A Network Evaluation Procedure

PETER S. LOUBAL, Bay Area Transportation Study Commission, Berkeley, California

A novel traffic assignment method is presented which greatly increases the number of network alternatives that can be evaluated at a given cost in computer time. Based on slight variations of the usual minimum path tree-building and traffic loading procedures, the method makes it possible to consider only the effects of new or improved network links, rather than complete networks, when evaluating alternatives of some basic (existing or future) network configuration. The same values for each alternative, such as interzonal travel times and flows on links, are obtained as if each network alternative were treated separately. Furthermore, such values as savings in travel time between any pair of zones, flow changes, and total vehicle hours are directly obtained. In addition, the procedure readily provides interzone travel times via a link or links, even if these do not contribute to the minimum time or cost path, and this information can be used for improved (more realistic) but still rather efficient capacity restraint and traffic diversion procedures. The present report describes the essential parts of the process and a procedure for evaluating sketch-plan network alternatives.

•THE network evaluation method described in this report utilizes several special network properties which make it possible to assess large numbers of transportation projects such as new bridges, freeways, or rapid transit lines without requiring a complete traffic assignment process for each alternative combination of projects. It is capable of evaluating a large number of network alternatives in the same amount of time it would take to evaluate a single alternative using standard procedures (e.g., the Bureau of Public Roads or TRAN/PLAN traffic assignment programs), and still obtain not only the same information at a comparable level of detail, but also additional data as well.

When using the procedure, the usual traffic assignment process is applied only to a "basic" network configuration, while additional routines make it possible to concentrate on possible effects of network changes, such as new or improved links, when evaluating the various alternatives. The procedure will provide the following data for each network alternative:

1. Interzonal travel times via minimum time paths;
2. Traffic flows on links;
3. Savings in travel time between all pairs of affected zones, due to some improvement to the basic network (inclusion of project or combination of projects);
4. Changes in traffic flows for each network alternative, i.e., the flow diverted to or from all existing and future facilities due to network changes;
5. The origins and destinations of all flows on any new facility in a network alternative;

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6. The total travel time required to satisfy given travel demands for a network alternative, and the difference in the total travel time between each alternative and the basic network;
7. Information regarding the degree to which several transportation projects (new or improved links) compete or cooperate in carrying traffic, and the area affected by any project; and
8. Interzonal travel time via any link or links, even if these are not on the shortest path.

The following input data are required:

1. Network description for each "basic" network;
2. Network changes needed for converting a base network into a network alternative; and
3. A trip desire (origin-destination) table.

The interzonal travel times for a "basic" network can be obtained first and used to determine a trip table by means of suitable land-use and traffic generation and distribution models. This trip table can then be used in conjunction with all the network alternatives which do not differ too significantly from the basic network. In case of the significantly different alternatives, it would be necessary to rerun the trip demand models, or, in the intermediate case, only a new trip distribution process would be required. The trip tables are actually only utilized as weighting factors for determining flows and cumulative travel times, and the decision as to whether the same trip table should be used for each alternative, or whether the trip tables should be adjusted for each alternative network, has to be left to the user.

The network evaluator procedure and related computer program, as developed for the San Francisco Bay Area Transportation Study, was envisaged primarily as a simple, efficient, and inexpensive management tool, suitable for testing and evaluating very large numbers of possible highway, transit, or multimode network alternatives. It will be used mainly to limit the large amount of possible alternatives to the more promising ones, to be evaluated in greater detail by means of a different process. The main emphasis was, therefore, on quantity rather than quality, as is usual in sketch planning. The general method, as described in the following parts, could, however, be just as well used in a detailed transportation planning process, and the development of suitable computer programs is presently being considered.

In developing the model, the author was mainly influenced by the general network methodology as presented by Ford and Fulkerson (1), and benefited greatly from many discussions concerning the transportation planning process with J. W. McBride, Technical Director, Bay Area Transportation Study Commission. The benefit/cost evaluation method is partly based on Kuhn's work (2) and Ridley's dissertation (3). It would be difficult to enumerate all the authors who contributed to the state-of-the-art in the field of traffic assignment, which, of course, forms the basis of the model.

MODEL DEVELOPMENT

Network Properties

The network evaluator utilizes a special tree-building procedure for determining the minimum paths that will use a specific project link. The procedure is an extension of the well-known dynamic programming (or Moore) shortest path algorithm, the only difference being:

1. Two or more "project" nodes—either the end nodes of a "project" link, or several nodes, such as the interchanges of a segment of freeway or the stops of a transit line segment—are used as origins at the start of the process, so that two or more disjointed tree branches are obtained.
2. Each node is labeled by a subset (tree branch) number to indicate from which node the branch originated.

The procedure is just as efficient as the fastest standard tree-building process and has the same computer core requirements.

At the end of the tree-building process a project tree is obtained, consisting of two or more branches, so that each node is connected with the closest project node. In case of equal travel times (it is, of course, also possible to minimize distances, costs, or some other value), one or the other project node is selected.

The project tree has the following properties (the properties mentioned hold strictly true only for symmetrical networks; similar ones apply to asymmetrical networks):

1. No two nodes belonging to the same subset can be connected by a minimal path that would include the project link, since their connection via the last common node on their branch cannot be longer than the sum of the shortest distances between them and the closer project node.
2. Only the paths between the nodes of different branches could possibly have been improved by the inclusion of the project link. Therefore, only these connections will have to be tested.
3. The minimal path between nodes, each belonging to separate subsets, via the project link(s) can easily be determined by summing the times from the two project nodes and the time required to cross the project link(s). The project link time, therefore, does not enter the actual tree-building process and can be varied depending on various conditions; for instance, it could be adjusted to reflect traffic flows, different tolls, etc.

Any standard minimum-path, tree-building routine can be used to determine a project tree by either (a) representing the project as a special centroid, connected to the two or more project nodes by "dummy" (zero-time) links, or (b) adjusting the routine so that the several project nodes can serve as "home" nodes, i.e., be initialized at zero and become the simultaneous origins of a single tree. Though it would be a simple matter to carry the subset number which identifies the origin node to each network node as it is reached in the tree-building process, it is more efficient to determine the subset numbers by means of a subsequent labeling routine.

Project Tree Routine Input and Notation

Network N is composed of nodes i, connected by links (i, j) with travel times $t(i,j) \geq 0$. Associated with each node i is a number $t(i)$. The nodes i can be divided into complementary subsets X, $\bar{X}$ such that $N = X \cup \bar{X}$. The project is represented by project nodes p = a, b, c, d, ... which form a chain of links (a, b), (b, c), (c, d), ... The project nodes and links are connected with the network.

Step 1—Initialization: Set all $t(p) = 0$ and all remaining $t(i) = M$ (high value). Assume that all nodes with $t(i) < M$ form a subset X of "reached" nodes, with the remaining nodes forming a complementary subset $\bar{X}$.

Step 2—Consider all links (i, j) connecting the node(s) i that have been assigned to the set X in the preceding step to nodes $j \in \bar{X}$, and calculate values $t'(j) = t(i) + t(i,j)$. Place the values $t'(j)$ in a sequence table, i.e., a table ordered by value $t'(j)$.

Step 3—Select the minimal $t'(j)$ from the sequence table. If $\min(t'(j)) < t(j)$, go to Step 4, otherwise remove $t'(j)$ from the sequence table and repeat Step 3. If the sequence table is empty, STOP.

Step 4—Set $t(j) = t'(j)$ and reassign the node j from the set X to the set $\bar{X}$. Place the link (i, j) into the next position of a tree trace vector.

Step 5—If the set $\bar{X}$ is empty, STOP, otherwise return to Step 2.

At the end of the process, the $t(i)$ values will give the travel time, via fastest route, to the node i from whichever project node p is the closest. The tree trace obtained in Step 4 is just a listing of all links (i, j) that form the project tree, in the sequence in which they entered the tree, i.e., ordered by increasing $t(j)$ values. The links can be identified by their addresses (positions) in the link table (network description). The tree trace is used as input to a labeling routine which determines for each node i the project node p from which it has been reached and, furthermore, is also used in the loading and unloading routines.

Labeling Routine

1. For each node i, initialize a value $\ell(i)$ in the following manner: (a) For each project node p set $\ell(p)$ at different non-zero values. For instance, $\ell(a) = 1$, $\ell(b) = 2$, $\ell(c) = 3$, $\ell(d) = 4, \ldots$; (b) Set all remaining $\ell(i) = 0$.

2. Starting at the first link, scan through the whole tree trace, setting $\ell(j) = \ell(i) + \ell(j)$.

3. Sort all centroids (nodes which represent a zone) by their $\ell(i)$ values, so as to form subsets of centroids S(a), S(b), S(c), S(d), ..., each comprising the centroids reached from the project nodes a, b, c, d, ...

The above algorithm can also be used to determine which nodes have been reached from any project node via some other node or nodes k. This is done by setting $\ell(k)$ equal to some unique non-zero value in Step 1, even though k is not a project node. In this case, it is convenient to use the numbers formed by the series 2^n (n = 1, 2, ...) as labels for all "initially tagged" nodes. Any sum of the label values then forms a unique identifying number which can be used to determine for any node i the "tagged" nodes or links through which it was reached and the project node p from which any particular branch of the tree originated.

Single-Link Projects

Assume now that the interzonal travel times for some "base" network have been determined by the standard method, and that an alternative network is to be evaluated. The alternative is formed by all links of the base network plus a project link (a, b).

The travel time between any pair of centroids u and v could have been improved only if there exists a shorter route between u and v via the project link (a, b), since that was the only change in the network.

All that needs to be done, therefore, is to build a single project tree, simultaneously from the project nodes a, b. In the case of symmetric networks, i.e., $t(i, j) = t(j, i)$, a time saving will have been obtained for any centroid pair (u, v), $u \in S(a)$, $v \in S(b)$ if

$$t(u) + t(v) + t(a, b) < t(u, v) \quad (1)$$

where t(u) is the minimum-time path between nodes u and a, t(v) is the minimum-time path between nodes v and b, t(a, b) is the estimated travel time on the project link (a, b), and t(u, v) is the minimum time between nodes u and v on the basic network.

In case the condition (1) has been met, the value of the time-saving d(u, v) can be determined as

$$d(u, v) = t(u, v) - t(u) - t(v) - t(a, b) \quad (2)$$

Assuming all-or-nothing loading, the project link (a, b) will get the flow f(a, b):

$$f(a, b) = \Sigma f(u, v)\text{: summed over all } (u, v) \text{ such that } d(u, v) > 0 \quad (3)$$

If the flow f(a, b) is greater than the planned capacity of the project link, the value t(a, b) can be appropriately increased. The time-saving d(u, v) for any affected pair of centroids will be decreased by the same amount so that some d(u, v) will become zero or negative and Eq. 3 will produce a decreased flow f(a, b). Capacity restraint relationships can, therefore, be introduced into the process without requiring a new tree-building procedure.

It must be stressed that not all pairs of centroids (u, v), $u \in S(a)$, $v \in S(b)$ need be evaluated for time savings, since if some centroid u does not achieve any time saving, obviously no centroid on the branch behind it need be considered in the time-saving evaluation. This greatly reduces the number of calculations which have to be performed.

The time savings in a network where not all links are symmetrical, i.e., some $t(i, j) \neq t(j, i)$, are determined in the following manner. Using the standard tree, as built for a centroid u on the "base" network, determine the closer project node—say it is node a. Then for subsequent centroids v of some other subset—say S(b)—check whether

$$t(u,a) + t(v) + t(a,b) < t(u,v) \tag{4}$$

If yes, then the time saving is determined as

$$d(u,v) = t(u,v) - t(u,a) - t(v) - t(a,b) \tag{5}$$

where t (u, a) is the minimum-path travel time from centroid u to project node a on the base network.

Note that for

$$t(u,a) + t(a,b) > t(u,b) \tag{6}$$

no time saving can be achieved for centroid u on routes to the centroids of the subset S(b) via the project. The travel times on the project link can also be different in both directions, when criterion (4) is used.

The centroids of the two subsets S(a) and S(b) have to be evaluated in both directions, but otherwise the process remains basically the same. It must be stressed that even for asymmetrical networks only a single project tree is required, built by the algorithm in the "outbound" direction.

Multi-Link Projects

Multi-link projects are treated in much the same manner as single-link projects, except that each centroid should be evaluated in conjunction with the centroids of all other centroid subsets. For instance, given a two-link project (a, b), (b, c), the centroid u of the group S(a) is evaluated against the centroids of the group S(b), in which case the criteria (1) or (4) are used, and against the centroids of group S(c) with the value t (a, c) = t (a, b) + t (b, c) replacing the t (a, b) of (1) and (4). Again, symmetrical networks need be evaluated in only a single direction, asymmetrical networks in both directions.

It is possible that the existence of a shorter path via some other project node in the direction of travel, rather than via the closest project node, will lead to errors if the above algorithm is applied to long chains of multi-link projects. The error becomes negligible if an actual project is broken up into several straight-line segments. This approach has been found to be more practical than the inclusion of additional checks in the evaluation routine.

Multi-Project Alternatives

Projects can interact in a complex manner, since various projects can either compete for traffic, or cooperate in carrying traffic, or as often occurs, do both at the same time, depending upon the origins and destinations of the various trips. The total time savings due to the inclusion of several projects, therefore, cannot be assessed directly from the time-saving tables of the individual projects.

Take, for instance, two projects A and B. Depending upon their location and other network values, some zone pair interchanges will not benefit from either of the projects, others from just one of them, and still others from both. With regard to this last possibility, a particular zone pair (u, v) could be in "series" and the time saving achieved by both projects will be greater than any achieved singly and

$$d(u,v)\,[AB] > d(u,v)\,[A];\ d(u,v)\,[B] \tag{7}$$

where the capital letters in brackets indicate the project alternative being evaluated—that is, the projects which were added to the base network to form an alternative.

The projects could also be "parallel" with regard to some other zone pair (u, v), then

$$d(u,v)\,[AB] = \max\,(d(u,v)\,[A];\ d(u,v)\,[B]) \qquad (8)$$

and the projects "compete" with regard to time savings, but cooperate in the sense of increasing the capacity on the routes between centroids u and v.

The procedure, as discussed so far, can be used to evaluate several projects by the inclusion of one project after another. For instance, if a network alternative formed by the base network and projects A, B and C are to be evaluated, it might be conveniently done by first evaluating project A, then adjusting the interzonal travel times of the base network by including the achieved time savings to produce a new "base" network. Then it would be possible to evaluate the additional effect of project B by building a project tree for B, with the links of project A included in the base network. After a second adjustment, the final effect of the inclusion of project C could be evaluated.

In this approach, three project trees were built in order to evaluate three alternatives to the base network N, and travel times, time savings, etc., will have been obtained for networks N + A, N + AB, and N + ABC.

If it is desired to evaluate project C by itself, it would now be necessary to return to the base network N by removing the project links, building a project tree for C, and evaluating it against the original base network.

A more efficient way of handling the above problem would be:

1. Evaluate project C against the base network N,
2. Evaluate project A against the base network N,
3. Evaluate project B against the network N + A, and
4. Evaluate project C against the network N + AB.

As can be seen, the greatest computational savings can be achieved if the various alternatives form logical combinations of projects, where each alternative differs from some other alternative which is of interest by only a single project. Luckily, this is also convenient from the planning standpoint. Since not all projects can be built simultaneously, we are interested not only in the effect of a large number of projects, but also in the order in which the projects should be built, so as to maximize the benefit at each stage of completion.

Whenever the alternatives to be evaluated can be set up in such logical chains, the improvement in efficiency of the procedure suggested here, as against the standard approach, is quite obvious. For instance, using the standard approach, the evaluation of 20 alternatives of a 1000-zone network requires the building of 20,000 trees (at, say, one second of computer time each), their loading (if flow comparisons are desired), and 20 evaluations of 1000 × 1000 interzonal travel time tables. The suggested procedure will require the building of only 1020 trees and the evaluation of substantially less than 1000 × 1000 values for each alternative. Also the flow changes on the network and project links can be obtained in a more efficient manner, as will be discussed later.

The number of computations to be performed in the evaluation phase differs with each individual case, but as a rough estimate for a single-link project, it can be assumed that in a 1000-zone network, perhaps 400 zones would be reached from one project node and 600 from the other, and that after evaluating possibly 100 × 150 "closer" centroids no time savings will appear, and the evaluation can be discontinued. Multi-link projects require the evaluation of several subsets of centroids, but the number of centroids in a subset is smaller. It can, therefore, be claimed that the travel-time effects of a network improvement can be obtained in a matter of seconds, rather than tens of minutes, on the same computer.

If it is desired to evaluate a combination of projects without evaluating the subsets, still as many project trees as there are projects have to be built, but some economies can be achieved in the evaluation phase. If it is desired to evaluate the combination AB, all the project links would be added to the base network N before the project trees are built. The evaluation of the first project, say A, will indicate the time savings that can be obtained by going via A or AB, whichever route is the best. The evaluation of project B will then indicate the additional savings, due to B, over the network N + A, but at no time will the individual improvements due to projects A or B over the base network N be considered.

Another point which should be made now is that the "base" network must invariably be the network with the worst connections in any group of alternatives. If a freeway will improve travel along its corridor but somewhat disrupts travel across the corridor, the links that are "cut" by the freeway will also have to be missing in the base network. These can then be added to evaluate the "existing" network, and then again removed, and the freeway links added to evaluate the freeway against the base network. This approach will provide both the positive and negative effects of the studied project.

Flow On Links

The manner in which the traffic flows on project links can be obtained by summing the flows between all pairs of zones with a time saving due to the project has been mentioned previously. In case the change in flows, due to the inclusion of one or more projects, is required for all links of the network, it becomes necessary to "load" the flows between all affected pairs of zones on each project tree and to unload all affected base trees. A loading and unloading routine which simultaneously determines all the flow changes on a project or network tree has been devised. In the case of multi-project alternatives, the flows will be rerouted to the project tree for which the maximum time saving has been obtained. The loading of the project trees will provide the additional flows on the project links themselves and on the links of the "outbound" branches behind them. The tree of every centroid for which a time saving has been obtained has to be loaded with the flows "toward" the respective project nodes where the rerouted flows enter the project, and the same flows have to be unloaded from the base network routes. This can be done in a simultaneous operation.

The loading and unloading process is relatively efficient by itself and, of course, not all centroid trees will have to be treated. Nevertheless, though more efficient than the standard process, the suggested procedure does not have as obvious an advantage as was the case in obtaining travel time values. It is, therefore, suggested that link flows or flow changes for the whole network be obtained only for some alternatives, and only the flows on the projects themselves or on significant "existing" links, treated as projects, for the remaining alternatives.

Benefit/Cost Evaluation

A major purpose of any transportation study is the evaluation of all important transportation projects such as bridges, transit lines, tunnels, and freeways, on the basis of their benefits and costs, taking into account other social, political, and general economic factors.

Since various projects can compete for traffic, or cooperate in carrying traffic, often doing both at the same time, depending on the origins and destinations of the various trips, the total benefit of several projects cannot be assessed as the simple sum of the benefits of these projects taken individually. This is in direct contrast to the total cost of these projects which will, in general, be the sum cost of the individual projects.

Since available investment funds are always limited, not all projects can be built, and it therefore becomes imperative to evaluate the costs and benefits of as many realistic project combinations and alternatives as possible. The sum of all possible project combinations is, however, an extremely high number, equal to 2^n, where n is the number of projects. Thus, there are in theory more than 1000 possible project combinations for 10 projects, more than 1,000,000 for 20 projects, and more than 1,000,000,000 for 30 projects. Obviously, only the more promising alternatives will be evaluated.

The project tree and time-saving evaluation steps described in the preceding section will provide data for any desired network alternative (project combination). They can be used to determine the total time spent in the system to satisfy given travel demands, or the time savings or losses when compared to some other alternative, or to the base network. This is done by multiplying interzonal traffic flows and travel times or time savings, and summing the resulting values. The benefit/cost evaluation process described here is suitable for a gross evaluation of hundreds of alternatives.

The cost (in dollars) of a network alternative is the sum of the costs of all new projects in the given alternative, such as construction costs, operating and maintenance costs, dislocation costs, etc., adjusted to a common scale suitable for purposes of comparison. The adjustment should utilize discounting and different interest rates, to take into account the fact that projects will be built at different times in the future under different financing schemes. Additional factors that can be evaluated in dollars, such as revenue (bridge tolls, transit operation profits) or accident costs, can easily be included. As can be seen, some costs could be negative (i.e., revenue), but in general a total project cost will be positive (outlay).

Benefits will be measured in time units, the major benefit being the cumulative time saving in man-hours for satisfying given travel demands due to a project or project combination. The use of a time/cost space for a comparison of benefits and costs of alternatives has several advantages. In the first approach evaluation of a large number of alternatives, the human mind can relatively easily operate with two values, and in urban transportation those of cost and time are probably the most meaningful ones. It is difficult to combine the various cost elements, but the combination of cost and time values on the basis of a time/cost factor is still more difficult. In the contemplated evaluation process the two basic measures of time and cost are therefore left separate until the final analysis. For comparing a limited number of alternatives, the ingredients that went into the study of the "cost" (such as construction, operating costs) and time saving (e.g., travel, terminal time) of several alternatives can, of course, be called for and viewed in detail.

The benefit/cost evaluation process can best be shown on a small example. Assume that all combination possibilities of four projects, A, B, C, and D, have been evaluated and their benefit in time savings and costs, as shown in the accompanying Table 1, have been plotted in Figure 1.

The costs of the individual projects are A:30, B:10, C:20, D:20 units. The maximal benefit is obtained by building all four projects, which also entails the largest investment costs. The sequence in which the projects should be constructed so as to maximize benefits at any stage of completion is indicated (Fig. 1) by the line 1-10-11-13-9 for the project sequence B, C, D, A. If, for instance, only thirty units of investment were available, then project combination 11 (projects B, C) should be chosen. In the case that, due to aesthetic, political or other considerations, project combination 12 (B, D) is selected instead, the implication would be that these "intangible" considerations have at least a value of 10 units of benefit.

It must be emphasized that the evaluation procedure suggested here is only to be used for a rapid determination of the network alternatives which should be investigated in greater detail, not as a tool for reaching any final decision as to an "optimal" alternative. Nevertheless, the benefit/cost values for network alternatives can conveniently be utilized for a more detailed analysis which, despite the fact that the data are gross, might be helpful in eliminating the less promising alternatives. For instance, the marginal effect of adding a particular project to, or removing it from, some project combination can easily be determined from the graph (Fig. 1). Another value which can easily

TABLE 1

BENEFITS AND COSTS OF ALL COMBINATIONS OF FOUR-PROJECT EXAMPLE

Seq. No.	Projects	Benefit	Cost
1	0	0	0
2	A	40	30
3	A, B	50	40
4	A, C	50	50
5	A, D	70	50
6	A, B, C	80	60
7	A, B, D	80	60
8	A, C, D	70	70
9	A, B, C, D	100	80
10	B	10	10
11	B, C	60	30
12	B, D	50	30
13	B, C, D	90	50
14	C	20	20
15	C, D	50	40
16	D	30	20

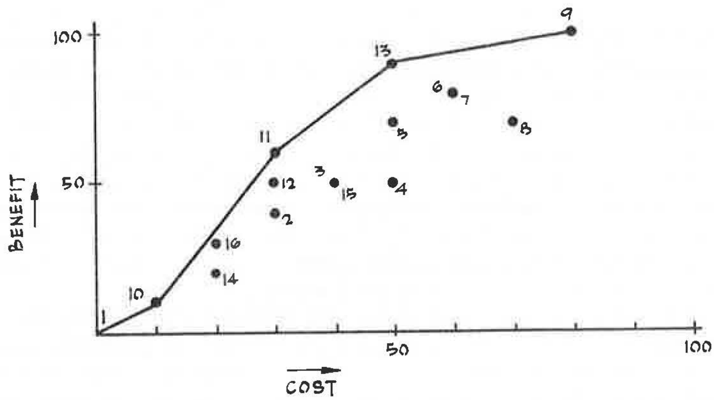

Figure 1. Benefits and costs of project combinations identified by sequence number (see Table 1).

be found is the maximum benefit cost ratio r_{max} which is the point of tangency to a line leading through the origin (0 benefit, 0 investment cost). This is shown in Figure 2 for the same example. The alternative with the highest benefit/cost ratio for any particular value of time r is the one farthest from the r line (Fig. 2).

It is difficult to evaluate all combinations of a larger number of projects. The following procedure is therefore recommended. Determine a priori some project combinations which should be evaluated, rank the results in the benefit/cost space, and then possibly decide on other combinations which should also be evaluated. It is, of course, always possible that some "optimal" combinations might be missed. This problem has been considered by Kuhn (2) and Ridley (3), with particular regard to transportation, and by Weingartner (6) as a general capital budgeting problem. The author has described a matrix method (5) which, on the basis of some simplifying assumptions, can evaluate all combinations of a larger number of projects. Since the procedure suggested in this report is only used for the secondary task of evaluating network alternatives, but not for the primary task of determining in some exact manner alternatives that should be evaluated, these methods will not be discussed in detail.

THE NETWORK EVALUATOR PROGRAM

The procedures described in the preceding sections were incorporated into three basic computer routines supervised by a monitor program. The functions of the three routines are:

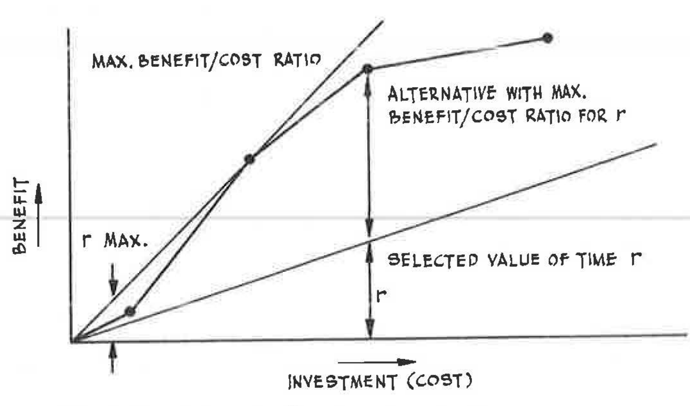

Figure 2. Values on the project evaluation curve.

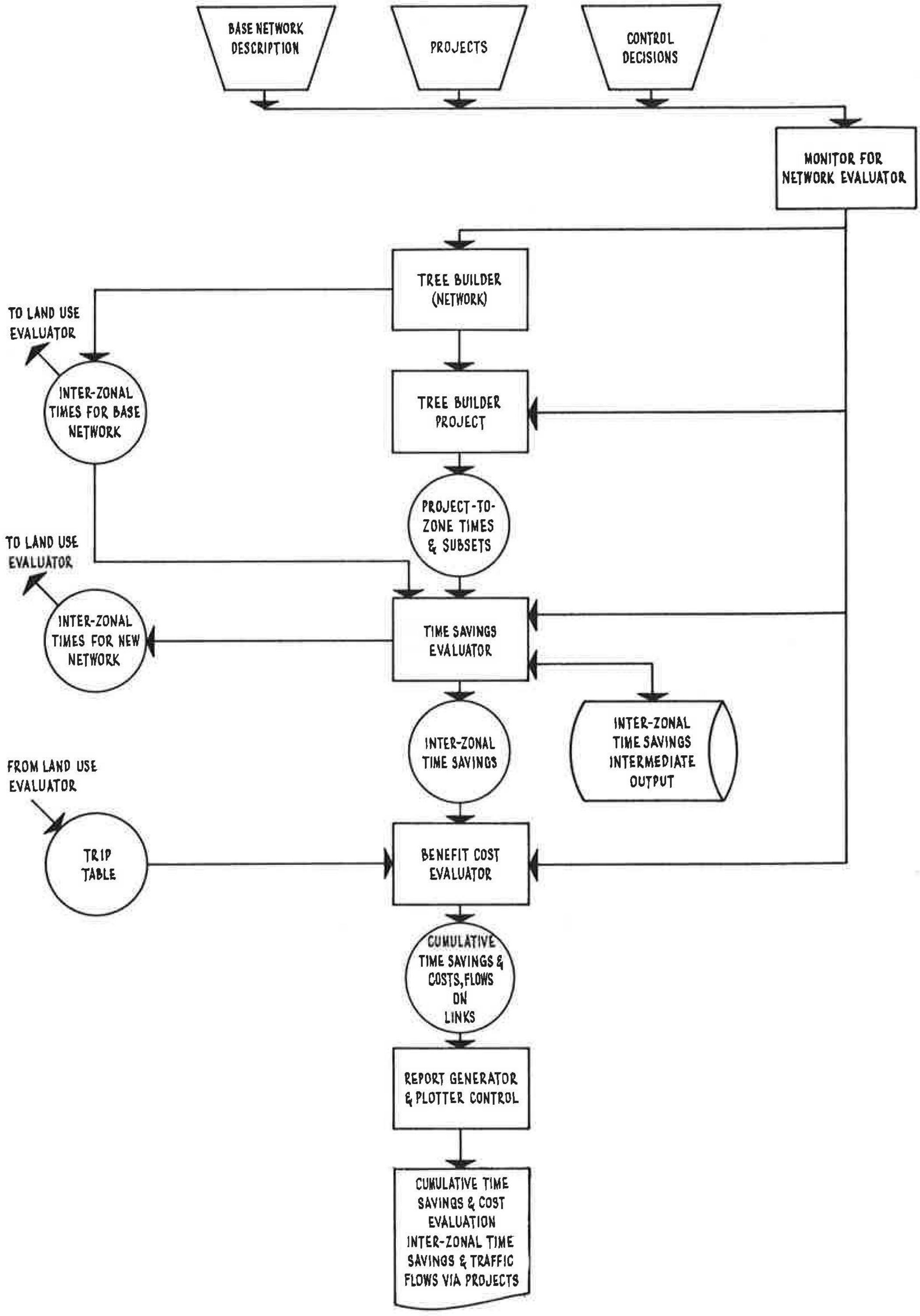

Figure 3. Network evaluator.

1. Tree Builder—To build minimum paths for all zones of the base network (network tree builder) and for all projects of a network alternative (project tree builder) as specified by the monitor;
2. Time-Saving Evaluator—To determine time savings between all pairs of affected zones for each network alternative; and
3. Benefit/Cost Evaluator—To determine the cumulative time savings and costs of each network alternative and the flows on project links (directly) and/or network links by means of the loading and unloading subroutine.

The monitor controls the interaction of the programs and the sequence in which the network alternatives and projects within an alternative are processed.

The network evaluator interacts with a land use evaluator by providing it with the interzonal travel times required for accessibility calculations. In turn, the land use evaluator and related traffic generation, distribution, and modal split programs are used to obtain one or more trip tables for the network evaluator. The operation of the network evaluator is independent of the other programs and they could be replaced by any other procedure which would provide a trip table.

The flow chart (Fig. 3) relates the routines and indicates the source data and output. The report generator programs are used for formatting the output and printing it.

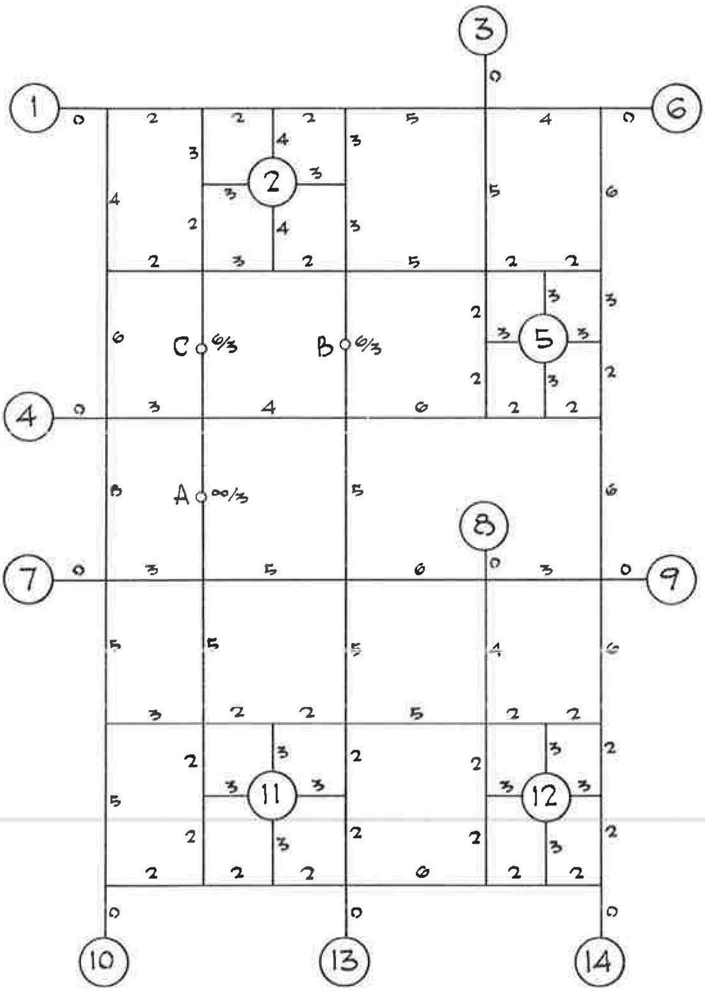

Figure 4. Project selection—test network.

EXAMPLE

The first version of the network evaluator program has been tested on a small 14-zone example (Fig. 4) with all combinations of three single-link projects evaluated. The values on the links are travel times. The three projects (A, B, C) have two values—a before-completion travel time and an after-completion travel time. As can be seen, projects B and C are improvements of existing links, while project A is a completely new link. The project tree for project A is shown in Figure 5. The nodes can be separated into two groups (subset 1 and subset 2), depending on the project node from which they were reached. The subset numbers on the printout indicate not only the project end from which a centroid was reached (last digit), but also whether some other project lies on the branch. The network is symmetrical, and a symmetrical trip table was assumed. Only the flows on the project links were determined. A cost of 20, 8, and 6 units was assumed for, respectively, the projects A, B, and C, and the resulting benefit/cost values were plotted.

The following flows were determined on the project links:

Alternative A: Flow on project A = 450
Alternative B: Flow on project B = 370

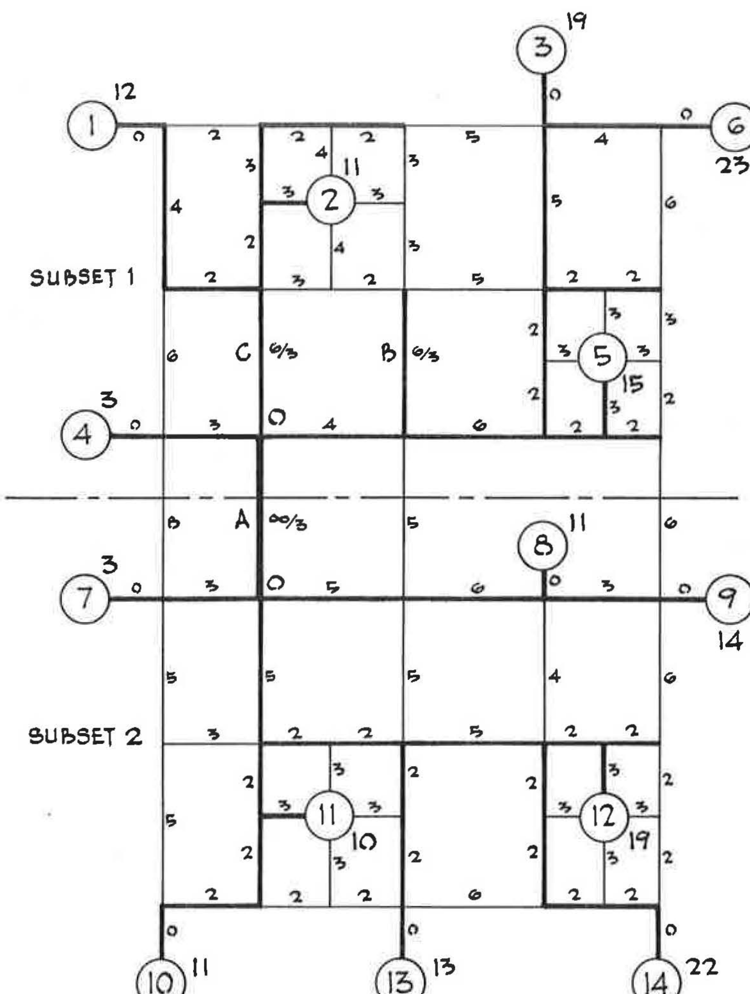

Figure 5. Minimum path tree for project A.

Alternative C:	Flow on project C = 210
Alternative AB:	Flow on project A = 390
	Flow on project B = 330
Alternative AC:	Flow on project A = 530
	Flow on project C = 390
Alternative BC:	Flow on project B = 260
	Flow on project C = 170
Alternative ABC:	Flow on project A = 470
	Flow on project B = 220
	Flow on project C = 270

CONCLUSIONS

The application of the network evaluator to gross planning, providing "relative" rather than "absolute" evaluations, has been emphasized in this report. The recent development of computer time-sharing and of display methods by means of cathode-ray tubes is leading toward a new type of man-machine interaction. The efficiency of the suggested procedure, or any similar approach, when dealing with the effects of slight changes to a network makes it possible for a transportation planner, sitting at a suitably designed console, to become familiar with an area by testing out various alternatives and directly obtaining at least a gross estimation of the effect of any decision. More detailed information could be called for whenever desired. The overall computer time requirements can remain within reasonable bounds, and yet the planner could reject obviously wrong alternatives within a few seconds and concentrate on the promising ones, call for increasingly detailed outputs, and study the effect of additional small variations of plans. Much remains to be done, yet both the computer hardware and the software capabilities are available, and the way toward this type of transportation planning is clearly open.

It remains to mention briefly the possible applications of the suggested procedure toward a more detailed evaluation of networks. The manner in which the speed on a project link can be varied to reflect expected traffic conditions has already been mentioned. Actually, it is possible to use the capability of the network evaluator to separate the travel times on "project" or "critical" links from those on the remaining links to form the basis of efficient capacity restraint and traffic diversion procedures. By assuming specific capacity restraint characteristics for the critical (bottleneck) links of a network, it becomes possible to assign traffic to these competing or cooperating links so as to balance flows in order to minimize individual or total travel times in accordance with Wardrop's two principles. In other applications, it would be possible to test the effect of differential tolls; determine how flows are affected if different tolls are placed on parallel facilities and a particular distribution is assumed for the value trip-takers place on time; study the effects of various emergency situations, such as stalled vehicles on a bottleneck link; and test different strategies which would cope with these situations. Analytical and graphical procedures utilizing the network evaluator routines for treating the above problems have been devised and are described elsewhere (7).

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