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Development of a Computerized Technique to Identify Effective Forest Roadway Networks

DAVID C. SHUNK AND ROBERT D. LAYTON

Forest transportation planning is a complex task that involves many decisions. This paper presents an algorithm and computer program that will assist in effective transportation planning and decisionmaking in the national forests. This identification of an efficient arterial, collector, and local roadway network is a primary component in the transportation planning process. An earlier study by Kehr and Layton identified the primary factors and important decision criteria used to evaluate forest arterial and collector networks. This study employs these decision criteria in the development of a computerized comprehensive analytical framework, PLANET1 and PLANET2, to identify and evaluate forest arterial and collector networks. Two main computerized network algorithms have been used in transportation network evaluation: the shortest path algorithm and the minimum spanning tree algorithm. The shortest path algorithm provides the most direct route to each point, without direct consideration of construction costs. The minimum spanning tree algorithm emphasizes the least-cost connective network and ignores the travel times and operating costs. The computerized technique presented in this report combines the advantages of the shortest path algorithm with those of the minimum spanning tree algorithm to determine a more efficient roadway network than is provided by either approach used individually. Examples of the use of these new algorithms, PLANET1 and PLANET2, are presented and discussed.

As defined by the Forest Service Manual, the objective of transportation planning is (1) "to ensure that plans for the development and operation of the forest development transportation system are made, and that they are consistent with land-use planning policies and procedures, and will effectively achieve resource management objectives".

The identification of an efficient arterial, collector, and local roadway network is a primary component of the transportation planning process. A previous study by Kehr and Layton (2) identified the primary factors and important decision criteria used to evaluate forest arterial and collector networks. The study employs these decision criteria in the developing of a comprehensive analytical framework to identify and evaluate forest arterial and collector networks. The method developed in the report by Kehr and Layton, however, is a manual method that takes a great deal of time to use.

Two computerized network algorithms used extensively in forest transportation network analysis and evaluation are the shortest path algorithm and the minimum spanning tree algorithm. The shortest path algorithm provides the most direct route to each point, measured by time, distance, or cost, usually operating cost. The minimum spanning tree algorithm provides the least-cost connective network, which is usually measured by the length of links or link costs, typically construction and maintenance costs.

The method developed by Kehr and Layton (2) recommends the use of a method that employs both the shortest path and the minimum spanning tree algorithms. However, no computerized technique is presented in that study. A primary analysis technique for national forest planning is the timber transport model (TIMBRI), a computerized method to find the least-cost timber haul routes (3). This technique relies heavily on the shortest path algorithm together with a mixed integer linear programming routine. However, that technique focuses on identifying the most efficient network for timber haul alone. The PLANET1 and PLANET2 algorithms combine the advantages of a shortest path analysis, which minimizes time or operating cost, and the minimum spanning tree analysis, which minimizes construction costs and, if desired, maintenance costs, to determine an efficient roadway network.

SCOPE

This paper presents a computerized method to identify effective forest roadway networks. The decision criteria used to evaluate forest road networks are divided into four major groups: physical, analytical, quantitative, and qualitative. The important decision criteria in each group are given below in rank order.

1. Physical criteria--connection to regional mills and markets, connectivity with surrounding road networks, types of vehicles and users present, extent of access to forest area, interface conflicts and delays, and access to adjacent lands;
2. Analytical criteria--total cost for timber haul, timber traffic volume, recreational traffic volume, least-cost connective network, construction cost, operating cost, maintenance cost, safety cost, level of service, and capacity;
3. Quantitative criteria--size of area served, speed of travel, and road design standards; and
4. Qualitative criteria--compatibility with environment, comfort and convenience, and safety.

The computerized methods described in this report incorporate some of the physical, analytical, and quantitative decision criteria, but not the qualitative decision criteria. The specific criteria taken into account, either directly or indirectly, by these methods are as follows:

1. Speed of travel,
2. Least-cost connective network,
3. Operating cost,
4. Maintenance cost,
5. Construction cost,
6. Safety cost,
7. Timber traffic volume,
8. Recreational traffic volume, and
9. Road design standards.

Forest transportation planning is a complex task that involves many decisions. The PLANET1 and PLANET2 programs assist the decisionmaker in making effective transportation planning decisions. This report presents PLANET1 algorithm and its development and briefly addresses the capabilities of PLANET2.

MODEL DEVELOPMENT

The goal of PLANET1 is to provide a computerized technique to find a roadway network that combines the advantages of the shortest path tree (more direct routes) and the minimum spanning tree (lower construction costs).

The shortest path algorithm can be formulated as a linear programming problem as follows:

$$\text{Minimize } Z' = \sum_{I=1}^{\substack{\text{Number of}\\ \text{centroids}}} \text{Centroid I travel time} \tag{1}$$

Such that,

Flow into each node = flow out of the node,
Flow at centroids = 1, and
Flow out at origin = - number of centroids.

where centroids are nodes that have some traffic-generating activity present, referred to as activity nodes in this paper.

This can be written for the network in Figure 1 as

$$\text{Minimize } Z' = 6\phi_{12} + 4\phi_{13} + 6\phi_{21} + 1\phi_{23} + 5\phi_{24} + 4\phi_{31} + 1\phi_{32} + 7\phi_{34} + 5\phi_{42} + 7\phi_{43}$$

Such that,

$$\begin{aligned}
&Y_1 + \phi_{21} + \phi_{31} = \phi_{12} + \phi_{13}\\
&Y_2 + \phi_{12} + \phi_{32} + \phi_{42} = \phi_{21} + \phi_{23} + \phi_{24}\\
&Y_3 + \phi_{13} + \phi_{23} + \phi_{43} = \phi_{31} + \phi_{32} + \phi_{34}\\
&Y_4 + \phi_{24} + \phi_{34} = \phi_{42} + \phi_{43}\\
&Y_1 = -3\\
&Y_3 = 1\\
&Y_4 = 1
\end{aligned}$$

where

All $\phi \geq 0$,
ϕ_{xy} = flow from x to y, and
Y_I = flow added at node x.

The minimum spanning tree algorithm can be formulated as a zero-one mixed integer problem as follows,

$$\text{Minimize } Z'' = \sum_{I=1}^{\substack{\text{Number of}\\ \text{Links}}} \begin{bmatrix} Z_I = 1 \text{ if link}\\ \text{is used}\\ Z_I = 0 \text{ if not} \end{bmatrix} \begin{bmatrix} \text{Link I}\\ \text{cost} \end{bmatrix} \tag{2}$$

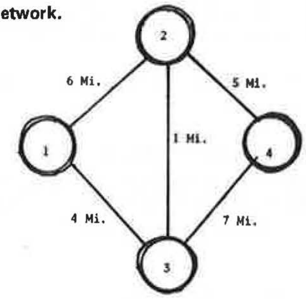


Figure 1. Example network.

Such that,

Flow into each node = flow out of the node,
Flow in at centroid = 1,
Flow out at origin = - number of centroids, and
Flow $x \rightarrow y$ + flow $x \leftarrow y$ $\leq$ (a large number) Z_I.

This can be written for the problem in Figure 1 as

$$\text{Minimize } Z'' = 6Z_1 + 4Z_2 + 1Z_3 + 5Z_4 + 7Z_5$$

Such that,

$$\begin{aligned}
&Y_1 + \phi_{21} + \phi_{31} = \phi_{12} + \phi_{13}\\
&Y_2 + \phi_{12} + \phi_{32} + \phi_{42} = \phi_{21} + \phi_{23} + \phi_{24}\\
&Y_3 + \phi_{13} + \phi_{23} + \phi_{43} = \phi_{31} + \phi_{32} + \phi_{34}\\
&Y_4 + \phi_{24} + \phi_{34} = \phi_{42} + \phi_{43}\\
&Y_1 = -3\\
&Y_2 = 1\\
&Y_3 = 1\\
&Y_4 = 1\\
&\phi_{12} + \phi_{21} \leq MZ_1\\
&\phi_{13} + \phi_{31} \leq MZ_2\\
&\phi_{23} + \phi_{32} \leq MZ_3\\
&\phi_{24} + \phi_{42} \leq MZ_4\\
&\phi_{34} + \phi_{43} \leq MZ_5
\end{aligned}$$

where

All $\phi_{xy} \geq 0$,
All Z_I = 0 or 1,
ϕ_{xy} = flow from x to y,
Y_x = flow added at node x, and
M = extremely large number.

The shortest path algorithm and the minimum spanning tree algorithm, as illustrated above, can be combined by using a trade-off factor. In both cases the mileage between the nodes is considered to be proportional to the travel cost for the shortest path algorithm and the construction cost for the minimum spanning tree. Since the mileage is used to represent both the travel and construction costs, it is necessary to add a trade-off factor, which is a ratio of the construction cost to the travel cost, when comparing the two. The trade-off factor assumes a uniform demand at each centroid and can be written as

$$\text{Trade-off factor} = [\text{Construction cost (\$/mile)}] / [\text{Uniform demand (vehicle)} \times \text{travel cost (\$/vehicle mile)}] \tag{3}$$

The ideal PLANET1 objective function can be formulated as a zero-one mixed-integer program as follows:

$$\text{Minimize: } Z''' = Z' + \text{trade-off factor } (Z'') \tag{4}$$

Such that,

Flow into each node = flow out of the node,
Flow in at centroids = 1,

Flow in at the origin = - number of centroids, and
Flow x→y + flow x←y $\leq$ (a large number) Z_I.

This can be written for the network in Figure 1 as,

$$\text{Minimize } Z''' = (6\phi_{12} + 4\phi_{13} + 6\phi_{21} + 1\phi_{23} + 5\phi_{24} + 4\phi_{31} + 1\phi_{32} + 7\phi_{34} + 5\phi_{42} + 7\phi_{43}) + \text{trade-off factor } (6Z_1 + 4Z_2 + 1Z_3 + 5Z_4 + 7Z_5)$$

Such that,

$$Y_1 + \phi_{21} + \phi_{31} = \phi_{12} + \phi_{13}$$
$$Y_2 + \phi_{12} + \phi_{32} + \phi_{42} = \phi_{21} + \phi_{23} + \phi_{24}$$
$$Y_3 + \phi_{13} + \phi_{23} + \phi_{43} = \phi_{31} + \phi_{32} + \phi_{34}$$
$$Y_4 + \phi_{24} + \phi_{34} = \phi_{42} + \phi_{43}$$
$$Y_1 = -3$$
$$Y_2 = 1$$
$$Y_3 = 1$$
$$Y_4 = 1$$
$$\phi_{12} + \phi_{21} \leq MZ_1$$
$$\phi_{13} + \phi_{31} \leq MZ_2$$
$$\phi_{23} + \phi_{32} \leq MZ_3$$
$$\phi_{24} + \phi_{42} \leq MZ_4$$
$$\phi_{34} + \phi_{43} \leq MZ_5$$

where

All $\phi_{xy} \geq 0$,
All Z_I = 0 or 1,
ϕ_{xy} = flow from x to y,
Y_x = flow added at node x, and
M = extremely large number.

This problem can be solved by using an integer programming technique. However, for large networks this would require excessive computational time to reach the optimum solution. The PLANET1 assumptions allow it to find a good solution, not necessarily the optimum, in a very short time.

The PLANET1 algorithm starts with the shortest path tree for the network. A tree, as used here, is a connected graph that contains no loops. It analyzes every unused link to determine if it should be added to the tree. This will be referred to as the candidate link. If the candidate link is added, one of the links already in the tree must be removed. The two decision criteria used are the savings in travel cost to the centroids (DTIME) created by using the link to be added and the increase in construction cost (DCOST) created by using the candidate link instead of another link. The unused link is added to the tree if

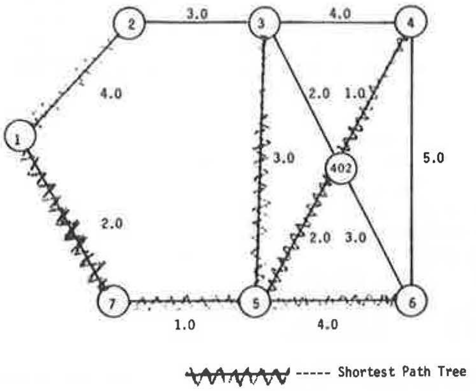
$$\text{DTIME} > \text{Trade-off factor} \times \text{DCOST} \tag{5}$$

Otherwise, it is not added and the next unused link is analyzed. As pairs of links are added and removed, PLANET1 moves closer to the optimum solution. Through this process the PLANET1 algorithm attempts to imitate the process that occurs in an integer programming approach. The PLANET1 algorithm does not guarantee the optimum solution, but it gives a good solution in a very short computation time and comes much closer to the optimum network than does the shortest path algorithm or the minimum spanning tree algorithm.

PLANET1 Algorithm

An algorithm is defined as a systematic set of mathematical steps for solving a problem. The PLANET1 algorithm combines the advantages of the shortest path tree and the minimum spanning tree in determining the most efficient network possible. The steps in the PLANET1 algorithm are as follows:

Figure 2. Example network for PLANET1.



Step 1. Find the shortest path tree from the primary activity centers by using the shortest path algorithm.

Step 2. Consider adding each link in the link file, in turn. This link will be referred to as the candidate link. Start with the first link.

Step 3. If the candidate link is already part of the tree, go to step 10.

Step 4. Consider removing the next link down the tree. Start with the predecessor link of the origin node of the candidate link. For example, in Figure 2 if link 3-2 were the candidate link, link 3-5 would be considered for removal, then link 5-7, etc.

Step 5. If removing this link creates a disconnected graph, go to step 10. A disconnected graph, as used here, is a network where all desired nodes cannot be reached from the origin node.

Step 6. Calculate the increase in link cost (DCOST) created by using the candidate link instead of the link being removed.

Step 7. Calculate the savings in travel times (DTIME) to the centroids created by using the candidate link instead of the link being removed.

Step 8. If Equation 5 is true, add the candidate link to the tree, remove the old link, and go back to step 2. Otherwise go on to step 9.

Step 9. If the destination node of the link to be removed is not the origin, go back to step 4. If it is the origin, go on to step 10.

Step 10. If the candidate link is not the last link in the link file, go back to step 2. If it is the last link, go on to step 11.

Step 11. If no changes have been made on this pass through the link file, terminate the algorithm. Otherwise, go back to step 2 and start through the link file again.

Example Illustrating the PLANET1 Algorithm

The following is an example that illustrates the use of the PLANET1 algorithm. Table 1 gives the steps involved in PLANET1 for the example network. Figure 3 shows the network and the shortest path tree, and Table 2 gives the initial link file to be used in this example. Figures 4 and 5 and Tables 3 and 4 show the steps in the algorithm in the first iteration as links are added and deleted in the network.

The KOUNT array used in this example indicates if a link is in the tree (KOUNT = 1) or not (KOUNT = 0). The column labeled TRADE? indicates whether the candidate link is traded for the link being considered for removal (LINK OUT). Notice that the trade-off factor is equal to 2.0. The number next to the link arrows in Figures 3-8 indicates the number of the link in that direction. The two numbers

Table 1. PLANET1 graphical example, iterations 1 and 2.

Candidate Link	Link Out	DTIME	Factor	DCOST	Trade	Remarks
Iteration 1						
4	3	-5.0	2.0	-1.0	No	Use Figure 3, Table 2
5	7	-1.0	2.0	0.0	No	Use Figure 3, Table 2
5	14	-22.0	2.0	2.0	No	Use Figure 3, Table 2
5	19	-22.0	2.0	1.0	No	Use Figure 3, Table 2
6	7	-4.0	2.0	1.0	No	Use Figure 3, Table 2
8	7	-1.0	2.0	-1.0	Yes	Use Figure 4, Table 3
9	11	-5.0	2.0	3.0	No	Use Figure 4, Table 3
10	11	-6.0	2.0	4.0	No	Use Figure 4, Table 3
10	23	-14.0	2.0	3.0	No	Use Figure 4, Table 3
12	-		No possible removals			
16	17	-4.0	2.0	1.0	No	Use Figure 4, Table 3
18	17	-1.0	2.0	-1.0	Yes	Use Figure 5, Table 4
Iteration 2						
4	3	-6.0	2.0	-1.0	No	Use Figure 5, Table 4
5	8	0.0	2.0	1.0	No	Use Figure 5, Table 4
5	23	-8.0	2.0	1.0	No	Use Figure 5, Table 4
5	14	-16.0	2.0	2.0	No	Use Figure 5, Table 4
5	19	-16.0	2.0	1.0	No	Use Figure 5, Table 4
6	8	-3.0	2.0	2.0	No	Use Figure 5, Table 4
7	8	1.0	2.0	1.0	No	Use Figure 5, Table 4
7	23	-5.0	2.0	1.0	No	Use Figure 5, Table 4
9	11	-5.0	2.0	3.0	No	Use Figure 5, Table 4
10	11	-7.0	2.0	4.0	No	Use Figure 5, Table 4
12	-		No possible removals			
13	-		No possible removals			
16	18	-3.0	2.0	2.0	No	Use Figure 5, Table 4
17	18	1.0	2.0	1.0	No	Use Figure 5, Table 4
17	23	-9.0	2.0	2.0	No	Use Figure 5, Table 4

Note: Since no changes were made in iteration 2, the network in Figure 11 and Table 5 is the solution.

Figure 3. Initial network for PLANET1 graphical example.

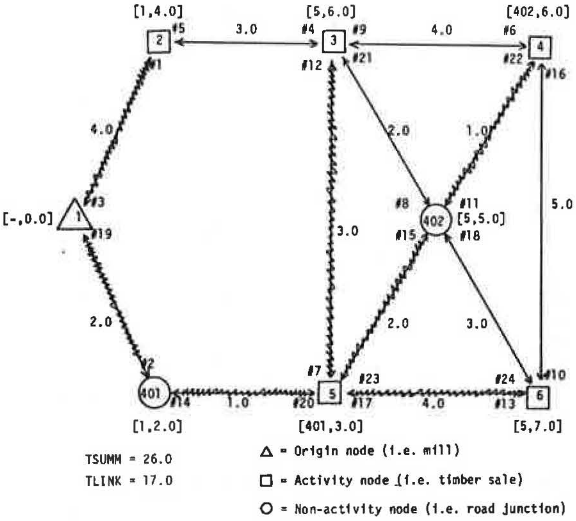


Table 2. Initial link file for PLANET1 graphical example.

Link No. (X)	Origin Node [NODE(X,1)]	Destination Node [NODE(X,2)]	Link Criteria [CRIT(X,1)]	KOUNT (X)
1	1	2	4.0	1
2	1	401	2.0	1
3	2	1	4.0	1
4	2	3	3.0	0
5	3	2	3.0	0
6	3	4	4.0	0
7	3	5	3.0	1
8	3	402	2.0	0
9	4	3	4.0	0
10	4	6	5.0	0
11	4	402	1.0	1
12	5	3	3.0	1
13	5	6	4.0	1
14	5	401	1.0	1
15	5	402	2.0	1
16	6	4	5.0	0
17	6	5	4.0	1
18	6	402	3.0	0
19	401	1	2.0	1
20	401	5	1.0	1
21	402	3	2.0	0
22	402	4	1.0	1
23	402	5	2.0	1
24	402	6	3.0	0

in brackets next to each node are the predecessor node number and the travel time from that node to the origin, [predecessor node number, travel time].

Figures 5-8, then, show the results for this network from PLANET1, BUILDER, MINTREE, and MINSPAN, respectively. BUILDER builds shortest path trees; MINTREE builds a network that contains the least-cost connective network from the origin activity node to all activity nodes; MINSPAN builds the least-cost connective network from the origin activity node to all nodes. The range for TSUMM, the sum of the link criteria from the origin to each activity node, is from 26.0 (BUILDER) to 34.0 (MINSPAN). Notice that TSUMM for PLANET1 (= 28.0) is close to the minimum. The range for TLINK, the total link criteria for the link in the tree, is from 14.0 (MINSPAN) to 17.0 (BUILDER). Notice that TLINK for PLANET1 (= 15.0) is close to the minimum.

MODEL APPLICATION

Figure 9 shows an example forest network. The lines that connect the three node ones (i.e.; 1, 1', and 1") represent the main arterial roadway. PLANET1 is used to find the best roadway network to connect the forest activities with the main arterial. All nodes on the arterial are indexed as node 1. Note that the network is not drawn to scale.

Figures 10, 11, and 12 show the results obtained from the shortest path tree algorithm (program BUILDER), the minimum spanning tree algorithm (program MINSPAN), and the minimum spanning tree algorithm (program MINTREE), respectively. MINTREE builds the minimum spanning tree from activity node to activity node without concern for nodes that rep-

Figure 4. PLANET1 graphical example: entering links 8 and 21.

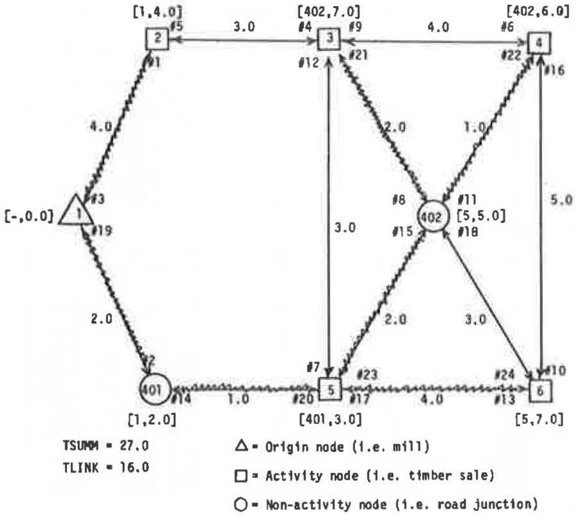


Figure 5. PLANET1 graphical example: entering links 18 and 24.

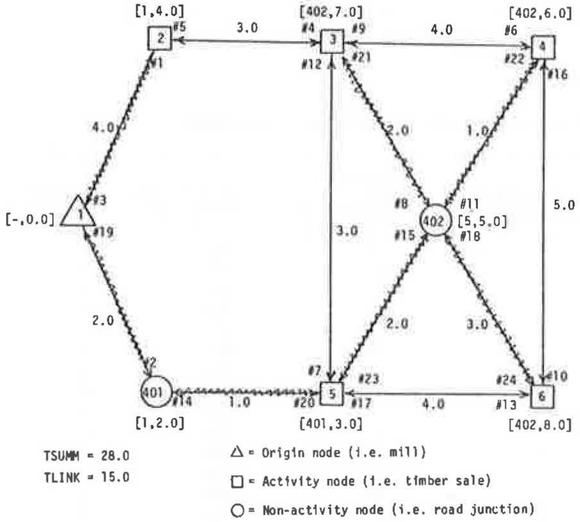


Table 3. Link file for PLANET1 graphical example: entering links 8 and 21 (shown as Figure 4).

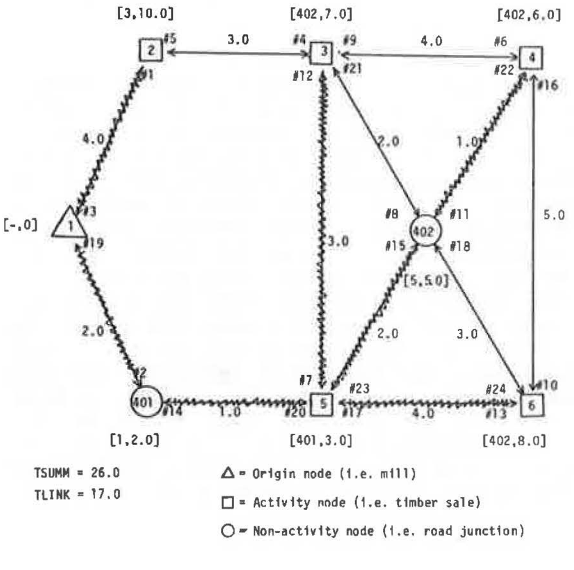
Link No. (X)	Origin Node [NODE(X,1)]	Destination Node [NODE(X,2)]	Link Criteria [CRIT(X,1)]	KOUNT (X)
1	1	2	4.0	1
2	1	401	2.0	1
3	2	1	4.0	1
4	2	3	3.0	0
5	3	2	3.0	0
·6	3	4	4.0	0
7	3	5	3.0	0
8	3	402	2.0	1
9	4	3	4.0	0
10	4	6	5.0	0
11	4	402	1.0	1
12	5	3	3.0	0
13	5	6	4.0	1
14	5	401	1.0	1
15	5	402	2.0	1
16	6	4	5.0	0
17	6	5	4.0	1
18	6	402	3.0	0
19	401	1	2.0	1
20	401	5	1.0	1
21	402	3	2.0	1
22	402	4	1.0	1
23	402	5	2.0	1
24	402	6	3.0	0

resent network intersections and nodes where road class changes. Figure 13 shows the results obtained from PLANET1 with a trade-off factor of 5.0. The TSUMM variable is accumulated travel time from the origin to each of the activity nodes. This represents the total travel cost for the network. The variable TLINK is the sum of the link measure used in the network tree, this represents the total construction cost required to provide this network. Table 5 gives the results obtained from the four programs. The travel times to each activity node from node 1 are listed for the four programs. Table 6 indicates how the accumulated times to activity nodes (TSUMM) and accumulated link costs (TLINK) vary. As the trade-off factor varies from 0 to 9999 for PLANET1, the tree identified changes in character. With a trade-off factor of 0, the PLANET1 network is the shortest path tree. With a high trade-off factor, the PLANET1 network tends toward the minimum spanning tree.

Table 4. Link file for PLANET1 graphical example: entering links 18 and 24 (shown as Figure 5).

Link No. (X)	Origin Node [NODE(X,1)]	Destination Node [NODE(X, 2)]	Link Criteria [CRIT(X,1)]	KOUNT (X)
1	1	2	4.0	1
2	1	401	2.0	1
3	2	1	4.0	1
4	2	3	3.0	0
5	3	2	3.0	0
6	3	4	4.0	0
7	3	5	3.0	0
8	3	402	2.0	1
9	4	3	4.0	0
10	4	6	5.0	0
11	4	402	1.0	1
12	5	3	3.0	0
13	5	6	4.0	0
14	5	401	1.0	1
15	5	402	2.0	1
16	6	4	5.0	0
17	6	5	4.0	0
18	6	402	3.0	1
19	401	1	2.0	1
20	401	5	1.0	1
21	402	3	2.0	1
22	402	4	1.0	1
23	402	5	2.0	1
24	402	6	3.0	1

Figure 6. Shortest path tree (BUILDER) for example network.



PLANET1 can be used for roadway systems where information on the construction, maintenance, and operating costs is not available. Program PLANET2 is an extension of the concepts of PLANET1 and was developed to analyze roadway systems where the cost information is available. Some of the additional features of PLANET2 are as follows:

1. The actual construction, maintenance, and operating costs can be used.
2. Different road classes such as arterial, collector, and local are allowed.
3. The actual demands for the individual activities can be used.

Figure 14 shows an example network obtained from PLANET2. In Figure 8 circles are used to represent activities. The area of the circle reflects the relative magnitude of the activity level.

CONCLUSIONS

PLANET1 and PLANET2 systematically combine the advantages of the shortest path algorithm and the min-

Figure 7. Minimum spanning tree (MINTREE) for example network.

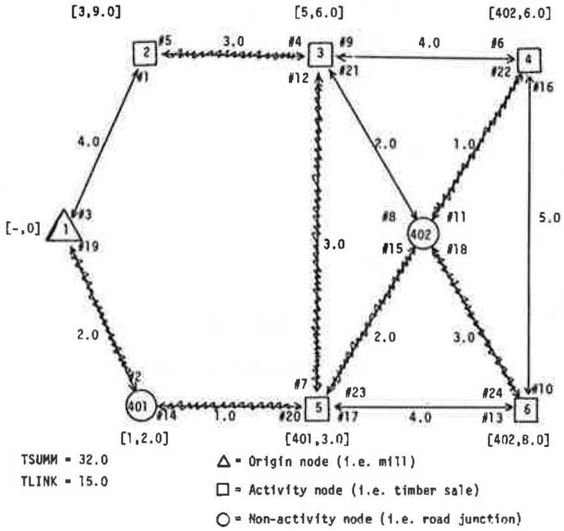


Figure 8. Minimum spanning tree (MINSPAN) for example network.

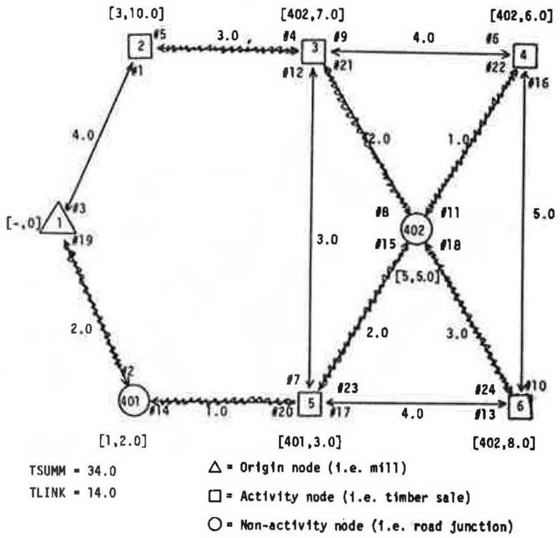


Figure 9. Network for sample forest.

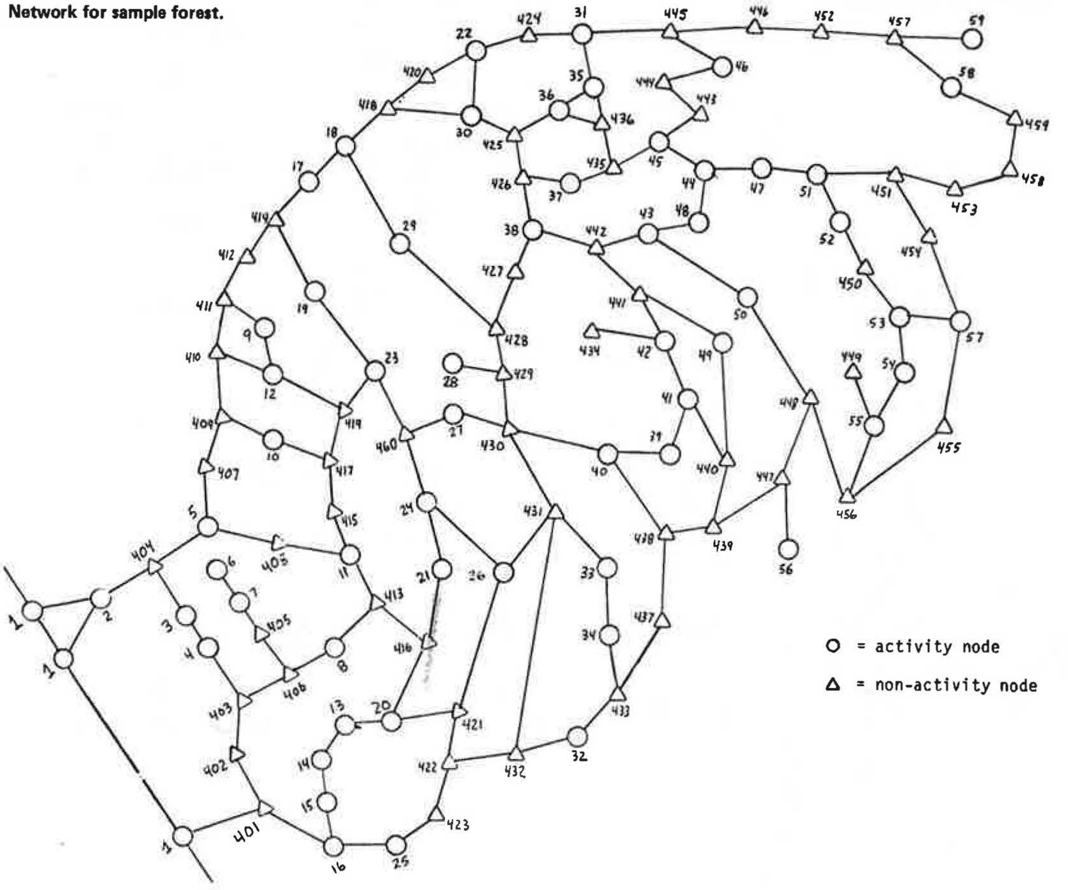


Figure 10. BUILDER results for sample forest network.

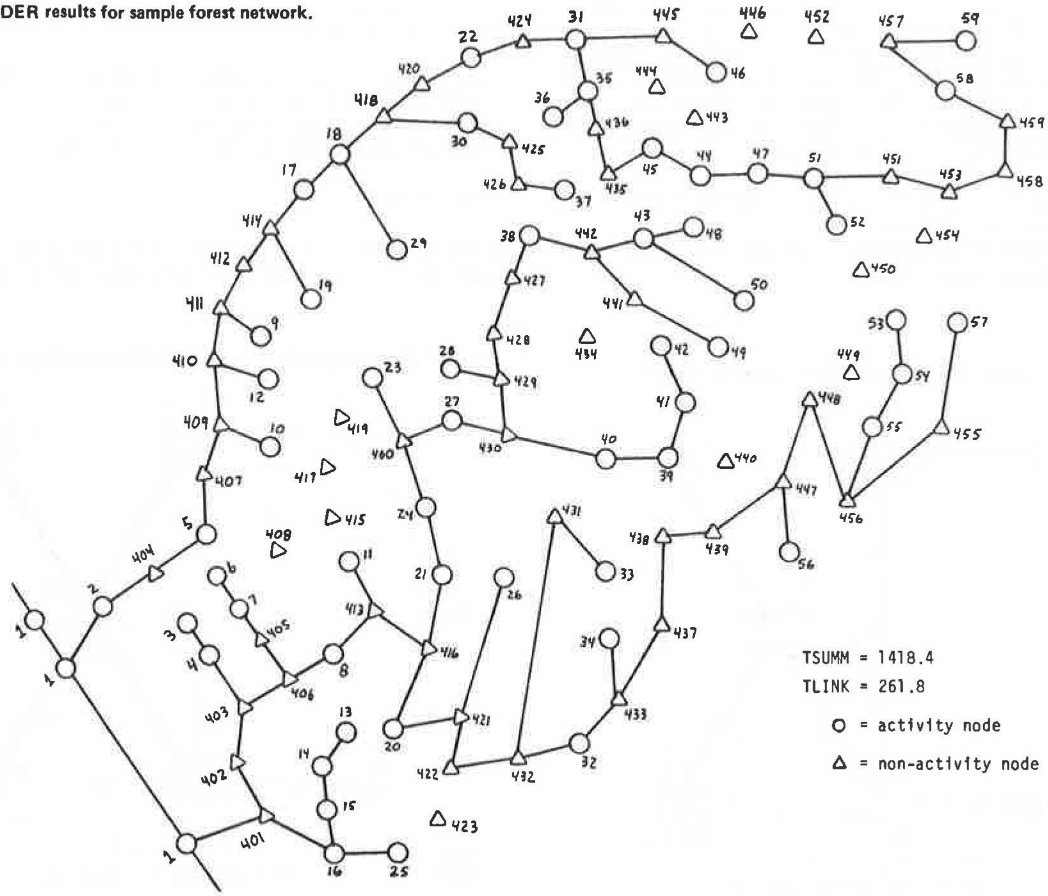


Figure 11. MINSPAN results for sample forest network.

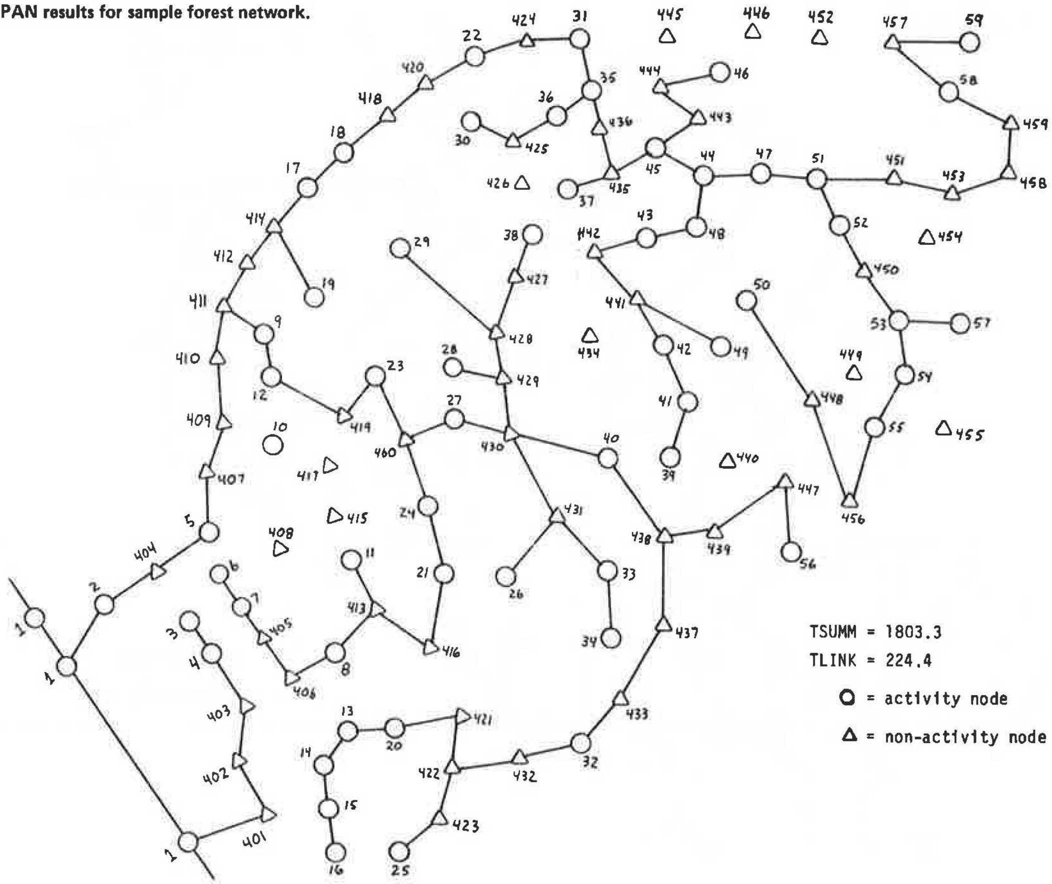


Figure 12. MINTREE results for sample forest network.

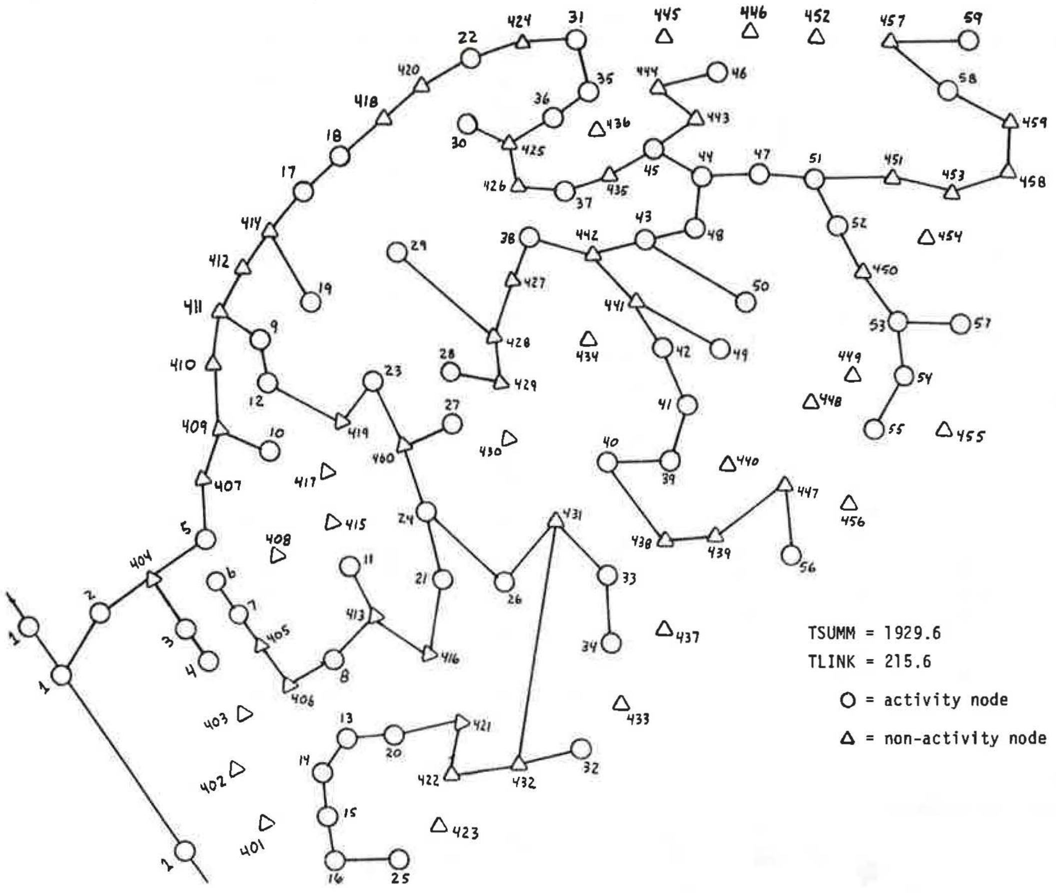


Figure 13. PLANET1 results for sample forest network.

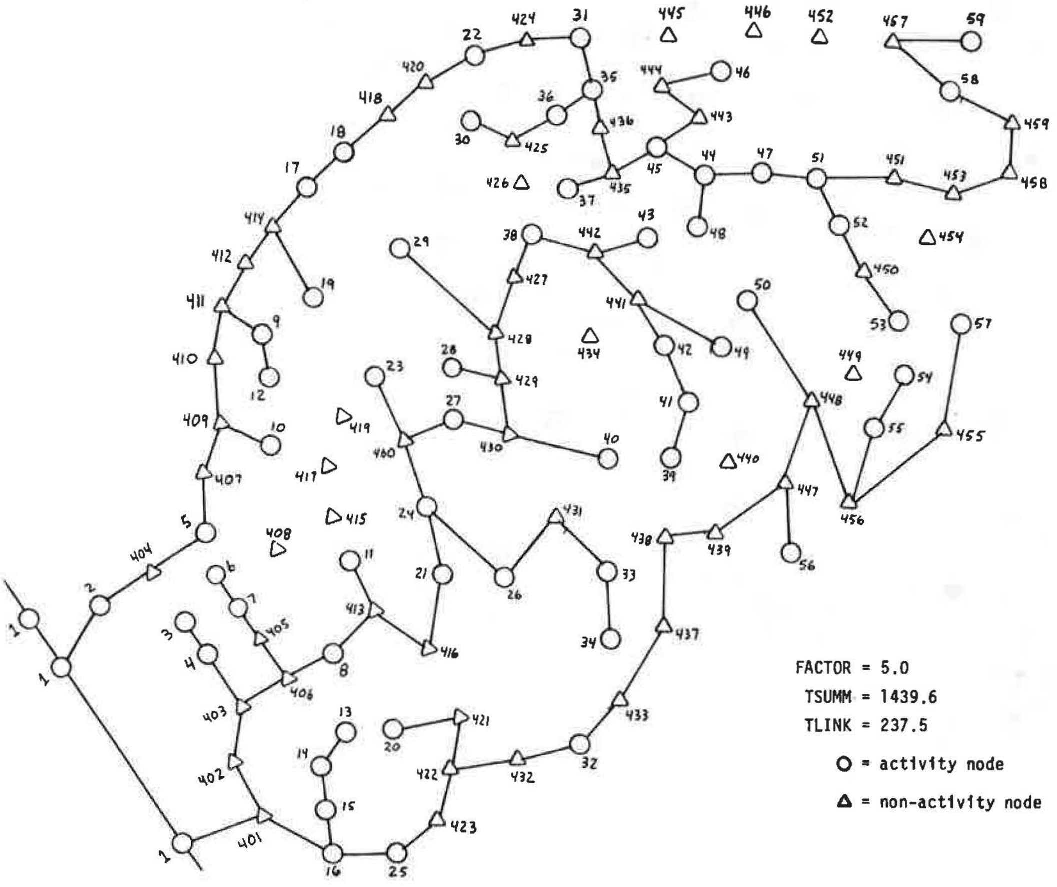


Table 5. Comparison of travel times with each activity node from node 1, highway arterial.

Node	MINSPAN	MINTREE	BUILDER	PLANET1
1	0.0	0.0	0.0	0.0
2	4.0	4.0	4.0	4.0
3	9.4	10.5	9.4	9.4
4	9.4	10.5	9.4	9.4
5	9.9	9.9	9.9	9.9
6	33.6	33.6	11.0	11.0
7	33.6	33.6	11.0	11.0
8	30.1	30.1	10.9	10.9
9	16.1	16.1	16.1	16.1
10	15.1	15.1	15.1	15.1
11	31.0	14.8	14.8	14.8
12	17.6	17.6	17.3	17.6
13	41.2	32.5	15.9	15.9
14	41.2	32.5	15.9	15.9
15	43.5	34.8	13.6	13.6
16	46.4	37.9	10.5	10.5
17	17.9	17.9	17.9	17.9
18	19.2	19.2	19.2	19.2
19	18.8	18.8	18.8	18.8
20	38.7	30.0	16.7	18.0
21	25.6	25.6	15.4	15.4
22	21.1	21.1	21.1	21.1
23	21.1	21.1	19.9	19.9
24	21.9	21.9	19.1	19.1
25	41.7	41.2	13.8	13.8
26	27.8	24.3	21.0	21.5
27	23.2	23.2	20.8	20.8
28	30.3	46.9	27.9	27.9
29	30.4	46.8	25.4	28.0
30	29.7	29.7	24.6	29.7
31	23.4	23.4	23.4	23.4
32	35.9	28.8	19.5	19.6
33	29.5	27.4	24.1	24.6
34	30.6	28.5	24.5	25.7
35	25.7	25.7	25.7	25.7
36	27.1	27.1	27.1	27.1
37	30.6	32.5	28.2	30.6
38	28.5	42.3	26.1	26.1
39	36.5	42.2	28.9	31.2
40	28.1	45.4	25.7	25.7
41	36.0	41.7	29.4	30.7
42	35.5	41.2	29.9	30.2
43	33.5	39.2	29.2	29.2
44	30.8	36.5	30.8	30.8
45	29.5	35.2	29.5	29.5
46	34.0	39.7	32.8	34.0
47	32.4	38.1	32.4	32.4
48	31.8	37.5	30.9	31.8
49	36.5	42.2	31.2	31.2
50	45.4	42.5	32.5	33.0
51	33.7	39.4	33.7	33.7
52	34.7	40.7	34.7	34.7
53	36.9	42.6	36.6	36.9
54	38.6	44.3	34.9	35.0
55	40.7	46.4	32.8	32.9
56	71.9	89.2	65.7	65.8
57	38.8	44.5	34.9	35.0
58	44.9	50.6	44.9	44.9
59	72.0	77.7	72.0	72.0
TSUMM	1803.2	1929.6	1418.4	1439.6
TLINK	224.4	215.6	361.8	237.5

Figure 14. PLANET2 results for sample forest network.

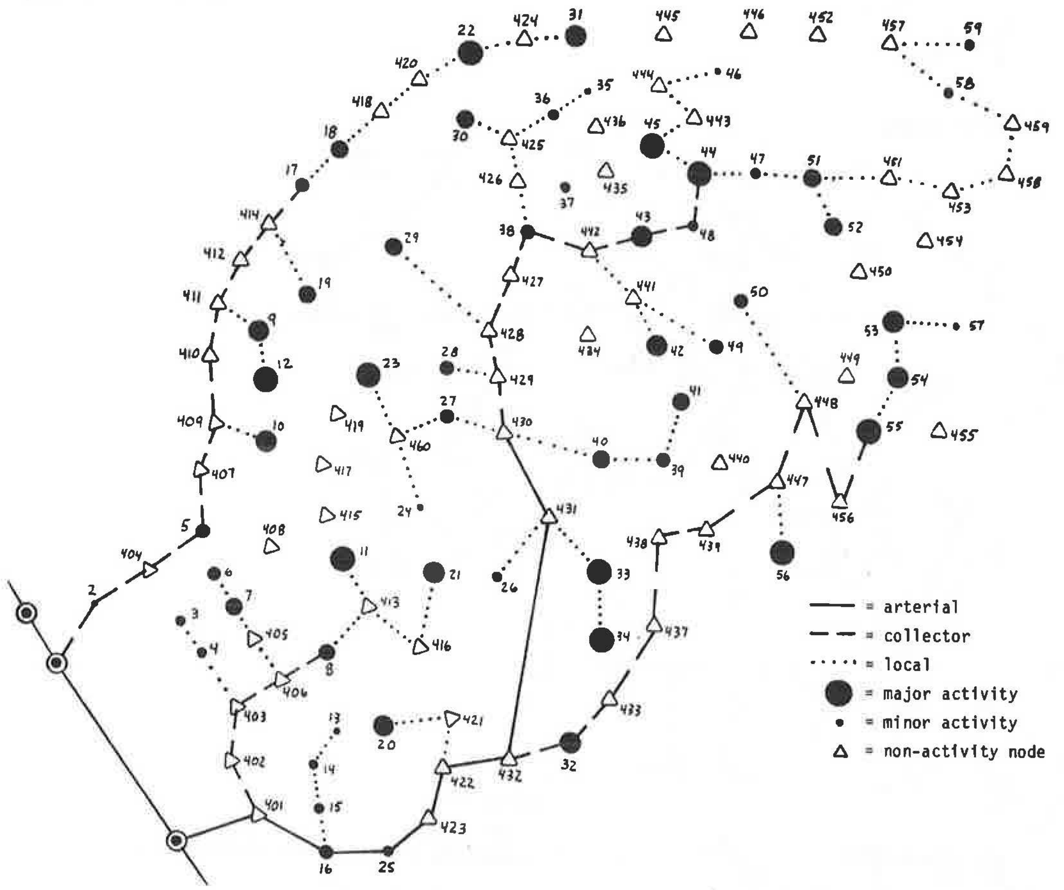


Table 6. Total network time (TSUMM) and total network distance (TLINK) versus trade-off factor.

Program	Factor	TSUMM	TLINK
BUILDER		1418.4	261.8
PLANET1	0.0	1418.4	259.5
PLANET1	0.2	1418.7	257.3
PLANET1	0.6	1421.0	249.5
PLANET1	1.0	1425.4	245.4
PLANET1	3.0	1432.1	241.7
PLANET1	5.0	1439.6	237.5
PLANET1	10.0	1481.0	228.9
PLANET1	15.0	1489.9	228.3
PLANET1	100.0	1558.2	226.0
PLANET1	999.9	1803.2	224.4
MINSPAN		1803.2	224.4
MINTREE		1929.9	215.6

imum spanning tree algorithm to determine the best network they can. PLANET1 and PLANET2 do this with very reasonable computation times. The computational times on Oregon State University's CDC Cyber 73 computer, for the network in Figure 9 were approximately 2.4 s for PLANF1 (PLANF1 generates the input file for PLANET1) and 1.4 s for PLANET1. For a similar network that has three links of different classes between each pair of nodes, the computation times for PLANET2 were approximately 10 s for PLANF2 (PLANF2 generates the input file for PLANET2) and 4 s for PLANET2.

PLANET1 should be used when the information about the network is limited. PLANET2 should be used if (a) the actual construction, maintenance, and operating costs are available; (b) different roadway classes are to be used; or (c) the demands for the individual activities are used. Some additions to PLANET1 and PLANET2 that may be possible are to

1. Divide the traffic into different vehicle classes,
2. Determine which links should be closed and which should be open at a lower class when they are not in the tree, and
3. Take roadway capacities into consideration.

These are some of the additions that should be considered in the future development of PLANET1 and PLANET2.

These two programs make it possible for the analyst or decisionmaker to analyze and evaluate the trade-offs in construction and maintenance cost as convenience is increased, that is as travel time or operating costs are reduced. Since many activities with varying objectives must be served by a forest road network, the transportation planning task is complex. Computerized techniques that indicate the trade-offs between networks identified according to differing criteria assist the decisionmaker in identifying the appropriate roadway arterial, collector, and local systems.

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Analyzing Transportation Networks for Rural Development

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This paper describes a new version of the Timber Transport Model, which is a comprehensive route analysis and network optimization computer program developed to support land management planning in rural forest areas. The technique is generally applicable to transportation economic analysis in any rural setting and involves the transportation of resources or agricultural commodities in a many-to-few shipping pattern. The overall capabilities and problem size limits of the program are described. Program features are illustrated through a simple example. The technique is compared with the classical transshipment problem, with which it has certain features in common. The mathematical formulations used in the program are also presented.

This paper describes the Timber Transport Model, a comprehensive network analysis computer program created to support national forest transportation and lane management planning. A previous version of this program has existed for a number of years and has been used in the selection of capital investments, maintenance levels, and, in some cases, network rehabilitation priorities following slides, floods, and other transportation emergencies (1,2). The current version contains several operational simplifications and enhancements, in many cases suggested by users throughout the country.

This technique was developed under sponsorship of the U.S. Forest Service, and consequently contains features intended to facilitate analysis of timber haul. However, it is suited to a wide range of rural transport planning situations--in particular, the analysis of penetration road networks in developing regions.

The problems to which the Timber Transport Model is suited have the following characteristics:

1. Network investment and management decisions are based primarily on service to resource-based commerce, such as agriculture, mining, or (as in the national forests) logging;
2. Transport needs are predominantly many-to-few in character, such as in farm-to-market or forest-to-mill transport;
3. Commercial transport needs are multicommodity in nature in that different market locations may exist for different goods;
4. Transportation planning, although attempting to serve numerous objectives and users, is dominated by considerations of economic and financial feasibility and market advantage; and
5. Engineering economic analysis considers the