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# Engineering Field Notes

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THE ENGINEERING FIELD NOTES SERIES is published periodically as a means of exchanging engineering-related ideas and information on activities, problems encountered and solutions developed, or other data that may be of value to Engineers Service-wide.

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# "ROADS" Working Group Gets Thanks for a Job Well Done

Chief Robertson recently recognized the ROad Analysis & Display System (ROADS) Working Group for results that surpassed expectations. In early June, the Chief made an award presentation to the two Washington Office members of the interdisciplinary team, while line officers at various field locations presented commemorative plaques and cash awards to Working Group members in the field.

## TEAM MEMBERS

Brought together by former Chief Peterson in September 1986, the Working Group comprised the following individuals:

Joy E. Berg, Group Leader, Management Systems, Region 9
James L. Davis, Jr., Forest Supervisor, Six Rivers National Forest, Region 5
Dan Erkkila, Forester, Washington Office, Policy Analysis
David F. Jolly, Deputy Regional Forester, Region 3
John Lowe, Deputy Director, Washington Office, Timber Management
Bruce Meinders, Director, Engineering, Region 8

The Group's two facilitators were:

Larry Hayden, Environmental Coordinator & Forest Planner, National Forests in North Carolina, Region 8
Walter T. Henry, Mendocino National Forest, Region 5 (now at Sequoia National Forest)

## WHY ALL THE FANFARE?

The ROADS Working Group developed a procedure that will greatly improve the Forest Service's ability to monitor and evaluate the effectiveness and efficiencies of its overall road program (for more detailed information on "ROADS," see "Road Program Costs: Continuing Efforts Addressing the Issue" in this same issue of Engineering Field Notes).

Expectations were high when, at the request of USDA, the Chief initiated the ROADS study in September 1986. It now seems that the Group has more than met those expectations and that the benefits to be derived from the ROADS system should be significant. At an absolute minimum, the system should produce a 1 to 2 percent improvement in the cost effectiveness of the overall road program for a period of at least 5 years. Based on the fiscal year 1987 program level, this could add up to about 2 million dollars a year.

The Group not only fulfilled its assignment by developing a process for tracking and objectively measuring Regional and Forest progress in managing road program costs, but it went a step further and developed a detailed user's guide for implementing the ROADS system. What's more--the Working Group members developed the system ahead of the target completion date, while still performing their regular duties!

Engineering Field Notes joins the Chief and others Service-wide in congratulating the ROADS Working Group on a job well done. EFN

# Dwyer Receives Awards

At its 26th Annual National Convention and Trade Show in Reno, Nevada, May 26-30, the National Ski Areas Association (NSAA) presented a plaque to Charles F. Dwyer, Washington Office Aerial Tramway Engineer. The award was made "In recognition of your many years of outstanding service to the ski industry of the United States."

Dwyer's activities involving NSAA centered on its sponsorship of the American National Standard for Aerial Passenger Tramways and Ski Lifts. He has represented the Forest Service on the ANSI B77.1 Committee for 21 years.

At the NSAA Convention, the International Organization for Transport by Rope-North American Continental Section (OITAF-NACS) held its annual meeting and awards ceremony. Their award this year was also made to Dwyer--for his outstanding achievement in advancing the aerial passenger tramway industry.

Dwyer has been designated representative for the Forest Service membership in OITAF for 20 years. He participated in organizing and served as first president of the North American Continental Section.

--Editor

# A Comparison of Travel Time Prediction Models Used by the Forest Service

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## INTRODUCTION

There are various situations when it is useful to have a good estimate of travel times on forest roads. Estimates are needed both for planning purposes, where there are currently no roads, and for existing roads, where field studies have not been undertaken to determine travel times.

As a part of the data collection process for a master's degree project to develop a procedure for analyzing double-lane versus single-lane roads, travel time data were collected on a forest road. This provided an opportunity to compare the actual travel times with the travel times predicted by some models currently available.

## LITERATURE REVIEW

The travel time prediction model that has received by far the most extensive use is that developed in the Logging Road Handbook (BNG) (1). This model predicts travel times for log trucks on both single-lane and double-lane roads. For single-lane roads, the assumption is made that speeds are limited by sight distance on curves and power limitations on grades. On a single-lane road, a vehicle is required to stop within half of the sight distance to avoid hitting an oncoming vehicle. BNG uses the alignment of the road, the surface width, and the cut-slope ratio to determine the safe speed. In addition, data are needed on the grade and surface type of the road, as well as the weight, horsepower, and efficiency of the truck. A method is given to determine what the amount of the delay is when vehicles are forced to wait in turnouts to allow oncoming traffic to pass. This is based on the traffic volume and the turnout frequency.

Jackson compared field travel times with predicted travel times from BNG (2). When the alignment was controlling the speed, he found that the observed speeds were 16.7 percent faster than predicted by BNG for the round trip. For grades above 11 percent where grade was controlling the speed, BNG predicted travel times much closer. Jackson felt that sight distance did not seem to be a factor in predicting speed mainly because of the extensive use of CB radios by truck drivers.

BNG's method for predicting double-lane travel time assumes that sight distance is not limiting, but instead a comfortable amount of side friction is. BNG uses a side friction factor of 0.16 to calculate the travel speed. BNG recognizes that superelevation has an effect on the amount of side friction that the driver feels, but assumes for the development of its tables that on forest roads no superelevation is present.

Another travel time prediction model available for use is the Vehicle Operating Cost Model (VOCM) (3). VOCM has been available at the Ft. Collins Computer Center for several years, but it has had little use. Recently, researchers at Oregon State University transferred it to IBM-compatible microcomputers. It can be used to predict travel times for vehicles other than log trucks, such as cars and pickups. For log trucks, the model assumes that sight distance is not a factor in determining speed. Instead of using the amount of side friction that the driver feels to determine what the speed around the corner will be, VOCM assumes that the driver will use all the available friction, except 0.2, which will be a factor of safety against slipping out.

VOCM does not take road width into consideration, nor does it take into account delays that would occur from meeting traffic on a single-lane road. For these reasons, VOCM is best classified as a double-lane travel time predictor.

## USING BNG

One thing that has made the BNG model so useful has been its ease of use. Tables in the Logging Road Handbook break down the travel times by grade, surface type, and alignment. A problem with these tables is that they were developed for trucks that were in use before 1960. Jackson has eliminated this problem by writing an HP-41 calculator program that goes back to the original equations and allows the user to input the horsepower of the truck. In addition, he has built in weights of 25,000 pounds for an empty truck and 80,000 pounds for a loaded truck, and allowed the user to input the road width. These are more accurate for trucks on the road today than the values used in the original document. The superelevation and the cut-slope ratio are two items that are still fixed.

The normal procedure with BNG is not to break the road down into very short sections. Instead, breaks are only made where there are major grade breaks, changes in surface type, or major changes in alignment. The alignment is classified as either excellent, good, fair, or poor, based on the number of curves and their degree of curvature. If the user wanted to be as precise as possible, the BNG method would allow breaking the road down into individual tangents and curves. For planning purposes, it is useful that the alignment can be lumped because the information available at this stage is usually very rough.

## USING VOCM

VOCM requires detailed data on the geometrics of the road, the characteristics of the vehicle, and the entering, exiting, and maximum speed. Obtaining typical characteristics for the vehicle or using the default values should pose no problem.

A problem may arise in obtaining the other data. Obtaining detailed information, including the length, degree of curvature, and superelevation of each segment of the road, almost requires that a survey be done before using the model. Estimates could possibly be made from a map for either an existing road or a planned road, but they would be quite rough. There is no way that the roads could be classified as to their alignment and still have a consistently reliable estimate. For instance, if a mile segment of road has 10 curves in it, with 10 tangents, there is no way that the user could say that this was equal to having a mile segment of road with a certain degree of curvature the whole way. If the user wants to determine what the predicted travel time is, the data would have to be input into the model for all 20 segments. This type of laborious work may not seem difficult if the road were short, but it could be a tremendous chore if it were to be used for a large area, especially mountainous terrain with numerous curves.

In addition to making an estimate of the road geometry, estimates need to be made for the maximum, entering, and exiting speeds. These estimates can be crucial to obtaining a good estimate. For an existing road, the entering and exiting speeds could be obtained by the use of a radar meter, but it would probably be just as easy to actually time the traffic. Obtaining an estimate of the average high speed would entail actually following traffic.

For roads in the planning stage, a reasonable estimate could only be obtained if the analyst were familiar with speeds on existing area roads that have similar characteristics.

An advantage that VOCM has over BNG is that it automatically accumulates the travel times, whereas, with BNG, this must be done by hand.

## DATA COLLECTION

### Study Area Description

The study area is in the Wind River Ranger District of the Gifford Pinchot National Forest. Figure 1 shows a map of the study area. The road that was analyzed is the Panther Creek Road, the Route 65 road. This is a single-lane paved road, which carries an average of 150 to 170 vehicles per day. Travel time data were collected during 4 days in September 1986 at the five points shown on the map at different times.

The Route 65 road had recently received some reconstruction work, and the survey for this was available for use to obtain some of the detailed geometric data that were needed.

### BNG Data Collection

To make a valid comparison with VOCM, the default value of 350 horsepower (gross) from VOCM was used. The entire 10-mile section of road was broken down into five road segments. The stations and elevations of these points were obtained from the road log, and the grades were calculated from this information. Survey information was used to find the curve radii for the alignment calculation. If this survey information had not been available, an estimate would have been made, and it is difficult to say whether or not the same alignment classification would have been obtained.

Once these data were obtained, they were entered into the calculator program. The program generates both the grade-restricted and the alignment-restricted travel times. The greater of the two must be selected as it is more constraining. Next, the delay caused by meeting vehicles was found. This entailed finding the average turnout spacing and cranking through the appropriate equation.

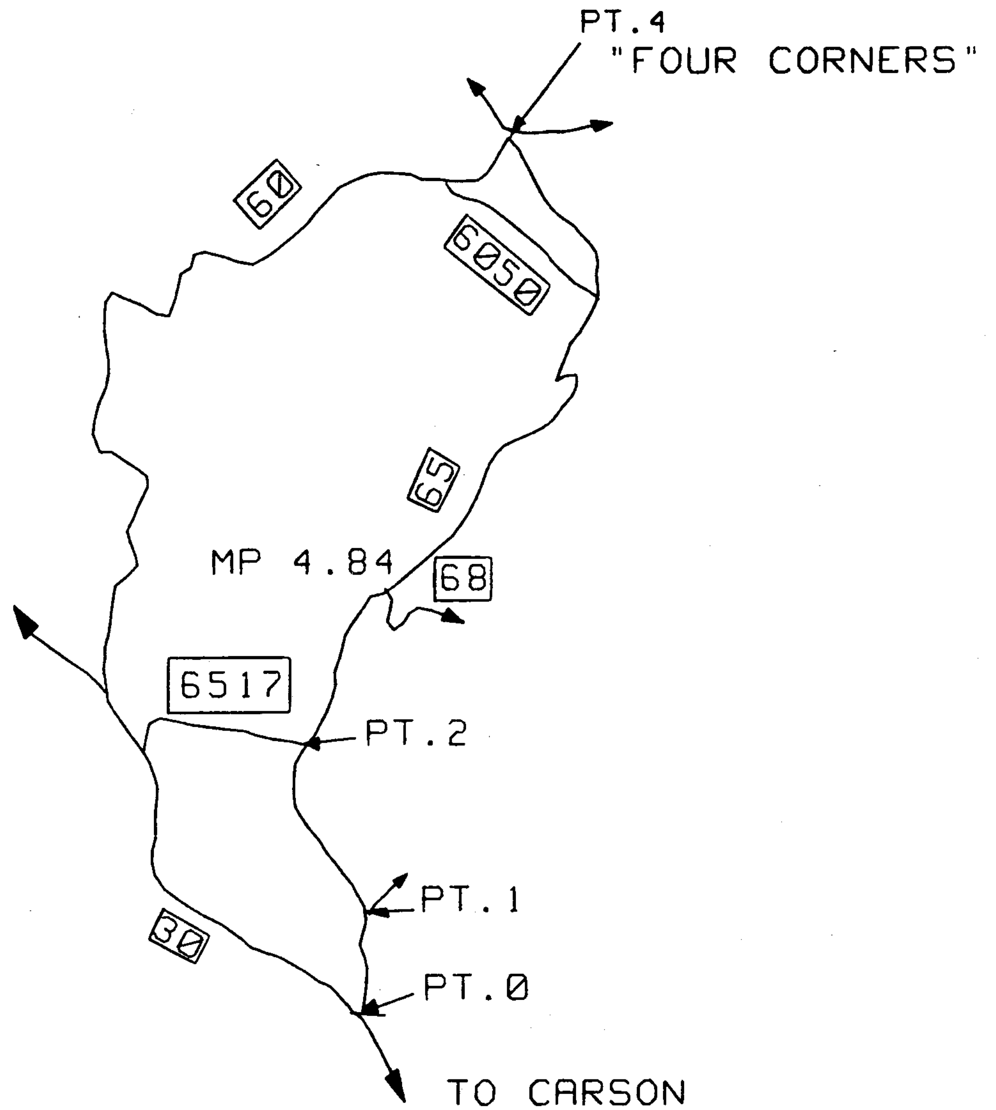


*Figure 1.--Panther Creek area map.*

## VOCM Data Collection

Only the lower 4 miles of road were analyzed because of the amount of time that VOCM takes to set up and run. This required breaking down the 4 miles of road into 33 segments. The stations and the curve radii were obtained from the survey. The survey had not included data on grade, so the same grades from the BNG study were used. The survey also was not detailed enough to get a good estimate of superelevation, so no superelevation was used. The entering and exiting speeds were estimated from the travel speeds that had been obtained from the field study. The average maximum speed was an estimate.

VOCM still requires a fixed-format type of input. Running this took about a half-hour of computer time.

## PRESENTATION & DISCUSSION of RESULTS

Table 1 summarizes the data from the three methods. There are several points that are worthy of note.

The BNG single-lane model predicted travel times that are much longer than the actual travel times, ranging from 121 to 174 percent of the actual times. This is consistent with Jackson's findings. This may be largely because CB radios are widely being used.

The BNG double-lane model predicted travel times that were too long for the unloaded truck, but those for the loaded truck were close to those observed in the field. They ranged from 94 to 122 percent of the actual times. The fact that the BNG double-lane model predicts travel times close to what were observed in the field for the single-lane situation again makes it look like traffic is driving significantly faster than would be predicted by considering sight distance alone.

*Table 1.--Travel time comparison: BNG, VOCM, and field (seconds).*

| | Segment 2 0 to 6,517 | Segment 3 6,517 to 68 | Segment 4 68 to 60 | Total |
|---|---|---|---|---|
| Unloaded: | | | | |
| BNG Single-Lane | 354.1 | 285.4 | 1,105.6 | 1,745.1 |
| BNG Double-Lane | 248.1 | 207.4 | 754.9 | 1,210.4 |
| VOCM | 176.6 | 161.4 | - | - |
| Field | 203.4 | 196.0 | 699.8 | 1,099.2 |
| Loaded: | | | | |
| BNG Single-Lane | 342.3 | 276.2 | 1,043.0 | 1,661.5 |
| BNG Double-Lane | 248.1 | 207.4 | 815.0 | 1,270.5 |
| VOCM | 181.5 | 169.6 | - | - |
| Field | 211.9 | 194.2 | 864.4 | 1,270.5 |
| Pickups up: | | | | |
| Field | 219.1 | 196.8 | 829.9 | 1,245.8 |
| VOCM | 213.4 | 186.6 | - | - |
| Pickups down: | | | | |
| Field | 204.4 | 199.9 | 748.3 | 1,152.6 |
| VOCM | 201.8 | 196.2 | - | - |

VOCM predicted log truck travel times that were consistently 82 to 87 percent of those observed. For pickups, VOCM predicted travel times 95 to 99 percent of those observed. VOCM predicted speeds would have been even faster had superelevation data been available. The average maximum speed may have been significantly off and caused this difference in travel times.

Since the single-lane BNG model is so far off, it was decided to take a closer look at the BNG double-lane and VOCM models because they are more accurately predicting travel times. It may be that the assumptions that the BNG double-lane and VOCM models are making are closer to what is actually happening. Neither of these models takes into account the delay due to meeting other vehicles. Since they do not, there is no reason why the delay method used for the single-lane BNG method cannot be used for these models also. The results including this delay are shown in table 2. The delay is assumed to apply to the empty trucks.

*Table 2.--Travel time including delay with BNG double-lane and VOCM (seconds).*

| | Segment 1 | Segment 2 | Segment 3 | Total |
|---|---|---|---|---|
| Unloaded: | | | | |
| BNG Double-Lane | 259.9 | 216.6 | 828.4 | 1,304.9 |
| % of Field | 127.8 | 110.5 | 118.4 | 118.7 |
| VOCM | 188.4 | 170.6 | - | - |
| % of Field | 92.6 | 87.0 | - | - |
| Field | 203.4 | 196.0 | 699.8 | 1,099.2 |
| Sum Loaded and Unloaded: | | | | |
| BNG Double-Lane | 508.0 | 424.0 | 1,643.4 | 2,575.4 |
| % of Field | 122.3 | 108.7 | 105.1 | 108.7 |
| VOCM | 369.9 | 340.2 | - | - |
| % of Field | 89.1 | 87.2 | - | - |
| Field | 415.3 | 390.2 | 1,564.2 | 2,369.7 |

The effect of adding on this delay is to make the travel times predicted by the BNG double-lane model as high as 128 percent of the field travel times, with an average of 109 percent. VOCM travel times are increased and brought to 87 to 93 percent of the actual travel times.

No conclusions can be made based strictly on the results of this study. However, combining the results of this study with Jackson's results indicates that the BNG single-lane model is very conservative. Neither the BNG double-lane model nor the VOCM model predicted travel times that were close to the actual travel times, but both were significantly better than the BNG single-lane model.

BNG lends itself more readily to Forest Service applications than VOCM. VOCM simply requires a level of data that is too detailed for our day-to-day needs. VOCM would be more useful as a research tool than as a planning tool.

## CONCLUSIONS

The BNG single-lane model predicted travel times that were significantly longer than those observed in the field. The BNG double-lane and VOCM models both predicted travel times that were closer to those observed in the field than the BNG single-lane model did. VOCM requires data that are too detailed to make it useful for predicting travel times on planned or existing roads that do not have a detailed survey. Because of the difficulty in obtaining accurate travel times from either of these models, obtaining actual travel times in the field may sometimes be the best option for existing roads.

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# Log Truck Performance on Curves & Favorable Grades

*Ron Jackson*
*Logging Systems Specialist*
*Gifford Pinchot National Forest*

## INTRODUCTION

The high cost of road construction forces consideration of the economic tradeoffs of construction costs against hauling costs. In addition, network analysis requires the ability to estimate the variable costs of hauling over roads. To adequately do these things, we rely on predictive models that estimate the effects of various design alternatives on vehicle travel speeds. In the Forest Service, most estimates of the effects of road design on travel times are based on the original approach developed by Byrne, Nelson, and Googins, commonly referred to as "BNG" (1).

Few published studies of log truck travel times have been done in recent years. The classic study of BNG is probably the most well known and widely used. During the subsequent 30 years, advances in truck technology, including the introduction of the Jacobs engine brake, have changed the braking ability of log trucks on favorable grades. Previously, it had been necessary to use cumbersome water-cooling devices to control brake temperatures while descending the steep mountainous terrain frequently encountered in logging operations in the West. In addition to better braking methods, improvements in engines, transmissions, and steering, along with the introduction of CB radios, have contributed to safer, more efficient log transportation today. Some of these technological changes can be expected to affect the accuracy of travel speed estimates based on pre-1960 truck technology.

This article presents the results of a recent study at Oregon State University (2) and some later work, which evaluate the assumptions contained in this model, and one other, the Vehicle Operating Cost Model (VOCM), which uses somewhat different assumptions (4).

## OBJECTIVES & SCOPE

The purpose of this study was to gather and analyze log truck travel speed data on selected favorable grades and curves and to compare the results to existing methods of travel time estimation. This study was limited to favorable (downhill) grades because most of the loaded haul cycle from forest to the mill is usually on favorable grades. Four specific objectives were identified:

(1) Compare observed speeds of log trucks on individual curves and favorable grades with speeds predicted by the BNG study. The BNG study assumed that sight distance controls speeds for curves on single-lane roads, and it used an empirically derived relationship for speeds on grades.

(2) Compare observed speeds of log trucks on individual curves and grades with speeds predicted by the VOCM. The VOCM assumes that available friction controls log truck speeds on curves and that engine-braking horsepower controls speeds on grades.

(3) Compare the BNG method and the VOCM with observed speeds over a portion of road to determine how well they predict overall trip speeds when the effects of curvature, grade, and speed transitions are included.

(4) Examine the appropriateness of extrapolating the BNG data to steeper grades. Today, many roads are being built on steeper grades, and travel speeds for these grades are not available except through extrapolation of existing data.

## DATA COLLECTION

Data were collected at three different locations in western Oregon. Travel times were recorded for a variety of log truck makes, models, and ages. Drivers sampled included both drivers who drive a truck owned by a trucking company and who are paid an hourly rate and independent contractors who own their own trucks and who are paid by the gross scale of the logs hauled. A total of 21 different drivers and trucks is represented in the data. Log trucks in this study were 18-wheelers, having engine horsepowers of 350 to 450 and weighing approximately 80,000 pounds when fully loaded. Drivers interviewed had from 10 to 30 years of experience. Data collected were grade, curve radius, superelevation, sight distance, ditch depth, width, time of day, and maximum engine-braking horsepower. Regression models were developed using time study data collected.

## RESULTS

The primary factors thought to influence vehicle speeds on single-lane roads are grade and alignment. Other factors, such as superelevation, surface type, width, and traffic type and levels, also can affect travel speeds.

### Speed on Grades

Downhill (loaded) truck speeds from the time study data were shown to be independent of grade up to 11 percent (figure 1). On favorable grades steeper than 11 percent, grade strongly influences truck speeds. The most probable explanation is that alignment sets the speeds on these roads when grade is less than 11 percent. This is typical of many forest logging roads where alignment would be classified as poor, as on this road. The relationship developed by BNG predicting speed versus favorable grade is for roads free of the effects of alignment. In mountainous terrain, few logging roads will be completely free of the effects of alignment. When selecting sites for this study, it was difficult to find any road sections that were not influenced to some degree by alignment.

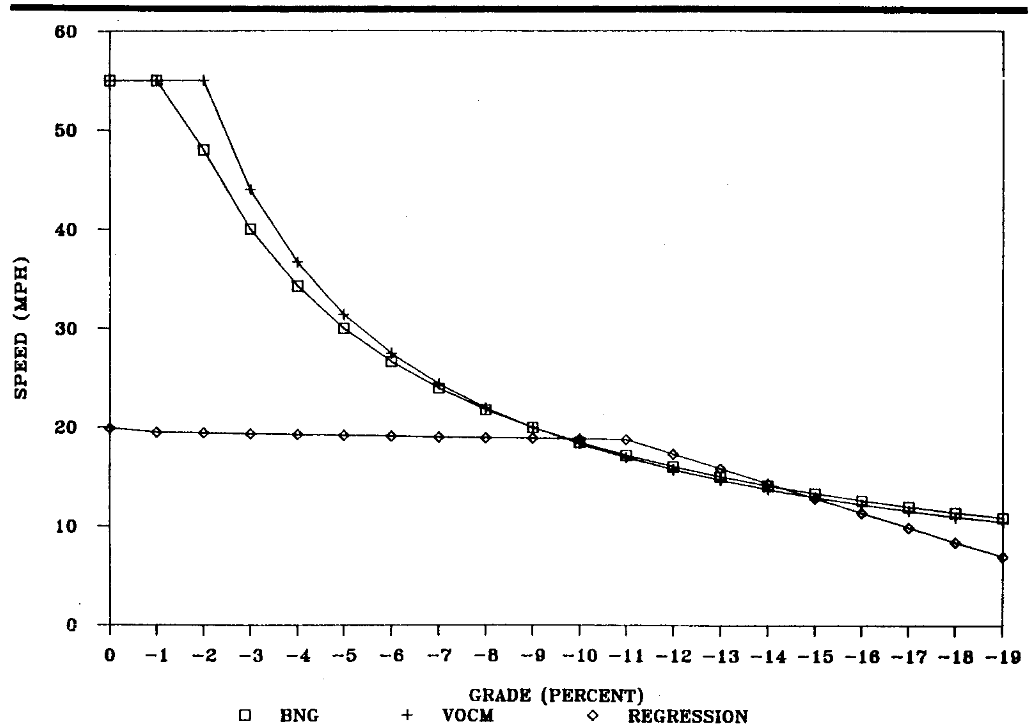


*Figure 1.--Speeds on grades predicted by BNG, VOCM, and regression model (loaded trucks).*

It seems that both the BNG and VOCM methods predict speeds reasonably well for favorable grades between 11 and 16 percent. For steeper grades, the observed speeds were slower than would be predicted by both methods. In this study, because of the poor alignment of the roads, no conclusions could be drawn concerning the speed versus grade relationship of these methods on grades below 11 percent.

Uphill unloaded travel times were affected by grade in a manner similar to the loaded trucks. Uphill times would be expected to be limited by alignment, traffic, and other factors, but not limited by grade on these roads. The horsepower-to-weight ratios for unloaded piggyback trucks were sufficient to permit travel uphill at nearly 38 miles per hour when grade was the only limiting factor. The data offer no explanation for the similarity in speeds between the unloaded and loaded trucks. Several drivers commented, however, that, "You generally go downhill in the same gear that you go uphill in."

### Speed on Curves

Figure 2 shows the relationship between curve radius and truck speeds observed in this study. The relationship between curve radius and speed indicates that truck speeds were less sensitive to increasing radii than predicted by either BNG or VOCM. The slope of the regression equation produced is somewhat flat above a 150-foot radius. This implies that truck speeds for this road are not affected by observed data so the other models are therefore valid. If adjacent road sections had affected the observed speeds, the differences between the observed speeds and the speeds predicted by BNG and VOCM would be even larger if the observed speeds were adjusted to eliminate the effects of adjacent segments.

Several drivers mentioned the importance of planning evasive action when driving on curves. With the curve widths on this road, it was sometimes possible for two meeting trucks to pass, provided they both kept to their sides of the road. This sometimes resulted in using a shallow ditch or other area that was not actually part of the usable road width.

## OVERALL COMPARISON

An overall comparison of predicted speeds against observed speeds using BNG and VOCM was carried out on a 7.71-mile section of road. Curve radii on this section of road ranged from 68 to 1,000 feet, and favorable grades ranged from 2 to 14 percent. Figure 3 shows the results of this comparison.

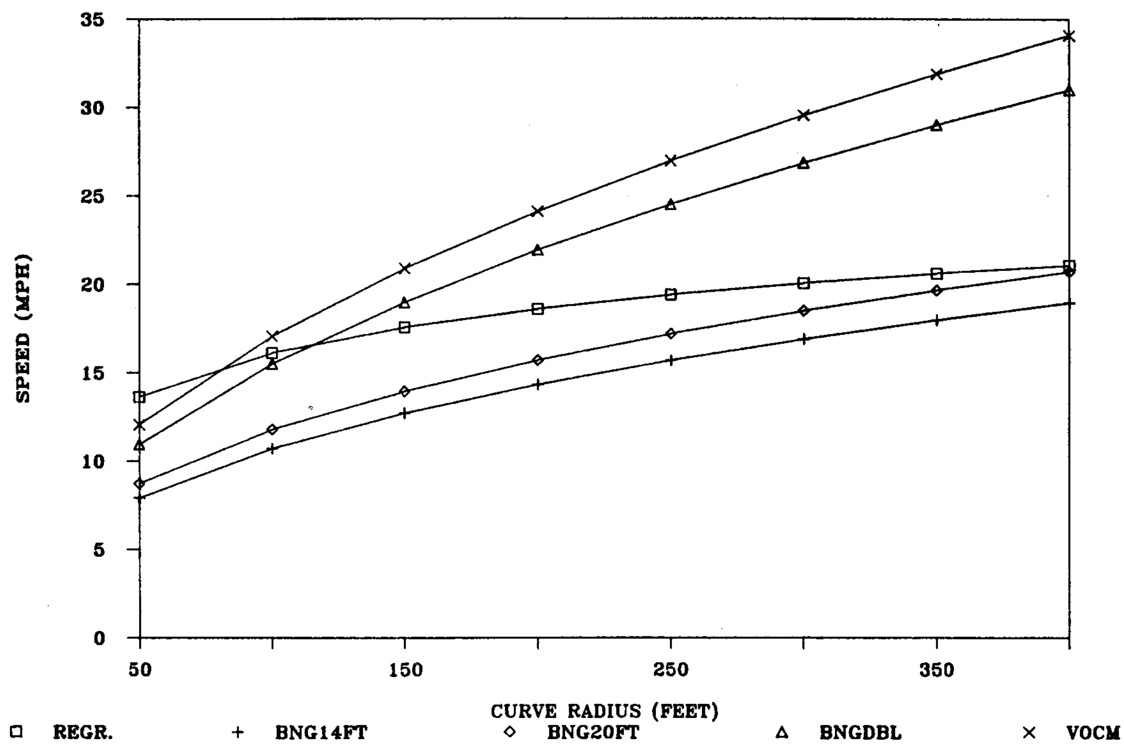


*Figure 2.--Speeds on curves predicted by BNG, VOCM, and regression model (VOCM does not use superelevation).*

Empty trucks were observed to travel an average of 4.4 percent faster than loaded trucks. However, the variation was large enough that no statistically significant difference between loaded and unloaded truck speeds could be determined. Speeds of the empty trucks were 20.2 percent faster than that predicted by BNG, while the loaded speeds were 13.1 percent faster than predicted. Round-trip speeds averaged 16.7 percent faster than predicted using the BNG method.

The VOCM seemed to predict observed speeds fairly well. When the mean superelevation was sampled and the mean engine-braking horsepower of the trucks in the study was used, the predicted speeds fell within the 95 percent confidence interval of the observed data. This suggests that the VOCM may be a good predictor of log truck speeds on roads similar to those in this study.

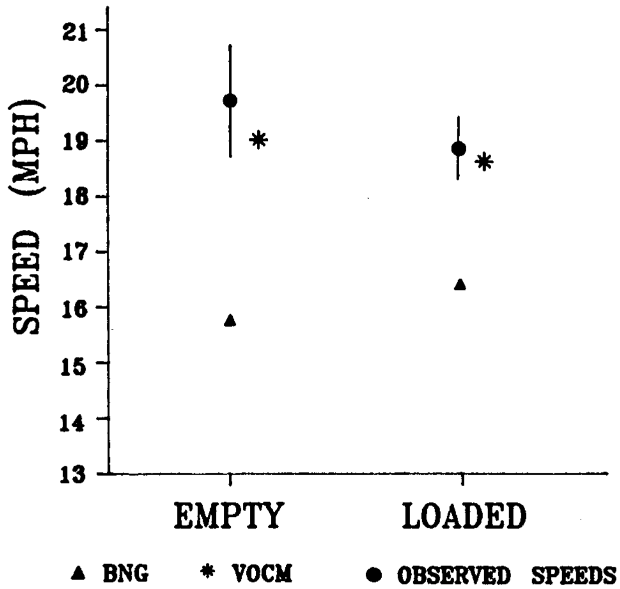


*Figure 3.--Comparison of BNG and VOCM with observed data over 7.71 miles of road (95 percent confidence limits of observed data shown).*

## IMPLICATIONS for ROAD DESIGN & CONSTRUCTION

The implications of this study could have important consequences for road design and construction. If previous assumptions concerning the effects of various road geometry factors on speed are not valid, these faulty assumptions may be leading to designs that are more expensive than needed. The marginal benefits of increased hauling speeds gained from alignment improvements may not be realized to the extent predicted if the models overestimate these gains. The rate of change of speeds with curve radius are more rapid than the observed data show. If the observed relationships are accurate, the reduced travel time predicted for improved alignments may not be as great as expected.

Construction costs can be greatly increased by increasing the radius of curve in a given situation. When comparing speeds predicted by BNG to observed speeds, it can be seen that observed speeds on a 100-foot curve radius were equal to speeds predicted using BNG for a 250-foot curve radius and using VOCM for a 100-foot curve radius. Nelson calculated costs for excavation and hauling for a variety of curve radii in a representative situation (3). For example, for a 100-foot curve radius, the excavation quantity required on a 28-percent side-slope was 1,800 cubic yards. For a 250-foot curve radius, the excavation quantity was 8,500 cubic yards (4.7 times more). Assuming a cost of $1.50 per cubic yard for excavation, this would result in a cost difference of $10,050.00 for this one curve.

The predicted reduction in travel time by going from a 100-foot curve to a 250-foot curve radius would be greater using BNG than using the observed data. If the full reduction in travel time assumed did not occur (as may be the case based on this study), the extra excavation would not have provided the same benefits as anticipated.

The estimate of the differences between speeds on curves is felt to be conservative because the calculations for speeds using BNG or VOCM are based on a constant velocity on curves and grades and they do not include the acceleration or deceleration present in this study. If these factors were included, both BNG and VOCM would predict even slower times, which would make the differences even greater than observed.

## CONCLUSIONS

The method used by BNG and VOCM seems to predict log truck speeds reasonably well for favorable grades free of alignment between 11 and 16 percent. The study could not conclude anything for grades less than 11 percent. Extrapolating the data above 16 percent could produce errors. On curves, the assumption that sight distance controls speeds did not seem to be valid. Neither BNG nor VOCM predicted speeds on curves well. However, when an overall comparison was made, the VOCM predicted log truck speeds well, while BNG underestimated speeds by 15 to 20 percent. The other variables of superelevation, width, ditch depth, time of day, sight distance, and engine-braking horsepower were not significant in affecting speeds in this study. EFN

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# Road Program Costs: Continuing Efforts Addressing the Issue

*Billy J. Reed*
*Chief*
*Engineering Management Branch*

## ROAD ANALYSIS & DISPLAY SYSTEM

In September 1986, the Chief and his Staff assembled and gave a six-member, interdisciplinary working group a charter to develop a process that provides for an objective measurement of Regions/Forests progress in managing road program costs. Simply stated or implied, the group was to:

(1) Be unconstrained by existing laws, policies, or processes if changes are needed to achieve the objectives; the benefits of new data requirements should, however, outweigh the costs of collection.

(2) Develop measurable criteria for the Chief to monitor and evaluate the efficiency of the road program.

(3) Provide for evaluating Regional effectiveness.

(4) Provide for Region and Forest comparisons.

(5) Allow for the tracking of funds.

(6) Avoid burdensome processes.

(7) Address total transportation costs affected by transportation decisions.

In February 1987, the Working Group submitted the ROad Analysis and Display System (ROADS) report. The objective of ROADS is to facilitate collection and display of information and describe how to monitor, evaluate, and present this information. Key indicators will provide guidance for:

(1) Tracking efficiency of expenditures.
(2) Measuring performance of managers.
(3) Comparing within and between units.

(4) Identifying relationships to other resource activities.
(5) Presenting annual program proposals.
(6) Monitoring road management objectives.
(7) Prioritizing project and program allocations.

The Chief's direction is to implement ROADS with the FY 1988 program. Successful implementation of ROADS and continued efficient management of the national road program will require complete support of Regional Foresters and Forest Supervisors. We recognize that the system is not perfect but intend to implement, review, and refine as needed. The use of the described "comparable units" is one example of this. The Forest groupings are a first cut at defining organizational units that may be expected to have similar costs. We will test and revise to ensure an equitable process, with an overall emphasis placed on the individual unit and its ability to improve management. This, too, is where we will concentrate our efforts in performance evaluations and reviews.

When the new system is fully implemented, it should produce, at a minimum, a 1- to 2-percent improvement in the cost-effectiveness of the overall roads program over the next 5 years. Based on our FY 1987 program, this means an approximate savings of $2 million per year.

For more detailed information, refer to the ROADS Report and the Chief's 7700/1930 letter dated February 19, 1987.

# An Evaluation of Timber Sale Scheduling Using the TRANSHIP Computer Model

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## INTRODUCTION

When planning harvest activities in a forest, it is useful to determine which combination of roads and harvest units best meets management's objectives. Some analysis techniques consider both fixed costs, such as road construction, and variable costs, such as log haul and road maintenance, if the logging unit location and harvest date are predetermined.

### Model Description

Of these programs, the Integrated Resource Planning Model (IRPM) is the only model that uses a technique that can assure the analyst of an optimal answer to this fixed and variable cost problem. It is also the only model that can analyze even more complicated situations than this fixed and variable cost problem.

TRANSHIP is a variation of IRPM. The main difference between the two is that TRANSHIP uses an additional program, NETWORK, to set up the equations for the transportation problem.

TRANSHIP allows a wide variety of resources to be considered. For instance, TRANSHIP can keep track of how much sediment is being produced by road construction and timber harvest and can determine the maximum present net value that can be obtained within a specified sediment constraint. TRANSHIP can also be used to maximize or minimize resources other than dollars. For instance, the objective could be to minimize sediment in the stream or to maximize volume.

Not only can TRANSHIP find an optimal solution when the timber unit harvest schedule is predetermined, but it also can select the units that produce the optimal solution. With the other models, the schedule must be fixed. An optimal schedule can be approached by iterating different sale schedules.

When TRANSHIP is used to select units, adjacency constraints often need to be incorporated into the formulation. This constraint ensures that, if a given unit is harvested in a given time period, then an adjacent unit cannot be harvested in that same time period.

TRANSHIP also can be used to deal with transportation problems. It can deal with questions such as what road standard to construct, whether a road should be paved, which roads should be built, how much traffic will be using a road, and which way timber will be hauled. It can consider a variety of different types of vehicles and can handle a variety of different types of products. It allows consideration of up to six time periods. Different types of vehicles can also be considered at the same time. Different types of vehicles and products can be given different generators and attractors (that is, sales and mills).

There are a number of ways in which the problem can be constrained to give a desirable solution. For example, the timber volume taken in a given time period can be required to take at least some minimum amount, or some maximum amount, or both. Another example would be to constrain the amount of volume that could be taken from units that are classified as tractor logging. A third example provides the capacity of a road so that if more traffic is to be carried, a higher standard of road must be constructed. Different traffic types can be weighted differently, if desired. For instance, a log truck can be weighted to have the same influence on capacity as two pickups. Another possible constraint would be to place a ceiling on the amount of money that could be spent on road construction in any one time period.

Most techniques that seek to solve this forest planning problem use heuristic algorithms. Instead of doing this, TRANSHIP uses linear and mixed integer programming. When run as a linear program (LP), the solution can be to build any of the roads or harvest any units at any level between 0 and 100 percent. Ideally, the roads and possibly the units should be taken entirely (100 percent) or not at all (0 percent). The way to accomplish this is through the use of the mixed integer programming (MIP) phase of TRANSHIP. Unfortunately, this requires extensive computer time, and solutions can become very expensive.

An alternative to MIP is the heuristic approach (HIP), which uses predetermined procedures to decide which variables should be made integers. This procedure tries to provide a good solution without claiming to give an optimal solution.

### Problem Definition

The specific problem addressed in this project was to determine the optimal harvest pattern as well as roads and hauling scheme for a planning area. Units were constrained so that adjacent units could not be harvested in the same time period. Harvest volumes were constrained to a certain level in each time period.

### Study Objectives & Scope

This study had two main objectives. The first was to use the LP and MIP portions of TRANSHIP to choose the logging unit harvest pattern as well as the roads and hauling pattern that optimized present net worth (PNW), while meeting adjacency and volume constraints for an example problem. The second objective was to document the difficulty in using TRANSHIP and assess the practicality of using the model routinely.

Only the LP and MIP phases of TRANSHIP were used. Running and comparing HIP with the other solutions would have taken more time than was available; consequently, it was not undertaken.

## STUDY PROBLEM DESCRIPTION

To make the problem manageable and to complete the project in the allotted time, it was decided to keep the problem fairly small. Rather than try to find an actual problem that would accomplish our objectives, an example problem was developed to evaluate. It was desired to have a problem big enough so it would not be intuitively obvious what roads should be built and which units should be harvested, yet small enough to be manageable.

Figure 1 is a schematic showing the general road and unit layout that was chosen. Figure 1 is for illustrative purposes only since the units actually vary in size and roads vary in length. The schematic is assumed to be accurate for the purpose of determining what units are adjacent to each other.

Some other assumptions also were made. The analysis was made over three time periods, 15 years apart. Maximum constraints of 15 million board feet (MMBF) in year 0 and 10 MMBF in years 15 and 30 were placed on timber harvest. This is less than the total amount of timber available, so some volume would

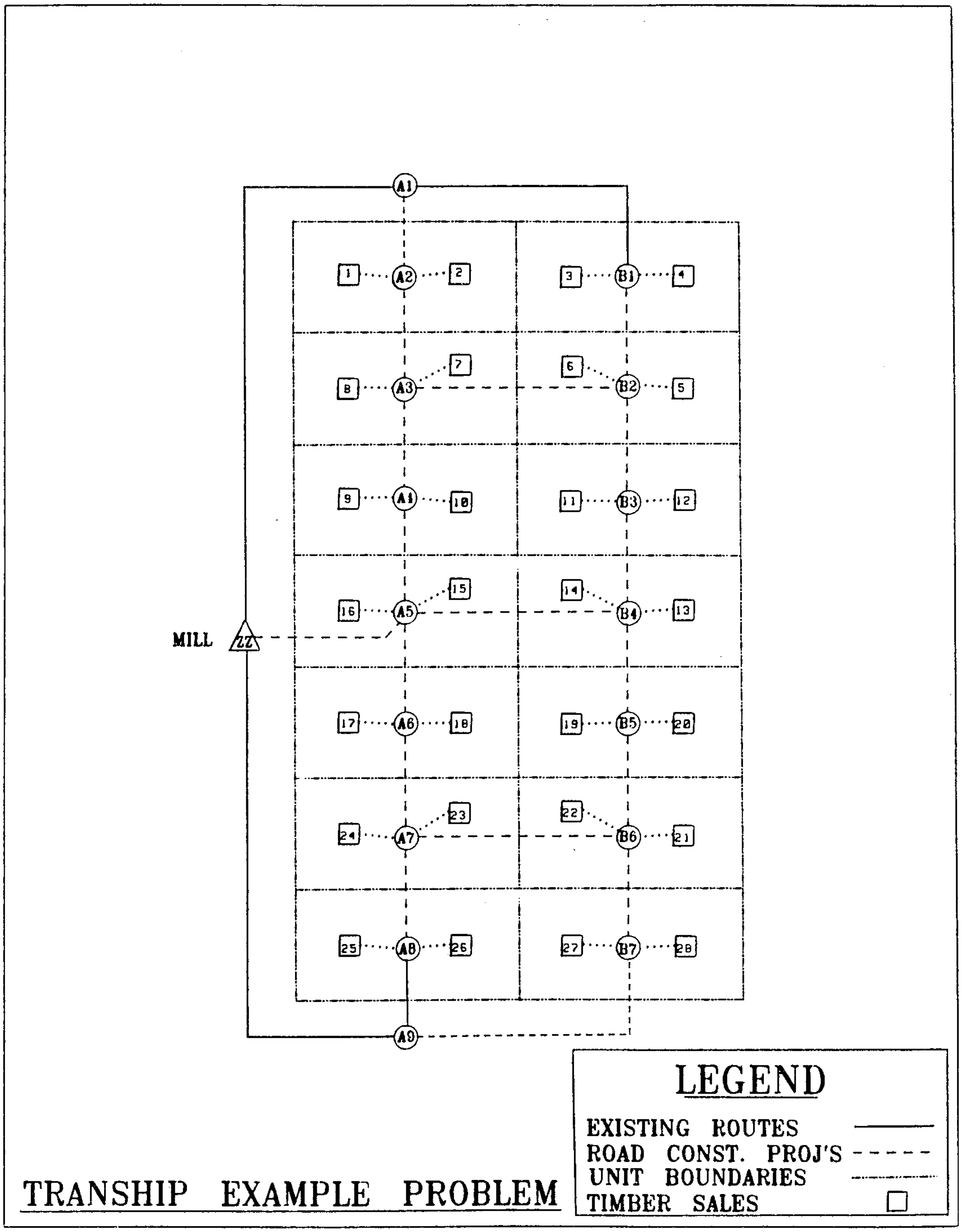


*Figure 1.--Network schematic.*

remain unharvested at the end of the 30-year planning period. The interest rate that was used was 4 percent.

## CARD TYPE FORMULATION

The cards for this study project were created by using the basic capabilities of the Data General computer currently installed in most Forest Service offices. The repetitiveness of the data can be eliminated by using the "Duplicate" and "Substitute" commands on the Data General. For example, the NB, NC, ND, and NE cards all have data that are similar. By creating only one file and duplicating the other files, a vast amount of keypunching was eliminated.

## RESULTS & DISCUSSION

The results of the analysis are shown in table 1 below. The computer costs are given for each of the runs as a means to relate the complexity of the problem to the cost of running the model.

The first LP run selected many of the units and roads at a fractional level, and some of the roads were built in two time periods. This is acceptable for the resource projects but provides a nonfeasible solution for the road projects. Since stage construction is not considered in this analysis, the road projects must be selected at the 100-percent level or not at all. Therefore, the results from this run are not entirely useful.

*Table 1.--Analysis results summary.*

| Run | Description | PNV (K$) | Computer Cost |
|---|---|---|---|
| 1. | Linear Program | 3891 | $22 (Demand) |
| 2. | MIP--Roads Set as Integers | 2755 | $63 (Batch) |
| 3. | Roads and Time 1 Set as Integers | 2566 | $84 (Batch) |
| 4. | LP--No Road Construction | 4179 | $22 (Demand) |
| 5. | Manual--No Road Construction | 4114 | - |

It is important to run the problem first as an LP solution in order to check the results for errors. The relative cost of an LP run compared to an MIP run is significant. LP runs cost a fraction of MIP solutions, and therefore it is important to run the LP solution first, even if the results are not entirely usable. The LP run also provides indications of where variables should be identified as integers, thus potentially reducing the cost of subsequent MIP runs. The LP solution also identified several instances where timber was hauled on different paths from the same unit providing a volume split. This is also undesirable but should not have a significant impact on the results.

The second run was the first MIP solution. All the roads were set as integers and the model run until reaching an optimal solution. As expected, the present net worth was much lower than the LP solution. This alternative was run in order to provide a realistic solution.

The third run attempted to force all units as integer values by specifying units in time period one as integers, with the hope that all the other units would become integers. By forcing units in time period one as integers, the solution decreased in value by approximately $150,000. This indicates that for this study problem, a cost of $150,000 exists by forcing the program to consider the unit boundaries identified in the problem formulation.

After completing the last three runs, we concluded that the most desirable answer was that found by specifying the roads as integers and allowing the units to vary between 0 and 100 percent. This solution was the most useful because it identified the amount of each unit to include in the solution. This would inform the land manager of the best unit size and mix to arrive at an optimal answer. This solution may not be desirable to the land manager; however, it identifies a good starting point. Various alternatives can be devised with knowledge of what is optimal, and the cost of deviating from the optimal can easily be determined. By harvesting full units, most probably stands, the amount of revenue is reduced.

The fourth and fifth runs were prepared to compare selection of units using manual procedures to the solution identified by TRANSHIP. Eliminating roads as part of the problem and using human judgment and insight, units were selected in specific time periods to determine how close the planner could come to the optimal solution. After manually selecting units with the objective of maximizing present net worth and then running the problem through TRANSHIP, a $65,000 increase resulted from using TRANSHIP. This shows that it is very difficult to identify the optimal solution manually when considering adjacency constraints. This would support the study performed by Greg Jones at the Intermountain Research Station, which showed that an increase in benefits can occur by using the TRANSHIP model.

## COMMENTARY on the USABILITY of TRANSHIP

Because there seems to be so much confusion as to whether TRANSHIP is too cumbersome to be of any practical value or not, we felt that it was important for us to comment on our experience in learning it.

Because of the complexity and flexibility of the model, it is more difficult to learn than other network analysis models. First, it is available only on the Ft. Collins Computer Center computer. This means that facilities are needed to access this computer, as well as requiring a certain skill level. Having computer personnel available to answer questions is almost a necessity when working with this system. A general knowledge of LP and MIP is necessary to understand how the model is solving the problem.

The most important task is formulating the problem correctly. This is complicated by the fact that the user's manual leaves numerous questions unanswered, and there are only a few people who have experience with TRANSHIP. Because there are so many different applications for the model, the particular application for which you would like to use the model is likely to be significantly different than those that other people have run. In addition, the troubleshooting can be a formidable task because of the sheer number of card types and the length of the files. A user could spend 2 months working with an initial problem of a small size before beginning to feel comfortable with the model.

The data input process has been streamlined by the various methods available so that it is no longer a major part of the process.

Once the model is learned, it is reasonably friendly and easy to use. To effectively compare its ease of use with other models requires that the same problem be attacked by the different models. Running a standard network analysis where the units and time periods are preselected and only the road construction and haul need to be determined would have been a much easier problem for us to set up and solve. It would still take considerably longer to formulate and run this simple problem with TRANSHIP than with other models. For this type of a problem, one of these other models may be sufficient. Some accuracy may be lost by using other models even on these problems because they do not always give optimal solutions for the fixed and variable cost problem, whereas TRANSHIP can. However, to analyze a type of problem that is any more difficult than the one analyzed here will require the use of TRANSHIP.

In summary, it is a more difficult and time-consuming model than others, but that is the cost of having a more powerful tool, which does a better job of answering the complex questions that arise in resource management.

## CONCLUSIONS

The LP solution should not be considered and used as the final solution to a problem, including road construction projects. Rounding of the road projects' variables to whole numbers can lead to suboptimal solutions. The LP solution can be used to determine whether variables should be set to integers, thereby reducing the cost of an MIP run.

The TRANSHIP model is difficult to learn in its present state. TRANSHIP is easy to use after understanding how the model determines solutions and knowing which card types are required to formulate the problem. The model is a very powerful tool and cannot be matched by any other network analysis model presently in use.

TRANSHIP effectively schedules timber sale units with adjacency considerations in forest development applications.

TRANSHIP identified a savings of $65,000, as compared to performing the same analysis using manual techniques.

# Acoustic Emission Testing of Wood Products

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## INTRODUCTION

When things break, they snap. The sound of the material breaking is one indication that the material has been stressed too much. Other indications of stress include deformations and, in some instances, excessive heat (noticeable primarily during fatigue tests). The audible snap is part of the "acoustic emissions" (AE) that can be recorded and can give insight into failure processes during material testing. Scientists at the USDA Forest Products Laboratory (FPL) are exploring analysis of AE during testing of wood products.

AE are energy releases in a material in response to stresses. AE generated during testing of wood products are small bursts of energy that originate at small microfractures and macrofractures. They propagate through the material as elastic waves. Low-frequency AE are the source of creaking mine timbers and rock fracture that give early warning of mine collapses.

AE are a part of many processes. Some applications of AE technology may be related to uses in the Forest Service, such as the following:

(1) AE-type analysis of an ultrasonic sound wave passing through living trees may indicate areas of decayed wood. FPL is evaluating this procedure for decay detection in wood structural members.

(2) AE generated by water movement in a plant may be used to optimize watering schedules.

(3) The utility industry uses AE equipment during periodic proof loading of cherry picker booms. High rates of AE indicate a damaged boom.

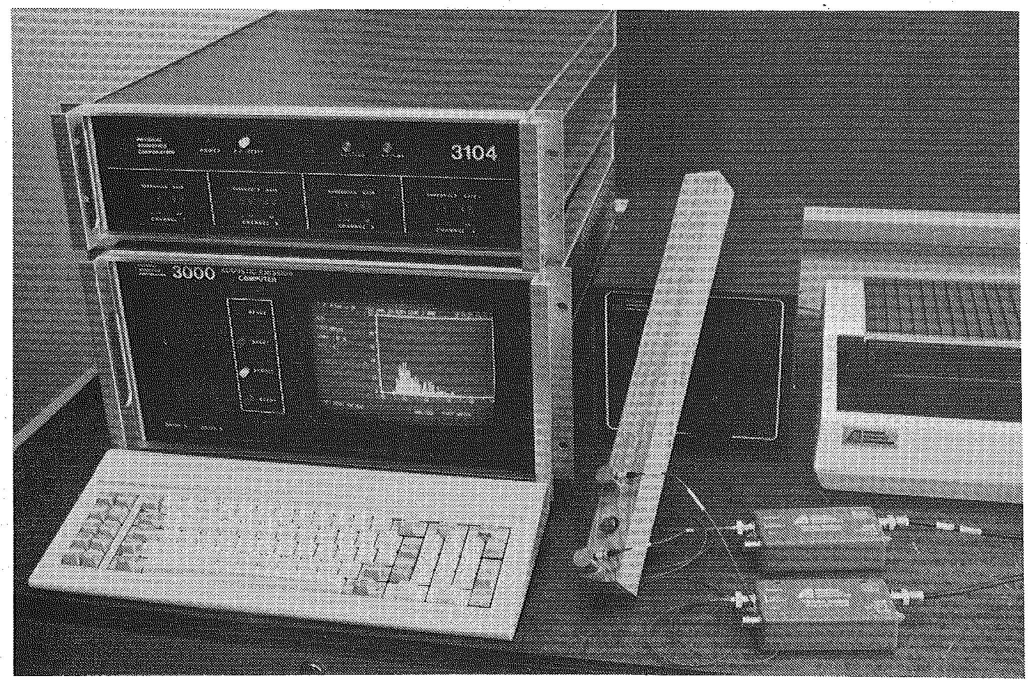


*Figure 1.--Piezoelectric acoustic emissions sensor attached to wood test specimen converts the acoustic emissions to an electrical signal, which is subsequently analyzed by the microprocessor and displayed on a microcomputer screen.*

(4) The nuclear power industry uses AE to indicate flow in pipes. AE also can indicate pipe leakage.

Scientists at FPL envision applying AE in many areas of wood science and wood engineering research. For example:

(1) It may be possible to optimize the drying rate of lumber by minimizing the microfractures "heard" in the form of AE as the wood dries.

(2) AE generated during destructive testing of wood products can give clues to failure location and failure mode.

(3) During proof loading, AE could be used to evaluate damage accumulation or glueline quality.

(4) AE generated at low stresses may show damage caused by redrying of treated lumber for fire retardant or preservative treatments.

Until about 10 years ago, AE testing was limited to areas where one could isolate the test material from sources of low-frequency acoustical noise (that is, audible noise). Current AE technology reduces testing problems by considering only frequencies between 50 kilohertz (kHz) and 1 megahertz (audible range is below 20 kHz). The analysis of AE data also has advanced because of "user friendly" microprocessor-based systems that include software and graphics for real-time data analysis.

## WHAT IS AE TESTING?

AE testing involves attaching AE sensors (piezoelectric transducers) to the wood product being tested (figure 1). Failure processes in the wood generate AE waves that propagate through the wood and excite the sensor in proportion to the energy contained in the wave. Subsequent signal processing includes amplifying, filtering, and determining event "parameters." Figure 2 shows the idealized AE burst "event" and defines AE event parameters such as counts, peak amplitude, duration, rise time, and energy.

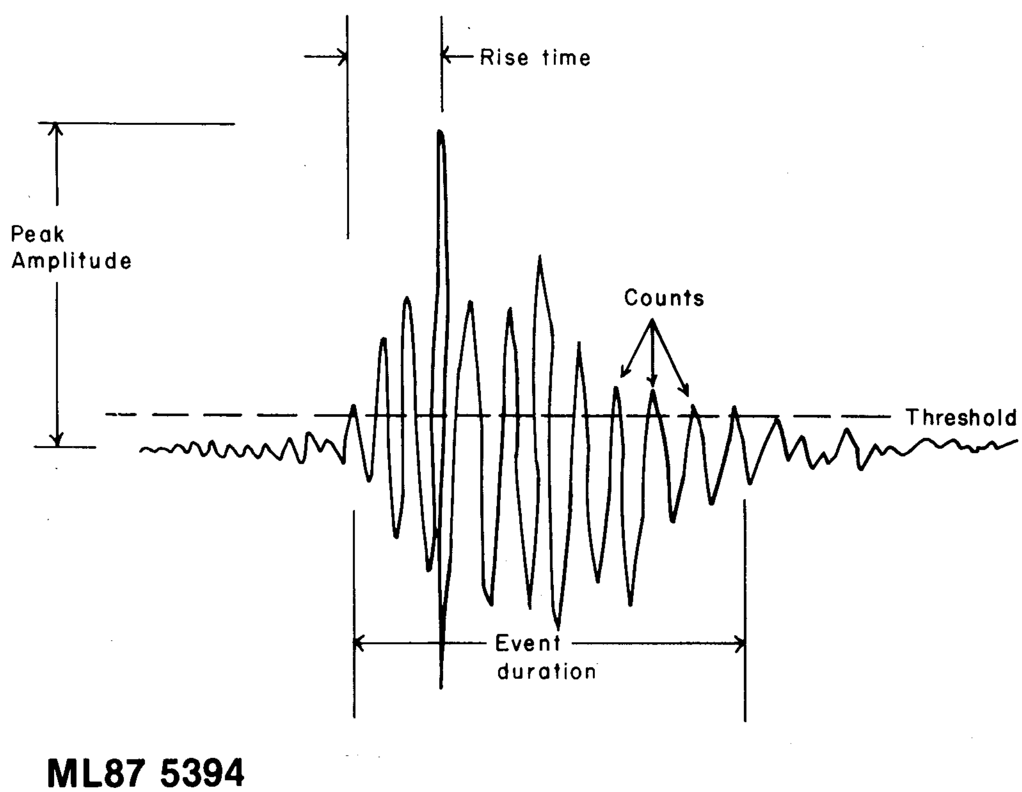


*Figure 2.--Idealized acoustic emissions burst event and parameters of the event. Area of the event above the threshold is event energy.*

Events per unit of time during the test give a relative measure of AE activity during different stages of the test. For example, figure 3 shows AE events per unit of time overlaid on a load-versus-time curve during tension tests of a bolted connection. Notice that very few AE were generated during the elastic or recoverable portion of the material response. AE events increased dramatically as the material response became nonlinear (that is, as the material was irreversibly deformed).

Using multiple sensors on the same test specimen allows one to determine the location of the AE source. The difference between arrival times of the "burst event" at different sensors determines the location of the event on a line between the two

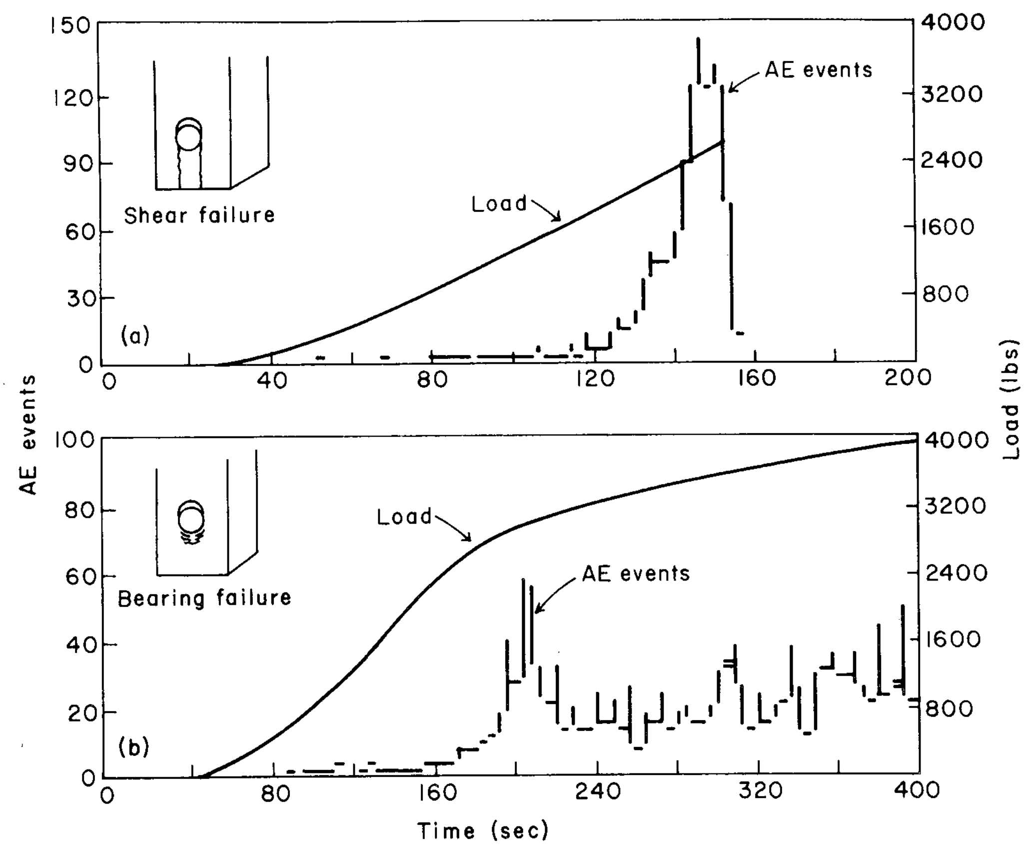


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*Figure 3.--Comparison of load versus time plots overlaid with acoustic emissions event rate plots for (a) shear failure and (b) bearing failure of a single-bolt connection.*

sensors. The location of AE in wood is complicated by the fact that sound travels along the grain about five times as fast as it travels across the grain. Nevertheless, linear location of AE activity along the grain is fairly accurate.

## HOW FPL SCIENTISTS ARE USING AE TESTING

Traditional laboratory testing of wood products for structural properties includes recording of the applied load and the consequent deformation of the material. From this load-deformation behavior, we evaluate how the material responds to stresses. Material stiffness (slope of the load-deformation curve) and strength give valuable insight into the quality and usefulness of the wood product for particular applications. However, deformations are only one indication of how loading energy is distributed in a test material.

Monitoring AE during testing of wood products can add a third dimension to the traditional two-dimensional (load and deformation) testing process. Because test specimens are increasingly complex, it is impossible to instrument every imaginable deformation mode. The location of AE sources and the relative intensity of the signal give qualitative measures of damage zones and failure modes. Adding AE analysis to a test can be compared to giving the sense of hearing to a person who could only touch and see.

The initial reason for investigating AE testing of wood was to find a tool that would locate failure progress during tests of multiple-bolt connections. However, because this is a fairly complex task, we began with simpler tests in which failure could be visually observed and the observation compared to the results of AE analysis. The first test involved bending a small wood beam with a notch cut in the tension face. As the test progressed and as a crack grew from the edge of the notch along the grain, we compared our observation of the growing crack with AE location and event rates.

The second method used to evaluate feasibility of AE testing on wood involved tension tests of single-bolt connections. In figure 3, load-versus-time plots for a bolted connection that failed because of wood bearing (noncatastrophic failure) are compared to load-versus-time plots of a similar connection that failed catastrophically in a shear-out mode. The rate of AE events versus time gave an early indication of the different failure modes.

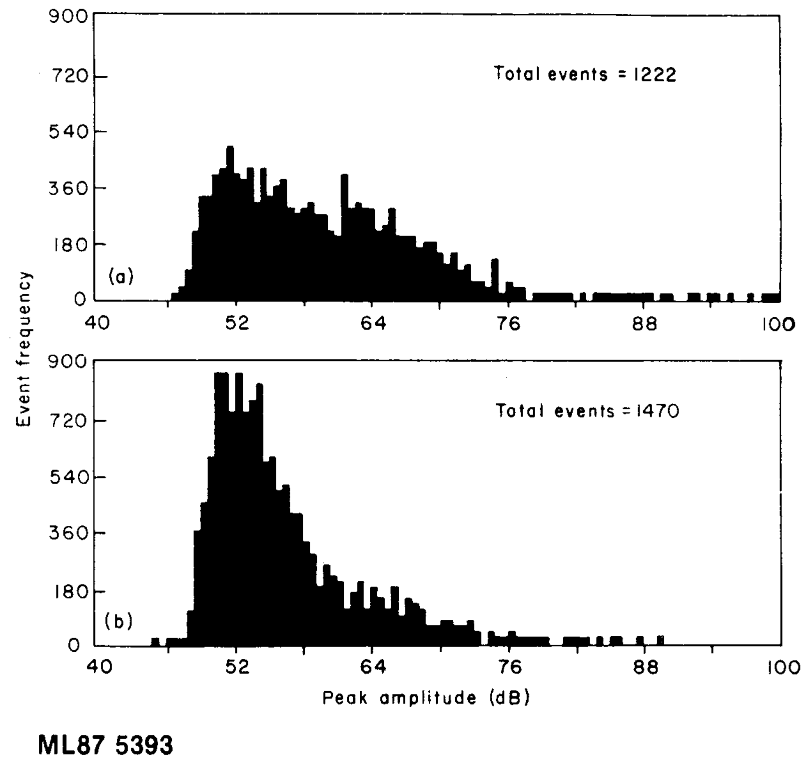


*Figure 4.--Comparison of acoustic emissions event amplitude distribution for (a) shear failure and (b) bearing failure in a single-bolt connection.*

Distribution of event peak amplitudes (figure 4) also indicated differences in the failure modes. These preliminary results show that AE data correlate well with observed failure phenomena.

Cooperative research between FPL and Virginia Polytechnic Institute and State University showed that AE generated during kiln drying of lumber could be used to control the drying rate and minimize drying defects caused by microscopic checking in the lumber (6).

AE analysis of a signal is not limited to emissions generated within a material. External ultrasonic pulses can be analyzed after traveling through a volume of the material. This technology is called acousto-ultrasonics. The loss of pulse energy as it passes through the material (that is, attenuation) is a function of the properties of the material. FPL scientists are investigating whether acousto-ultrasonics can be used to detect incipient decay in wood products. This effort is funded by a USDA Competitive Grant and, if successful, will significantly contribute to the nondestructive evaluation of wood members in service both within and outside the Forest Service.

## OTHER USES of AE TESTING

Analysis of AE promises to be a useful tool in many areas of wood products research. AE generated during wood-cutting processes can be used to evaluate tool wear (7). In a recent workshop on applications of AE testing to forest products, Calkin described monitoring AE of plants to set an optimum watering schedule (5). Because AE are generated in response to material damage, monitoring AE during proof loading may show damage caused by redrying treated wood. This concept has been used extensively in the composites industry during proof loading of fiberglass pressure vessels and "cherry picker" lift booms. Many general articles on AE testing provide valuable background on the technology (4,8). Other articles describe AE testing specifically of wood products (1-3).

## CONCLUSION

In our daily world, sound quality tells us whether our car needs new bearings, warns of a falling tree, and indicates whether equipment is operating as expected. AE equipment supplements the human brain and ear with piezoelectric transducers and computer memory. AE technology promises to add useful information to material testing at the Forest Products Laboratory. (EFN)

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# A Procedure for Analyzing Double-Lane Versus Single-Lane Roads

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## INTRODUCTION

A number of road agencies have roads that are one lane or one and a half lanes wide with turnouts. The Forest Service alone has more than 250,000 miles of single-lane roads (6). The question sometimes arises as to whether these roads should be widened to two full lanes.

The purpose of this article is to help an analyst in making a double-lane versus single-lane comparison. This is done by first educating the reader about the nature of the problem. Criteria that may be useful in making a road standard comparison are discussed. Different methods for obtaining these data are presented. A procedure is outlined for doing an analysis, and an example is given that shows how the procedure was used for an actual problem.

The Forest Service Road Preconstruction Handbook states that single-lane roads should be selected where projected traffic volumes are less than 100 vehicles per day, and double-lane roads should be selected where projected traffic volumes are greater than 250 vehicles per day (8). The correct number of lanes for roads with traffic volumes between 100 and 250 vehicles per day depends on other considerations in addition to the traffic volumes.

In 1982, a traffic study was done for the Mount St. Helens National Monument. Six single-lane roads were studied, both gravel and paved, which accommodated an average daily traffic (ADT) of more than 250. As a result of this study, Ou suggested that the Forest Service should consider raising from 250 to 400 the minimum required ADT for double-lane roads (6).

## METHODS of COMPARISON

There are two basic ways to compare the need for single-lane and double-lane roads. The first is to say that the problem is too difficult to make any quantitative study, and base the decision on a qualitative evaluation. This is what the Highway Capacity Manual approach does (2).

The second approach involves an economic analysis, including all the factors that can be quantified, and a subjective evaluation of the other factors.

## Level-of-Service/ Highway Capacity Manual Approach

Level of service as defined in the Highway Capacity Manual is a "qualitative measure describing operational conditions within a traffic stream, and their perception by motorists and/or passengers" (2). The level-of-service concept could be extended to include single-lane roads. Table 1 summarizes the Highway Capacity Manual descriptions for the different levels of service. Two characteristics are addressed: maneuverability and driver comfort.

Each of the different road types mentioned in the Highway Capacity Manual uses a different method to quantify the level of service. For example, for freeways, traffic density is used as the parameter to define level of service. A good parameter for measuring the level of service of a single-lane road would be the percentage of the total travel time that consists of delay. This would be the delay time divided by the total travel time. The design hour volume, which often is assumed to be the 30th highest hour during the year, would be used for this calculation.

Managers would determine what the acceptable level of service is. When a road begins to operate at an unacceptable level of service, then the standard of the road would be improved to bring the level of service back to an acceptable level.

*Table 1.--Level-of-service descriptions.*

| Characteristic | A | B | C | D | E |
|---|---|---|---|---|---|
| Maneuverability | Unimpeded | Slightly restricted | Noticeably restricted | Severely limited | Impossible |
| Driver physical and psychological comfort | Excellent | High | Increased tension | Drastically increased tension | Extremely poor |

Before this system could be used, the percentages of delay to distinguish among the different levels of service for single-lane roads would need to be determined. This would require a concentrated effort by a group of people working with several roads to determine appropriate values, which is beyond the scope of this project.

There are some limitations to this method of determining the level of service for single-lane roads. Because it does not take speed into account, a road with twice the speed capability of another road could have the same level of service. To determine the percentage of delay, a field study would need to be completed.

## Economic Analysis Approach

There are two types of costs for this approach: agency costs and user costs.

Agency Costs. Construction and maintenance costs are the main agency costs that need to be considered in a single-lane versus double-lane analysis. Most work units have a cost guide available to determine the construction cost and maintenance rates for both single-lane and double-lane roads for different surface types. Because of differences in terrain and the condition of the existing road, construction and maintenance costs can vary widely. Construction costs may require survey information if accuracy is required.

User Costs. Not only do costs to the road agency need to be considered, but also the costs to the road user. There are several types of user costs.

1. Vehicle Operating Costs. Vehicle operating costs include any value attached to the driver's time and the cost incurred in operating the vehicle itself, based on the speed and hourly cost of the vehicles.

The Logging Road Handbook (BNG) method is one way to predict travel times (1). BNG gives a method for determining speeds for log trucks if the power/weight ratio, surface type, grade, and alignment are known. The main advantage of this method is that it is quick and easy to use.

The Vehicle Operating Cost Model (VOCM) is another method available for predicting travel times (1). Engineers at Oregon State recently converted the model from the Ft. Collins computer to work on microcomputers. VOCM does not take into account opposing traffic or road width. It therefore is basically a double-lane speed predictor. VOCM calculates speeds for vehicles other than log trucks, such as passenger cars and pickups. A problem with VOCM is that accurate data are difficult to obtain for some of the factors that are considered.

There are so many variables affecting speed (such as surface type, traffic direction, dust, turnout spacing, road width, alignment, grade, and traffic mix) that neither of these models can be accurate for all situations. The most accurate way to get the existing travel times is to make actual field observations.

There are two components to the travel time difference between single-lane and double-lane roads. These are illustrated in figure 1. The difference between the travel time on a single-lane road with no meetings and a double-lane road is labeled A. This is the sight distance delay, which results because people drive slower on single-lane roads; they do not know whether or not an opposing vehicle is coming around a curve in their lane. A meeting is when two vehicles from opposite directions pass each other.

The amount of time that it takes to travel a section of single-lane road increases as the number of meetings increases. This increase in travel time over the travel time with no meetings is labeled B. The meeting delay, portion B, can be estimated by studying travel time on the existing single-lane road. The travel times need to be recorded for each vehicle. The road section must be short enough and have limited access at intermediate points so that the number of vehicle meetings can be found. Then a regression analysis can be done, where travel time is the dependent variable and the number of delays is the independent variable. The regression analysis gives an intercept and a slope for the line. The intercept is the single-lane travel time with no meetings. The slope is the amount of the delay for each meeting for a given vehicle type.

To determine the sight distance delay, the double-lane travel time must be determined. An estimate can be obtained in the field by simulating a double-lane road by creating a one-way traffic pattern. Speeds on a one-way road would approximate those on

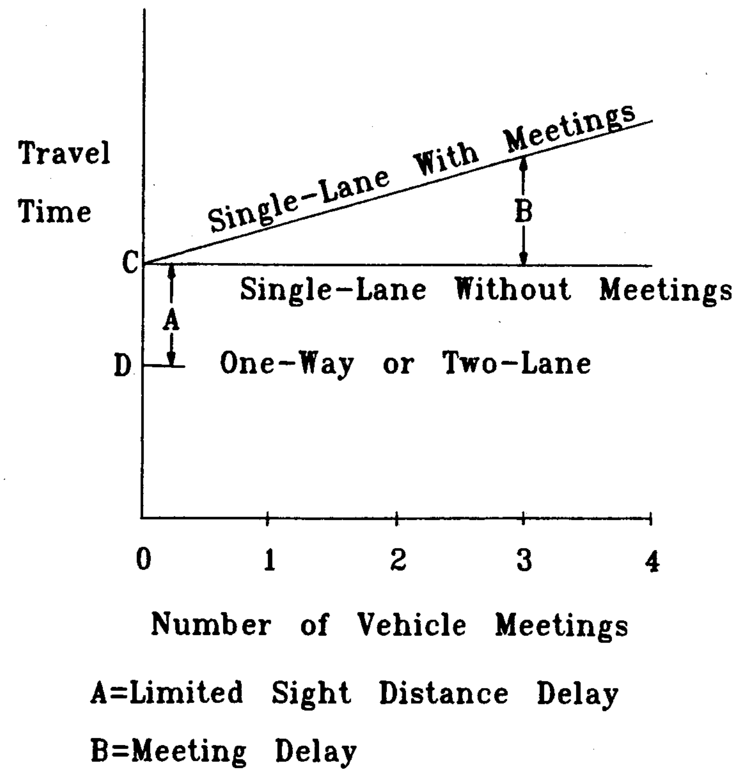


*Figure 1.--Travel time versus vehicle meetings.*

a double-lane, two-way road because neither situation has drivers worried about meeting oncoming traffic in their lane. This assumption would not be true if the double-lane road were not going to be built to a full width. Oglesby found that if the width of the roadbed were 24 feet or wider, there would be no friction between opposing traffic lanes (5).

The method of determining travel times for both the single-lane and double-lane roads based on travel times is called the field method. There are two ways that a one-way situation can be set up. The first, the detour method, detours traffic moving in one direction to an alternate route as needed. Then, if it is desired, the direction of the one-way can be reversed.

The other method, the stop-and-go method, requires a test section of road with a person at each end of it. Signs must be placed at both ends to inform vehicles of a one-way road ahead or to stop them. Traffic would alternatively be stopped from one way, allowing people to proceed unobstructed, then reversing the direction of traffic flow. The researchers could be equipped with CB radios at each end. By monitoring the log truck traffic, they could organize the one-way travel so that traffic is delayed the minimum possible.

There are potential problems with either way of creating a one-way road. People do not drive a one-way, single-lane road exactly as they do a two-way, double-lane road. It may take drivers awhile before they begin to drive the road as a one-way road. Either method will cause some delays. The stop-and-go method has the potential to be quite confusing. Both methods are useful only if the double-lane road is to be the same surface type as the existing road. The stop-and-go method is only useful if no major alignment changes are made.

There are three basic types of traffic: commercial, administrative, and recreation. Commercial and administrative traffic both require that the time of the operator and passengers be valued at a certain rate. With recreation traffic, the value attached to people's time is usually assumed to be zero (4). This is because for many recreationists, driving on forest roads is part of the recreational experience.

Per mile costs would be the same for both the single-lane and double-lane alternatives. So they do not need to be included. Tire costs are likely to be per mile costs rather than hourly.

There are at least two methods available for determining the hourly operation cost for equipment. VOCM calculates the vehicle operating cost by considering the characteristics of the road. Another tool is a program called PACE, which is available from the Forest Engineering Department at Oregon State University. Both tools will work well if accurate data are available.

2. Accident Costs. To date, no accident prediction method has been developed specifically for single-lane roads, yet in talking with individuals about single-lane versus double-lane road comparisons, the safety issue is often the first one to surface. It

seems obvious that single-lane roads are more dangerous than double-lane roads because there are two vehicles traveling in the same lane in opposite directions, creating the potential for a head-on collision.

Although potentially more dangerous, single-lane roads often do not have high accident experiences. Oglesby stated that people drive at their fear level; because low-standard roads have more characteristics that make them potentially more dangerous, people tend to be more alert and cautious when driving these roads than when driving high-standard roads (5). Because of this, some low-standard roads actually have lower accident rates than high-standard roads. Even if accident rates are lower on double-lane than single-lane roads, the chance of serious accidents occurring may be greater on double-lane roads because of higher speeds.

There are two basic ways that road safety can be analyzed. Accident potential can be based either on accident data for a specific location or on safety relationships based on accident experience at similar locations. Both methods are addressed by Layton (3). Comprehensive and accurate safety records are necessary to use the accident records analysis approach. These types of records are rarely available for long periods of time for forest roads, and especially for single-lane roads. In addition, the traffic volumes on these roads are low enough that it is difficult to find accident locations with statistically significant accident rates.

The roadway elements analysis approach is more applicable to low-volume roads where few or no accidents have been reported and where accident reporting and statistics may not be very good. It uses research findings and accident experience with similar roadways to estimate the accident potential for the road in question. The problem is that this type of data has not been gathered for single-lane roads, only for double-lane roads, including some as narrow as 16 feet.

The question is whether or not single-lane roads function like narrow double-lane roads where accidents are concerned. Some lane-and-a-half roads seem to function as double-lane roads, but the narrower roads are likely to have different characteristics than double-lane roads.

Since the data for the roadway elements analysis approach are from double-lane roads, the characteristics for single-lane roads are many times near or out of the range of the data that were used to construct the nomographs. This is typically not a problem for single-lane roads that are being considered for reconstruction to double-lane standard because these roads normally have better geometric characteristics.

3. Benefit Calculation Considering Attracted Traffic. When an existing single-lane road is widened to two lanes, it is very likely that the traffic count will increase. Some of this is due to the attraction of traffic from other roads in the area, and some is due to newly generated traffic. Figure 2 shows a supply/demand curve depicting this situation. One parallel secondary road is used to represent all the roads from which traffic is attracted. The supply curve is the cost to the user of supplying service to a given number of vehicles. The demand curve shows the number of vehicles that are willing to pay a certain amount to be able to use the road. The unit price is the cost that the user sees (vehicle operating and accident costs). An equilibrium will be reached at the point where the supply and demand curves meet, usually at a point less than the capacity of the road. When the primary road is widened, the cost the user sees decreases. This can cause the traffic volume to increase to a new equilibrium point. A portion of this new traffic is diverted from the parallel secondary road, and a portion is new traffic that is generated by the improvement.

The calculation of the benefit to the users can be shown using figure 2. The benefit to the existing users of the improved road is found by calculating the area of ABCD, the difference in price times the existing traffic volume. The benefit to the generated traffic is the area of the triangle BCE. The benefit to the traffic that is attracted from the secondary road is found by calculating the area of EFGH. The benefit to the traffic that remains on the secondary road is IJKL. Totaling all these calculations gives the total benefit.

The cost then can be found by totaling all the costs that the user does not see, such as construction and maintenance. Dividing the benefit by the cost gives

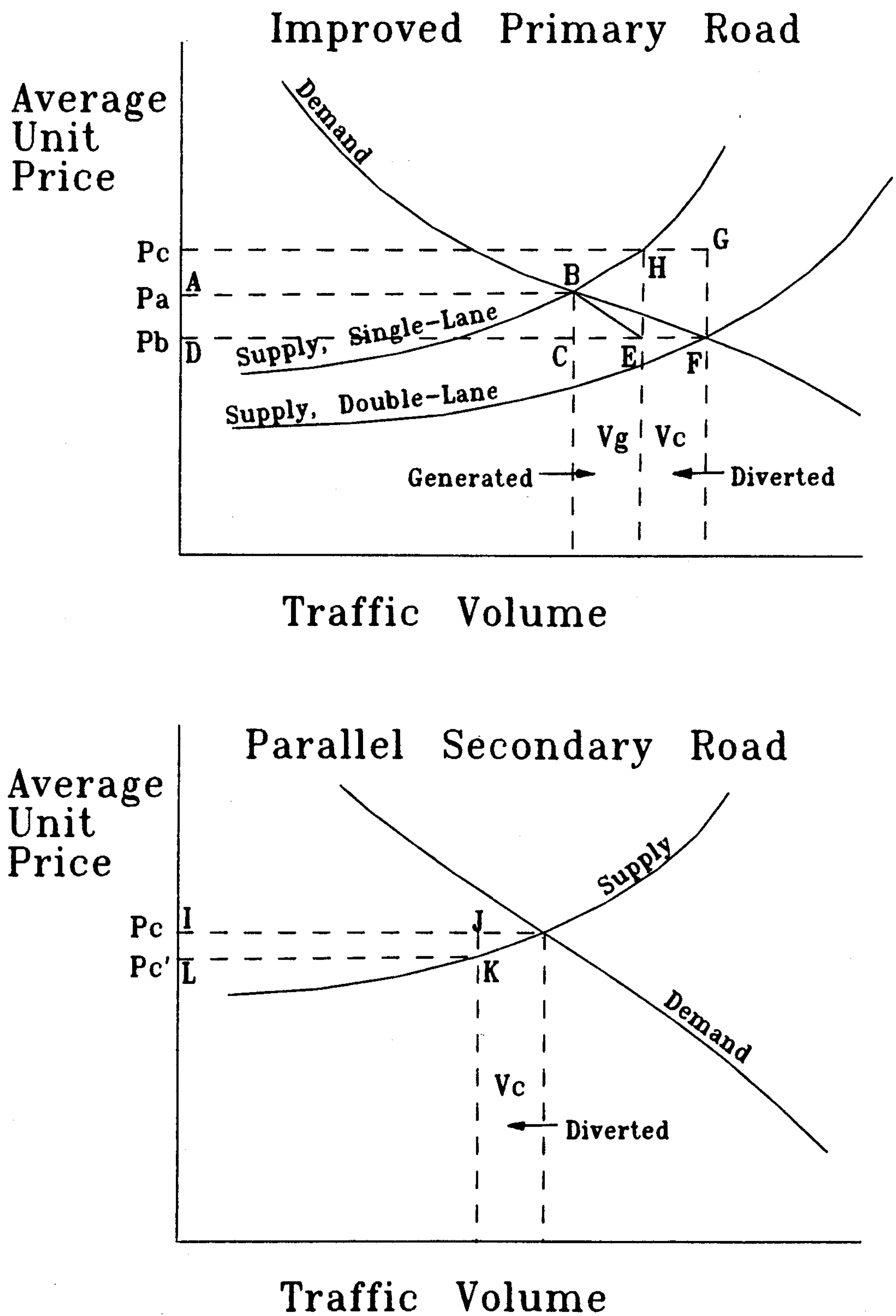


*Figure 2.--Benefit calculation for corridor improvement.*

the benefit/cost ratio (BCR). If the BCR is above 1.0, then the project will pay for itself with the benefits to the users.

### Noneconomic Factors

Other resource values must be considered, such as the increased erosion and sediment in a stream caused by constructing a double-lane road. Driver comfort also needs to be a consideration.

The land manager needs to determine the road management objective--the desired function of a given road. A useful decision criterion is how well each road standard serves the desired use of the road.

## EXAMPLE PROJECT

The Panther Creek Road (Route 65) on the Wind River Ranger District of the Gifford Pinchot National Forest was analyzed to show how the procedure can be applied. It is a single-lane paved road that serves as a major timber-haul route as well as a major recreation access route. Figure 3 is a map of the area. The 65 road accesses a large area that is also accessed by the 60 road. The 65 road has an ADT of about 150 to 160, and the 60 road has about a 60 to 70 ADT. Upgrading the 65 road would encourage some of the traffic to use the 65 road instead of the 60 road. The option presented here is for double-laning the 10-mile segment from the end of the county road to Four Corners. Travel time data were obtained for 4 days during the summer of 1986 for the analysis.

### Level-of-Service/ Highway Capacity Manual Approach

The percentage of delay time was 13.9 for this road. At present, there is no way to know to what level of service this relates because no system has been developed for single-lane roads. However, a qualitative review of the level of service of the road shows that it is performing adequately, probably at a level of service B or C for the 30th highest hour. During most of the year and certainly during September when the field study was done, the road provides an acceptable level of service. It is not until hunting season that the traffic levels get so high that a high number of vehicle meetings begins to increase the congestion and decrease the travel speeds on the road to the point that the level of service could drop to C or even D for brief periods. On the other hand, if the road were double-lane, the level of service would stay very high at all times because the traffic level is much less than capacity.

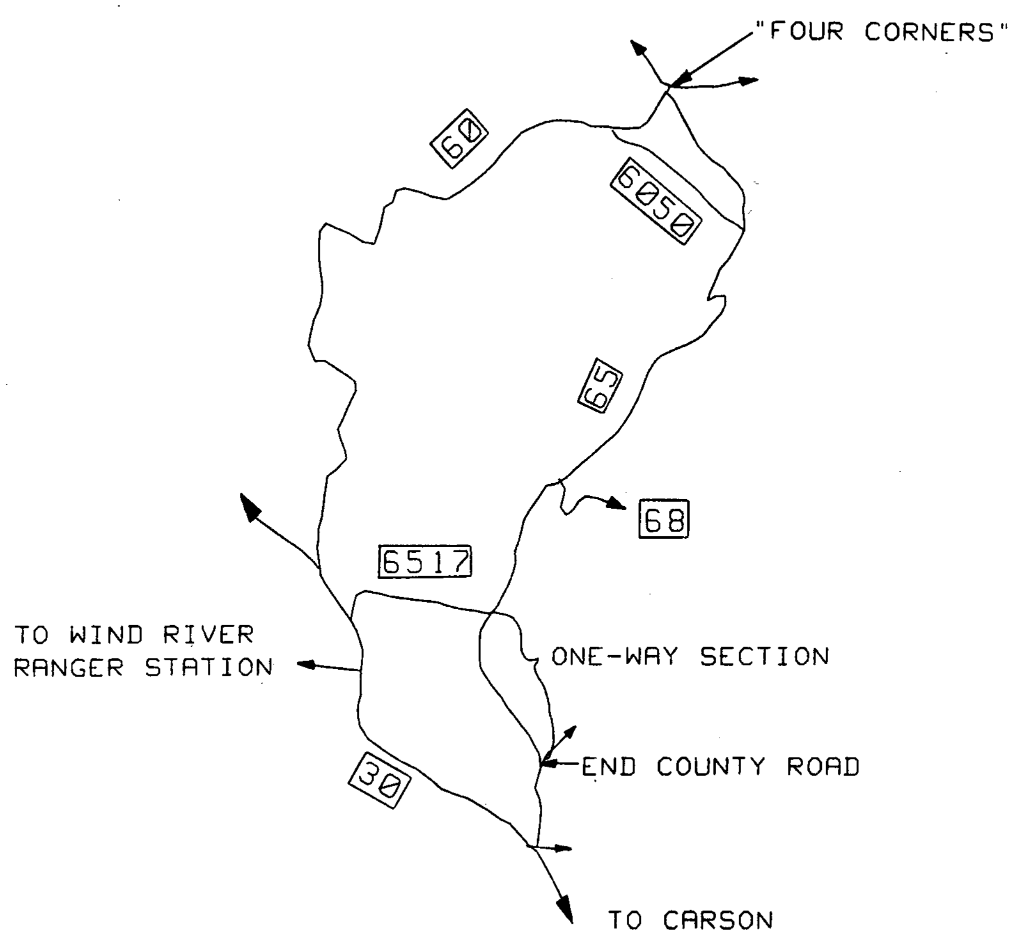


*Figure 3.--Map of Panther Creek area.*

The type of traffic that is on the road when it is providing level of service C or D should be considered. In this case, most of the high volume days result from hunters during hunting season.

**Economic Analysis Approach**

Agency Costs. The construction cost was $824,000. An existing survey that had been used to design a recent reconstruction project was used to determine design quantities. The maintenance cost is $60,000 per year for the existing single-lane road or $82,000 per year for the double-lane option.

User Costs

1. Vehicle Operating Costs. First, a comparison was made of the BNG, VOCM, and field methods for estimating travel times. Figure 4 summarizes the travel time information. The predicted travel times

are shown as a percentage of the observed travel times. This comparison shows that the single-lane BNG predicted travel times that are quite higher while VOCM predicted travel times that are quite lower than those actually observed in the field. For an unloaded truck, even the double-lane BNG predictor predicted travel times that are too high. For the loaded log trucks, the double-lane BNG model came very close to the actual measured travel times.

For a more detailed discussion of the travel time results, refer to "A Comparison of Travel Time Prediction Models Used by the Forest Service" in this issue of Engineering Field Notes.

The first step in calculating the meeting delay was to do a regression analysis relating the travel time to the number of vehicle meetings. Next, the theo-

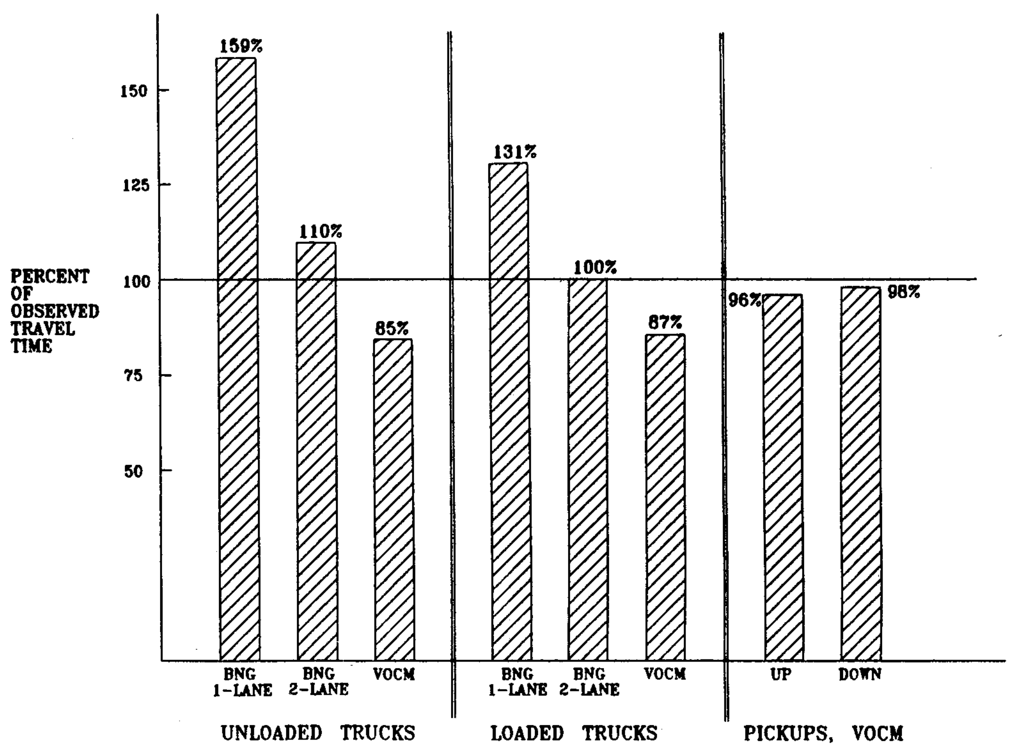


*Figure 4.--Predicted versus observed travel times.*

retical number of meetings was determined for each vehicle per hour (VPH) category. The number of hours in each VPH category was determined for the design year. Knowing these variables, the total meeting delay could be calculated. The sight distance delay was found by subtracting the one-way travel time from the two-way travel time with no meetings (the zero intercept from the regression analysis).

There was a high amount of variability in the data, so the values obtained cannot be used with a high degree of confidence. They do seem reasonable. One-way travel times were only obtained for the uphill direction, so the percentage decrease in travel time by double-laning was applied to downhill traffic also, and may or may not be accurate.

PACE was used to determine the vehicle operating costs used in this analysis. The costs used in this analysis were $38.00 per hour for log trucks, $43.05 per hour for logging-related traffic, $50.81 per hour for Forest Service traffic, and $12.56 per hour for recreation traffic. The operating costs that VOCM produced for log trucks were in the same range as those from the PACE program.

2. Accident Costs. For the lower 4 miles of the project, an accident cost of $9,420 per year was obtained for the single-lane road and $6,567 per year for the double-lane option. For the upper 6 miles of the project, an accident cost of $8,042 per year was obtained for the single-lane road and $8,954 per year for the double-lane option. For the lower 4 miles, the accident cost for the double-lane road was less, but for the upper 6 miles, the single-lane road had the lesser cost. This shows that it may not be necessarily safer to have a double-lane road. With a wider road, there should be fewer cases where vehicles run off the road. However, with the wider road, the travel speeds are faster and result in accidents that are more costly. This increase in cost per accident offsets the decrease in the accident rate.

## Summary of Example Project

The following is a summary combining the benefits and costs:

| Annual Costs | Annual Benefits | Benefit/ Cost Ratio | Net Annual Benefit |
|---|---|---|---|
| $60,383 | $20,521 | 0.34 | -$39,862 |

The benefit/cost ratio shows that only 34 percent of the cost of the project would be paid for by the benefits. A large amount of money would be spent and never recovered if this project were undertaken.

Figure 5 compares the costs for a single-lane road with those for a double-lane road on a cost-per-vehicle basis. The benefits of building the double-lane road would be a reduction in the vehicle operating cost by $0.30 and the accident cost by $0.07

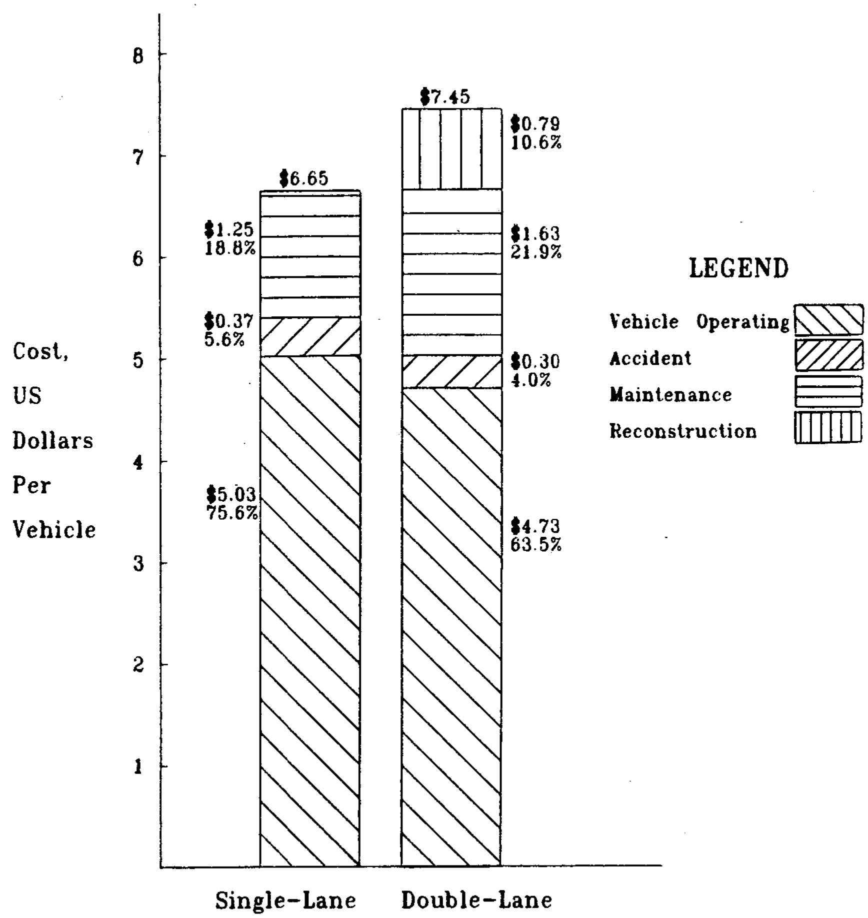


*Figure 5.--Single-lane and double-lane cost comparison.*

for a total benefit of $0.37 per vehicle. The reconstruction cost is $0.79, and the maintenance cost increases $0.38 for a total cost of $1.17 per vehicle. The double-lane road is therefore more expensive than the single-lane road by $0.80 per vehicle.

The accident cost is a minor factor compared to the other costs. The method used could be off by a large percentage and still not affect the total cost by a significant amount. Because the vehicle operating cost is more than 60 percent of the total cost, this is the cost on which effort should be placed to be sure that accurate values are obtained. Maintenance costs would be next in importance, and then reconstruction costs as far as their relative effect on the total cost.

Once these economic factors have been accounted for, the noneconomic factors need to be combined with the economic analysis and presented to the decisionmaker. An additional benefit would be the reduction in the congestion for the user if the road were double-laned. An additional cost would be the increase in the sediment in the creek from road construction. The road management objective would identify the desired use of the road. In the case of the example, it is unlikely that noneconomic factors would cause the decisionmaker to decide to widen the road to double-lane, but if the costs were closer, they certainly could make the difference.

*This paper is a condensation of the author's master's degree project. If more information on this project is desired, the entire master's project can be obtained from FS-INFO-NW, University of Washington, Mail Stop AQ-15, Seattle, WA 98195, or Oregon State University. Please contact Randall Nielsen at FTS 421-6273 if you would like to discuss any aspects of this article.* EFN

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## ERRATA

*Please note the following editorial corrections to the "HP-41C Estimate of Uncertainty for Conventional Ground Method Closed Survey Traverses" article in* *__Engineering Field Notes__*, *Volume 19, May-June 1987:*

*__Page 51__: In the 4th line from the bottom, " . . . 1-foot transit default" should read " . . . 1-minute transit default."*

*__Page 54, figure 3 continued__: On line numbers 316, 323, and 345, replace "X=Y?" with "X≠Y?"*

*If not corrected, the above error in figure 3 could lead to erroneous program output.*

*--Editor*

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