climate should be explored to see whether comprehensive, definitive, and unambiguous descriptors for these items can be defined.

3. The models are currently limited by the range of the data collected; extrapolation beyond this range may lead to misleading results. Additional data and case studies will not only validate the models in the future (or suggest where adjustments are necessary) but should also lead to new insights that could not be uncovered in this research, such as the relation among earthwork quantities, road gradient, and horizontal alignment (circuity).

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Effect of Road Design on Timber-Hauling Speed in the United States

FONG-LIEH OU, ALLEN J. HESSEL, LEE W. COLLETT, AND DAVID R. NORDENGREN

The development of cost-effective low-volume roads is becoming increasingly important in public policy decisionmaking. The recent effort to investigate the relation between traffic performance and design standards was centered on county roads. The purpose of this study is to evaluate the effect of road design on timber-hauling speed on forest roads. A generalized regression dummy variable approach is used for analyzing the data collected from the Mount St. Helens Volcanic Monument area traffic study. The results of the preliminary analysis show that roughness, grade, and traffic composition are significant variables for explaining timber-hauling speed, and that recreation vehicles tend to slow traffic. The results of this study have been found to be consistent with experiments done three decades ago in the United States. The different results between this study and studies made in Brazil and Kenya may be influenced by the different design standards between county roads and forest roads or by other geographical characteristics such as life-style, fuel price, and other socioeconomic factors.

Low-volume-road transportation planning is still in its embryonic stages. Unlike its sister systems, such as the urban transportation network and Interstate highway system, much of the existing body of knowledge in transportation planning was accumulated over the past three decades, during which time both methodological development and empirical studies took place.

In the 1940s and 1950s, the effect of low-volume-road geometry and surface on the cost of hauling logs by motor truck and trailer was investigated in the United States, and the results of these investigations were compiled and contained in the Logging Road Handbook: The Effect of Road Design On Hauling (1). Since that time, the handbook has been used by forest road designers as a primary tool to evaluate alternative designs in terms of the cost of hauling logs. The traffic engineering practice for low-volume roads outside forest lands was performed based on high-volume-road planning technology (2).

It was not until the mid-1970s that both energy and budgets became constraints on the transportation system, and the development of cost-effective low-volume roads took on an increasingly important role in public policy decisionmaking. Therefore, it is very important to understand as accurately as possible the relation between traffic performance and design standards if enlightened decisions concerning low-volume roads are to be made. This realization has given rise to a great deal of research on the investigation of low-volume-road travel behavior, such as studies made in Kenya (3-6) and Brazil (7-10). Comparing the results of these new studies with the results found in the United States (1) indicate that the effects of design standards on operating costs are different. For instance, the relation between speed and grade is linear in the United States (1) and nonlinear (speed versus the square root of grade) in Brazil (9). The difference in operating costs between aggregate and dirt roads was found to be approximately 10 percent in the United States (1) and more than 30 percent in Kenya

(6). These discrepancies raise three following questions:

1. Are the traffic cost-estimation models developed from empirical studies during the 1940s and 1950s in the United States still valid today? The technical change in transportation over the past three decades may have changed logging truck-driving behavior significantly.
2. Is the effect of design standards on operating cost the same for both county roads as those investigated in Brazil and Kenya and forest roads that were studied in the United States? Considering that the traffic mix is significantly different between the two types of roads and most of the logging trucks are equipped with citizen-band (CB) radios, the driver may respond to the traveling environment differently.
3. Can a traffic model developed from Kenya or Brazil be transferred to the United States? The difference in geographical factors may result in different driving behavior.

The search for answers for the above questions motivated a traffic study in the Mount St. Helens Volcanic Monument of the Gifford Pinchot National Forest. The project is sponsored by the Forest Service, U.S. Department of Agriculture. In order to haul approximately 900 million board feet of salvage timber in the next two seasons, many road segments in the area will reach or exceed design capacity. Since May 1982, the study has been under way and field data collection is expected to be completed in September 1982.

The principle objective of this paper is to evaluate the effect of design standards on vehicle operating speed on forest roads and provide part of the answers to the above questions. It is emphasized that the results are from an early analysis of selected data. Final analysis of all data is still in progress.

INITIAL SELECTION OF VARIABLES

The quality of travel can be expressed by speed, travel time, and travel costs. This study selected vehicular speed as an indication of effectiveness because the rate of vehicle movement has significant economic, safety, time, and service (comfort and convenience) implications to both the user and the nonuser. It is influenced by driver, vehicle, roadway, traffic, and environment. In this study, both driver and vehicle are represented by six vehicle classes, which include:

1. Light vehicles,
2. Forest Service light vehicles,
3. Recreational vehicles with trailers,
4. Empty log trucks,
5. Loaded log trucks, and
6. Other trucks.

Factors considered in describing the roadway are alignment, grade, lane width, number of lanes, surface type, shoulder width, and roughness. The alignment is defined by the ratio of the average radius to the number of curves per mile, and it was classified into a category of poor, fair, good, or excellent based on the ratios of less than 20, 20-50, 50-100, and more than 100, respectively. The traffic characteristics include traffic volume and composition, while the environment was treated as a constant variable.

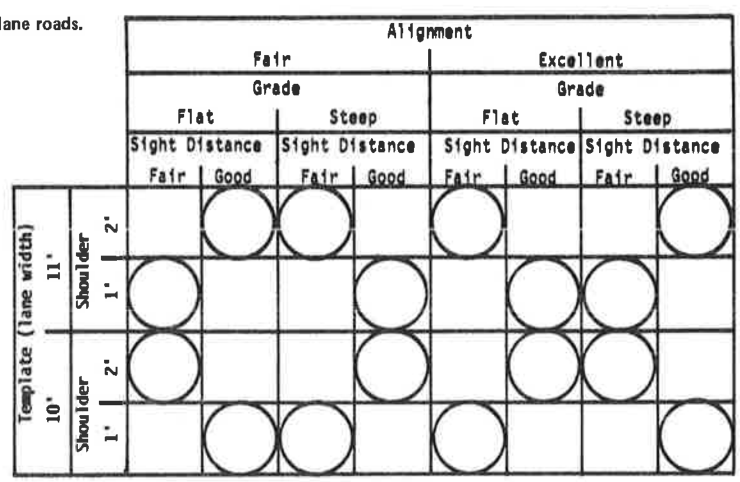
In order to design an effective sample scheme, the selected variables were classified into three groups: temporally stable, partly temporally stable, and temporally unstable. Temporally stable variables include alignment, grade, lane width, number of lanes, and shoulder width. The type of surface was considered as a partly temporally stable variable, while speed, roughness, traffic volume, and traffic composition were treated as temporally unstable variables. It is obvious that the first group of variables is composed of geometric design standards. Because these variables are not changed over time, they need to be measured only once during the study period.

The second group has only one single variable--road surfacing. Without road improvement in terms of surfacing or resurfacing, the type of surface can be treated as a temporally stable variable, as those contained in the first group. The last group comprises traffic performance variables that are interrelated and changed over time. They must be measured and collected at the same time. The method for data collection is discussed in the following section.

SURVEY DESIGN AND DATA COLLECTION

Two basic factors considered in survey design are the representativeness of the sample and the time and cost for data gathering. In order to minimize the sample size, a survey scheme that considered both lower and upper extremes of various variables was developed (11). A typical scheme for paved, double roads is shown in Figure 1. In this example, alignment was classified as fair or excellent, grade was distinguished as flat or steep (8 percent or higher), sight distance was divided into those with

Figure 1. Sample scheme for paved, double-lane roads.



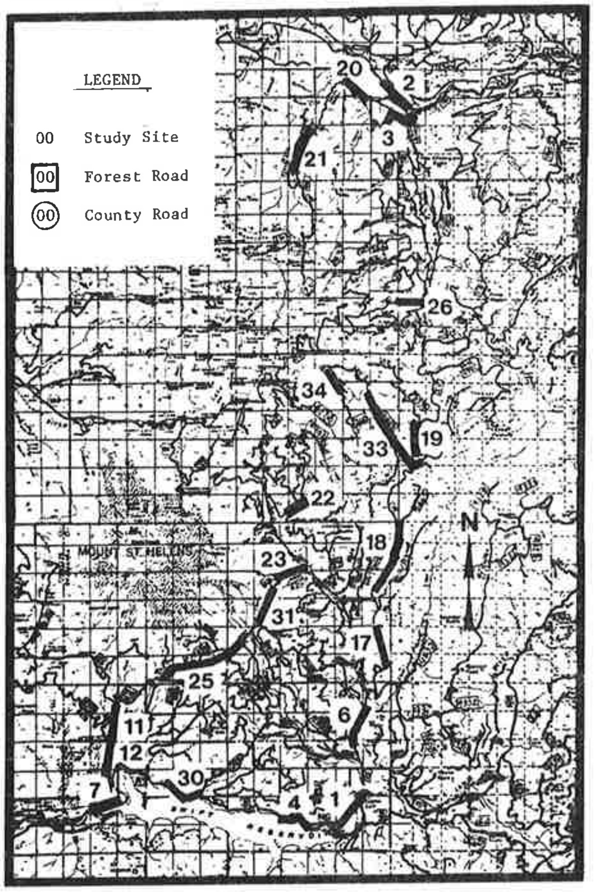
one minimum sight distance and those with indefinite sight distance, templete was identified by 10- and 11-ft lane width; and shoulder was specified by 1- and 2-ft categories.

The next step of survey design is to select candidate study sites with road characteristics similar to the squares or circles in Figure 1. It is favorable that all sites fit either all squares or all circles. Two factors considered in site selection are as follows:

1. The road segment must be long enough to obtain a good measurement for roughness, speed, and other variables, and
2. The road segment must be homogeneous enough to be identified under all temporally stable variables, as indicated previously.

With this consideration, 31 candidate sites were selected; more than 70 percent of sites fell into either the circle category or the square category for each type of road. The third step in the survey design was to perform field verification. After this verification, 10 candidate sites were eliminated. The location of the 21 selected study sites is shown in Figure 2, and their characteristics are given in Table 1. Most of the temporally unstable variables were measured by traffic count, except roughness. A Mays ride meter with electromechanical paper was used for roughness estimation. The paper output contains three traces: (a) road surface roughness, (b) odometer distance marking, and (c) special event trace controlled by the operator. The paper chart flow is a function of the roughness measured, and this feature allows roughness to be summed continuously. The measure vehicle for this study was a 1979 Dodge van that had heavy-duty suspension.

Figure 2. Location of selected traffic study sites in Mount St. Helens Volcanic Monument area.



METHODOLOGY

Regression analyses are the most common technique used in low-volume-road performance analysis. Some of them used linear (7) or nonlinear regression (9), while others used nonlinear regression along with analysis of variance (ANOVA) (10). This study selected Gujarati's generalized regression dummy variable approach as an analytical tool (12). Gujarati's approach, like ANOVA, automatic interaction analysis (13), and contingency-table analysis (14), can be used to partition the sample of non-overlapping subgroups and to detect whether a subgroup can explain more of the variation in the dependent variable than any other such set of subgroups. By using the stepwise regression procedure, it would allow differential intercept and slope for each group of study areas that enter the model.

Table 1. Road characteristics of selected traffic study sites.

Site	Type of Road	Type of Surface	Alignment	Grade	Sight Distance	Template				Shoulder (ft)		
						10 ft	11 ft	Passing	No Passing	0	1	2
1	Double lane	Paved	Excellent	Flat	Good	X						X
2	Double lane	Paved	Fair	Flat	Fair		X				X	
3	Double lane	Paved	Fair	Steep	Fair		X				X	
4	Double lane	Paved	Fair	Flat	Fair	X						X
6	Double lane	Paved	Excellent	Flat	Good	X				X		X
7	Double lane	Paved	Fair	Steep	Fair	X						
11	Double lane	Gravel	Fair	Steep	Good	X					NA	
12	Double lane	Gravel	Excellent	Steep	Good	X					NA	
17	Single lane	Paved	Good	Flat	Good			X			NA	
18	Single lane	Paved	Good	Flat	Good			X			NA	
19	Single lane	Paved	Fair	Steep	Fair			X			NA	
20	Single lane	Paved	Fair	Steep	Fair			X			NA	
21	Single lane	Paved	Good	Flat	Good			X			NA	
22	Single lane	Dirt	Poor	Flat	Fair			X			NA	
23	Single lane	Gravel	Poor	Steep	Fair			X			NA	
25	Single lane	Gravel	Good	Flat	Good			X			NA	
26	Single lane	Gravel	Good	Flat	Good			X			NA	
30	Double lane	Paved	Fair	Flat	Good	X						X
31	Single lane	Gravel	Good	Flat	Fair			X			NA	
33	Single lane	Gravel	Good	Steep	Fair			X			NA	
34	Single lane	Dirt	Fair	Steep	Good			X			NA	

Note: NA = not applicable.

Assume the selected model structure includes N explanatory variables and M route characters in variable condition. The generalized dummy variable equation can be expressed by

$$Y = a_o + \Sigma a_j D_j + \Sigma B_i X_i + \Sigma B_{ij}(D_j X_{ij}) + U_{ij} \quad i = 1, 2, \ldots, N; \; j = 1, 2, \ldots, M \tag{1}$$

where

Y = dependent variable (performance measure);
X_i = independent variables (road design standards and traffic characteristics);
X_{ij} = independent variable i that lies in group j;
D_j = 1 if the observation lies in group j, 0 otherwise;
a_o = intercept for all subgroups;
a_j = differential intercept for group j;
B_i = slope coefficient of Y with respect to X_i for all subgroups;
B_{ij} = differential coefficient of Y with respect to $D_j X_{ij}$; and
U_{ij} = stochastic error term.

Among various forms of the regression model, linear, product, exponential, logarithmic, and combination forms were all used for appropriate travel performance measures. These forms were chosen in order to keep the statistical estimation problem tractable and to account for possible nonlinearities (15), which are presented below:

Linear: $Y = a + bX$,
Product: $Y = aX^b$ or $\ln Y = a + b\ln X$,
Exponential: $Y = ab^X$ or $\ln Y = a + bX$, and
Logarithmic: $Y = a + b\ln X$,

where Y is the dependent variable, X is the independent variable, and a,b are parameters to be estimated.

RESULTS OF PRELIMINARY ANALYSIS

In the preliminary analysis, only data for six study sites were used. They are site numbers 2, 6, 17, 21, 26, and 33; each pair represented paved, double-lane roads; paved, single-lane roads; and gravel, single-lane roads, respectively. A total of 456 samples were collected for these sites with a range from 31 samples in site 26 to 114 samples in site 33. However, by road type the samples are well distributed with 175, 136, and 145 for each of the three categories. Based on these data, a linear regression that describes the relation of timber-hauling speed with road design standards and traffic characteristics was calibrated. The linear regression is shown below:

$$\begin{aligned} Y = (76.1364 &- \underset{[5.0]^{*}}{0.015\,94G} - \underset{[53.4]^{**}}{8.8369R} + \underset{[3.0]^{*}}{0.0159N}) - \underset{[53.7]^{**}}{0.1590X_1} \\ &- \underset{[25.6]^{**}}{0.9804X_2} - \underset{[146.3]^{**}}{0.4221X_3} \end{aligned} \tag{2}$$

$R^2 = 0.7201$, df = 449, and $S_e = 5.728$.

where

Y = speed (mph);
X_1 = roughness (in/mile);
X_2 = grade (percent);
X_3 = traffic composition (percentage of trucks);
G = 1 for government vehicles, 0 otherwise;
R = 1 for recreation vehicles, 0 otherwise;
N = 1 for negative grade, 0 otherwise;
[ ] = F-value;
* = significant at 1 percent level; and
** = significant at 0.1 percent level.

The statistics of Equation 2 indicate that timber-hauling speed is highly related to roughness, grade, and traffic composition. Roughness is the most significant explanatory variable, which accounts for nearly 50 percent of the total variation explained by the model, while grade explains another 13 percent of the total variation. In other words, both road design variables explain approximately 63 percent of total variation. Their importance to traffic performance can be illustrated by the elasticity concept, which is often used in economics for demand analysis:

$$\eta = (\partial Y/Y)/(\partial X/X) = (\partial Y/\partial X) \cdot (Y/X) \tag{3}$$

where η is the percentage change in speed that corresponds to a 1 percent improvement of design standard, while Y and X are as defined previously. Based on Equation 3, the roughness elasticity (η_r) and grade elasticity (η_g) were derived. They are -0.10 and -0.12, respectively. This indicates that a 1 percent reduction of roughness or grade tends to increase speed about one-tenth of a percent.

The most important traffic characteristics variable is traffic composition. The high portion of trucks will slow traffic. Equation 2 also shows that, on average, the speed of government vehicles is slightly slower than other vehicles, while the speed of recreational vehicles could be 9 mph below general traffic.

The relations between speed and design standards shown in Equation 2 are consistent to that found in previous U.S. studies (1). For instance, the relation between speed and grade is linear in both cases. The grade elasticity was found to be -0.12 in this study and -0.08 in previous U.S. studies. This indicates that the current travel speed is more sensitive to grade than it was three decades ago. On the other hand, the linear relation between speed and roughness is similar to that found in the Brazilian study (9). However, the relation between speed and grade does not agree with that found in the Brazilian study, which is nonlinear.

As indicated previously, this paper does not intend to answer all of the three related questions to verify the results of the U.S. studies made in the 1940s and 1950s, to examine the consistency of travel behaviors between county and forest roads, or to investigate the model transferability in low-volume roads. However, the above comparisons indicate that the result of this study is consistent with the results found in the U.S. studies three decades ago. The different results between this study and the experiment in Brazil may be caused by the different road designs between county roads and forest roads or other geographical characteristics. Different geographical characteristics such as life-style, cultural background, and other socioeconomic features could result in different driving behavior.

CONCLUSIONS

An attempt has been made to evaluate factors that affect timber-hauling speed. These factors include design standards and traffic characteristics. The specific results are as follows:

1. Roughness has been found to be statistically significant for explaining timber-hauling speed;
2. Current travel is more sensitive to grade than it was three decades ago;
3. On average, the speed of recreational vehicles

is approximately 9 mph below the general traffic; thus, recreational vehicles may become critical vehicles in the heavy timber haul route; and

4. The speed of government vehicles on forest roads is slightly slower than other vehicles, except recreational vehicles.

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Vehicle Operating Costs in the Caribbean

H. HIDE, G. MOROSIUK, AND S.W. ABAYNAYAKA

This paper describes an investigation into factors that affect vehicle operating costs in the Eastern Caribbean. The study was designed to check the validity of the vehicle operating cost relations derived from an earlier study in Kenya and to extend these relations to include the effects of road geometry and poor bituminous surfaces. Data were collected over a two-year period and the effect of various road and vehicle parameters on the components of vehicle operating cost was examined. The results of the analysis are presented and are compared with the results obtained from the Kenya study.

This paper describes a study of the factors that affect vehicle operating costs in the Eastern Caribbean. The study was designed to extend the vehicle operating cost relations derived in the Kenya Road Transport Cost Study (1) to include the effects of road geometry and poor bituminous surfaces. These relations form part of the Transport and Road Research Laboratory (TRRL) road investigation model for developing countries (RTIM2) (2), which is designed to assist investment decisions concerning nonurban roads in developing countries. The vehicle operating cost relations may also be used manually for this purpose if computer facilities are not available. The Kenya study could not isolate the effect of road geometry on the components of vehicle operating cost other than fuel consumption because the rolling or flat terrain of Kenya precluded the possibility of obtaining data on vehicles that operated predominantly on roads that have steep gradients or high degrees of curvature. In order to investigate this effect it was necessary to obtain operating cost data on fleets of vehicles that operate in separate areas with significantly different kinds of terrain. The islands of the Eastern Carib-