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# Cost Estimators for Construction of Forest Roads in Central Appalachians

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## Abstract

Regression equations were developed for estimating the total cost of road construction in the central Appalachian region. Estimators include methods for predicting total costs for roads constructed using hourly rental methods and roads built on a total-job bid basis. Results show that total-job bid roads cost up to five times as much as roads built when equipment is rented hourly. The estimates presented are for well-drained, stone-surfaced, permanent, minimum- to high-standard roads.

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## Introduction

The construction of forest roads is the most expensive and time-consuming task involved in forest operations. Road construction costs are difficult to estimate because of the variability of terrain, soils, rock outcrops, machinery used, special design features, and other factors (Koger 1978; Kochenderfer et al. 1984; Ou and Swarthout 1984; Layton 1990). There is a need for cost-prediction methods that can be used in conjunction with other stand- and forest-level planning models. Ideally, road cost models should be developed in such a way that they can be used to estimate the cost of a given road section and also in combination with other algorithms as a forest management planning tool.

In this paper we investigated the factors that have a major impact on the cost of forest road construction in the central Appalachians, and developed equations that will enable planners to estimate the cost of constructing roads to different standards for the central Appalachians. (Central Appalachians refers to the mountainous sections of Pennsylvania, Maryland, Virginia, and West Virginia.) Our objective was not to compare one method or variable with another. Rather, the data presented here is representative of well-drained, stone-surfaced, permanent, minimum- to high-standard roads that were constructed on similar site conditions in the central Appalachians.

**Table 1.—Sources for the roads constructed on an hourly rental basis**

| Source | Number of roads |
|---|---|
| Monongalia County ASCS | 1 |
| Nicholas County ASCS | 20 |
| Allegheny National Forest | 5 |
| Monongahela National Forest | 6 |
| Maryland State Forests | 2 |
| West Virginia State Forests | 3 |
| Pennsylvania Department of Environmental Resources | 10 |
| Private Forest Industry | 1 |
| Literature (Monongahela National Forest) | 9 |
| Total | 57 |

## Methods and Procedures

Road construction data were divided into two groups: Group I included roads built with equipment rented on an hourly basis. Group II included roads built under a total-job bid system. Cost data for forest road construction were compiled for 57 roads (76 miles) constructed using hourly rental equipment and 67 roads (172 miles) constructed on a total-job basis. All of the Group II roads studied were constructed on the Monongahela National Forest in West Virginia. Data collected included when and where the road was constructed; slope position; sidehill percent slope; aspect; length; design speed; soil and rock types; road grade; laborer and foreman hours and cost; machine hours; type; and cost per hour; road-surfacing types; quantities; and cost per ton; drainage structures installed (type, size, cost/foot); cleared and surface width; average annual precipitation; vehicles per day using the road; postharvest treatment, and cost; and estimated savings for the next harvest if the road was reused. Hourly rental data were compiled from state, national, industry, and private practitioners (Table 1). Some data were collected at the headquarters of the Monongahela National Forest in Elkins, West Virginia, and at the Nicholas County ASCS office in Summersville, West Virginia.

The data sets for Group I and II roads were used independently to develop regression equations for estimating total road construction costs. We also used a subset of 30 Group I roads and 40 Group II roads. Many roads for both data sets were eliminated due to outliers, missing data, and inconsistencies in the reported results. SAS CORR procedures were used to examine relationships between the variables and road construction cost. The SAS RSQUARE option of the SAS REG procedure was used to determine those combinations of independent variables with the best coefficient of determination ($R^2$) and most closely approached a Mallow's C(p) statistic equal to the number of variables included in the model. Finally, the SAS REG procedure was used to develop the individual equations and to conduct a residual analysis to detect any nonhomogeneity of variables and nonlinearity.

**Table 2.—Descriptive Statistics for hourly rental roads**

| Variable | Average | Range |
|---|---|---|
| Put-to-bed cost (includes water bars and seeding) (dollars) | 148 | 0 to 3,784 |
| Cleared width (similar to acres cleared) (acres) | 24 | 0 to 50 |
| Culvert length (feet) | 166 | 0 to 640 |
| Percent sideslope | 24 | 5 to 47 |
| Percent grade (finished road surface) | 7 | 4 to 15 |
| Quantity of surfacing material (tons) | 968 | 0 to 6,600 |

## Results

### Hourly Rental Data

For the Group I data set, the average road length was

1.27 miles (range: 0.20 to 4.60). The average road width was 13.7 feet (range: 12 to 18). Bulldozers used to construct Group I roads ranged in horsepower from 46 to 310 with an average of 132. The total road cost ranged from $1,363 to $94,342 (average: $11,104). Other averages and ranges are shown in Table 2. Table 3 shows the average total cost of road construction by location.

**Table 3.—Average total cost of construction by location for hourly rental roads**

| Location | Cost/mile |
|---|---|
| | *Dollars* |
| Monongalia ASCS District | 3,052 |
| Maryland Dep. Nat. Resour. | 5,471 |
| PA Dep. Environ. Resour. | 10,379 |
| Penn.-Va. Corp. | 2,500 |
| Nicholas ASCS District | 5,978 |
| Monongahela National Forest | 9,891 |
| West Virginia Dep. Nat. Resour. | 11,128 |

Although we began with about 20 independent variables and many variables were highly correlated with total road-construction cost, the collinearity between some of the variables and the degree of difficulty in measuring some of them prior to road construction resulted in their exclusion from the model (Layton 1990). The cost equation selected for hourly rental roads

$$SQRT(Y_1) = 34.801 + 36.167 * X_1 + 0.095 * X_2 \quad (1)$$

$R^2 = 79.0$ percent

where: SQRT = square root

$Y_1$ = total road construction cost, dollars

$X_1$ = length of road, miles

$X_2$ = dozer horsepower, integer

It is interesting to note that the regression coefficient for $X_2$ (dozer horsepower) indicates that total road cost increases with increasing dozer size/horsepower. This refutes the commonly held belief that using a larger dozer saves so much time that the higher cost per hour is offset. For forest roads constructed in the central Appalachians, substantial savings probably could be realized by using the smallest dozer capable of doing the job; though certain site conditions might require a larger dozer for grubbing and excavating.

## Total Job Bid Data

For Group II roads, the average road length was 1.98 miles (range: 0.1 to 5.7). The average length of culverts used was 461 feet (range: 0 to 1930). The average number of acres seeded (roadbanks, etc.) was 2.3 (range: 0 to 8.6). The average total cost for this set of roads was $68,385 (range: $4,537 to $197,584). Other averages and ranges are shown in Table 4. The cost equation selected for total-job bid roads was:

$$Y_1 = 1740.879+14433.181*X_1+8767.48*X_2+38.765*X_3 \quad (2)$$

$R^2 = 94.8$ percent

where:

$Y_1$ = total road construction cost, dollars

$X_1$ = length of road, miles

$X_2$ = area seeded, acres

$X_3$ = total length of culverts, feet

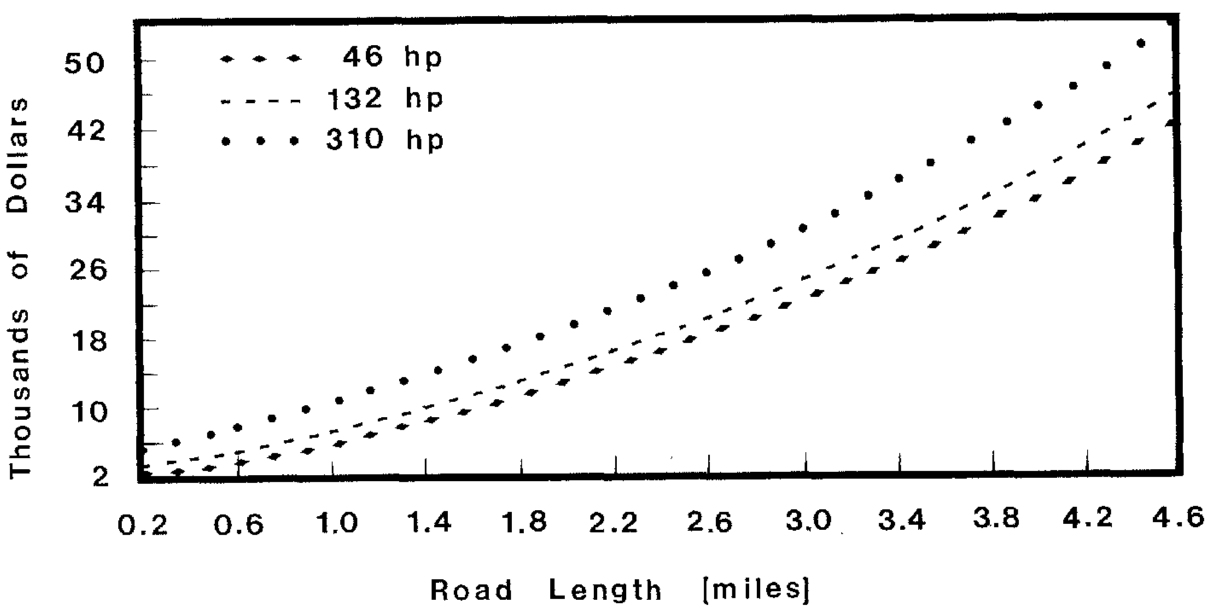


Figure 1.—Total costs for roads constructed using hourly rental methods.

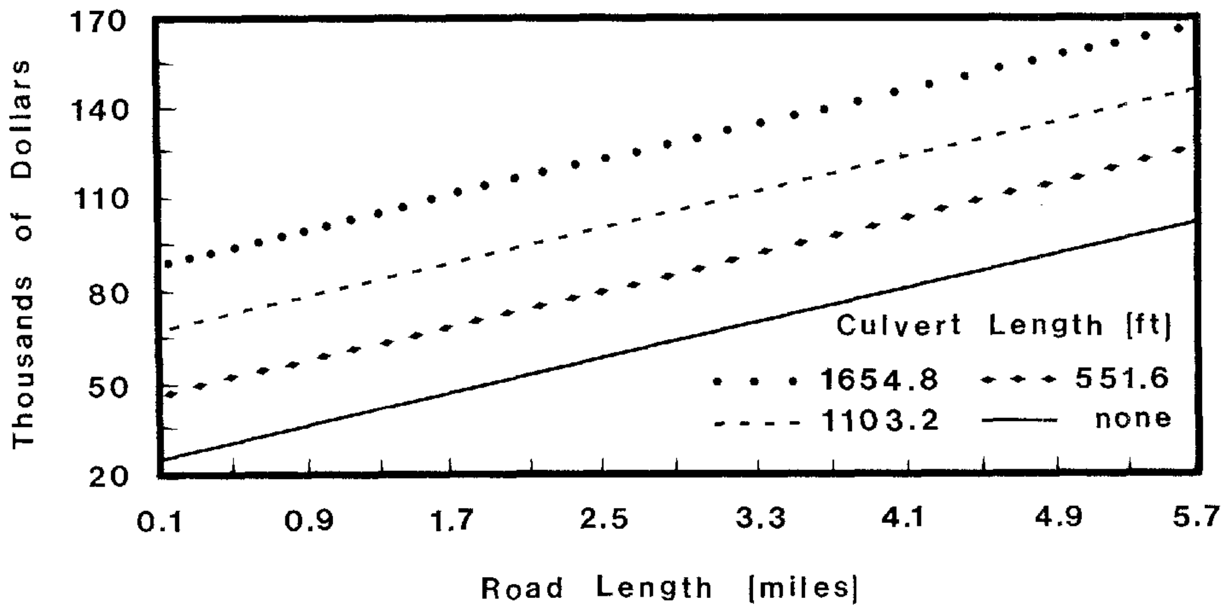


Figure 2.—Total costs for roads constructed using total-job bid methods (average seeded acres = 2.3).

**Table 4.—Variables for total-job bid roads**

| Variable | Average | Range |
|---|---|---|
| Acres cleared (no.) | 5.42 | 0 to 17.1 |
| Surfacing (tons) | 1004.33 | 0 to 4400 |
| Gates (no.) | 0.40 | 0 to 2 |
| Riprap (tons) | 6.46 | 0 to 25.4 |
| Seeded acres (no.) | 2.31 | 0 to 8.6 |
| Signs (no.) | 0.63 | 0 to 4 |
| Culvert (feet) | 460.77 | 0 to 1930 |
| Road length (miles) | 1.98 | 0.1 to 5.7 |
| Percent sideslope | 31.93 | 0 to 45 |
| Total | 68385.07 | 4537 to 197584 |

## Discussion

Equations 1 and 2 were used to develop Figures 1 and 2. Total cost for hourly rental construction increases with length of road built and with increasing horsepower (Fig. 1). Total cost for total-job bid construction increases with length of road built and increasing area seeded, and total length of culverts (Fig. 2). In the central Appalachians, it costs up to five times as much to build a road that is bid on in total than when equipment is rented hourly. One reason for this difference is that Davis-Bacon wage rates must be paid for any contracted government project. These rates vary from state to state and even from county to county, and are often three to five times higher than those for independent equipment operators as they are based on union wages for an area. Also, hourly rental roads require only about one-third as much culvert pipe as total-bid roads. More culvert pipe also requires more ditching and excavation. And total bid roads generally require more gates, riprap, signs, etc. than hourly rental roads. However, the effect of increasing horsepower on total cost is relatively small. For example, the total cost for 50- and 70-hp dozers at 0.2 mile is $2,188.78 and $2,370.17, respectively or an increase of about 8.3 percent. By contrast, the cost for 50- and 90-hp dozers at 0.2 mile is $2,188.78 and $2,558.78, respectively, an increase of about 17 percent (Table 5). The total cost by horsepower class decreases with increasing road length because setup costs are spread over more miles of construction. For example, the total cost for 50- and 70-hp dozers at 4.6 miles is $42,402.71 and $43,188.81, respectively, a difference of only 1.85 percent. Clearly, for short segments of road construction (fewer than 2.5 miles), one would generally enjoy a cost advantage by using the smallest dozer capable of doing the job. The total cost of a 2.5-mile road segment with 2.3 acres seeded and no culverts is $57,989.03. By contrast, the same segment, seeded the same and with 522 feet of culverts is $79,371.80, an increase of about 37 percent.

## Use of Estimators

The equations for Group I and Group II roads can be used

**Table 5.—Incremental construction costs for hourly rental roads, by length of road built and dozer horsepower**

| Road length | Horsepower | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (miles) | 50 | 70 | 90 | 110 | 130 | 150 | 170 | 190 | 210 | 230 | 250 | 270 | 290 | 310 |
| | *Dollars* | | | | | | | | | | | | | |
| 0.2 | 2,188 | 2,370 | 2,558 | 2,754 | 2,975 | 3,167 | 3,385 | 3,610 | 3,842 | 4,081 | 4,327 | 4,581 | 4,841 | 5,110 |
| 0.6 | 3,751 | 3,988 | 4,231 | 4,482 | 4,740 | 5,005 | 5,278 | 5,557 | 5,844 | 6,138 | 6,440 | 6,748 | 7,064 | 7,387 |
| 1.0 | 5,733 | 6,042 | 6,323 | 6,628 | 6,941 | 7,262 | 7,589 | 7,924 | 8,266 | 8,615 | 8,971 | 9,335 | 9,705 | 10,083 |
| 1.4 | 8,133 | 8,479 | 8,833 | 9,193 | 9,561 | 9,937 | 10,319 | 10,709 | 11,105 | 11,510 | 11,921 | 12,339 | 12,765 | 13,198 |
| 1.8 | 10,951 | 11,353 | 11,761 | 12,177 | 12,600 | 13,030 | 13,467 | 13,912 | 14,364 | 14,823 | 15,289 | 15,763 | 16,243 | 16,731 |
| 2.2 | 14,189 | 14,645 | 15,108 | 15,579 | 16,057 | 16,542 | 17,035 | 17,534 | 18,041 | 18,555 | 19,076 | 19,605 | 20,140 | 20,683 |
| 2.6 | 17,845 | 18,356 | 18,874 | 19,400 | 19,933 | 20,473 | 21,020 | 21,575 | 22,137 | 22,706 | 23,282 | 23,865 | 24,456 | 25,054 |
| 3.0 | 21,919 | 22,485 | 23,059 | 23,639 | 24,227 | 24,822 | 25,424 | 26,034 | 26,651 | 27,275 | 27,906 | 28,544 | 29,190 | 29,843 |
| 3.4 | 26,412 | 27,033 | 27,661 | 28,297 | 28,940 | 29,590 | 30,247 | 30,912 | 31,583 | 32,262 | 32,949 | 33,642 | 34,343 | 35,050 |
| 3.8 | 31,323 | 32,000 | 32,683 | 33,374 | 34,071 | 34,776 | 35,489 | 36,208 | 36,935 | 37,669 | 38,410 | 39,158 | 39,914 | 40,677 |
| 4.2 | 36,654 | 37,385 | 38,123 | 38,869 | 39,621 | 40,381 | 41,149 | 41,923 | 42,705 | 43,494 | 44,290 | 45,093 | 45,904 | 46,721 |
| 4.6 | 42,402 | 43,188 | 43,982 | 44,782 | 45,590 | 46,405 | 47,227 | 48,057 | 48,893 | 49,737 | 50,588 | 51,446 | 52,312 | 53,185 |

by managers, planners, loggers, and contractors to estimate road-building costs; and in evaluating alternative silvicultural treatments where road building is required. The estimators can be integrated with system models to evaluate the impact of road building costs on entry timing and forest management.

Individual point estimates can be obtained by substituting the desired values in the equations. For example, say one wishes to develop total costs for a 1-mile road segment using a 80-hp dozer. For hourly cost rental we have

$$\begin{aligned} \text{SQRT (Total cost)} &= 34.801 + 36.167 * (1) + 0.095 * (80) \\ &= 78.568 \\ \text{(Total cost)} &= (78.568)^2 \\ &= \$6172.93 \end{aligned}$$

For the same road with no culvert, no seeding, and total-job bidding we have

$$\begin{aligned} \text{(Total cost)} &= 1740.879 + 14433.181 * (1) + 8767.48 * (0) + 38.765 * (0) \\ \text{(Total cost)} &= \$16{,}174.06 \end{aligned}$$

Thus, the total bid road costs about 162 percent more than the hourly rental road.

These equations are based on data that represent similar road-construction conditions in the central Appalachians. As stated earlier, the statistical analysis eliminated many independent variables and resulted in equations with different variables. Our intent was not to compare the two methods of road construction but to provide methods for estimating the total cost of road construction by financing method. These results can be used in conjunction with other stand- and forest-level planning models.

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**Keywords:** Forest roads, minimum standards, regression equations

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