NETWORK 2001 – Transportation Planning Under Multiple Objectives

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ABSTRACT - NETWORK 2001 has been developed to provide transportation planners with additional flexibility in analyzing road systems. While NETWORK 2000 was limited to minimizing costs, NETWORK 2001 can use weighted objective function components to minimize road system length. This paper presents NETWORK 2001 and the new algorithm implemented in the program with its applications. Total open road length can be constrained while minimizing road and transportation costs. This method can extend to include road deactivation and obliteration as optional activities.

Keywords: network analysis, transportation planning, combinatorial optimization

INTRODUCTION

The NETWORK II program developed by Sessions (1985) has been widely used for solving fixed and variable cost transportation problems during the last 15 years. The NETWORK algorithm in the program, which is similar to the Prorate Algorithm (Schnelle 1980), uses a series of rules to avoid stalling in a local minimum (Sessions 1985).

NETWORK 2000, developed by Chung and Sessions (2000), improves the user interface and enhances the problem solving capacity. It also provides the users with two additional heuristic solution techniques; Simulated Annealing (Kirkpatrick et al. 1983) and Great Deluge (Dueck 1993). A Geographical Information System (GIS) interface is newly added to the program to help the users with generating a large network from GIS data.

Although the algorithm used in both NETWORK II and NETWORK 2000 can be used for multiple period, multiple product, value maximization or cost minimization problems, the applications are limited to minimizing costs. Consideration of side constraints is restricted. Changes in forest management goals resulting from environmental considerations have brought new challenges to forest road system management. Multiple goals and additional side constraints such as open road length restrictions or road deactivations require a new problem solving technique and decision making support tool for large problems.

A new version of the NETWORK 2000 program, NETWORK 2001 has been developed to provide transportation planners with additional flexibility in analyzing road systems. While NETWORK 2000 was limited to minimizing costs, NETWORK 2001 can use weighted objective function components to minimize road system length or other link attribute. This paper presents NETWORK 2001 and a new algorithm implemented in the program with the applications. Additional flexibility of the new algorithm allows users to consider multiple goals and side constraints in solving transportation planning problems.

ALGORITHM

A new network algorithm developed by Sessions et al. (2001) has been implemented in NETWORK 2001. The algorithm combines past network heuristic approaches with a combinatorial heuristic technique (Simulated Annealing) to provide additional flexibility in formulating the objective function and to apply side constraints to forest transportation problems.

The algorithm generates alternative routes for each sale using the route approach of the Timber Transport Model (Sullivan 1974) combined with use of equivalent variable costs that was the foundation of the Prorate Option (Schnelle 1980). Then, it optimizes each route using the Simulated Annealing heuristic while considering multiple goals and side constraints of the problem. The basic process of the algorithm is presented in the following four steps and illustrated in Figure 1.

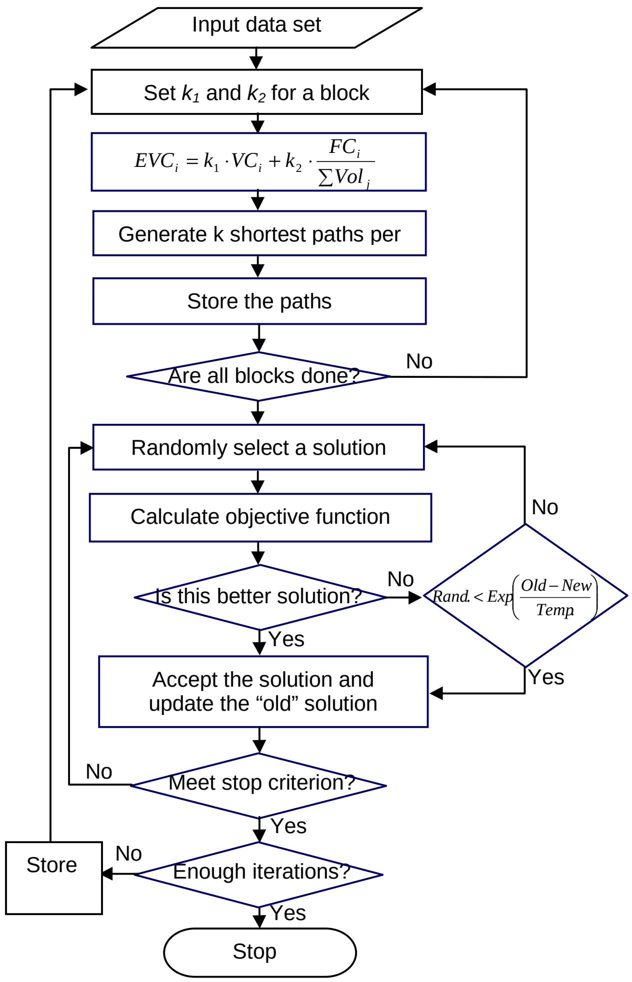


Figure 1. A flowchart for the NETWORK 2001 algorithm.

Step 1. Generate k-shortest paths from each origin to the destination. The k-shortest paths can either be based on variable costs only or can include equivalent variable costs. We can generate "blocks" of k-shortest paths with each block based upon the equivalent variables cost multiplied by a weighting factor. For example, for each origin, develop the k-shortest paths for n blocks of k-shortest paths where the equivalent variable cost of road segment *i* (EVC_i) is calculated using the following equation:

$$EVC_i = k_1 \cdot \text{Variable Cost}(VC_i) + k_2 \cdot \frac{\text{Fixed Cost}(FC_i)}{\sum \text{Volume over segment } i} \quad \text{(Eq 1)}$$

Step 2. Solve the combinatorial optimization problem of assigning the best route to each origin (sale) to minimize the sum of fixed and variable costs using a heuristic. Multiple goals are formulated into the objective function and additional side constraints are used to determine the feasibility of solutions.

Step 3. Using the volumes over each road segment resulting from the assignment in Step 2, recalculate the equivalent variable costs for each road segment.

Step 4. If the number of desired cycles has not been completed, return to Step 1 using the equivalent variable costs calculated from Step 3.

Our initial computational experience is that this algorithm can find the optimal solution for a set of test problems and with some experimentation with weighting factors and block sizes has yielded superior solutions over NETWORK (Sessions 1985) for a large problem. However, it is not within the scope of this paper to compare this algorithm with other possible network algorithms.

APPLICATIONS

Advantages of the NETWORK 2001 algorithm are that its objective function is more flexible than NETWORK and side constraints can be easily added. Alternative objective functions such as minimizing total road length, minimizing cost subject to an open road length constraint, and including decommissioning costs can be readily accommodated.

This paper presents two approaches to constraining total open road length using NETWORK 2001. Approach 1 considers the road length constraint as part of the objective function goal (Equation 2), while Approach 2 considers road length as a “subject to” constraint (Equation 3).

<u>Approach 1</u>

$$\text{Min.} \quad \sum_{i=1}^{I}\left(VC_i \times \sum Vol_i + FC_i \times X_i\right) + \left|\sum_{i=1}^{I}\left(RL_i \times X_i\right) - TL\right|^n \quad \text{(Eq. 2)}$$

<u>Approach 2</u>

$$\begin{aligned} \text{Min.} \quad & \sum_{i=1}^{I}\left(VC_i \times \sum Vol_i + FC_i \times X_i\right) \\ \text{st.} \quad & \sum_{i=1}^{I}\left(RL_i \times X_i\right) \le AML \end{aligned} \quad \text{(Eq. 3)}$$

where,

VC_i : variable cost on link *i*

FC_i : fixed cost on link i

Vol_i : volume transported over link i

X_i : binary variable (1 if link i is used, otherwise 0)

RL_i : road length of link i

TL : target road length

I : total number of links in a network problem

n : weighting factor

AML : allowable maximum road length

The objective function in the Approach 1 consists of two weighted components: deviation from a target length and total road system costs. Approach 1 penalizes objective function not only when total road length exceeds the target but also when it is lower than the target (two way goal). The advantage of this approach is that the users can generate alternative solutions resulting from trade off between two components by applying different weight factors. Relaxing the road length constraint may decrease road costs. It also permits investigation of “infeasible” areas of the solution space.

In Approach 2, the road length constraint determines feasibility of solution, but it does not affect quality of the solution. This approach can be used when the open road density in a management area is tightly fixed. Approach 2 does not permit the investigation of part of the solution space that violates the constraint.

Other components rather than road length can also be included in the formulation of transportation planning problems. Since it is hard to express environmental considerations in terms of economic values, some user-defined indices could be introduced. The indices could represent environmental hazard level such as potential soil erosion, soil sediment production rate, or other quantifiable values related to environmental considerations of road segments. NETWORK 2001 allows the users to modify the formulation of objective function and to add side constraints in order to consider multiple management goals in the planning area.

EXAMPLE

The input and results from a single period network (Figure 2) modified from Sessions (1985) are shown in Tables 1, 2, and 3. For this example, each link is assigned to an arbitrary road length. Approach 1 was used to minimize total project costs while considering total open road length constraint. Three different cases were tested: Case 1) without road length constraint, Case 2) with target = 10 miles and weight factor (n) =10, and Case 3) with target = 10 miles and weight factor = 100.

NETWORK 2001 found the minimum total cost $506,234 and total open road length 14.6 miles without road length constraint (Case 1). The results from the three cases showed total open road length can be close to the target at the expense of the project costs (Table 3). Figure 2 illustrates alternative solutions found by NETWORK 2001 for each case.

Table 1. Network Input for Example.

Link Identifier		Round Trip Haul Cost ($/truck/link)	Road Cost ($/link)	Road length (Miles)
(From)	(To)			
1	4	10.74	68,400	1.0
1	5	3.46	61,300	0.7
2	1	6.16	38,200	0.9
2	4	3.28	50,000	1.5
3	2	5.50	27,800	1.2
3	4	3.73	32,500	1.6
3	7	3.48	72,700	3.5
4	5	4.55	50,000	1.0
4	6	3.16	-	1.5
4	11	2.50	10,000	1.5
5	4	4.55	50,000	1.0
5	6	1.42	32,500	2.4
5	8	3.16	-	0.4
6	7	2.28	50,000	1.6
6	8	3.62	28,000	2.1
7	6	1.28	50,000	1.6
7	8	3.36	-	4.5
7	10	5.97	-	3.0
8	9	2.70	-	2.5
8	10	11.56	-	3.3
9	10	5.17	-	1.8
11	6	-	-	0.0

Table 2. Harvest Input for Example (Single Period).

Harvest Node	Destination Node	Harvest Volume	Year
1	10	4,800	0
2	10	10,200	0
3	10	6,200	0

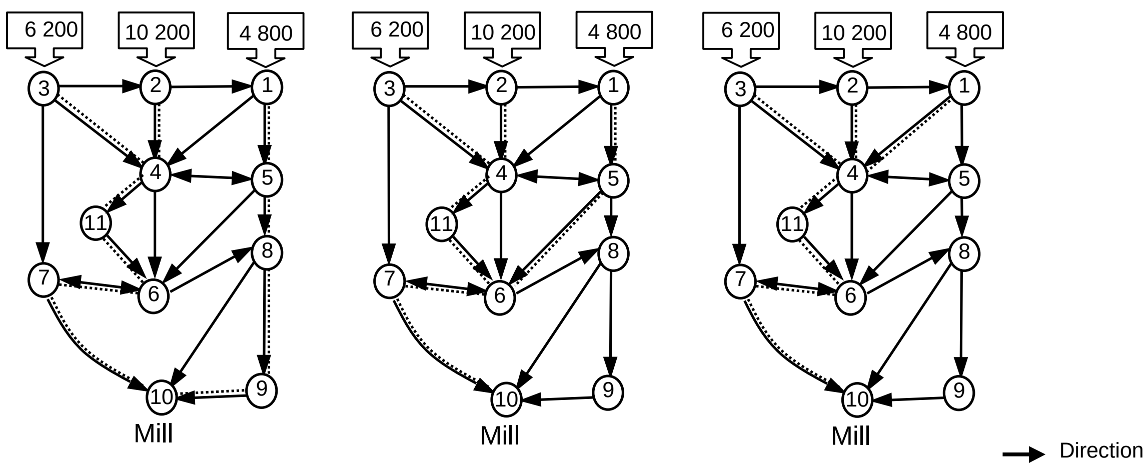
CONCLUSION

A computer program, NETWORK 2001, has been developed for optimizing large fixed and variable cost transportation problems under multiple objectives. The new algorithm implemented in NETWORK 2001 has been discussed. A technique for the formulation of the multiple objectives and constraints in transportation planning problems has been presented.

NETWORK 2001 has the ability to formulate multiple road system management goals. It can allow the users to explore solutions satisfying multiple objectives and side constraints arising from environmental considerations and requirements. NETWORK 2001 is easy to understand by both field personnel and analysts and can be learned quickly. Its interactive capability and GIS interface are also advantages of this program.

Table 3. Total project costs and open road length in solutions found by NETWORK 2001.

Case	Total costs ($)	Total open road length (miles)
1	$506,234	14.6
2	$532,206	12.3
3	$546,934	10.2



Case 1 Case 2 Case 3

Figure 2. Solutions found by NETWORK 2001 for three different road length constraining cases.

There are limitations to NETWORK 2001. The greatest limitation is that it is a heuristic algorithm and the solution may not be optimal. Furthermore, additional objectives and side constraints usually increase complexity of the problems. Finding good solutions to a complex transportation planning problem requires the user's effort to explore the solution space in order to better understand the problem to be solved and the trade offs between goals.

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