit to induced car trips in year n]
+
inducing tendency for trucks x [time "savings" benefit (hours) to induced truck trips in year n x **value of truck time** + vehicle operating cost "savings" benefit to induced truck trips in year n]

} consequences on trips estimated to be induced by set of network changes

additional highway department costs in year n related to the set of network changes

]

Figure 21. Determining the present value of benefits minus costs for an alternative set of network changes.

Table 4 summarizes these year-by-year differences in costs for alternative sets of improvements in the Simpleisle example. The various alternatives for sets A and C reflect differences in the ordering of improvement projects in the sets. To present such a tabulation is not to claim that data for such estimates are readily available in local road departments. Rather, it is to claim that while increasingly reliable local data are being developed, some start in analysis may be made with derived data (4, 5) coupled with rough estimates developed locally.

Phase XIII—Develop Economic Consequences of Alternative Sets of Network Changes in Relation to Continuing the "As Is" Level of Service

The procedure for determining the present value of benefits minus costs for an alternative set is summarized in Figure 21. The choice of "h," the planning horizon to which benefits and costs are considered, has been decided in Phase I. Assignment of values to the variables shown shaded in Figure 21 is necessary, of course, before computation of the net present value of a set may proceed.

The attachment of any dollar values to savings in travel time has been postponed purposely until this final phase so that local judgment may be applied or so that sensitivity to these values may be explored. The "inducing tendency" factors for cars and trucks provide a convenient means for inserting local judgment as to the extent that increased trips are likely to result from decreases in interzonal travel times. Assigning a value of one to inducing tendency is to include these benefits as they have been computed in earlier phases; that is, it is to assume that the percent increase in interzonal trips (over trips estimated to develop without network change) is equal to the percent decrease in interzonal travel time. Assigning a value of zero to inducing tendency, on the other hand, is to assume that demand is completely inelastic—that no more trips will be induced regardless of travel time decreases; stated differently, assigning a zero value is to omit the inclusion of any benefits to induced trips (cars, trucks, or both) in the analysis. Values other than zero or one may, of course, be used.

The choice of that set which maximizes present value of benefits minus costs (referring here to the benefits which have been assigned a money value) may often be sensitive to the discount rate (i). Local officials may be able to establish with some confidence a discount rate which reflects opportunity foregone. It is more likely, however, that decision-makers will welcome an assembly of results which reflects the relative advantage of alternative sets over a range of discount rates.

An "Evaluating and Graphing Benefits-Costs" computer program (written by James W. Spencer, Jr., to accomplish both evaluation and graphing, the latter in conjunction

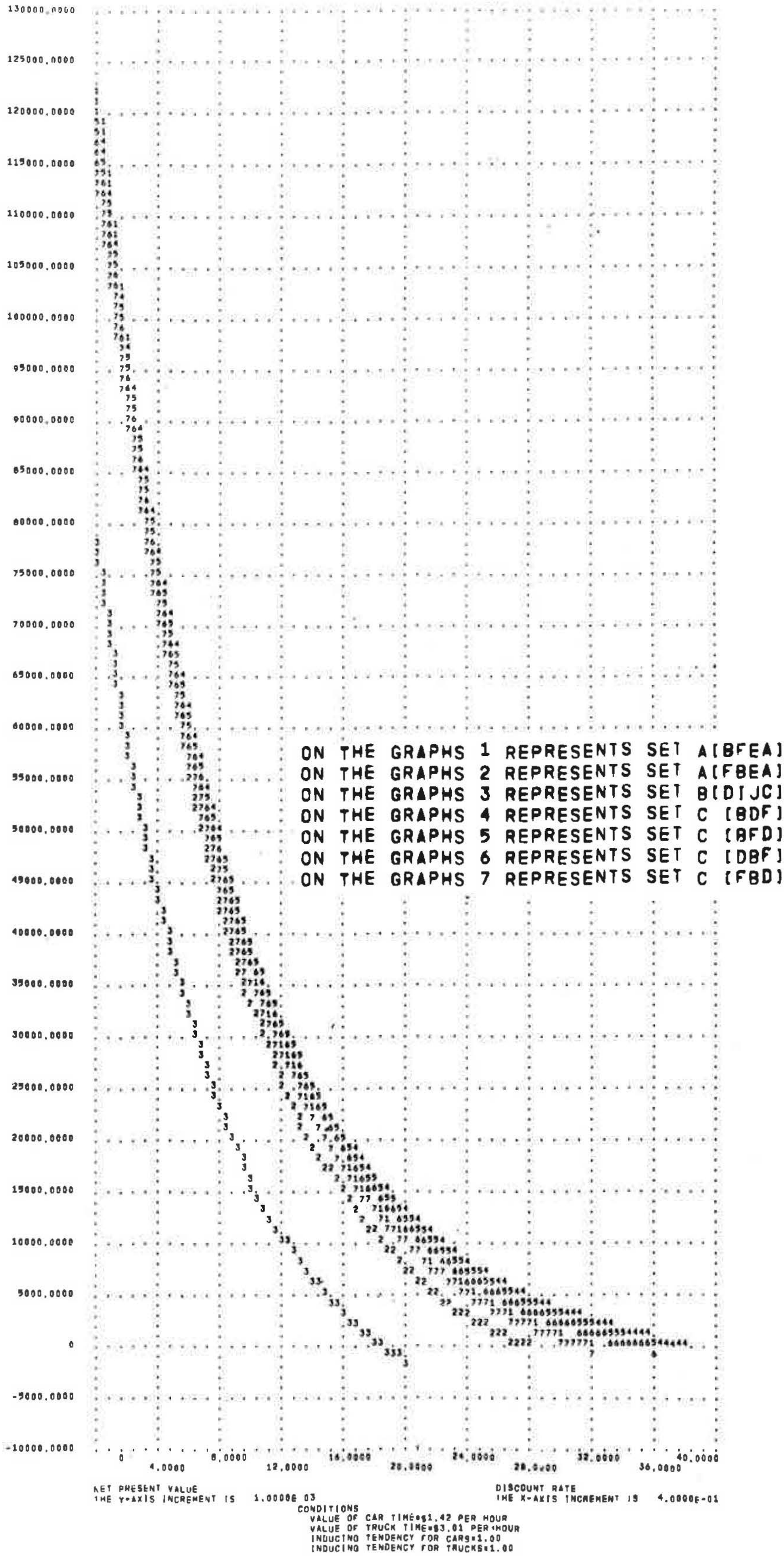


Figure 22. Sample of computer graphing of net present value of alternatives against discount rate.

with a set of subroutines for general purpose plotting developed at the Cornell Computing Center) was developed to accomplish the procedure shown in Figure 21 based on data developed in the earlier phases.

The evaluation portion of this program computes, for sets of assumed values for variables other than discount rate, the net present value at a discount rate of zero percent and at regularly stepped increases in discount rate until the net present value in relation to the "remain as is" alternative becomes negative. These data are then converted to plots as shown in Figure 22. Such plots permit visualization of how "that set which maximizes present value of benefits minus costs" varies with discount rate. Also, they furnish for a particular discount rate and for the values assigned to the other variables, some quantitative guidance as to how the non-quantified differences between alternatives must be valued if an alternative with a lesser net present value is selected. Turning from "within plot" to "cross plot" analysis, the latter offers an opportunity to extend the sensitivity analysis to an assessment of what such a speculative variable as value of passenger-car time must be to establish preference of one alternative over another.

The plots in Figure 23, show, for three alternative sets of improvements in the Simpleisle setting, the present value of benefits minus costs at various discount rates.

These graphs were plotted manually from the output of the evaluation portion of the "Evaluating and Graphing Benefits-Costs" computer program. Only three alternatives are shown on these graphs to minimize clutter. Set A (BFEA) is used since this yields higher net present values than the (FBEA) order of improvement at all discount rates and for all other conditions assumed for the analysis. Similarly, set C (BDF) is preferable to the other orders (BFD, DBF, or FBD) which were considered for the projects in this set. All of the seven alternatives or subalternatives considered are shown on the graphs prepared by the computer. The computer-prepared plot in Figure 22 is for the same conditions as in the upper left plot in Figure 23.

Eight combinations of conditions are included. In the upper four plots, the "inducing tendency = 1" indicates that for both cars and trucks, induced benefits are included as the "triangular area under the demand curve." In the lower four plots where "inducing tendency = 0," any benefits to induced trips are excluded from the analysis. In the upper and lower plots at the far left, time savings were valued at $1.42 per hour for cars and $3.01 per hour for trucks (the $3.01 value for trucks is based on data used for single-unit trucks with two axles and six tires, the classification closest to the 12-kip truck assumed in the Simpleisle example) (6). Holding the value of truck time saved at $3.01 per hour, the more nebulous value of passenger-car time is dropped progressively to $1.00, to $0.50 and finally to zero.

If factors which have not been assigned a money value are ignored, the following are examples of the statements which could be made from the plots of Figure 23:

1. Set B (DIJC) would be economically preferable to continuing the "as is" level of service were the opportunity (discount) rate less than values ranging from 19 percent (for conditions in upper left plot) to 4 percent (for conditions in lower right plot).

2. Alternative sets A (BFEA) and C (BDF), however, would be preferable to set B (DIJC) under any of the combinations of conditions considered. These sets offer higher net present values than set B (DIJC) for all discount rates in each of the plots.

3. Set C (BDF) is preferable to set A (BFEA) if benefits to induced traffic are ignored.

4. Set C (BDF) is preferable to set A (BFEA), with benefits to induced traffic considered, if savings in passenger car time are valued at something less than $1.00 per hour.

5. Set A (BFEA) would be preferable to set C (BDF) only where benefits to induced traffic are included and where the opportunity rate of return in highway or other investments would be less than about 2 percent, if car time were valued at $1.00 per hour, or about 4 percent, if car time were valued at $1.42 per hour.

6. Set C (BDF) is the preferred set, for all combinations of time value and inducing tendency, if the opportunity rate of return in highway or other investments is greater than about 4 percent.

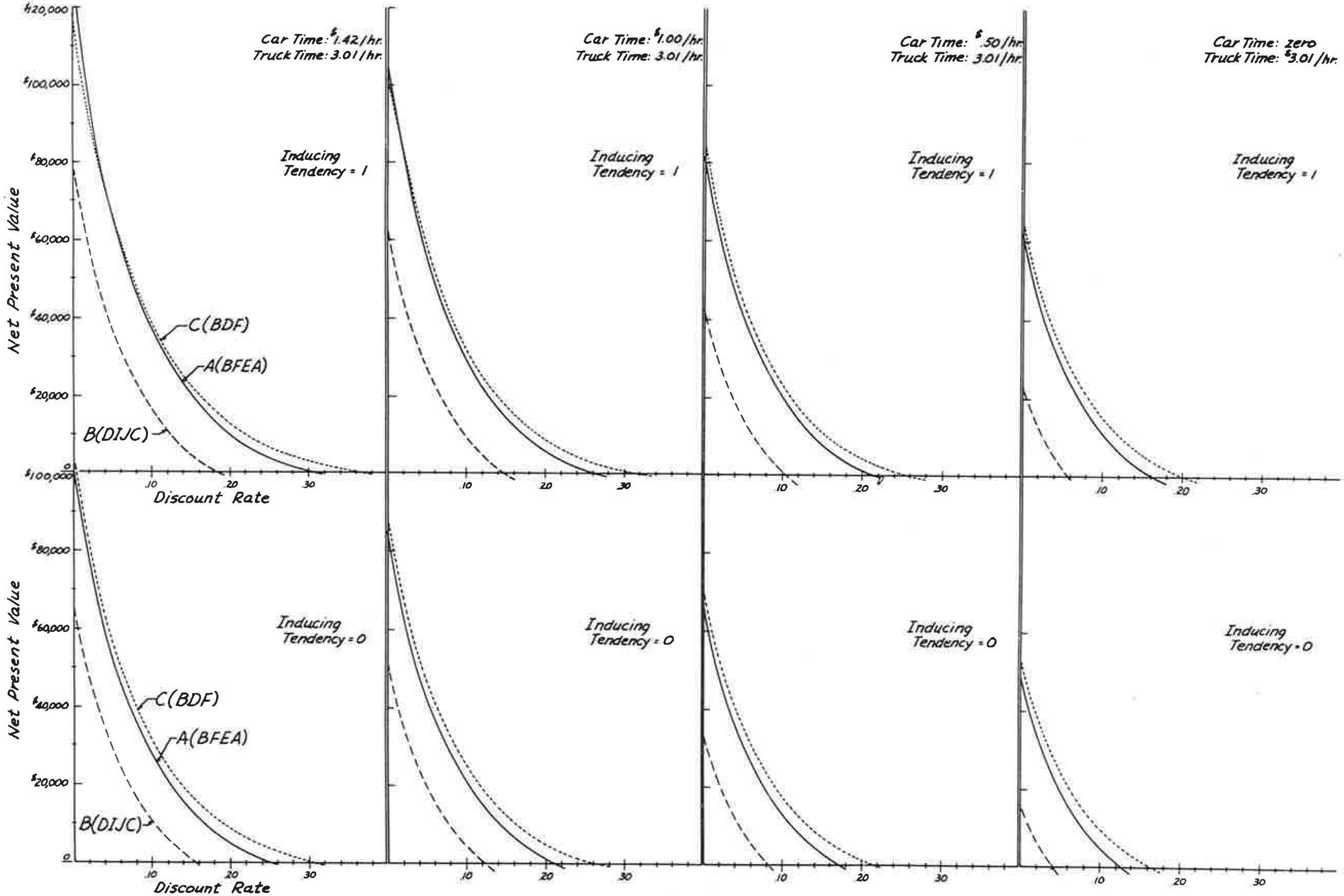


Figure 23. Plots of net present value of sets A (BFEA), B (DIJC) and C (BDF) at various discount rates and for various assumptions of inducing tendency and value of time savings to cars and trucks.

Plots such as those in Figure 23 can provide helpful guidance or discipline in weighing social or political factors which have not been considered previously in the analysis. Assume, for example, that some board members considered set B (DIJC) to be extremely desirable because of its service to persons now living and farming in zone 8. If it were agreed by the board that benefits to induced traffic should be considered, and that a realistic opportunity rate was about 8 percent, the discipline of knowing that to choose set B (DIJC) over set C (BDF) would be to forsake a probable area-wide economic gain of about $25,000 (present value) should be helpful. With such plots at hand and adequately interpreted, a board choice of set B (DIJC) over set C (BDF) would indicate that the board valued the unquantified advantages of set B (DIJC) at or greater than a present sum of $25,000 (an approximate differential of $25,000 holds irrespective of the value assigned to passenger-car time). This supports the claim that such an analysis helps to attach a price to value judgments.

The plots in Figure 23 indicate that, for the Simpleisle example, a rank order of net present values of the alternative sets is quite insensitive to discount rate. Considerably greater sensitivity could be expected where alternative sets did not have such similar patterns of expenditure. Greater sensitivity would be expected, for example, where alternative sets included differences in levels of improvement, some with higher first cost and lower maintenance and others with lower first cost and higher maintenance.

The alternative sets for this Simpleisle example were intentionally defined to provide guidance in decision concerning network structure. The analysis has illustrated how the economic advantage of different orderings of projects in a set may helpfully guide programming decisions. However, the primary emphasis has been on indicating how the economic consequences of alternatives in functional classification may be assessed. Refinements in such an analysis could desirably extend to an evaluation of the economic advantage of spot as well as blanket improvements, to alternative choices in roadbed width and other geometry, to alternatives in type of roadbed surfacing or treatment, and even to stage construction.

EVALUATION OF APPROACH AND PROCEDURE

The application of approach and procedure in the hypothetical Simpleisle situation cannot itself be considered an evaluation of the method. It has, nevertheless, provided enough experience that some evaluative comments may be offered. On the positive side:

1. The approach tends to lower the wall between planning and economics. Economic consequences are used as a positive planning tool and not merely as a post-planning straitjacket.

2. It is admitted that the consequences on existing and induced trips and in highway department expenditures do not constitute the total consequences of road improvement. They do, however, provide a datum of measurable differences between alternatives against which qualitative differences can be weighed.

3. Expressing the money differences between alternatives as "present value of benefits minus costs" provides an especially useful format for the weighing of unquantified differences.

4. The approach avoids any "once and for all" assumptions for dollar values on quantified consequences where the market offers no guide for pricing. For example, savings in passenger-car time are carried in hours until the final stage of analysis when sensitivity to a range in money values of time may be assessed.

5. The approach applies the principles of engineering economy in a format of analysis which includes network interrelationships.

6. Although attention to budget constraints is made informally in the definition of alternative road-improvement programs, it is possible to include alternatives which might be preferable if additional funds were made available. Decisions as to whether or not financial constraints should be relaxed may be helpfully guided by attention to incremental rates of return determinable from plots of net present value of the various schemes against discount rate.

On the negative side, the following shortcomings or limitations should be noted:

1. The approach offered here is based on a forecast of changes in land use and related trips that may be expected to develop without changes in the road network; these trips provide the basis for computing benefits on "existing use." Changes in land use and related trips resulting from improvements in the road network are not considered directly; these induced trips are assumed to be proportional to reductions in interzonal travel time. The validity and usefulness of the approach might be extended considerably by explicit attention to (a) land-use changes that are expected to result from alternative patterns of road network improvement, and (b) estimates of interzonal trips related directly to these changes in land use.
2. The approach does not assure optimum timing of projects. It does, however, permit an analysis of the consequences of postponement or advancement of a project from the timing adopted in the basic alternative.
3. This "feasible beginning" approach does not provide the efficiency of evolving an economically optimum year-by-year program of construction and maintenance from among all the possible alternatives for improving, maintaining, or even neglecting each element in the road network. Furthermore, the approach gives no assurance that a particular program is the best that can be found.
4. Without optimization tools, some attention to improving the efficiency of the approach is needed. It is likely that some "rough cuts," less complete than year-by-year simulations to find the consequences of alternative plans, could be useful in narrowing in on the more attractive alternatives.
5. Existing origin-destination data in rural areas are scarce and gathering such data by conventional means is costly. It could be argued that despite the comfort of the engineer in working and projecting from "real data," the usefulness of the planning/programming approach presented here may rest on progress in synthesizing origin-destination information from patterns in land use.
6. The Fratar technique used in this study provides a convenient means for projecting from an existing pattern of interzonal movements. Although reasonably valid where slight changes in land use are expected, to use the Fratar expansion where profound changes in land use are likely is to be projecting from largely irrelevant data.
7. The instantaneous insertion of a road improvement, and the assumption that total consequences to users for that year are related to the completed facility, are convenient simplifications. It would be more realistic and possibly justifiable to simulate consequences to users during the construction period.
8. It was assumed in the Simpleisle example that consequences on induced use develop in the very year that a reduction in interzonal travel time is introduced. The reality of time lag could, if desired, be recognized quite simply by discounting consequences on induced use as though they developed one or more years later.
9. The accumulation of total time savings without attention to sizes of the blocks of time saved assumes that a saving of 2 minutes by 30 persons is equivalent to a saving of 30 minutes by 2 persons. Such an equivalency is very doubtful but it is also questionable whether a refinement which would compute a size distribution of time savings could be justified at the present state of knowledge concerning the value of time.

The approach and procedure are claimed to be technically feasible. The justification of the additional effort required in comparison to present methods remains unexplored. To be consistent with the efficiency concepts at the root of the approach, efforts to use and refine the method itself would halt where marginal gain did not promise to exceed marginal cost. The marginal gain in using the method at all, or in refining the procedure in areas of shortcoming, might be approached by comparing the economic consequences of decisions likely without and with this procedure and various increments of refinement.

ACKNOWLEDGMENTS

This paper is adapted from "Planning and Programming Local Road Improvements: An Approach Based on Economic Consequences," Report EEP-23, Program in

Engineering-Economic Planning, Stanford University, May 1967. Acknowledgments made there apply here as well but it is appropriate to mention here three persons whose help was particularly significant. C. H. Oglesby was principal advisor to the author and made many conceptual and editorial contributions to the basic report. Bill G. Bullard provided considerable advice as the author sought to adapt the BPR battery of computer programs for the purposes of this study. Larry R. Seiders provided direct assistance in the application of the BPR programs; he prepared several program patches and provided assistance as various problems were encountered in the Simpleisle example.

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Spacing of Grade Separations on Rural Freeways

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D. S. BERRY, Northwestern University

This paper proposes methods for economic analysis to aid in determining where to provide grade separations on new freeways. Three hypothetical situations were investigated, with estimates made of reorganization of travel, and changes in travel costs, using a net present worth economic analysis. Results indicate that presently used methods tend to overestimate travel benefits from grade separations.

•THIS paper describes an investigation of the warrants for spacing of grade separations on rural freeways. The study dealt mainly with warrants based on economic criteria which are only a portion of the relevant criteria. There are three general classifications of pertinent criteria:

1. Continuity. To perform their function in the road system many roads must be continuous. For example, if the road intersecting the freeway is an arterial or collector then for continuity it should be grade separated.
2. Public Interest (non-economic). The public interest of the area local to grade separation locations, includes: (a) division of communities, (b) disruption of public services, such as fire protection and school districts, and (c) the level of local road service.
3. Economic Considerations. The balancing of the cost of the grade separations against the additional travel costs, the value of landlocked properties, and other economic costs of not providing the grade separations.

The first criterion generally overrules the others. If a grade separation is warranted because of route continuity then that is sufficient justification. If this criterion does not apply then the decision must be made by applying criterion 2 (comparing non-monetary costs and benefits), in conjunction with an economic analysis (applying criterion 3).

This research is concerned only with applying criterion 3; the problems of quantifying the non-monetary considerations and making the final decision are outside the scope of this investigation (1).

MAIN ASSUMPTIONS

1. It was assumed that the rural highway system would be classified into four basic road systems: freeway, arterial, collector and local (e.g. freeway, state primaries, state secondary and county primaries, and local roads). Any intersection of freeway with freeway or freeway with arterial, because of the first criterion, would warrant an interchange, which includes a grade separation. Since a collector road requires continuity, it was assumed that freeway-collector intersections would be grade separated.
2. Intersections of local roads with a rural freeway never require interchanges but may be grade separated or terminated. Connection of a terminated local road to a frontage road can also be treated by the analysis.

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TABLE 1

COSTS AND BENEFITS FOR RURAL GRADE SEPARATIONS

Costs	Benefits
Cost of grade separation:	Reduction in circuity of travel:
Construction	Time savings
Maintenance	Vehicle operating costs
	Comfort and convenience
Loss of property tax revenues	Accident costs
Increased maintenance costs on approach roads	Decreased maintenance costs on terminated road

3. After a freeway is constructed, the travel patterns of people residing in the vicinity of the freeway will change from the pre-freeway pattern. These changes will take place over a number of years and once completed the resulting travel behavior can be modeled by a traffic model such as the gravity model.

ECONOMIC ANALYSIS

The factors to be considered in the economic analysis are given in Table 1. For most rural areas the most important are the cost of the grade separations and the costs or benefits of circuity of travel. Comparisons of costs and benefits were carried out by the Net Present Worth method. The interest rate used was 7 percent but this was varied to test the sensitivity of the results. A 20-yr analysis period was used and it was not varied (3) because a similar study indicated the analysis period was not critical (2). The travel benefits were measured as changes in vehicle-miles and vehicle-minutes of travel. The former were evaluated by applying the unit monetary values given in Woods (3) for 0 to 3 percent composite grades and 15 percent single-unit trucks. The value of travel time used was $1.20 per vehicle-hour (4). As recommended by AASHO (5) a convenience cost of one cent per mile of travel on the local gravel roads and zero cents on all paved roads was assumed.

ESTIMATES OF ADDITIONAL TRAVEL

The central concern of the investigation was the estimation of the additional vehicle-miles and vehicle-minutes of circuitous travel if any given combination of grade separations were or were not provided.

The existing method for estimating circuity of travel is shown in Figure 1. The additional travel cost is based on rerouting all traffic from the nearest intersection on one side of the freeway to the nearest intersection on the other side of the freeway by the nearest grade separation. There are two difficulties with this estimate. First, the interaction between adjacent grade separations is not considered. Second, not all traffic is necessarily required to be completely rerouted and may, in fact, suffer no excess travel if a particular grade separation is not provided. In the proposed method these difficulties are overcome by treating a system of grade separations and considering the whole route of a trip rather than a small segment of its route.

The travel costs considered in the analysis were limited to trips made by existing or future inhabitants of the existing stock of dwelling units. The future travel benefits generated by dwelling units constructed in the future should not be counted, since in locating these units, due consideration would be given to the travel costs involved, regardless of the spacing and location of grade separations decided upon.

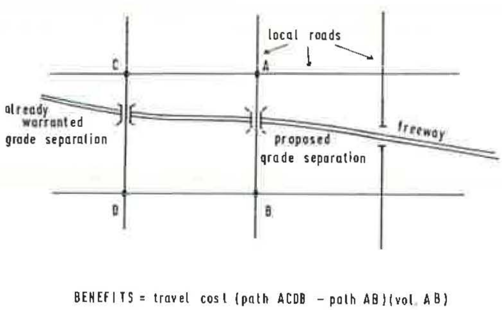


Figure 1. Current practice in measuring travel benefits for grade separations

It was postulated that immediately after the construction of the freeway, if any local roads were terminated, the local pattern of trip origins and destinations would be the same as before the freeway. Later, because of the longer travel distances, changes in family life cycles, changes in occupants, etc., this travel pattern would, over a period of time, reorganize to some stable level. Furthermore, this reorganization of travel could be simulated by a traffic model. One further assumption was that the change in the level of travel would be at a uniform rate from completion of the freeway until complete reorganization of trip ends.

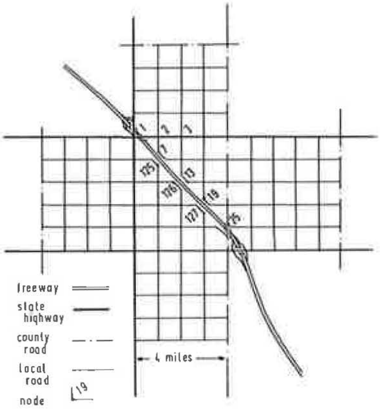


Figure 2. Example problem

TABLE 2

TRAVEL CHARACTERISTICS OF ONE-WAY DAILY PERSON TRIPS FOR RURAL AREAS OF OZAUKEE AND WASHINGTON COUNTIES, WISCONSIN

(Excluding Truck Drivers)[a]

Trip Purpose		No. of Trips (per day)	Average Trip Length (miles)	Average Trip Speed[b] (mph)	Average Generation, Trips per Household
To home:	car driver	2493	10.81	30.6	1.95
	car passenger	1019	9.09	30.9	0.80
	school bus	555	4.61	10.0	0.43
	truck passenger	18	14.18	31.8	0.014
Work:	car driver	1373	13.21	33.0	1.072
	car passenger	153	11.35	32.1	0.119
	truck passenger	11	13.59	32.0	0.009
Personal Business:	car driver	897	6.99	27.0	0.70
	car passenger	253	9.77	30.8	0.198
	truck passenger	9	12.23	33.7	0.007
Medical:	car driver	81	11.60	30.4	0.063
	car passenger	28	16.08	32.6	0.022
School:	car driver	63	17.25	38.5	0.049
	car passenger	352	3.84	19.2	0.275
	school bus	572	4.63	10.0	0.447
	truck passenger	2	—	—	—
Social Eat meal:	car driver	192	8.97	29.9	0.150
	car passenger	119	10.83	33.9	0.093
Shop:	car driver	451	7.17	26.8	0.352
	car passenger	156	8.61	30.0	0.122
	truck passenger	1	—	—	—
Recreation:	car driver	89	18.01	59.3	0.070
	car passenger	69	28.89	85.0	0.054

[a]Sample—1281 households.
[b]Average trip speed includes terminal time.

EXAMPLE PROBLEM

The hypothetical situation in Figure 2 was used as an example. The section of freeway being analyzed is between node 1 and node 25. At these locations grade separations are warranted because of continuity of the state highway and county road systems. The grade separation spacing problem is to determine which combinations of the three possible grade separation sites, 7-125, 13-126 and 19-127, are economically justified. The combinations tested were (a) no grade separations, (b) only grade separation 13-126, (c) grade separations 7-125 and 19-127, and (d) all three grade separations.

Figure 2 also shows the extent of the detailed analysis area. In this area all local roads were included in the coded network and every intersection was a loading node. The boundary of this area is defined by locations of the points of cost indifference, for trips desiring to cross the freeway, in the area between points 1 and 25. Trips originating outside the boundaries are not affected from the cost standpoint by presence of a potential grade separation. This detailed analysis area was surrounded by a buffer area in which the zones gradually increased in size.

Rural trip generation rates, trip length distributions, and trip time distributions were extracted from the home interview data of the Southeastern Wisconsin Regional Planning Study for two rural counties (Table 2). These generation rates were applied to the households in the example area. The population density was about 70 persons per square mile. The siting of the sample area corresponds to the actual rural framework approximately 30 miles from Milwaukee.

RESULTS WITH CONVENTIONAL TRAFFIC MODELS

Two traffic models, an uniterated gravity model (i.e., attractions were not normalized to input values) and a revised version of the opportunity model were calibrated to the Wisconsin travel data, using in each case a four-trip-purpose model. (In the revised model the opportunities are discounted over distance to obtain a fit to the trip length distribution without using the concept of short and long trips; a test of this model in urban areas is presently being carried out.) An uniterated gravity model was used as it was considered desirable for the trip destinations to be unconstrained. Trip generation rates were held constant and the two trip distribution models along with a minimum path assignment were used to simulate the travel behavior of the pre-freeway situation. They were then applied to the post-freeway networks being tested. The differences between the pre-freeway vehicle-miles and minutes of travel and those for each of the post-freeway networks provided the estimates of the circuity of travel.

At this point a comparison of these additional travel estimates was made against a logical upper limit. This upper limit was the additional travel found from an assignment of the pre-freeway O-D table to the post-freeway grade separation combinations being tested. This assumed that all trips would be made to their original distinations in spite of the excess travel involved (no reorganization of trip ends).

The traffic model estimates of additional travel in all cases were two or three times greater than these upper limit estimates. This meant that the total vehicle-miles and vehicle-minutes predicted by both the gravity and the revised opportunity models were very sensitive to small changes in the network. This was found to be due mainly to the nature of the trips involved. Both models attempt to reproduce the calibrated trip distribution or "average" trip. In the case of grade separations on local roads the trips involved are "non-average" as they are as a group shorter than the average trip. In effect, this characteristic led in the application of the gravity and opportunity models to replacing some shorter non-average trips by longer average trips (6). The remedy suggested was to look for a model which simulated only the shorter, non-average group of trips, i.e., those using the potential grade separation locations.

This sensitivity of predicted total vehicle-miles and minutes of travel to changes in the road network that affect non-average trips indicates extreme caution should be used when utilizing outputs of these traffic models to evaluate networks (7, 8). For example, in comparing two possible urban networks, an extensive freeway system and an all-arterial system, the differences in the networks affect longer than average trips and the differences in total travel estimated would probably be greater than might be expected. This sensitivity of the uniterated, gravity model and the opportunity model came to light in the grade separation case because a logical check on the answer was available in the form of the upper limit estimate. Logical checks for predictions in urban areas are more difficult to obtain.

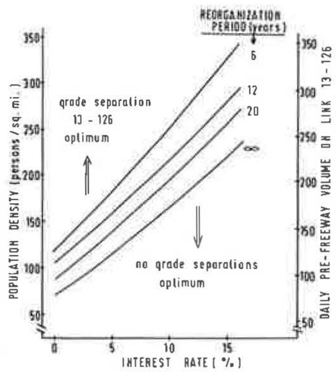
An interated gravity model (i.e., model attractions made equal to input values) was also used to simulate travel and estimate the additional travel costs. On the basis of the results of models described later the iterated gravity model underestimated the additional travel costs by about 40 percent, but it was much better than the uniterated gravity model or the opportunity model. It is clear that more work is required in this area and that caution is necessary in using traffic models to predict differences in travel between different road networks.

TRAFFIC MODELS FOR GRADE SEPARATION TRIPS ONLY

Two methods were used to simulate travel behavior for only those trips using the potential grade separation locations (7-125, 13-126 and 19-127). The first method was to isolate the origins and destinations of these "grade separation" trips and calibrate a gravity model to these trips. This was done by utilizing the trip origins as generations in the model and the trip destinations as attractions. The calibrated model reproduced the trip length distributions satisfactorily but was 13 percent low in predicting trips that crossed the freeway.

The second method, called a heuristic model, was again derived from the pre-freeway traffic using the potential grade separation locations. It was hypothesized that these trips were a model of the traffic behavior. That is, the set of individual trips made before the freeway is constructed are a representative set of all likely trip patterns that would be described by a traffic model of local travel behavior, given the local land use and road network. Then the additional travel for any post-freeway situation, after complete reorganization of trip ends, is simulated by considering the possible changes for the set of pre-freeway trips. For each trip the maximum additional travel for the post-freeway trip would be a trip between the same origin and destination. The minimum additional travel would be zero under conditions where an alternative destination, equal in all respects, and the same travel distance is available to the trip. This could be the pre-freeway destination. In between these two limits it was assumed that the expected additional travel, after complete reorganization of trip ends, for any trip in the model set, would be one-half of the upper limit. All traffic models indicate a preference for shorter trips that would suggest an expected value less than one-half. On the other hand, many of the alternative destinations for any trip would have a longer travel distance in the post-freeway network. These tendencies were assumed to balance each other.

This model is a heuristic "guestimate" that requires checking. There is some evidence that travel does reorganize and at a lower level than the upper limit (9, 10). However, the importance of the assumed value of one-half is moderated by the time period selected for complete reorganization of trip ends.



(grade separation cost - $140,000, $1.20 /veh. hr., one mile grid of local roads, 4 mile spacing of arterials, and diagonal freeway)

Figure 3. Solution space for example problem.

RESULTS FOR THE EXAMPLE PROBLEM

The two models of grade separation trips were used to estimate the additional travel for the four combinations of grade separations tested in the example. These travel estimates were evaluated at $1.20 per vehicle-hour and the appropriate operating costs for the vehicle-miles. Then the additional travel cost for each combination of grade separations being tested was calculated for each of the 20 years of the analysis period. Three periods for complete reorganization of trip ends were used: 6, 12 and 20 years. The present worth of each series was found and the construction cost of the grade separations subtracted to find the net present worth.

The optimum solution was taken as the maximum net present worth for a given interest rate and reorganization period. One further step was to solve for the breakpoint between selection of the no-grade-separation solution as optimum and the central grade separation, 13-126 as optimum, both in terms of population density and pre-freeway traffic volumes. Figure 3 is the solution space for the example problem. Results are shown for the heuristic model for three reorganization periods and for the upper limit estimate of no reorganization of trip ends which corresponds to an infinite reorganization period. The grade separation gravity model not shown gave slightly higher estimates of additional travel than the heuristic model, thus requiring less traffic to justify the central grade separation. The discrepancy between the two models is relatively negligible in comparison with the effect of changes in the interest rate.

When the average population density reaches 1,200 persons per square mile, the optimum solution for the example problem is construction of all three grade separations, assuming an interest rate of zero percent and a reorganization period of 12 years.

The breakpoint between the no-grade-separation solution and the one-grade-separation solution being optimum is given by the following empirical equation.

$$\text{Average pre-freeway volume on central grade separations} = \frac{K \cdot C \cdot e^{-.021RP}}{e^{-(.038I + .1068\sqrt{I})}} \qquad (1)$$

where

- K = a constant for a particular class of freeway alignment, distance between warranted grade separations, etc.;
- C = cost of the central grade separation less any construction costs incurred if it were not built ($1,000);
- I = interest rate (%); and
- RP = reorganization period (years) (up to 30 years).

Three cases have been investigated, as follows: (a) a diagonal freeway with 4 miles between continuity-warranted grade separations (Fig. 2), (b) the case of a freeway paralleling a complete-grid local road system and 5 miles between continuity-warranted grade separations, and (c) a freeway paralleling an irregular grid of local roads with 4 miles between warranted grade separations. The values of K for the three cases are 1.0, 1.97 and 2.50, respectively.

In each case, the heuristic model was used to estimate the completely reorganized trip ends. This method was used because of its ease for practical applications. Field measurements can be made to establish the O-D pattern of the pre-freeway traffic at potential grade separation locations. This trip matrix can then be assigned to the proposed configurations of grade separations to yield an estimate of both the initial additional travel as well as the additional travel after reorganization of trip ends.

A computer program was written to make a selected O-D minimum path assignment for this type of field data. It is given in the Appendix. The outputs of the program are the vehicle-minutes of travel and the vehicle-miles of travel by road system, as well as a link volume table.

GENERAL DISCUSSION

It is expected that by taking field measurements of O-D trip patterns, utilizing the assignment program and applying appropriate values of travel costs, an agency could develop K-values for a variety of local characteristics (see Appendix for methodology). After the initial development period then Eq. 1 could be used directly to provide the economic indicator for optimizing grade separation locations on new freeways.

As previously mentioned, non-economic warrants must also be considered. The investigation indicated that for most rural areas the number of grade separations on local roads warranted by an economic analysis is small, with most local roads needing to be terminated. A recent study in Illinois (11) found that in practice the reverse is true; more local roads are grade separated than terminated. There are two explanatory factors. Consideration of non-economic factors will tend to justify more grade separations than indicated by the economic analysis. Also, existing methods as outlined in Figure 1 overestimate the additional travel costs. For example the existing methods applied to the problem in Figure 2 overestimated the additional travel costs of not providing the grade separation by about 300 percent.

With regards to non-economic costs and benefits it should be remembered that the breakpoints in Figure 3 are points of economic indifference between two solutions. Movement away from a breakpoint strengthens the economic benefit to be obtained from the indicated solution, but in the region of the breakpoint the economic warrant is relatively weak and more importance should be attached to non-economic criteria.

For the example problem solution space in Figure 3, with 7 percent interest rate and 12-yr reorganization period the economic indifference point is at a pre-freeway volume of 170 vehicles per day crossing the freeway. At a volume of 70 vehicles per day the cost of selecting the uneconomic solution—providing the grade separation—is $86,000. At a volume of 140 vehicles per day the cost is $32,000. Such costs as these must be balanced against non-economic benefits.

CONCLUSIONS

1. The investigation indicated that for a 4-mi spacing between continuity-warranted grade separations, a diagonal freeway and a 1-mi grid of local roads, an interest rate of 7 percent, 12 years for complete reorganization of trip ends and grade separation costs of $140,000 each, additional grade separations are not economically warranted on local roads at pre-freeway volumes of less than 170 vehicles per day desiring to cross the freeway. In the example problem, this represented a population density of about 170 persons per square mile.

2. The economic warrant for grade separations is sensitive to the angle of the freeway with the local road network and also to the interest rate assumed.

3. The use of traffic models to estimate changes in total vehicle-miles and vehicle-minutes of travel between networks which affect non-average trips is subject to error and should only be done with caution.

4. The concept of reorganization of trip ends over time and the resulting decrease in travel benefits has a significant effect on the economic warrant for grade separations.

ACKNOWLEDGMENT

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Appendix

ANALYSIS PROCEDURE AND COMPUTER PROGRAM

Analysis Procedure

To carry out the analysis of a particular situation, the following procedure is suggested.

1. Obtain roadside O-D information for vehicles using all local roads between the already warranted grade separations.

2. Code the O-D information and also code as large a local road network as necessary.

TABLE 3

FACTORS TO CONVERT ANNUAL TRAVEL COSTS TO NET PRESENT WORTH WITH REORGANIZATION OF TRIP ENDS[a]

Time for Complete Reorganization of Trip Ends (years)	Interest Rate (%)		
	0	7	15
6	11.50	6.57	4.20
12	13.00	7.55	4.84
20	15.00	8.52	5.34

[a]Assuming a linear decline in annual cost until it is one-half its initial value, and a 20 year analysis period.

3. For each of the potential grade-separation spacings, run the computer analysis program, deleting links which represent terminated roads.

4. Apply unit costs of vehicle operation and travel time to the outputed vehicle-miles and vehicle-minutes, to give an annual travel cost by road system.

5. Convert annual travel cost to Net Present Worth using the factors in Table 3. For each solution find the reduction in net present worth of travel costs from the no-grade separation solution less the construction cost for the solution. The solution with the largest positive value is optimum. If none are positive the no-grade separation solution is optimum.

Computer Analysis Program

Inputs (with Fortran Format)

1. Title Card, 55H.
2. Proportion of travel time, F10.0, The proportion of travel time (0.0 to 1.0) in the linear combination of travel time and travel distance used to build the cost trees. A value of 0.5 is suggested for rural conditions.
3. Trees to be printed out, 25I3, up to 25 trees arranged in numerical order.
4. Travel speeds on road systems, 5F10.0, a single speed for each classification of road system, in order.
5. Coded road network—node from, node to, road system classification, link length: 3I5, F10.0, one card for each link with a dummy link, node from = 999, to end.
6. O-D trips to be loaded—origin node, destination node, number of trips: 3I5, one card for each O-D movement with a dummy origin = 999, to end.

Outputs

1. Listing of minimum cost trees.
2. Volumes assigned to links—directional.
3. Vehicle-miles and vehicle-minutes by road system and for the total area.

PROGRAM LISTING FOR ASSIGNMENT OF ORIGINS AND DESTINATIONS

```
$JOB    WATFOR  P0251J.B.KERR,PAGES=150
$TIME           6
C       ASSIGNMENT PROGRAM FOR AN EXAMPLE CITY
        DIMENSION  I(225),J(225),NLINK(225),DIST(225),TMDS(225),LF(100),
      1  NSEE(25),VOL(225),NSYS(225),VEHTIM(5),VEHMIL(5),SPEED(5),
      2  NORDR(100)
        READ(5,5)
        READ(5,24)C
   24 FORMAT(F10.0,I5)
C       READ TREES TO SEE IN ORDER
        READ(5,939)(NSEE(N),N=1,25)
  939 FORMAT(25I3)
        READ(5,940) (SPEED(K),K=1,5)
  940 FORMAT(5F10.0)
        NX=1
 5      FORMAT(55H COMMENTS
        WRITE(6,5)
C       READ NETWORK LINKS
        DO 21 IT=1,3000
```

```
      READ(5,2)I(IT),J(IT),NSYS(IT),DIST(IT)
    2 FORMAT(3I5,F10.0)
      IF (I(IT).EQ.999) GO TO 22
      N=NSYS(IT)
      TMDS(IT)=C*(DIST(IT)*SPEED(N))+((1.-C)*DIST(IT))
 21   CONTINUE
 22   LL=IT-1
      WRITE(6,23)LL
   23 FORMAT(13H NO. OF LINKSI5)
      NFRMO=0
C     SET UP LF REGISTER
      LF(1)=I(1)
      NODES=1
      KN=1
      DO 1001 KNL=1,LL
      IF(I(KNL)-KN)1002,1001,1004
 1002 WRITE(6,1005)I(KNL)
 1005 FORMAT(20H ERROR IN NETWORK I=I5)
      GO TO 1001
 1004 KN=I(KNL)
      NODES=NODES+1
      LF(KN)=KNL
 1001 CONTINUE
      KNOD = NODES
      WRITE(6,715)NODES
  715 FORMAT(14H NO. OF NODES=I5)
C     BUILD TREE
      VTIM = 0.0
      VDIST=0.0
      DO 6002  NNN=1,225
 6002 VOL(NNN)=0.0
 1207 READ(5,1202)NFRM,NTO,NTRP
 1202 FORMAT(3I5)
      IF(NFRM-999)1204,1203,1204
 1204 FNTP=NTRP
      IF(NFRM-NFRMO)1206,1205,1206
 1206 CALL TREE(I,J,NLINK,DIST,TMDS,LF,NSEE,NODES,LL,NORDR,C,KNOD,NFRM)
C     ASSIGN VOLUMES
 1205 NN=NTO
   60 NNN=NLINK(NN)
      VOL(NNN)=VOL(NNN)+FNTP
      NN=I(NNN)
      IF(NLINK(NN))601,601,60
  601 NFRMO=NFRM
      GO TO 1207
 1203 CONTINUE
C     WRITE OUT LINK VOLUMES
      WRITE(6,260)
  260 FORMAT(86H FROM    TO        VOL    TO         VOL    TO         VOL    TO
     1    VOL    TO       VOL          )
      ITM=I(1)
      DO 6011 K=1,5
      VEHTIM(K)=0.0
 6011 VEHMIL(K)=0.0
      IK=1
      DO 261 IT=1,LL
      K=NSYS(IT)
      VEHMIL(K)=VEHMIL(K)+VOL(IT)*DIST(IT)
      VEHTIM(K)=VEHTIM(K)+(VOL(IT)*DIST(IT)*SPEED(K))
      IF(I(IT+1)-ITM)263,262,263
  262 IK=IK+1
      GO TO 261
  263 IKT=IT-IK+1
      WRITE(6,264)I(IT),(J(KT),VOL(KT),KT=IKT,IT)
```

```
  264 FORMAT(1H I5,6(I5,F 10.3))
      IK=1
      ITM=I(IT+1)
  261 CONTINUE
C     WRITE VEH MILES AND VEH MINUTES
      TOTMIN=0.0
      TOTMIL=0.0
      DO 401 K=1,5
      WRITE(6,267)K
  267 FORMAT(22H TOTALS FOR ROAD CLASSI4)
      TOTMIN=TOTMIN+VEHTIM(K)
      TOTMIL=TOTMIL+VEHMIL(K)
      WRITE(6,8)VEHTIM(K)
      WRITE(6,15)VEHMIL(K)
    8 FORMAT(22H TOTAL VEHICLE MINUTESF10.1)
   15 FORMAT(20H TOTAL VEHICLE MILESF12.1)
  401 CONTINUE
      WRITE(6,402)
  402 FORMAT(24H TOTAL-ALL TRIP PURPOSES)
      WRITE(6,8)TOTMIN
      WRITE(6,15)TOTMIL
      WRITE(6,1504)VTIM,VDIST
 1504 FORMAT(17H TOTAL VEH. MILESF10.2,16H TOTAL VEH. MIN.F10.2)
      CALL EXIT
      END
      SUBROUTINE TREE(I,J,NLINK,TIME,TMDS,LF,NSEE,NODES,LL,NORDR,C,KNOD,
     1  IT)
C     MINIMUM TIME AND DISTANCE TREE PROGRAM
      DIMENSION  I(225),J(225),NLINK(225),NORDR(100),TTIME(225),TTMDS(22
     15),TIME(225),TMDS(225),LF(100),NSEE(25),NK(225),TMDSS(225),IS(225)
     2 ,JS(225),NLS(225),TTS(225)
C     BUILD TREE
      DO 1000  N=1,KNOD
      TTIME(N)=0.0
 1000 TTMDS(N)=0.0
      DO 599 K=1,225
  599 NK(K)=0
      TDMIN=0.0
      TMIN=0.0
      NLINK(IT)=0
      NORDR(1)=IT
      TTMDS(IT)=.000001
      TTIME(IT)=0.0
      N=IT
      NS=1
      NO=2
      NNC=2
C  ADD LINKS FROM NODE JUST ADDED
  402 L=LF(N)
      K=1
  405 IF(I(L)-N)403,404,403
  404 IF(NK(K))502,501,502
  501 NE=NS
      NS=NS+1
      GO TO 503
  502 NE=NK(K)
      K=K+1
  503 JS(NE)=J(L)
      NLS(NE)=L
      TMDSS(NE)=TDMIN+TMDS(L)
      TTS(NE)=TMIN+TIME(L)
      L=L+1
      GO TO 405
  403 TEST=999999999.0
```

```
      K=1
      NST=NS-1
      DO 406 NSS=1,NST
      IF(JS(NSS).NE.0) GO TO 509
  508 NK(K)=NSS
      K=K+1
      GO TO 406
  509 NT=JS(NSS)
      IF(TTMDS(NT).LE.0.0) GO TO 407
      JS(NSS)=0
      GO TO 508
  407 IF(TMDSS(NSS).GE.TEST) GO TO 406
      TEST=TMDSS(NSS)
      NTEST=NSS
  406 CONTINUE
      N=JS(NTEST)
      NLINK(N)=NLS(NTEST)
      TTMDS(N)=TMDSS(NTEST)
      TTIME(N)=TTS(NTEST)
      NORDR(NO)=N
      NO=NO+1
  582 TDMIN=TTMDS(N)
      TMIN=TTIME(N)
      JS(NTEST)=0
      NK(K)=NTEST
      K=K+1
      NK(K)=0
      IF(NNO.GE.NODES) GO TO 523
      NNO=NNO+1
      GO TO 402
  523 CONTINUE
C     WRITE OUT MINIMUM PATH TREE
      WRITE(6,97)
   97 FORMAT(1H0,18H MINIMUM PATH TREE)
      WRITE(6,94)C
   94 FORMAT(37H TTMDS=SUM(C.TIME+(1-C)DIST),WHERE C=F7.3)
      WRITE(6,96)(N,NORDR(N),TTMDS(N),TTIME(N),NLINK(N),N=1,KNOD)
   96 FORMAT(5(2I3,2F7.1,I3))
   32 CONTINUE
  521 CONTINUE
      RETURN
      END
$ENTRY
```

Two Procedures To Improve the Economic Evaluation of Alternative Highway Systems

SALVATORE J. BELLOMO and STEVEN C. PROVOST, Alan M. Voorhees and Associates, Inc.

An integral part of any comprehensive transportation planning study is the economic evaluation of future alternative highway systems. A discussion of two procedures is presented to improve the method of economic evaluation that is generally used today. The first considers peak and off-peak travel to obtain improved system measures for the user cost quantification. The second utilizes a range of unit time values and interest rates to enable the decision-maker to evaluate more effectively the significance of these two variables in the economic evaluation. The procedures are demonstrated through the use of economic analyses conducted for two medium-sized urban areas: Erie, Pa., and Waterloo, Iowa.

Improvements are suggested in system measures to reflect true intersection delays and in the determination of a value for time that is representative of the real costs incurred by trip makers.

•THE plan development phase of a transportation study typically involves the preparation and evaluation of several alternative transportation systems. An important part of this evaluation is the economic analysis to determine which system will cost the least to construct and operate for the planning period under consideration. The purpose of this paper is to present two procedures to improve the economic evaluation of alternative highway systems in medium-sized urban areas having minimal transit usage. Erie, Pa., and Waterloo, Iowa, are the two case examples used to demonstrate these procedures.

This report is divided into three sections: system measures, sensitivity analyses, and conclusions. The first section discusses the methodology used in determining system measures required for the user cost quantification. The importance of considering both the peak and off-peak periods in the economic evaluation is illustrated using data from the Erie Area Transportation Study. The second section discusses the use of a range of unit time values and interest rates in determining the most economical highway system for the Waterloo metropolitan area. The need is stressed for the use of this approach to enable the decision-maker to understand fully the results of the economic analysis. The last section summarizes these two approaches, and suggests areas of further research to improve the state of the art of the highway system economic evaluation.

SYSTEM MEASURES

During the plan development phase of the Erie Area Transportation Study, three 1985 highway system alternatives were developed, each containing certain firmly committed projects (1). The 1985 traffic was assigned to the existing and committed system and to each future system using the Bureau of Public Roads "all or nothing"

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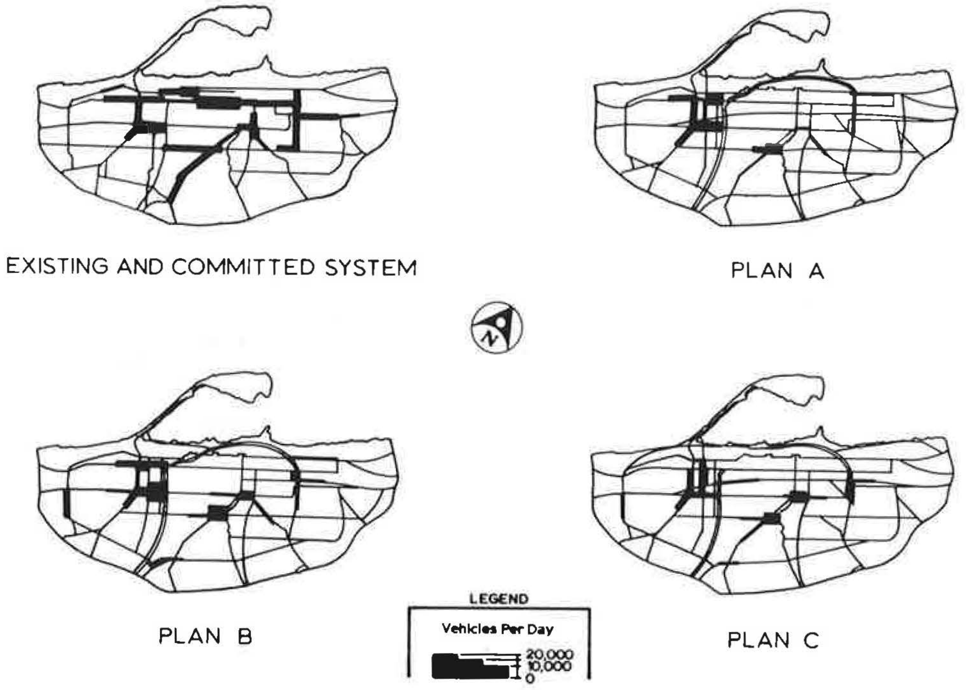


Figure 1. Alternate systems—deficiencies, Erie, Pa.

assignment technique. The capacity deficiencies resulting from the balanced traffic loadings are shown in Figure 1.

The "all or nothing" assignment program output contains a summary of vehicle-miles, vehicle-hours, and average speeds. These inventory speeds based on an inventory of off-peak travel times, were modified during calibration of the computer network. The actual vehicle-hours of travel for each system, however, should be based on an average peak and off-peak speed as expressed by Eq. 1.

$$VH = \sum_{i=1}^{n} PH_i \frac{D_i}{SP_i} + \sum_{i=1}^{n} OP_i \frac{D_i}{S_i} \tag{1}$$

where

VH = total system vehicle hours of travel;

PH_i = peak-period vehicular traffic;

D_i = length of link i (miles);

SP_i = average peak-period speed of link (mph);

OP_i = off-peak vehicular traffic;

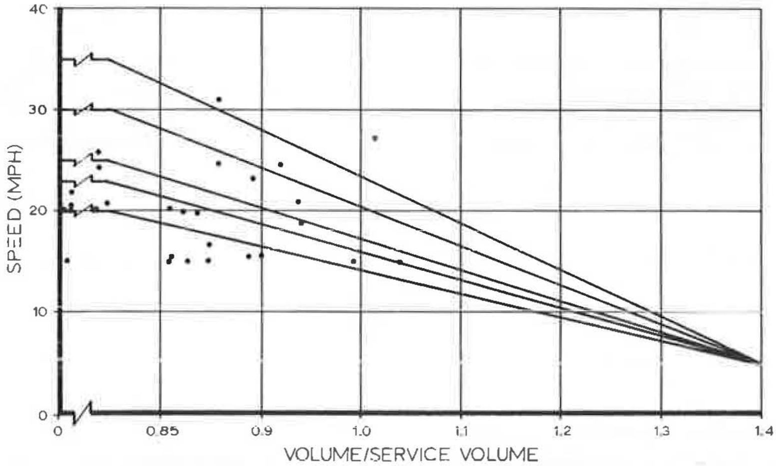
S_i = average off-peak speed of link (mph);

i = individual link in system; and

n = the last link in system.

The peak and off-peak speeds were determined using a relationship between the volume to serve volume ratio and speed, as shown Figure 2.

As an aid to the development of total system vehicle-hours, a distribution of percent of vehicle-miles versus speed was determined for each alternative based on both



*BASED ON STREET DESIGN SPEED AND LEVEL OF SERVICE C
Source: Appendix B, Technical Report 4, Erie Transportation Study, January, 1964. Extrapolation based on PATS (3).

Figure 2. Speed and volume/service volume ratio* areterial streets, Erie, Pa.

the off-peak speed and the adjusted speed (Fig. 3). The differences between the existing and committed system and each of the alternatives are much less after the peak-period speed adjustment. The new distribution curve clearly indicates how traffic congestion is overstated using unadjusted vehicle-hours. With the adjusted distribution, the vehicle-hours of travel for the system were obtained by dividing vehicle-miles by the appropriate speed class. This division approximated the vehicle-hours of travel stated in Eq. 1 and gave a reasonable distribution of vehicle-hours that was required for the economic evaluation.

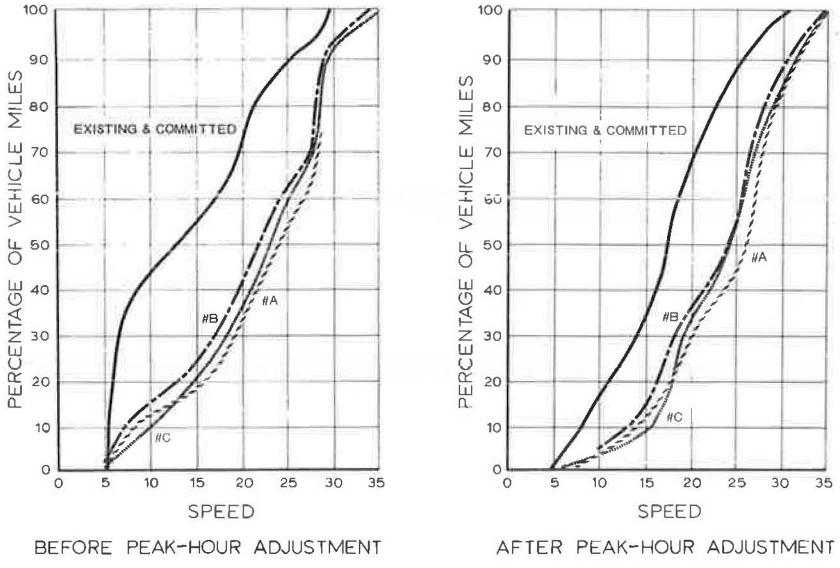


Figure 3. Cumulative percentage of arterial street vehicle-miles by speed, Erie, Pa.

TABLE 1

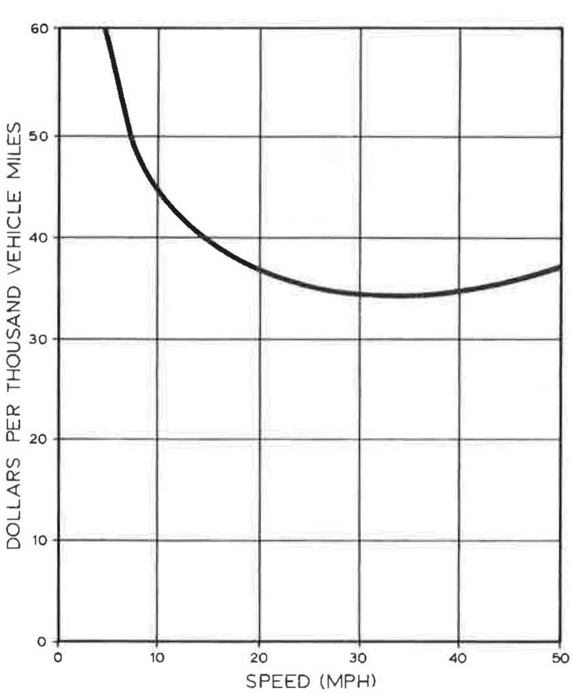
AVERAGE DAILY VEHICLE-MILES AND VEHICLE-HOURS OF TRAVEL—ARTERIAL SYSTEM, ERIE, PA.

Arterials	Vehicle-Miles	Vehicle-Hours		
		ADT	Peak and Offpeak	Difference (%)
Existing and committed system	1,535,500	109,600	90,003	22
Alternative:				
A	1,620,800	82,800	69,249	19
B	1,548,900	86,690	70,885	23
C	1,737,700	87,680	74,581	17

Source: Ref. (2).

The vehicle-hours of travel considering both the peak and off-peak average speed are summarized in Table 1, which also shows the vehicle-hours obtained from the "all or nothing" ADT computer assignment without the peak-period adjustment. The adjusted values are less by approximately 20 percent due to the overstatement of vehicle-miles in the lower speed classes (Fig. 3). The difference in vehicle-hours between each alternate and the committed network is less with the peak and off-peak adjustment, thereby indicating smaller benefits.

For the Erie area study, a user cost curve was developed relating average speed to operating cost per vehicle-mile. This curve was derived from cost data presented by Winfrey (4). To use that data, representative values were assigned for the percentage and composition of the trucks in the study area. Although it was recognized that this was an approximation of existing conditions, it was felt that since the economic evaluation deals with differences rather than absolute costs, a finer stratification was not warranted. The final user cost curve is shown in Figure 4.



Source: Motor Vehicle Running Costs For Highway Economy Studies by Robley Winfrey (4).

Figure 4. Vehicle operating cost versus speed, Erie, Pa.

The operating cost per vehicle-mile (Fig. 4) was applied to the vehicle-miles within each speed class (Fig. 3). By aggregating these costs, the total 1990 operating cost for each alternate was quantified as summarized in Table 2.

The benefit-cost ratio method based on equivalent annual costs (see Appendix, section 4(b)) was used to make the economic comparison between alternatives. The benefit-cost ratios comparing each alternative to the existing and committed system are given in Table 3. Comparison of the benefit-cost ratios before and after peak-period adjustment clearly shows that the benefits derived for the proposed alternatives are overstated when the operating costs are based on off-peak conditions alone.

TABLE 2

1990 ANNUAL OPERATING COSTS, ERIE, PA.

Existing and committed system	$21, 620, 000
Alternative:	
A	$23, 450, 000
B	$23, 750, 000
C	$23, 450, 000

Source: Ref. (2).

TABLE 3

BENEFIT-COST RATIOS, ERIE, PA., ALTERNATIVES COMPARED WITH EXISTING AND COMMITTED SYSTEM

Alternative	Interest Rate, Peak-Period Adjustment					
	6%		8%		10%	
	Before	After	Before	After	Before	After
A	2. 1	1. 1	1. 6	0. 8	1. 2	0. 6
B	1. 8	0. 8	1. 4	0. 6	1. 0	0. 4
C	1. 7	0. 8	1. 1	0. 6	0. 9	0. 4

Source: Ref. (2).

SENSITIVITY ANALYSIS

The purpose of any economic evaluation of alternative transportation systems is to provide inputs for a decision-maker who weighs the economic analysis along with other factors such as social and community impacts, level of service, and financing. The previous section suggested improvements in system measures for both the level of service and user cost quantification. An economic evaluation should focus attention on those items in the analysis that are subject to judgment to show their possible variation. This can be done effectively by a sensitivity analysis where a range of "values" is used for those items subject to judgment. This approach allows the policy maker to obtain an understanding of the significance of each item to the final decision.

The importance of the sensitivity analysis was demonstrated in the economic evaluation of alternate highway plans for the Waterloo Metropolitan Area Transportation

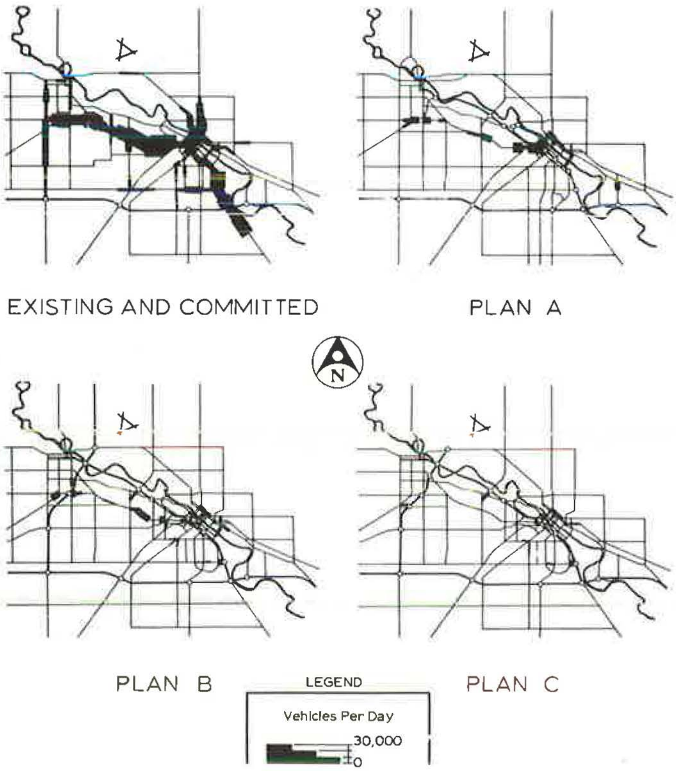


Figure 5. Alternate systems—deficiencies, Waterloo, Iowa.

TABLE 4

INTEREST RATES AND UNIT TIME VALUES, WATERLOO, IOWA

Interest Rates: 6, 8, and 10 percent			
Value of Travel Time Savings	Dollars		
Value per person-hour	0.85	1.00	1.25
Value per truck-hour	4.00	4.50	5.00
Value per vehicle-hour[a]	1.32	1.52	1.86

[a]Based on the following formula:
Value per vehicle-hour = (Value per person-hour) (persons per car) (% auto) + (value per truck-hour) (% trucks)

where persons per car = 1.3; % auto = 93; and % trucks = 7.

Source: Ref. (5).

TABLE 5

TOTAL EQUIVALENT ANNUAL COST, WATERLOO, IOWA
(Thousands of Dollars)

Alternative	Interest Rate (%)	Time Value Per Vehicle-Hour		
		$1.32	$1.52	$1.86
Committed system	6	95,288	105,096	121,776
	8	90,242	99,364	114,907
	10	85,799	94,303	108,765
Plan A	6	54,500	58,122	64,283
	8	54,192	57,669	63,583
	10	54,144[a]	57,491[a]	63,185
Plan B	6	58,475	62,424	64,102
	8	58,199	61,978	68,388
	10	58,216	61,328	67,985
Plan C	6	54,068[a]	57,499[a]	63,327[a]
	8	54,092[a]	57,381[a]	63,013[a]
	10	54,329	57,750	62,965[a]

[a]Minimum equivalent annual cost alternative for a given interest rate and time value.

Source: Ref. (5).

Study (5). Figure 5 shows the highway system and the 1990 deficiencies for the existing and committed system and each of the three plans tested. Initially an interest rate of 6 percent and a value of $1.55 per hour (6) for travel time savings were assumed. However, it has been recommended (7) that higher interest rates be used to provide a better measure of the risks involved in the traffic forecast output. A range of interest rates varying from 6 percent to 10 percent was assumed. A range of values for travel time savings considering the inherent difference in travel time cost savings, as compared with the savings in vehicle operating cost was also used. The interest rates and values for travel time savings used in the Waterloo economic evaluation are given in Table 4.

Using these values, the equivalent annual cost of each investment and user cost component was computed for each highway system alternative. A summary of the equivalent annual costs is given in Table 5, and a more detailed breakdown is presented in the Appendix, section 3.

Table 5 shows that the least equivalent annual cost alternative varies with interest rate and time value. Plan A is less costly for the lower time values, at an interest rate of 10 percent, whereas Plan C is less costly for the other combinations of time values and interest rates.

TABLE 6

BENEFIT-COST RATIOS, WATERLOO, IOWA

(a) Alternatives Compared With Committed System

Alternative	Interest Rate (%)	Time Value Per Vehicle-Hour		
		$1.32	$1.52	$1.86
Plan A	6	12.0	13.5	16.3
	8	8.8	10.1	12.2
	10	6.8	7.8	9.4
Plan B	6	8.4	9.5	11.5
	8	6.2	7.1	8.5
	10	4.8	5.4	6.7
Plan C	6	9.8	11.1	13.4
	8	7.3	8.3	10.3
	10	5.6	6.3	7.7

(b) Incremental Analysis—Plan C Compared With Plan A

		$1.32	$1.52	$1.86
	6	1.46	1.66	2.00
	8	1.09	1.25	1.53
	10	0.85	0.97	1.16

Source: Ref. (5).

To present the economic analysis results in a form that would be more clearly understood by the decision-makers, benefit-cost ratios were computed: (a) comparing each plan with the committed system, and (b) comparing the incremental benefits and costs.

In undertaking the incremental analysis, Plan B had both the highest investment costs and the highest user costs (which would have resulted in negative benefit-cost ratios); therefore, this alternative was dropped from the incremental analysis. Table 6 gives the results of the benefit-cost computations.

The incremental analysis is further illustrated in Figure 6 which shows the acceptance areas for Plans A and C. Combinations of interest rate and time value occurring above the curve result in the acceptance of Plan C, while those combinations occurring below the line result in the acceptance of Plan A.

Had the economic evaluation been conducted using the initial interest rate and time value,

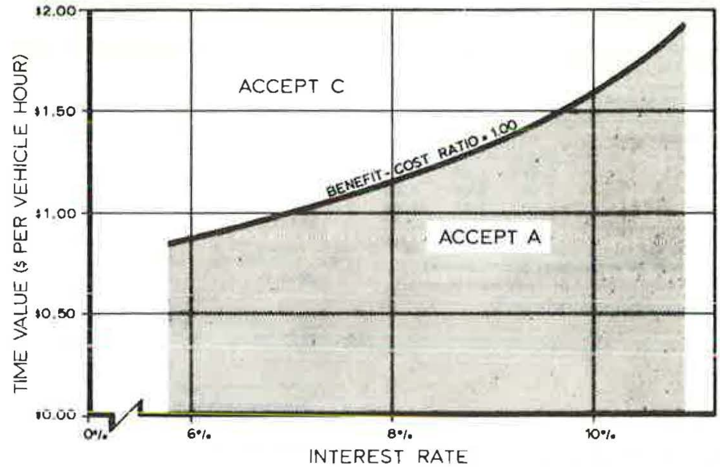


Figure 6. Incremental comparison Plan C versus Plan A, Waterloo, Iowa.

Plan C would have been the least cost alternative. The economic similarity between Plans A and C, however, indicated that both plans were equal from an economic standpoint. Therefore, other than economic criteria became important in the decision as to which plan was the best. Table 7 summarizes these criteria for each alternative and indicates how the economic sensitivity analysis allowed for better decision-making.

CONCLUSIONS

This paper has presented two major findings with respect to the economic evaluation of alternatives in medium sized cities. First, peak and off-peak volume flow and their corresponding volume-service volume ratios must be considered in the evaluation of alternative street and highway systems. Failure to do so will result in different vehicle hours, and hence, user costs, which will affect the economic evaluation. Second, sensitivity analyses using different interest rates as well as time value ranges should be employed so that decision-makers have a clearer understanding of the significance of these variables in the economic evaluation.

With respect to new areas of research, it is felt that there are certain deficiencies in the manner in which vehicle-hours are calculated. More consideration should be given to the actual delay time at an intersection, due to conflicts occurring during the peak period. Perhaps with the emergence of TOPICS (Traffic Operations Program for Increased Capacity and Safety) and other similar programs, it may be possible to merge the transportation study assignments and data from traffic engineering studies to arrive at better system measures.

Furthermore, research is required to determine the value of travel time savings to trip makers. While recently published research on the value of travel time savings to peak-hour commuters (9) is a significant step in the right direction, there are rather severe constraints on the applicability of the results due to the difficult task of obtaining useful data. However, the fact that

TABLE 7

SUMMARY OF CRITERIA, WATERLOO, IOWA

Criterion	Best Alternative(s)
1. Minimize traffic congestion with best overall system performance.	C
2. Minimize negative community and social impact.	Existing and Committed
3. Maximize service to present land uses.	C
4. Foster the land development pattern desired.	B, C
5. Minimize total annual transportation costs.	A, C
6. Maximize system flexibility	B, C

Source: Ref. (8).

the value of travel time savings is often the most significant component of the benefits derived from a new highway facility or system, strongly indicates the need for better data on the value of travel time savings to off-peak and non-commuter peak-hour travelers.

ACKNOWLEDGMENTS

The authors are indebted to the staff of Alan M. Voorhees and Associates whose critical review helped shape the final content of this paper. Particular acknowledgment goes to Atila Alpoge and Walter G. Hansen for their contributions to the economic evaluation for the Erie Area Transportation Study.

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Appendix

ECONOMIC EVALUATION DATA AND METHODOLOGY—WATERLOO, IOWA METROPOLITAN AREA TRANSPORTATION STUDY

1. Travel Demand Measures

	System				
	Existing	Committed	Plan A	Plan B	Plan C
Vehicle-miles	798,000	2,233,500	2,262,900	2,308,600	2,300,200
Vehicle-hours	28,660	314,100	88,600	100,400	81,600

2. Construction, Salvage and Maintenance Costs ($ thousands)

	System			
	Committed	Plan A	Plan B	Plan C
Total Construction Cost	40,390	91,300	107,910	103,860

		Equivalent Annual Cost			
Construction (I)	6%	3,105	7,021	8,298	7,987
	8%	3,736	8,445	9,983	9,607
	10%	4,410	9,966	11,779	11,337
Salvage (S)	6%	81	244	276	266
	8%	60	180	204	197
	10%	44	132	150	145
Maintenance (D)	6%	608	639	644	641
	8%	606	633	638	635
	10%	603	629	633	630

3. User Costs ($ thousands)

(a) Existing System (1964)

Operating Cost		10,174
Accident Cost		3,420
Time Cost	$1.32	13,052
	$1.52	15,029
	$1.86	18,391

(b) Annual Cost Increment, 1964–1990

			System			
			Committed	Plan A	Plan B	Plan C
Operating Cost		6%	11,278	7,975	8,584	7,917
		8%	10,290	7,276	7,832	7,223
		10%	9,400	6,696	7,155	6,578
Accident Cost		6%	2,030	1,600	1,580	1,559
		8%	1,852	1,960	1,442	1,423
		10%	1,592	1,334	1,317	1,300
Time Cost	$1.32	6%	51,702	10,863	13,001	9,996
	$1.52	6%	59,533	12,508	14,970	11,035
	$1.86	6%	72,851	15,309	18,316	13,509
	$1.32	8%	42,173	9,912	11,861	8,743
	$1.52	8%	54,317	11,412	13,658	10,070
	$1.86	8%	66,468	13,964	16,711	12,320
	$1.32	10%	43,093	9,055	10,836	7,987
	$1.52	10%	49,620	10,425	12,477	9,200
	$1.86	10%	60,720	12,750	15,266	11,255

(c) Equivalent Annual User Cost (U)

		Committed	Plan A	Plan B	Plan C
$1.32	6%	91,656	47,084	49,809	45,706
$1.52	6%	101,464	50,706	53,758	49,137
$1.86	6%	118,144	56,867	55,436	54,965
$1.32	8%	85,960	45,294	47,782	44,047
$1.52	8%	95,082	48,771	51,561	47,336
$1.86	8%	110,625	54,685	57,971	52,968

\$1.32	10%	80,830	43,681	45,954	42,507
\$1.52	10%	89,334	47,028	49,066	45,968
\$1.86	10%	103,796	52,722	55,723	51,143

4. Computation Methodology

(a) Equivalent Annual Cost (EAC)

$$EAC_P = I_P - S_P + D_P + U_P$$

(b) Benefit Cost Ratio (BC)

$$BC = \frac{(U_B - U_P) - (D_P - D_B)}{(I_P - I_B) - (S_P - S_B)}$$

where

I = (Total Construction Cost) $(crf_n^{i\%})$

S = (Total Salvage Value) $(sff_n^{i\%})$

D = (1964 Maintenance Cost) + (Annual Increase in Maintenance Costs) $(gf_n^{i\%})$

U = (1964 User Cost) + (Annual Increase in Total User Costs) $(gf_n^{i\%})$

i = Interest rate

n = Analysis period, 26 years

$crf_n^{i\%}$ = Capital recovery factor at i% for n years

$sff_n^{i\%}$ = Sinking fund factor at i% for n years

$gf_n^{i\%}$ = Equivalent annual uniform gradient factor at i% for n years

P = Subscript that refers to proposed condition

B = Subscript that refers to base condition

Economics of Design Standards for Low-Volume Rural Roads

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ABRIDGMENT

•THIS paper is a condensation of a portion of the final report of NCHRP Project 2-6. Low volume is defined as less than 400 vpd; yet some two million miles of rural road, or two-thirds of the total in the United States, fall within this category.

The paper examines current standards for roadbed width (shoulder break to shoulder break) for roads of comparable volumes and shows the wide diversity among them. It explores the rationale underlying these standards and finds that they have almost no scientific, engineering, or economic base; rather they are blended from past practices, political considerations, and the financial "facts of life." Also, standards such as those of AASHO, that are imposed from "the top down" by higher levels of government are usually among the most exacting.

The paper presents a set of derived costs and benefits to highway agencies and highway users through a range of roadbed widths and demonstrates that, from an economic standpoint, there is little or no justification for wide roadbeds and none for shoulders. It then explores accidents and accident costs to see if they offer justification for wider roadbeds or shoulders, either on economic or humanitarian grounds. It is found that wider roadbeds do not improve the accident experience of low-volume rural roads, and that, even if such improvements eliminated all accidents of given classes, the savings would be trivial in amount.

The paper concludes that present-day standards for low-volume rural roads which are expected to remain rural in character should be modified as follows:

1. Abandon the concept of continuous constant width cross sections; they are costly, since they require that a road be reconstructed from end to end. Substitute standards based on spot improvements.
2. If there are to be standards for roadbed width, they should stipulate maximums rather than minimums, and encourage the use of narrower roadbeds where they can be shown to be economical.

Paper sponsored by Committee on Highway Engineering Economy and presented at the 47th Annual Meeting. The complete paper on NCHRP Project 2-6 is scheduled for publication in the NCHRP series in 1968.