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Field Notes

Volume 4, Numbers 3 and 4
March-April 1972

FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

ENGINEERING FIELD NOTES

This publication is a monthly newsletter published to exchange Engineering information and ideas among Forest Service personnel.

The publication is not intended to be exclusive for engineers. However, because of the type of material in the publication, all engineers and engineering technicians should read each monthly issue.

The publication is distributed from the Washington Office directly to all Forest, Regional, Center, Station, Area, Laboratory, and Research Offices. Adequate copies are printed to provide all who wish a personal copy. If you are not now receiving a personal copy and would like one, ask your Office Manager or the Regional Information Coordinator to increase the number of copies sent to your office. Use form 7100-60 for this purpose. Copies of back issues are also available from the Washington Office and can be ordered on form 7100-60.

It is intended that the material in the Field Notes be primarily written and used by Forest Service Field Engineers; however, material from other publications may be used.

Field Note material should always be informative and cannot contain mandatory instructions or policy. The length of an article may vary from several sentences to several typewritten pages. Material need not be typed (neatly written or printed is acceptable), or edited before being submitted to the Washington Office. The Washington Office will edit and prepare the camera copy to accommodate our format and allowable space.

Each Region has an Information Coordinator to whom field personnel should submit both questions and material for publication. The Coordinators are:

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F I E L D N O T E S

APPLICATION OF NETWORK ANALYSIS TO NATIONAL FOREST TRANSPORTATION PROBLEMS

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INTRODUCTION

Network analysis techniques are widely used in solving a variety of problems, where many alternative paths or routes exist. Minimum path solutions yield the most efficient route between two points in a network. The application of minimum path network analysis to National Forest transportation problems is the subject of this presentation. The purpose of this work is to expand the existing timber sale network analysis technique developed for the Transportation System Planning Project (TSPP) by the University of California's Institute of Traffic and Transportation Engineering and present guidelines for applying this technique to current forest network problems.

Two analysis techniques are presented: route analysis and link analysis. Route analysis a procedure that determines a minimum path from an origin to a destination. Segments within the available system are only considered for their contribution to that minimum route (a chain). The types of transportation problems that can be solved by a single route are short-range or near-term in the economic sense. For this reason, route analysis is considered a short-range study tool.

Link analysis is a technique to analyze or develop networks of routes from systems of possible alternative links. Minimum paths between many origins and destinations contribute simultaneously to link use. The result is a set of links that collectively make up a branching network serving all origins and destinations. By its nature, link analysis is capable of dealing with long-range transportation problems.

The network procedure presented herein is flexible and can be applied to numerous minimum path problems. This presentation is intended to provide a basic understanding of network analysis and show how the techniques may be used to solve forest transportation problems.

DEFINITION OF PROBLEM AREAS FOR THIS STUDY

Three problem areas have been selected for study. They are: analysis for road closure, planning new developments, and construction or maintenance of existing roads.

Many forests have networks that are dense interconnected systems, with many unnecessary roads. These systems now exist and must be properly managed. Management efficiency would be improved by eliminating some roads and upgrading the standards of other roads. The problem is to find some technique to analyze road efficiency and establish a basis for retaining necessary roads on the system.

In planning the multiple-use management of developing areas, many alternative routes exist for providing transportation. All alternative segments and links must be included for study to insure that a meaningful plan will be obtained. This study often leads to a complicated network of possible alternative routes and links that serve the resource. The problem is similar to analyzing an existing system. The question then is: Which routes or combination of routes are most efficient for providing access?

In construction and maintenance planning, the question always arises as to priorities of projects. Frequently, it is not clear as to which routes within the network are the most important. A technique is needed to identify projects which show the most economical advantage so that they may effectively compete for budget funds.

NETWORK ANALYSIS PROCESS

The typical network analysis process is shown schematically in Figure 1. This diagram shows all the activities and their interaction in developing useful systems for applying network analysis to any transportation problem.

The process is divided into five basic functions that must be completed in logical order. Each of these functions is discussed below:

1. Process Planning. Each study requires initial direction to insure that a meaningful plan will be developed. The plan must have a specified purpose; a defined end to work toward. Plan preparation

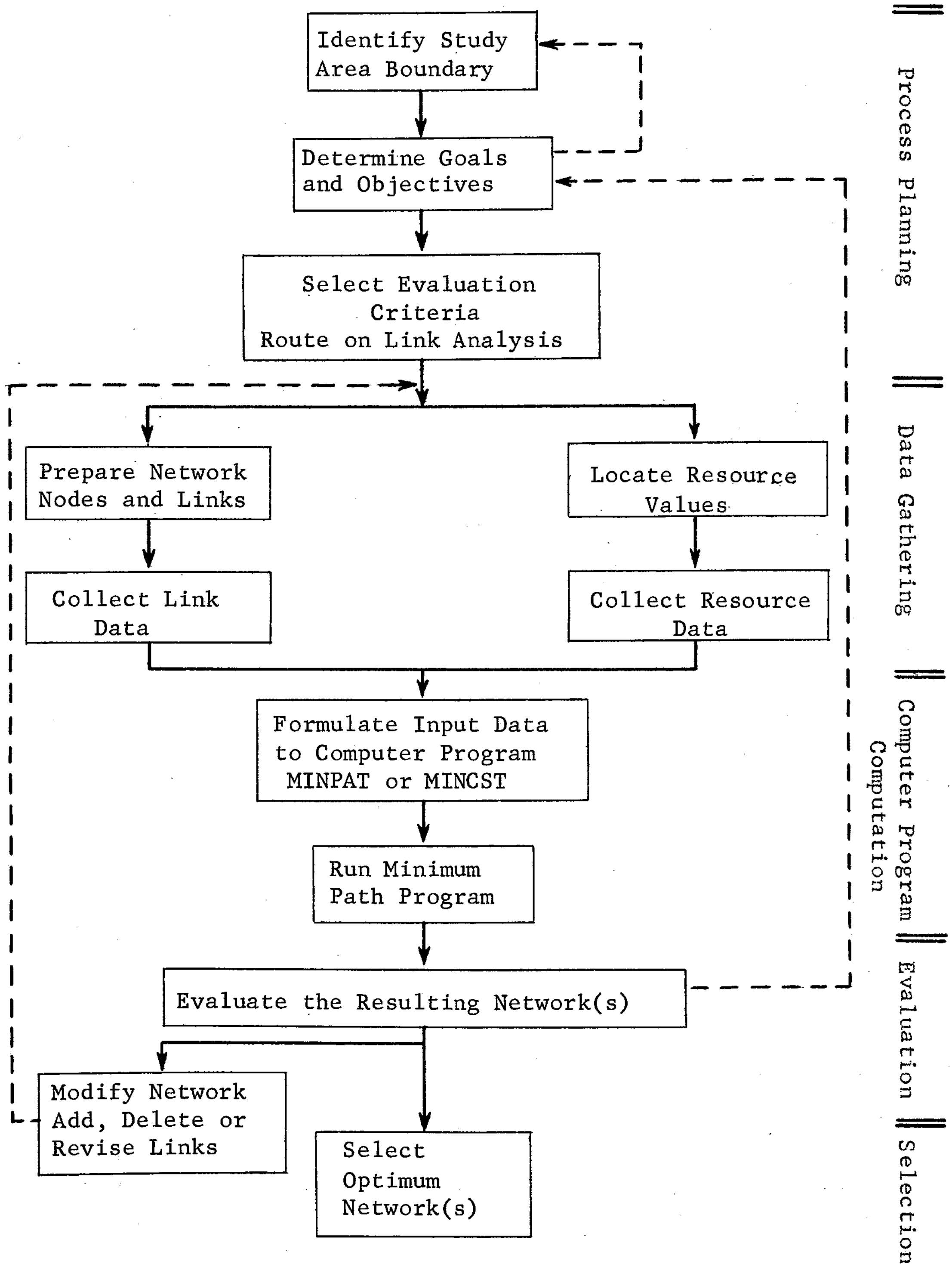

FIGURE 1.--NETWORK ANALYSIS PROCESS

is also a necessary place to work out differences of opinion and provide clear understanding on the part of individuals involved. Lack of commitment here leads to confusion when the analytical results are evaluated.

2. Data Collection. Data collection is one of the most time-consuming tasks in the process. It is important to obtain only what is necessary to fulfill the objectives. Planning may be required to create and expedite efficient methods and schedules of data collection since many disciplines are involved.

3. Computer Program Computation. The computer programs necessary to solve network analysis problems are on file with TSPP and are available to the Regions. The program "MINPAT" is used for route analysis and "MINCST" is used for link analysis. Some manipulation of data may be required, however, to fit the data to program input formats.

4. Evaluation. In the evaluation phase, the analytical results for each alternative are weighed against each other in light of the goals and objectives, and the type of study being performed. The results may require conversion of quantifiable economic values to present values for comparison.

In evaluation, considerable judgment is necessary to determine whether a satisfactory solution has been obtained. An iterative process involving many revisions is usually necessary to arrive at the best answer. The judgment of an experienced analyst is valuable to determine which alternatives are worthy of further study.

5. Selection. The evaluation-revision process eventually leads to a set of alternatives so nearly equal that only outside influences can be used for decision. At this point, the analysis is completed. The alternatives and their consequences are then ready for management to review and make the final decision.

ROUTE ANALYSIS

The Route Analysis Program was developed for timber haul cost appraisal, but it has application in many other ways. The main feature of this program is that it selects the most efficient route from an origin (timber sale) to a destination (market) by either distance, time or haul cost for assigned road conditions.

The Program

The basic analysis technique used in this study is a computer program called MINPAT developed for TSPP by the University of California's Institute of Transportation and Traffic Engineering.

The program looks at all possible routes and then selects the most efficient route for log and lumber haul. Efficiency can be expressed in three ways; (1) minimum distance, (2) minimum travel time, or (3) minimum operating cost. In addition, the program lists the associated values of distance, time, or cost for each minimum route.

The Network

The network representation is the most important part of the analysis. Considerable effort at the field and office level is required to prepare a useful network.

Each section of road is identified by node numbers that mark its beginning and end points. Nodes are located at each road intersection, and at location where changes in road features lead to different operating characteristics. Nodes also identify each timber sale, mill, and market. The section of road between two nodes is called a link.

Data Collection

The basic unit of data is distance or length of each link. Travel time and haul costs are optional features that the user may or may not require. Travel time may be included as actual travel time over the link, or the program will calculate travel time if link speed is given.

A road class number is assigned to each link for each direction of travel. Class numbers represent the operating cost characteristics of the link and are a function of surface type and condition, roadway template, alignment and grade. Ten classes can be used. Each class has three cost factors that depend on distance of travel.

A second cost function is available for lumber haul cost. In many cases, lumber haul cost is not required because the sawmill is the appraisal point. A dummy link with zero distance and travel time is required where mill and market are the same place.

APPLICATION OF ROUTE ANALYSIS

Route analysis produces the most efficient route from a given timber sale to a mill and market under assigned road conditions. Where more than one mill-market combination is available, the program selects the mill-market pair that yields the minimum path route by distance, travel time or haul cost. The technique is useful, however, in solving many other types of problems.

Initially, a base network is established to serve as a reference point against which other route oriented objectives will be analyzed. The alternatives and how they are generated depends on the objectives and type of study being performed. Following are example applications that show how route analysis can be used to solve some typical forest problems.

1. Select the Most Economical Haul Route. For timber sale appraisal purposes the computer output from the "MINPAT" program shows the minimum haul cost route and associated values for distance tance and travel time.

If minimum haul cost is the only objective, then the basic run provides the answer and no further work is required. This basic analysis may be retained for further analysis or optimization.

2. Select the Most Economical Haul Route with Road Improvement. To optimize a network, the analyst must select those links contributing high haul costs and revise their haul class. The program can only reflect reduced cost through a change in haul class. A rerun of the network with improved links determines: (1) which route is now the minimum cost route and (2) how much improvement in haul cost is obtained (if any). This iterative process is continued until an acceptable level of benefits relative to costs is attained.

3. Select Road Segments for Maintenance. An assumption in the analysis process is that each segment will be maintained at its assigned haul class. In this type of analysis, the analyst selects those links which, if left unattended, will yield the greatest detriment to haul cost.

Experience must be used to identify those links subject to greatest deterioration and to estimate their haul class in the deteriorated state. A rerun of the analysis program shows actual haul costs in the deteriorated condition. A before and after comparison of haul cost with estimated maintenance cost serves as the basis for selecting and optimizing maintenance expenditure. This type of application can also be effectively used to justify a request for an increase in maintenance budget allotment.

A variation that may be helpful in solving a maintenance problem is to systematically delete the links that have high maintenance costs to force the haul to another path. This procedure can be used to test many alternative routes and will eventually lead to an optimum solution.

4. Select the Most Economical Route Based on Haul, Construction, and Maintenance Cost. The selection of the most economic route requires analysis of alternatives using a method that simultaneously accounts for all road costs. This technique lends itself to studies where high construction or maintenance costs greatly influence route selection.

The problem can be solved by assigning each link a value that is the sum of haul, construction, and maintenance costs. The procedure requires calculation of haul cost for each link using the sale volume, distance, and haul cost for that link's haul class. Cost of new construction or reconstruction and maintenance is estimated for each link in the system.

For processing, the appropriate sum of all costs for each link is inserted in place of link travel time for the network program. The resulting minimum total cost route and its actual cost appears as minimum time in the computer output.

The purpose of presenting this application of the MINPAT program is twofold. Primarily this technique provides a means of minimizing any link associated variable between an origin and destination. Specifically, the subject variable is inserted in the travel time column of the MINPAT input data format. Program output then shows the total value of that variable along its minimum path under the heading of "Minimum Travel Time".

The method presented here requires manual calculation of haul cost and link total cost values. The program MINCST discussed in the following was developed specifically to handle total cost type problems, and should be used for these applications.

LINK ANALYSIS

Link analysis provides a comprehensive study of a transportation system. For this reason it generally applies to long-range analysis of broad geographic areas.

Link analysis is performed (on computer) in three steps; (1) individual minimum travel paths are determined for each sale, (2) each link's usage is summed for all sales, and (3) the cost for each link is summed to obtain a total system cost. Link cost and corresponding total network cost are used to evaluate each alternative network.

The application of link analysis presents three problems; (1) timber sale conditions, (2) road class conditions, and (3) network configuration.

Timber sale data required as program input frequently requires long-range estimates of both volume and date of harvest. Since these factors are affected by political , economic, and environmental constraints, their value is difficult to forecast with certainty.

The problem in assigning road classes is that "trade offs" exist between road class (haul cost) and construction/maintenance cost that could result in a more economical system. High standard roads have lower haul costs but cost more to construct and vice versa. Initially the high usage links are not known; therefore an iteration process is necessary to develop a system that has the proper haul class and construction and maintenance cost on each link.

The network configuration often leads to inefficient alternatives. This feature is best illustrated by a network with parallel paths. The computer analysis may generate a system of parallel routes. In most cases it is more economical to develop a "tree" type configuration.

THE PROGRAM

The link analysis computer program developed by TSPP is called MINCST (for minimum cost). This program is much like the MINPAT program with the following exceptions:

1. Additional input data is required.

   a. Timber sale volume
   b. Construction cost
   c. Maintenance cost

2. Additional output is produced in the form of a link usage table and total system cost.

THE NETWORK

Network preparation procedure is identical with that required for route analysis.

In laying out the network nodes and links it is important to have realistic study area boundaries. The type of study being performed usually dictates the study area boundary. District and even forest geographic boundaries should not be barriers in the layout of a transportation system network.

DATA COLLECTION

Data collection for link analysis is more arduous than for route analysis. The difficulty lies in the area of forecasting and estimating those input variables that occur in the future. Realistic and accurate projections based on the best interdisciplinary judgment available are mandatory.

APPLICATION OF LINK ANALYSIS

The link analysis technique typically applies to three National Forest transportation network problems; (1) road closures, (2) planning, and (3) construction and maintenance. Again attention is called to the network analysis process shown in Figure 1. The step-by-step process of applying link analysis is necessary to draw out and identify the particular interests that lead to a successful study.

Road Closure

The problem of road closures is a concern common to many forests. Road closure may be a misnomer in that we are really concerned with a dense network of roads. For a road closure problem link analysis determines which roads are needed to serve the resource. Those "not used" links then become candidates for deletion or travel restriction measures.

In setting up the link data for a closure problem, only haul and maintenance costs are needed. New construction or reconstruction costs may be included later if the user plans to optimize the resulting useful network. All sales within the study period must be included with the data from each sale reduced to acceptable form. In dealing with future sales, it must be recognized that incremental haul cost is a set of fixed values that are constant for any study period. To properly analyze economic worth then requires discounting sale volume to either present volume or uniform annual volume throughout the period.

Output data is useful in two ways; (1) system optimization and (2) analysis for road closure. For system optimization, the output is a starting point or base from which alternatives are generated. For closure analysis the analyst must optimize the network configuration. The technique of deleting links is used to generate alternative system configurations until a satisfactory solution is attained.

Planning

Link analysis has perhaps its greatest application in planning transportation networks for new developments. The reason is that appropriate transportation costs can be assigned to each road. Three examples follow:

1. State highway links will only have haul cost.
2. Existing forest roads require haul and maintenance costs.
3. New forest roads use all three costs.

These costs are then used in selecting an economical network which serves the long-range transportation needs of the study area. Initially a base network is established using all possible links (both existing and all new proposed links) in the study area. Alternative networks are then generated by manipulating the base data. Alternative networks are developed in two ways; (1) by altering the network configuration, and (2) optimizing the haul and construction/maintenance costs.

As each new alternative is developed, the analyst must review the results and decide whether a satisfactory network has been obtained or other worthwhile alternatives exist. An almost infinite number of network possibilities exist; therefore the iteration process is continued only until the analyst feels he has obtained the most economical network.

Construction and Maintenance

Link analysis is a valuable tool in preparing construction and maintenance programs. It is used to analyze alternatives involving construction of new links, reconstruction or heavy maintenance of existing roads, and general road maintenance. This technique is applicable to any length of study period but it will frequently be used for short-range studies.

Initially a computer analysis is made using the existing road network and its related haul class and maintenance data to establish a base for developing alternatives. Alternative programs are generated by:

1. Deleting high cost links, thereby forcing the program to select an alternate route.

2. Revising (either upward or downward) the haul class and its resulting construction and maintenance costs.

3. Adding new links with their construction and maintenance costs. Again, the analyst uses the iteration technique to develop worthwhile alternatives. The process is much like that used in planning. The revision-evaluation process is continued until all worthwhile alternatives have been investigated. The alternatives can then be ranked in order of economic value and programmed for work.

CONCLUSIONS

Network analysis is a very flexible technique that is useful for solving National Forest transportation problems. It applies equally well to small studies of a single drainage or to broad "regional type" systems.

The importance of the analyst cannot be over-emphasized. Through imagination, the analyst is free to manipulate the computer programs to suit his own particular problems. He selects the alternatives to be analyzed. Experience and judgment are the essentials necessary to produce a successful study.

An important feature of network analysis is that the programs can easily be manipulated by remote computer terminals. The program and data are usually loaded on storage files through a high-speed reader. The iteration process can then be performed by a low-speed terminal located at the Forest or practically anywhere.

A user's manual on network analysis programs MINPAT and MINCST is being prepared by TSPP. The programs and their applications are discussed in detail and example problems are included. This manual should be completed in the spring of 1972 and will be distributed by the Washington Office. TSPP personnel will be available to assist the regions in implementing the programs. The programs discussed are the first step in the evolutionary development of timber travel models. New, more comprehensive models are now being developed.

To date network analysis programs have been used in Regions 4, 5, and 6. Network planning and data collection are now underway in Regions 1 and 2.

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NEWS ITEM taken from an article by Ed Tomm, Civil Engineer, and Sam Fischer, Forest Engineer, Eldorado National Forest

The Eldorado Forest has a new twist in managing the time of survey crews in situations of high daylight temperatures, rugged terrain, and very long walk-in and walk-out distances. Some of the survey crews are scheduled to work their first 40 hours of the week in the first 4 days. In addition, the crews are also allowed to put in this time on an unscheduled basis; i.e., they can leave as early or come in as late as they would like on any single day. The possibilities of hazards pertaining to traversing very steep side slopes, bluffs, large rocks, etc., have been reduced by as much as 20 percent. The morale of the crew has improved and productivity has increased while working a 4-day, 40-hour week. The wear and tear on equipment has decreased as the 4-day week saves one round trip of getting to the jobsite and carrying the equipment over the long walk-in and walk-out distances. Another advantage of the 4-day week is the savings on per diem costs and lower absentee rate of the survey crew.

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EDITOR'S NOTE

CONGRATULATIONS to Clinton Peterson, Wallowa-Whitman National Forest.

The article "Stepped Cutbank Slopes," by Clinton Peterson, published in the Volume 3, Number 6, June 1971 Field Notes, has been added to the Highway Research Board's data bank. An abstract of the article appeared in the Highway Research Abstract--Volume 42, Number 1, January 1972 publication. Our library is busy filling the many requests for the article. Good work, Clinton!

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CORRECTION

Field Notes Volume 3, Number 10, October 1971, contained three typographical errors in the article "Ski Lift Thrustor Brake Problem," by Charles G. Bovey. Please note the following corrections:

1. Page 10, line 26, should read, "(...check while observing the rod movement closely.)"

2. Page 11, line 3, should read, "d. Full release."

3. Page 11, line 12, should read, "...torque can be set..."

Mr. Bovey also notes that subsequent checking has shown the tables on page 7 of General Electric publication GEH 982F are in error. He suggests using Table 2 on page 4 of GEH 982F, and interpolating for the required spring length.

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