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

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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
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 addi­
tional 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 con­
strained 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 re­
lease 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 years 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 conse­
quences 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 im­
provement 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 charac­
teristics, 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 per­
sions 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 be­
come 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-destination 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.
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.

Set B 1981

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.

Road 1966 1967 1968 1969
X ~ ~ ~
Y ~ ~
Z ~
Σ Σ

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 unequivocally 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 Bureau 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 Simplicisic, 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.
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 IIAn—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

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

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).
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

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

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:

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

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568 TRIPS FROM THIS ZONE

### VIII-4 INTERZONAL UNIT TRAVEL TIME SAVING FOR SET A(FB) CARS

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TRIPS FROM ZONE 2 TO ALL ZONES

0.76 min

### VIII-5 MULTIPLY 1968 TRIP TAB BY UNIT TRAVEL TIME SAVING-A(F3) CARS

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<td>149</td>
<td>642</td>
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TOTAL 149,642 hours

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

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<td>642</td>
<td>169</td>
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</tbody>
</table>

149 TRIPS FROM THIS ZONE

149 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).

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

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).

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

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).
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.

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**

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The development of these data is illustrated by samples of computer output.
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.
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<th>Additional Costs of Alternative Sets Over Continuing &quot;As Is&quot;</th>
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<td>C (BFD)</td>
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<td>C (FBD)</td>
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</table>
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 "n", 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 Computation 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-cartime). 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-cartime 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.

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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.

REFERENCES

5. Program in Engineering-Economic Planning, Stanford University, Report EEP-26, Figure 5-5, p. 129, July 1967.