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Title: THE DEVELOPMENT OF A RAIL TRANSPORT MODEL AND ITS USE FOR THE PREDICTION OF RAIL SHIPPING COSTS FOR FOREST PRODUCTS IN OREGON.

Abstract Approved: ______________________________
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Transportation costs compose fifty to sixty percent of the total operating cost in the forest products industry. This paper develops a framework for incorporating rail transportation into a statewide multi-modal transportation planning model. It will allow for the analysis of various transportation scenarios that can possibly increase the efficiency of the forest products industry by reducing transportation costs.

This paper has two objectives. First, to develop a rail transport model (RTM) that is capable of predicting shipping cost for forest products within Oregon as a function of route alignment, grade, and volume shipped. Second, to construct a model of the Oregon rail network. The nodes in the network were created at rail intersections, major cities, and towns with wood processing facilities.

The Rail Transport Model was constructed by simulating train performance over the 47 rail routes in the state with

varying quantities of lumber, plywood, and wood chips. The simulation results were then analyzed using simple linear regression to produce an equation for each route that predicts transportation cost for the quantity of wood products shipped. The coefficient of determination (R^2) for the individual products varies from 0.50 to 0.99. The average coefficient of determination for the regression equations over all links in the rail network for lumber, plywood, and chips is 0.736, 0.828, and 0.930 respectively. The average coefficient of determination for the combination of forest products is lower at 0.445.

An example of the use of transport cost equations is developed to find the breakeven volume between truck and rail transport for the route between Eugene and Coos Bay.

THE DEVELOPMENT OF A RAIL TRANSPORT MODEL AND ITS USE FOR THE PREDICTION OF RAIL SHIPPING COSTS FOR FOREST PRODUCTS IN OREGON

by

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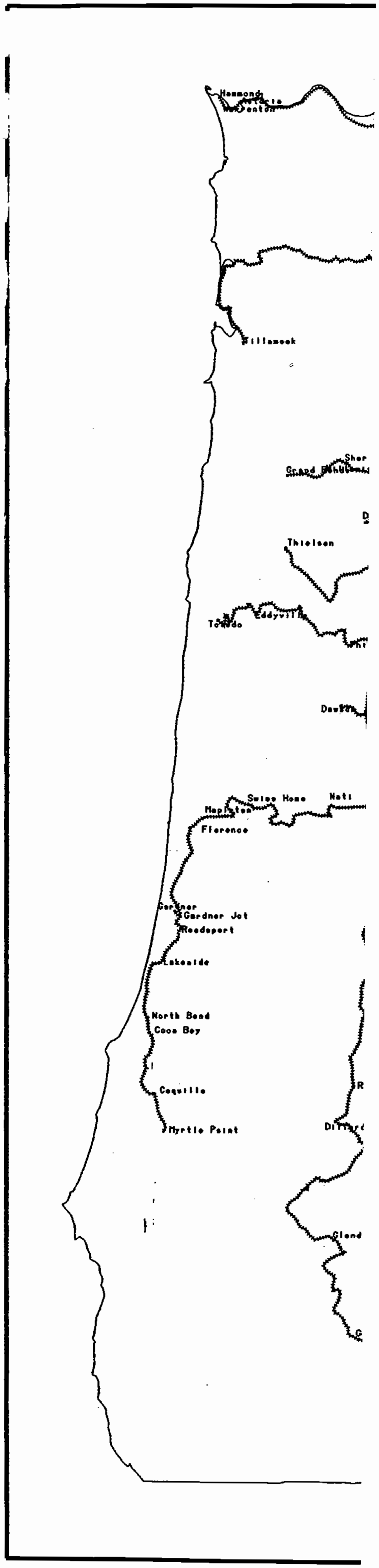
THE DEVELOPMENT OF A RAIL TRANSPORT MODEL AND ITS USE FOR THE PREDICTION OF RAIL SHIPPING COSTS FOR FOREST PRODUCTS IN OREGON

INTRODUCTION

There are approximately 2700 miles of track in Oregon (Figure 1). The track can be divided between main lines and secondary or branch lines sometimes referred to as shortlines . Of these 2700 miles, 970 miles of track are main lines; the remainder of the track are secondary lines. There are three principal owners of track in Oregon. The major owner is Southern Pacific Transportation Company, followed by Union Pacific Railroad and Burlington Northern (Oregon Department of Transportation, 1986). There are 47 branch lines in Oregon. They are owned by the large railroad companies, timber companies, small railroad companies or municipalities such as the City of Prineville Railroad.

The decline of the railroads began in the late 1950's following the completion of the tax-funded interstate highway system. These highways were designed for large capacity trucks that competed directly against railroad for long-haul transportation. The deregulation of the trucking industry in the 1970's further increased the competition from trucking. The number of trucking firms increased and trucking rates decreased (Ascot, 1986). Another factor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Myrtle Point

contributing to the decline of the railroads was the change in United States economy. The economy has changed from a manufacturing economy --where raw materials needed to be transported to the factories and final products are shipped to markets-- to a service economy. The manufacturing economy required periodically transporting large loads of a single commodity, a strength for railroads, to a service economy which favored diversified shipments and flexibility in scheduling that trucking provides.

Transportation costs compose fifty to sixty percent of the total operating cost in the forest products industry (Conway, 1976). As energy prices increase and the forest products industry becomes increasingly centralized, transportation costs will become an increasingly larger portion of the total product cost and will merit closer examination in order to determine the potential importance of railroads in the forest products industry. Railroad shipping costs are difficult to obtain in terms useful for policy analyses involving economies of scale. On routes with currently low traffic, fixed costs of line maintenance prorated into variable costs may provide biased cost estimates for alternative evaluation.

Existing cost data are not only difficult to find, but it may also be difficult to interpret. Not only are railroads the most frugal users of cost data (Carruthers, 1983), but cost data gathered by rail companies are limited to the circumstances in which they were gathered. An example is a line where rail traffic is diminishing. The company may defer maintenance if the long term plan is to abandon the line. The maintenance cost data collected will underestimate the maintenance cost required to keep the line in its optimal working condition; therefore, analysis of the data for historic maintenance cost will underestimate the actual maintenance cost required to operate the line.

This project is part of a larger effort to develop a comprehensive model for analyzing road, water, and rail transportation issues in the forest products industry. This Master of Forestry project concentrates upon the development of the rail transport portion of the overall model. It is envisioned that results from this project will be combined with similar models for the other transport modes to develop a network analysis system to analyze various policy questions concerning transportation problems in the Oregon timber industry, such as the location of sawmills, transfer yards, and sort yards.

OBJECTIVES

The objectives of the Rail Transport Model are threefold:

(1) Assemble a rail network database containing the track structure and track geometry for the state of Oregon.

(2) Develop a train simulator that will estimate cost based upon the quantity of goods shipped.

(3) Develop cost equations for each link in the rail network for lumber, plywood, and wood chips.

SCOPE

Due to the time and resources available for this project, the rail model developed for the Oregon used many assumptions. Among the most significant largest are:

(1) Due to lack of data, main lines are modeled in the same manner as branch lines. However, there are some assumptions that will hold true on the branch lines that will not be valid on the main lines. First, the model only looks at three forest products, lumber, plywood, and veneer. The contribution of other commodities to the fixed cost is ignored. Most of the branch lines in Oregon are entirely dependent on wood products for their traffic. On main lines there is traffic from multiple commodities as well as from freight passing through Oregon; thus, the fixed cost contribution from this traffic is not accounted for.

(2) This study ignores interference from trains traveling in opposite directions. Trains generally run less than once a day on most branch lines so this will have little effect on cost for branch lines. On mainlines with multiple trains each day as well as Amtrak traffic, long delays can occur from trains traveling in both directions over a segment of track with no side tracks. The model does not account for this added cost on main lines.

(3) The model will use a single maintenance level and a single engine type. Although there are an infinite number of locomotive combinations, this model uses only 2500 diesel-electric locomotives.

METHODOLOGY

To accomplish the objectives of this project, the following steps were undertaken:

(1) Compile a data base for all the rail routes in the State of Oregon.-- This data base provided information for investment and route maintenance costs as well as data for route simulation. The data base for each link in the rail network contains information on rail size, ballast, grade, curvature, and the location of tunnels and bridges.

(2) Develop a railroad performance simulator.-- This permitted calculation of travel times and costs as a function of route alignment, grade, and volume transported. Although various train simulators already exist, a new train performance simulation model was developed because the available models do not meet the needs of this project. Existing models require more information than is available, or they do not have the ability to predict travel costs.

(3) Simulate train performance for various tonnages of forest products over each rail route.-- These simulations provided cost data to derive relationships between product type and tonnages for each rail route.

(4) Derive cost equations from train simulation data.--Using regression analysis, the results of the train simulations were used to derive a relationship between transport costs, product type and tonnage over each route.

LITERATURE REVIEW

At one time tariff bureaus set all rates for rail transportation. The tariff bureaus are an independent board set up by the rail companies and state governments. The tariff rates are the rates charged to ship a specified product a given distance. Tariff rates were excluded from anti trust legislation with the Reed Bulwinkle Act of 1948 (Leilich, 1983). The tariff rates are based upon the cost of shipping plus a fair return to the rail company. Prior to the Staggers Rail Act of 1980, tariff rates were the cost basis for interstate shipping (Leilich, 1983). Although the power to set rail rates has been diminished, the tariff bureaus still exist.

The Staggers Rail Act did several things. Two of the most significant were:

(a) It reduced the control of published tariff bureau rates and allowed the railroad corporations and shippers to negotiate rates (deregulated the industry), and

(b) It allowed rail companies to abandon unprofitable lines with less government interference.

An important objective of the Staggers Rail Act was to make rail transportation more competitive with trucking by allowing the rail companies more freedom in determining the rates. In fact, shippers now may have to negotiate with multiple rail companies when shipping products across several different rail systems. Because rail companies can now negotiate rates based on competition with other modes of shipping, the negotiated rates may not be based upon actual costs with a fair return on investment, but be based upon strategies to achieve or maintain a market share.

Several regional studies have used tariff rates to compare the relative advantages of rail and truck transport. At least one of these was in Oregon. Hyde and Corder (1971) compared both interstate and intrastate transportation cost for rail, truck and barges for mill residues in Oregon. Their interstate transportation rates are based on tariff rates, while intrastate transportation rates are based on negotiated rates between the mills and rail companies. The contract rail rates for wood chips varied from 3.85 cents per ton-mile for a 48 mile haul to 1.6 cents per ton-mile for a 377 mile haul. These are negotiated rates and may not reflect the actual cost for shipping. Their model did not permit the user to predict the shipping cost based on the quantity of goods shipped across the line, the physical condition of the track, and the distance traveled.

A number of analytical railroad modeling studies have been done. These can be divided into two categories: (a)

Table 2: Data required for Train Performance Simulator

Item	Units
Beginning and ending mile post	miles
Curvature of track	degrees
Average grade of track	percent
Rail weight	pounds per yard
Maximum speed	miles per hour
Ballast	tons per mile
Ballast life	years
Bridges	number per link
Tunnels	number per link
Trains	number per week

The data for the model comes from a variety of sources. The track geometry for the Southern Pacific lines are from track charts obtained from the Oregon Department of Transportation. For other rail lines, the geometry from the closest Southern Pacific line is used. For example, the track geometry data for the Toledo line was used for the Astoria to Portland line.

Rail weight -- For the Southern Pacific lines, rail weights were obtained from the track chart. The rail weights for the other lines were obtained from the Oregon Rail Report (1986).

Maximum speed -- For the Southern Pacific lines, maximum speeds were obtained from the track chart. The maximum speeds for the other lines were obtained from the Oregon Rail Report (1986).

Ballast -- The tons of ballast per mile and ballast life were obtained from communication with the Oregon Department of Transportation.

Tunnels and Bridges -- The number of bridges and tunnels for the Southern Pacific lines was obtained from the Southern Pacific Conductors Handbook; for the other lines, the information was obtained from the Oregon Rail Report.

Trains per Week -- The number of trains per week was obtained from the Oregon Rail Report.

Car Combinations

The Oregon Forest Products model assumes that trains can carry three types of forest products: lumber, plywood, and chips. Lumber is carried in box cars, plywood is carried in box cars, and chips are carried in chip cars. The maximum net load used for flatcars is 100 tons, for wood chip cars -

- 121 tons; and for box cars -- 70 tons (Railtex, 1985). The tare weight for these cars arc 30 tons for flat cars, 40 tons for box cars and 35 tons for wood chip cars (Grunman Corp, 1986).

The weight of green Douglas fir lumber is assumed to be 2830 pounds per Mbf. Green wood chips are assumed to weigh 38 lbs per solid cubic foot with 71 solid cubic feet per Unit (200 cubic feet). Plywood is assumed to weigh the same as green lumber, 38 pounds per cubic feet. (Wenger, 1984).

Car combinations are created automatically. The model builds unit trains of lumber, plywood, and wood chips. Lumber trains begin with 1.5 MMBF and increase to 7 MMBF, while plywood trains begin with 1.5 MSQFT 3/8 inch to 7 MSQFT 3/8 inch. Wood chip trains begin with 1500 units and increase to 7000 units. This is one of the main differences between the Rail Transport Model and other models which require you to specify the locomotive and car combinations prior to running the program. The train building subroutine will calculate the number of rail cars and engines required to haul the specified mix of products.

The following relationships were developed (Appendix A) to determine the number of cars required for quantity of each product shipped:

Number of flat cars = 0.01429 x MBF

Number of box cars = 0.0069 x MSQFT 3/8" plywood

Number of wood chip cars = 0.0270 x Units

Engine Requirements

The number of engines is determined by the relationship of 3/4 horsepower per ton of traveling weight (Leilich, 1986). Locomotives range from 500 horsepower to 3600 horsepower (Leilich, 1983). This model has assumed that each engine has 2500 horsepower. This assumption may overestimate the cost on small shortline railroads which may not be able to afford an engine of this size, or prefer to use a small engine at slower speeds. Helper units are an extra source of horsepower. They are an extra locomotive or a slave unit that is controlled from another locomotive. They are used to help a train over a steep grades. They are incorporated into this model.

Resisting Forces

Given a train configuration, resisting forces are calculated based upon the track geometry from the input file. The MOTION subroutine sums the resisting forces acting on the train. The horsepower required to overcome the resistance is subtracted from the total horsepower; the remaining horsepower is available for acceleration.

Resistance forces are calculated for grade resistance, curvature resistance, internal resistance, air resistance and wheel rolling resistance.

Grade resistance -- Grade resistance is the change in potential energy. This model assumes the train behaves as a single point with all of the forces acting on that point. Grade resistance is calculated from the following equation:

$$\text{Grade resistance} = \text{SIN}\ (\text{ARCTAN}(\text{grade}/100)) \qquad \text{Eq. [4]}$$

Curve resistance -- Curve resistance is the resistance caused by centripetal force while traveling in a curve. Curve resistance is empirically estimated as 0.8 pounds per ton per degree of curvature (Hay, 1982).

Internal resistance -- Internal resistance is the forces which resists rolling within each freight car. It varies with the condition of the rail car and the track. The range of internal resistance has been empirically measured and varies between three pounds per ton to twenty-eight pounds per ton (Hay, 1982). Eight pounds per ton was chosen for this model.

Combined rolling resistance and air resistance -- Rolling resistance and air resistance are functions of train velocity. The equation for rolling and air resistance used in this model is the modified Davis equation (Hay 1982):

$$R = .6 + 20/(W/2000) + .01 \times V + (.035 \times V^2)/(W/2000) \quad \text{Eq. [5]}$$

R = Rolling and air resistance, lbs

V = Velocity, mph

W = Weight of train, tons

N = Number of axles

Equation 5 underestimates the air resistance as it does not include resistance on the sides of the car which is a function of car type and velocity, and the car placement in the train.

Train Velocity

Train velocity is derived by solving the relationship that power is equal to the product of force multiplied by velocity. The efficiency rate for diesel-electric engines of 82% (Hay, 1982).

$$V = 375 \times E \times HP / TR \qquad \text{Eq. [6]}$$

V = train speed, mph

HP = engine horsepower

TR = total resistance, lb

E = efficiency for diesel-electric engines

Since the total resistance is also a function of velocity, the secant method was used to solve Eq. 5 and Eq. 6 simultaneously.

Track Cost and Wear

The TRACK subroutine is used to calculate the fixed costs for rail, ballast, and ties.

Ballast Investment

The ballast used in this model is crushed rock. Ballast cost is estimated by calculating the average annual investment for ballast per mile of rail. The Oregon Department of Transportation provided information on ballast life and tons of ballast used per mile. Real costs and an inflation free discount rate of 4 % were used to estimate the average annual investment cost. Row et al. (1981) have proposed 4 % as an average return on investment for long term investment. A ballast cost of $52.00 per ton was used (O.D.O.T., 1986). The ballast cost includes excavation, crushing, transportation to the site, and tamping to place the ballast at the proper density. This cost may be low for certain coastal regions where a shortage of suitable ballast rock exists.

Rail Ties

Rail tie cost is based on replacing 150 ties per mile per year at a cost of $46.00 per tie (Oregon Department of Transportation, 1986). This cost includes the cost of the tie and its installation and the salvage value of the remaining tie.

Right-Of-Way Maintenance

The annual cost for vegetation removal has been estimated by the Oregon Department of Transportation (1986) as $160 mile per year. The same cost was provided by ODOT for ballast resurfacing cost per mile per year. In areas of rapid vegetative growth, such as the coastal mountains, the cost for vegetation removal will be much higher; while in the basin area of Eastern Oregon very little vegetation removal will be required. The total right-of-way maintenance cost is $ 320.00 per mile.

Rail wear

Rail wear is based on the size of the rail and the annual tonnage that travels across the rail. Rail life is determined by the following empirical relationship (Hay, 1982):

$$\text{Rail life} = (\text{Annual tonnage})^{.565} \times .92 \times \text{Rail weight} \qquad \text{Eq. [7]}$$

Rail life = years

Rail Weight = pounds per yard

Rail cost used in this model is $190.00 per ton (O.D.O.T., 1986). The cost includes installation labor and assumes that the salvage value is equal to removal cost.

Additional factors that affect rail wear are grade and curvature. Changing from a zero percent grade to a 2.5 percent grade can increase rail wear by almost fifty percent (Table 4). Curvature can increase rail wear by thirteen percent for a 2.5 degree curve to 150 percent for a 8.5 degree curve (Table 5). The combined effects of increasing rail wear due to grade and curvature are additive. It has been assumed that both rails wear evenly.

Table 3. Increase in Track Wear Due to Grade

Grade Range (%)	Rail Wear Increase
1.0 - 1.5	0.035
1.5 - 2.0	0.107
2.0 - 2.5	0.248
2.5 >	0.466

Table 4. Increase in Track Wear Due to Curvature

Curvature (degree)	Rail Wear Increase
1.5 - 2.5	0.136
2.5 - 3.5	0.260
3.5 - 4.5	0.429
4.5 - 5.5	0.613
5.5 - 6.5	0.818
6.5 - 7.5	1.083
7.5 - 8.5	1.273
8.5 - 9.5	1.500
9.5 >	1.703

Special Structures

Both tunnels and bridges use a thirty year economic life. The annual cost for bridges is $7900.00, and for a tunnel is $8500.00 a year. These figures are from the total cost for tunnels and bridges from 1985 road and equipment property accounting form #410 for the Oregon division of the Southern Pacific Transportation Company (personal communication). These figures are for existing structures only. Any new structures will have to be determined on a project by project basis.

Operating Cost

The locomotive ownership cost is $14.75 per hour for a 2500 hp locomotive based upon a thirty year economic life and a purchase price of $1,000,000 (Appendix B). Flat car cost is $29,300 per car; box car cost is $40,100; and chip car cost is $34,300 (Liech, 1982). The economic life of the rail car is 25 years with salvage value equal to removal. The hourly costs are computed using the following car utilization. Flat cars are utilized for 365 days per year, while box cars are utilized 264 days per year, wood chip cars have a car utilization of 165 days per year (Liech, 1982). The estimated ownership cost is $0.26 per hour per car for flat cars, $0.49 per hour per car for box cars and $0.66 per hour for wood chip cars (Appendix B).

A fuel consumption rate of 3.2 gallons per mile is based on the steady state condition reported by General Electric Electromotive Division. This value appears reasonable as a combined loaded and unloaded rate for a 2500 hp. For example, a typical diesel engine consumes about .4 lb per hp-hour at full throttle. If we assume that the train is using 2500 hp, it would consume (.4)(2500) or 1000 lbs per hour or about 142 gallons per hour. A train speed of 30 mph would equate to 4.7 gallons per mile in the loaded direction. If we assume that the empty weight is about 1/4 of the loaded weight for the train, and that we are using about 0.6 lb per hp at partial throttle and going the same speed, the fuel consumption would be 1.8 gallons per mile. The average (4.7+1.8)/2 is 3.25 gallons per hour. Due to the difficulty in modeling braking, accelerating, fuel consumption at partial throttle, this model assumes that fuel consumption is constant at 3.2 gallons per mile.

Labor Cost

Labor costs were difficult to model in this type of analysis. Crews are paid for a full day when they complete a given route. The time required can vary based upon traffic, weather or a variety of other factors. Three categories of labor are used on the train; engineers, firemen and brakemen. Firemen and brakemen are on some trains but not on others. The people in fireman and brakeman positions are moving into other areas as these positions are being eliminated. The best available labor cost for this model is an average of $25.00 per man-hour including benefits with a three man crew. It was not possible to incorporate full pay for a route completed in this model. The routes are not specified in this model, and with the location of additional facilities such as sort yards and transfer yards, the traffic patterns may change.

Loading Cost

Loading costs vary with the facility, the product, and car type. Based on personal communications, loading costs are estimated at $30.00 per hour, including labor and equipment. Loading time for flatcars is thirty minutes per car, thirty minutes for chip cars, and two hours for box cars. Using the same relationships to calculate the number of cars required, the loading costs are as follows:

For Lumber:	$30.00 x 0.5 x 0.0142 x MBF	Eq. [8]
For Plywood:	$30.00 x 2.0 x 0.0067 x Msqft 3/8"	Eq. [9]
For Chips:	$30.00 x 0.5 x 0.0270 x Units	Eq. [10]

Inventory Cost

Inventory cost is the cost of having the material in shipping. One of the common complaints against rail transportation is the length of time it takes to get products to market compared to truck transportation. The model assumes that the product will spend the first day in the yard. The inventory cost is calculated by the following equation:

$$IC = [7/N + T] \times V \times (I/365) \quad \text{Eq. [11]}$$

IC = Inventory Cost, dollars

N = Number of trains per week

T = Total travel time in days

V = Value of product, dollars

I = Annual interest rate, decimal

The values used are $225.00 for lumber per MBF, $500.00 per thousand square feet 3/8-inch basis for plywood, and $40.00 per Unit for chips. These values were derived from the 1986 Western Wood products index and from USDA Forest Service Region Six Appraisal Handbook. This assumes that proper car tracking occurs, allowing each rail car to reach its proper destination with no side trips.

MODEL VALIDATION

Three comparisons between the TPS train performance simulator (Transportation Systems Center, 1979) and the Rail Transport Model developed in this project are briefly described.

The first comparison is on a section of track that has a moderate degree of curvature and a slight downhill grade (Figure 2). The model developed for this project has a longer travel time and lower fuel consumption than TPS, but it does have a higher ending velocity. This is due to a slower acceleration rate for the Oregon State train model.

The second comparison has no grade and a high degree of curvature. Both TPS and this model have the same ending velocity, with travel time and fuel consumption that are almost identical (Figure 2).

The third comparison has a 2% grade and no curvature. The travel time, fuel consumption, and ending velocity are similar. From these three comparisons, our train model develops a slightly longer travel time and less fuel consumption than TPS. TPS has had limited validation against actual train operations, although no statistical test were performed; our model produces results similar to TPS.

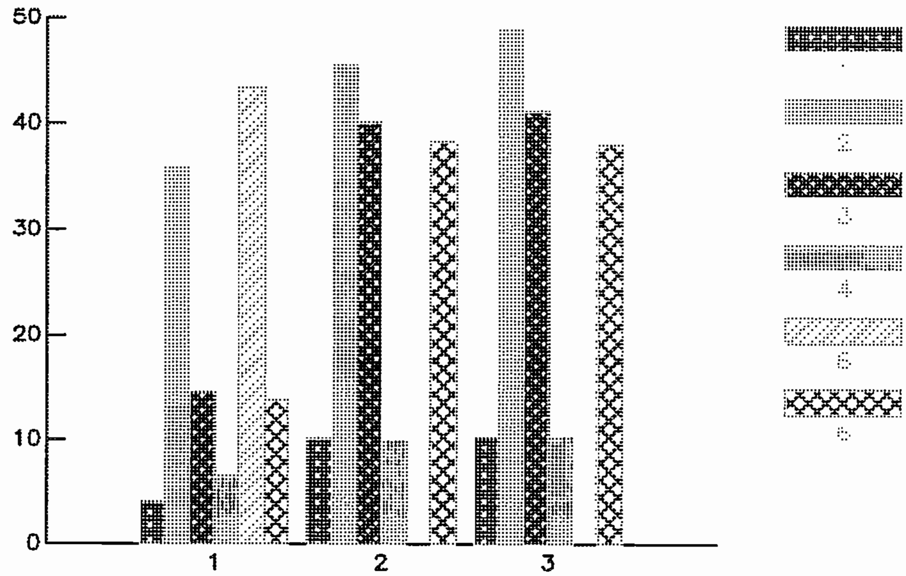

Figure 2: Comparison of Travel Time, Fuel Consumption, Ending Velocity Between TPS and the Oregon Forest Products Train Simulator.

Comparison with Tariff Rates

As previously discussed, tariff rates are suggested prices charged to ship a specific product a given distance. The Willamette Tariff Bureau has established prices for lumber for Oregon. Three comparisons between tariff bureau rates and the cost per ton from the Rail Transport Model are presented. These comparisons were made in the following way. Three sections of track were selected. These line sections represented line lengths of 20 to 100 miles. The tonnage for each train is 2000 tons of cargo, which is a common train size on many short lines in Oregon.

The first comparison (Figure 3) is between a tariff rate for 20 miles and the City of Prineville line, a line of about 20 miles. The tariff rate for 20 miles is $0.66 per 100 pounds or $13.20 per ton.

The second comparison (Figure 4) is between a tariff rate for 60 miles and the line section between Albany and Canby in the Willamette Valley. The tariff rate for 60 miles is $1.09 per 100 pounds or $21.80 per ton.

The third comparison (Figure 5) is between a tariff rate for 100 miles and the line section between Junction City to Milwaukie in the Willamette Valley. The tariff rate for 100 miles is $1.34 per 100 pounds or $26.80 per ton.

For all three comparisons, the tariff rate is much greater than the cost predicted by this model. The difference between this model and tariff rate does not indicate that this model is incorrect. The simulation predicts cost based on a round trip basis, with the return trip having all cars unloaded. Without having access to rail traffic flow data, this is a worst case approach, there is some return traffic from the branch line and the tariff rates will account for this traffic. Some of the other differences are due to the method in which tariff rates are developed. Tariff rates include a fair return on investment, while this model includes a cost of money for multiple year investments, no profit and risk are added to the total cost. Tariff rates also consider rates charged by other modes of transportation; thus, the cost for transportation in only one consideration in the tariff rate. In this model, the cost for transportation is the only consideration.

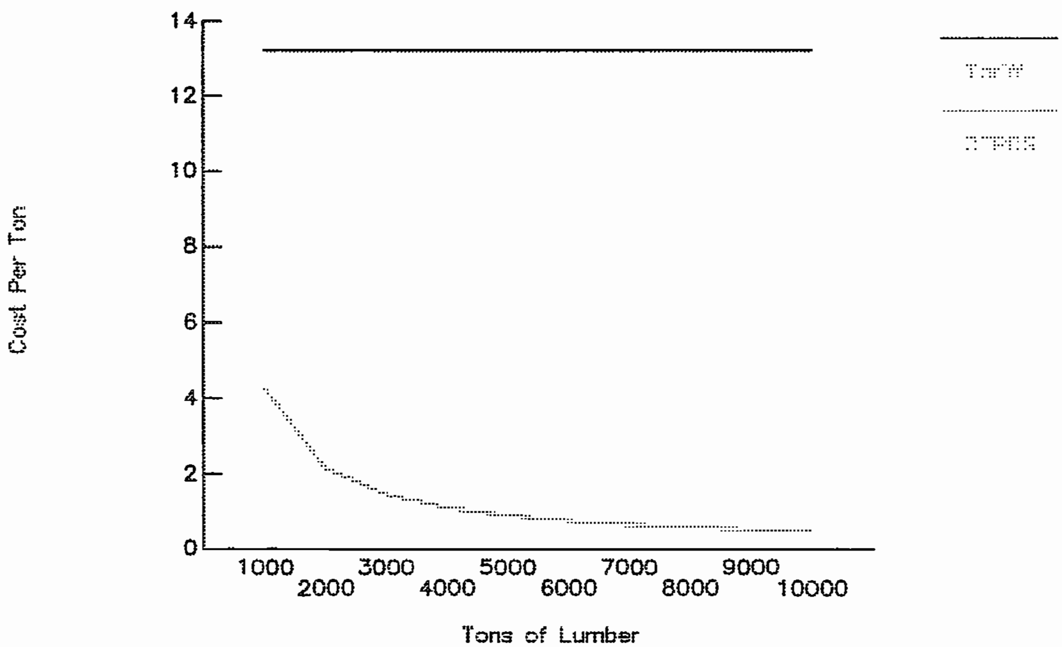

Figure 3. Cost per ton comparison between Tariff Rate and the Oregon Forest Product Simulator for 20 mile trip one -way.

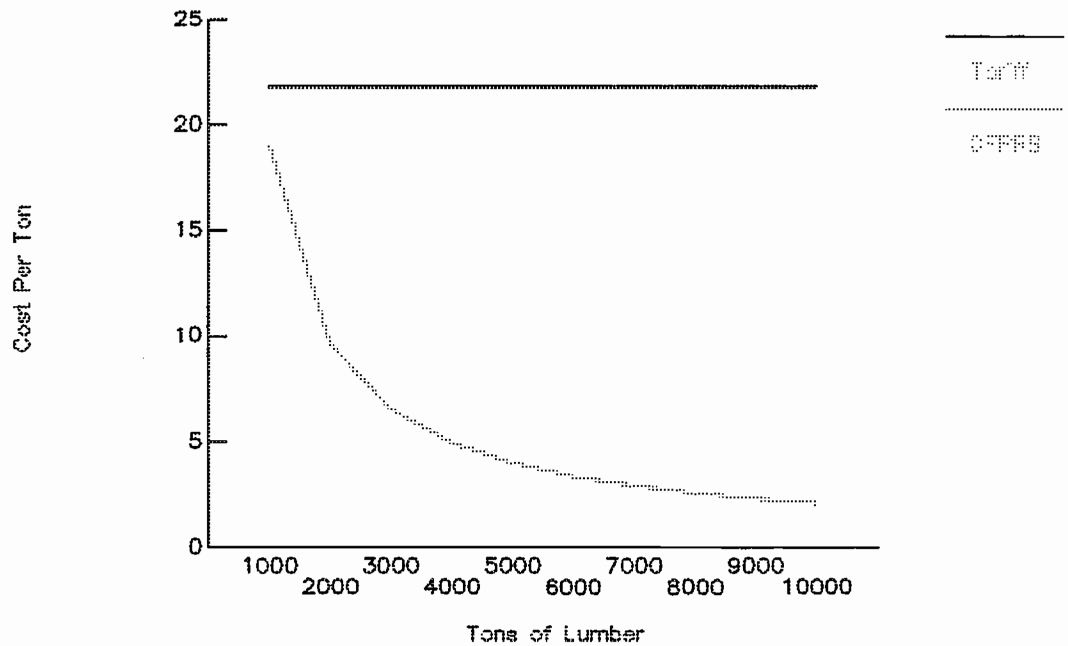

Figure 4. Cost per ton comparison between Tariff Rate and the Oregon Forest Product Simulator for 60 miles trip one-way.

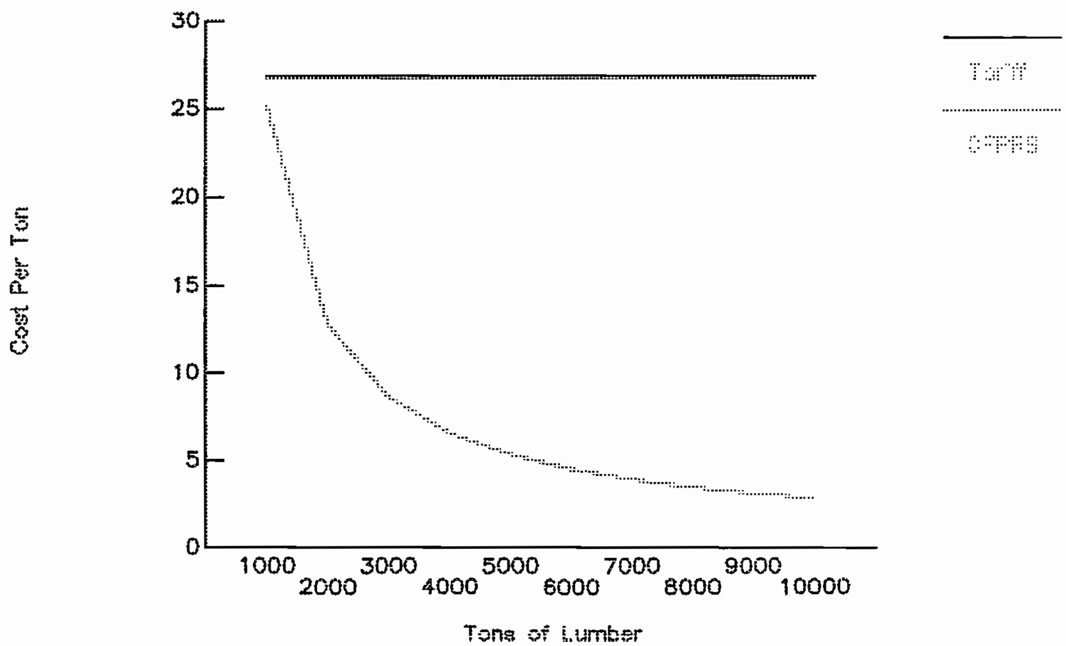

Figure 5. Cost per ton comparison between Tariff Rate and the Oregon Forest Product Simulator for 100 miles trip one -way.

TRANSPORT COST EQUATIONS

To facilitate policy analysis, transport cost equations were developed for each line by simulating train performance and then by fitting a regression equation to the cost points derived by simulation. A cost equation was derived for each product; lumber, plywood, and chips for each line. A fourth cost equation for carrying multiple products over each line was also developed. Carruthers (1983) has suggested that a linear model in the form

$$\text{cost} = a + b \times \text{Tonnage} \qquad \text{Eq. [12]}$$

where

cost = total shipping cost, \$/train

a = fixed cost component, \$/train

b = variable cost component, \$/train/ton

is useful for modeling a single locomotive type and a single track maintenance level. In this model, a 2500 hp diesel electric is used. The maintenance level is a composite of vegetation removal, track maintenance, including ballast replacement and resurfacing, and tie and rail replacement. If a combination of 1500 hp, 2000 hp, or 2500 hp locomotives are used, a multiple regression equation would be required (Carruthers,, 1983). If multiple maintenance levels are to be modeled, they too would require multiple regression equations. Such a scenario would exist if a transportation company were planning to abandon a rail line because it forecasted low volumes of traffic in the future. The company would no longer resurface the track with the same frequency and would not replace the ties and rails with such regularity. The Federal Railroad Administration may reduce the speed and decrease the maximum load limit on the line; thus increasing the variable cost of travel. The model would need to have these items incorporated into a multiple regression analysis.

The products varied from 1500 MBF to 7000 MBF for lumber, 1500 MSQFT 3/8 inches to 7000 MSQFT 3/8 inches for plywood, and 1500 to 7000 units for wood chips. There were 55 simulation runs for each product. The transportation cost for each run was calculated for the loaded and the unloaded direction. The output is a table containing the link name, the product code, the tonnage shipped, the distance traveled, and the shipping cost. These data are transferred into SAS, where the data are fit to a linear equation using the least squares procedure. An equation is developed which predicts the cost for each train for a given level of product shipped.

The coefficient of determination is high for all three single product simulations. The coefficient of determination for lumber averaged from all lines is 0.736;

while the coefficient of determination for plywood is 0.828. The coefficient of determination for the wood chips is 0.930. The coefficient of determination for a combination of wood products is much lower at 0.445. The increase in variation with the combination of wood products is due to variation in the car cost and car capacity over the three products.

There are over 120 links in the Oregon rail network. The link between Eugene and Noti is shown as an example of the output from the rail transportation model. The simulations for the line between Eugene to Noti in Figures 6-8 for lumber, plywood, and wood chips respectively. For lumber, the total cost rises steeply to a point of approximately 5000 tons, then the slope becomes more gradual. For plywood, there is a steady increase throughout the range of tons shipped. For wood chips there is a slight but steady increase in total cost through the range.

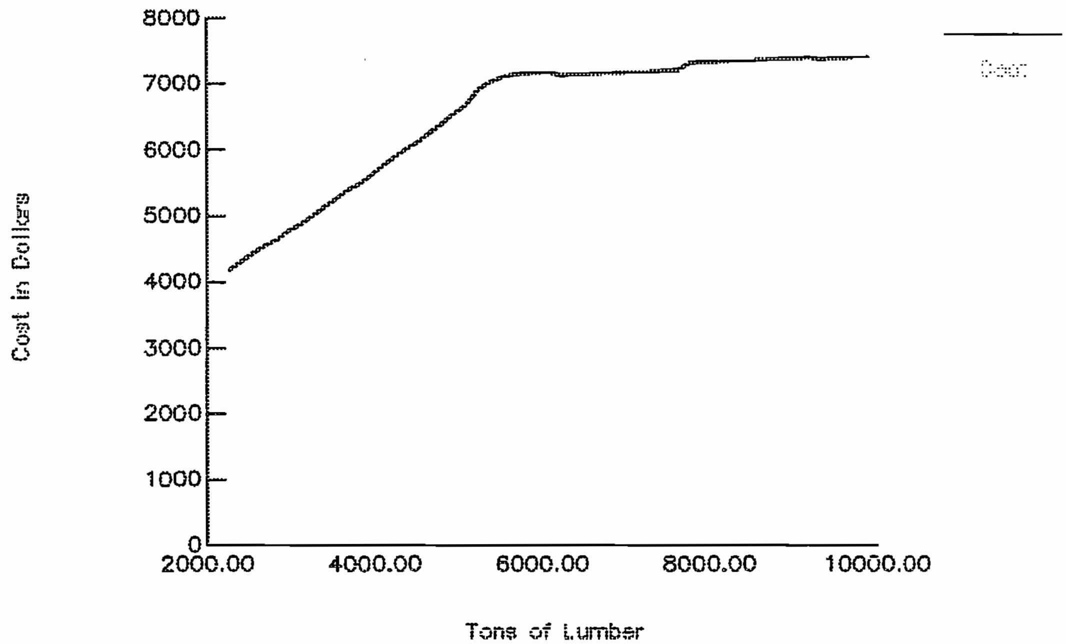

Figure 6. Total cost as a function of tonnage for lumber for the Oregon Forest Product Simulator.

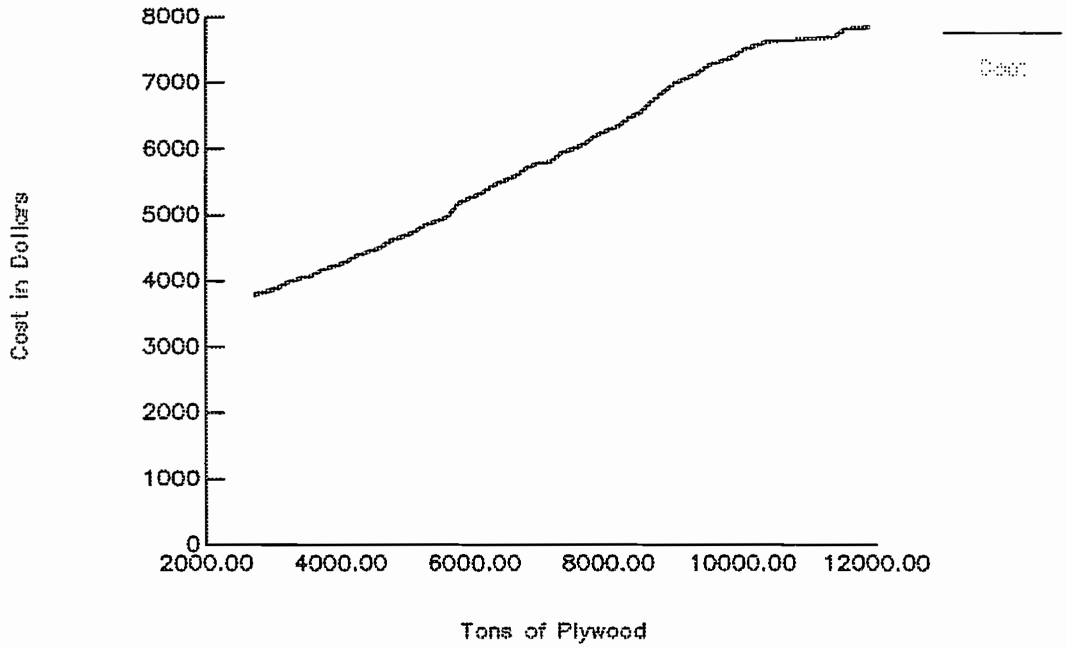

Figure 7. Total cost as a function of tonnage for plywood for the Oregon Forest Product Simulator.

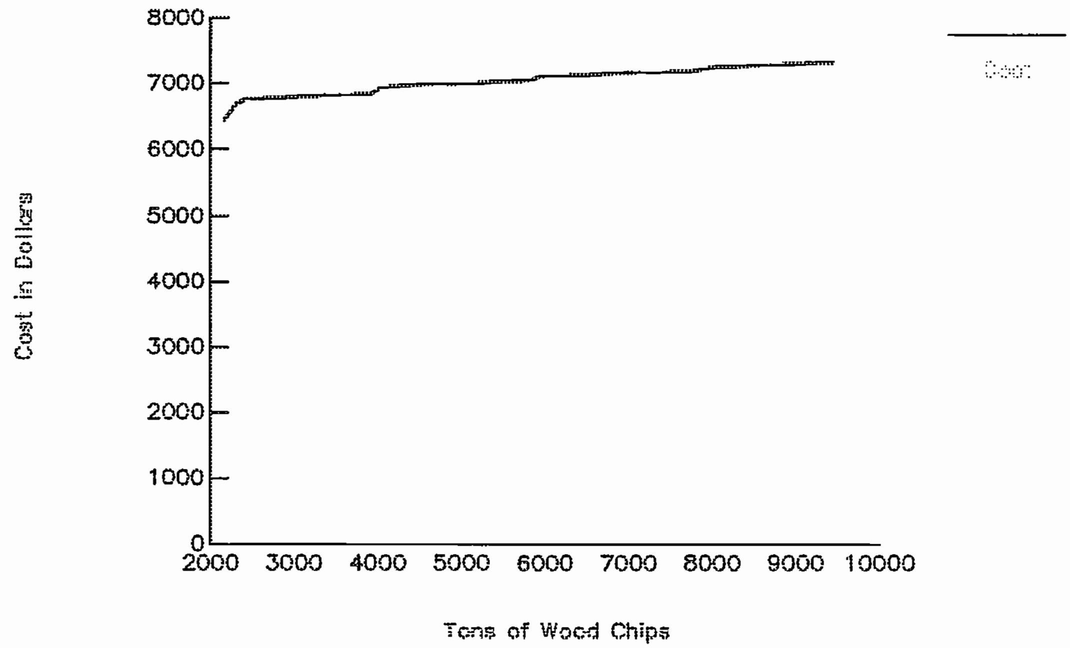

Figure 8. Total cost as a function of tonnage for wood chips for the Oregon Forest Product Simulator.

Table 5. Regression Equations for Eugene to Noti

Product	Intercept	Slope	R2
Lumber	4346	.41	.810
Chips	6857	.09	.941
Plywood	2854	.47	.959
Combination	5032	.28	.427

The regression equations for each product and combined products for the Oregon rail network are in the Appendices (Lumber, Appendix C; Plywood, Appendix D, and Wood Chips, Appendix E, and the Combined Products are in Appendix F). Those links with lower coefficients of determination have shorter distances where the high fixed cost dominates travel cost, and there is little effect for increased tonnage on the total cost.

USE OF THE MODEL

It is anticipated that the information from the rail model will be used in analyses to compare the rail transport cost with other modes of transport or to evaluate mixed mode transportation alternatives. An example of the application of the information developed from this model is presented.

Let's assume a company with sawmill and wood chipping facilities in Eugene foresees a strong export market for wood chips. The company has decided to expand into this market. Storage and stevedoring of wood chips has been obtained at Coos Bay. Two options exist for transporting the chips to Coos Bay; one is by rail from Eugene through Noti to Mapleton, then along the coast to Coos Bay. The truck route is south along Interstate 5 to Drain. At Drain, the route turns left along State Highway 38 towards U.S. 101. At Reedsport Junction the route turns left on to U.S. 101 heading south to Coos Bay. Establishment of a rail loading facility in Eugene will cost $ 250,000, while the trucking requires no new facility. The company wants to determine the break-even point between the truck and rail shipping. The company would like to determine the quantity of chips that would have to be shipped by rail to recover the $ 250,000 loading facility cost. The cost equations for each arc in the rail network from Eugene to Coos Bay are:

Eugene	to	Noti	6,857	+	.09	x	(tonnage)
Noti	to	Swiss Home	1,785	+	.16	x	(tonnage)
Swiss Home	to	Mapleton	8,017	+	.04	x	(tonnage)
Mapleton	to	Florence	6,917	+	.16	x	(tonnage)
Florence	to	Gardner Jct	7,442	+	.09	x	(tonnage)
Gardner Jct	to	Reedsport	1,298	+	.01	x	(tonnage)
Reedsport	to	Lakeside	6,789	+	.04	x	(tonnage)
Lakeside	to	North Bend	8,643	+	.30	x	(tonnage)
North Bend	to	Coos Bay	4,591	+	.06	x	(tonnage)
		Total Cost:	52,339	+	.95	x	(tonnage)

The truck operating cost is $42.00 per operating (traveling) hour and $27.00 per hour for standby cost. The highway distance is 118 miles with a round-trip travel time of 4 hours 55 minutes. Standby time for loading and unloading is 1 hour. The total cost per trip is $233.50. Each truck contains 15 units, which is 20.50 tons. The cost per ton is $11.39.

The break-even point for the facility requires a two step process. The first step is to determine if a break-even point exists. The cost for each train from Eugene to Coos Bay is represented by equation 13. The cost for truck transportation is represented by equation 14.

$$52,339 + .95 \times T = \text{Total Cost} \qquad \text{Eq. [13]}$$

T = Tons of wood chips shipped for each train

$$11.39 \times T = \text{Total Cost} \qquad \text{Eq. [14]}$$

T = Tons of wood chips shipped for each truck

The break-even point is represented by equation 15.

$$52{,}339 + .95 \times T = 11.39 \times T \qquad \text{Eq. [15]}$$

T = Tons of wood chips shipped

The break-even point is 5,013 tons. This size train, about 101 cars, can easily travel the route. The route from Eugene to Coos Bay has no train length restriction noted in the Southern Pacific Conductors Handbook.

The firm must decide what quantity of wood chips can be stored. Assuming the firm has decided it can ship in 6,000 ton trains and make three trips per week, the cost for each train would be $58,039 or $9.67 dollars per ton. The break-even point for the new facility is represented by the following equation.

$$250{,}000 + 9.67 \times T12 = 11.39 \times T12 \qquad \text{Eq. [16]}$$

T12 = The number of 6,000 ton trains

The break-even point for the 6,000 ton trains is 145,348 tons of wood chips. This equates to twenty-four 6000 ton trains.

CONCLUSIONS AND FUTURE RESEARCH

The Oregon Forest Products Transportation Model could be a useful element in the overall transportation planning model for wood products in Oregon. The rail transportation model produces results similar to TPS; a train simulator which has had been validated with actual train operation. The regression equations derived from the simulations have high coefficients of determination for predicting the travel cost. The combination of products regression equations have a much lower value due to the variability in the cost due to the variability in car cost and car capacity. These equations can be easily incorporated into a network analysis software where a variety of transportation policies can be investigated.

Further research is needed to refine all parts of the model. The first element of the modeling is the track data. Actual track data needs to be specified. One source is Rail Garrison Data for the United States Air Force. This data would provide the complete track geometry and the location of all rail structures such as tunnels and bridges. The next element needing improvement is the train building subroutine. RTM uses 3/4 horsepower per trailing ton. This is an average number that can vary between 0.6 to 3.0 depending on the grade and condition of the track. Each route should have a horsepower per trailing ton ratio specified. Multiple locomotive power ratings need to be included. The last element that needs improvement is the economic model. The model currently uses statewide averages. For example, it is assumed that 150 ties per mile are replaced per year and that ballast is resurfaced annually at a cost of $ 160.00 per mile. The economic data needs to be route specific in order to develop more precise cost information.

To accomplish these goals, a geographic information system (GIS) could be implemented to collect and manage this data. Track data could be digitized as line data. The attributes assigned to the track would be the track geometry such as grade and curvature. The track components such as number of ties, rail weight and ballast can also be managed. Other point data would include crossings, culverts, bridges and tunnels.

The geographic information system can store tabular data while maintaining the relation between the tabular data and the geographic feature. Maintenance records such as vegetation management and the quantity of ballast replaced for rail right-of-way can be collected and maintained in the data base manager that is included in the geographic information system. Once this data set is complete, files for both cost and track geometry can easily be created. Simple modification to the train program can be made to read these files. The program would then use the actual track data and cost data that is specific to each segment of track in the rail network. This complete system could be used for transportation planning, rail line abandonment, and taxation with accurate data. Such a system would also allow provide sufficient information to develop a multi-variate cost equation based on track maintenance class and engine type. Within the GIS, overlays can be made with the rail lines and mill locations; thus allowing the interaction between the location of timber stands that supply raw materials, the demands points, and the transportation routes.

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APPENDIX A

Derivation of Rail Car Capacities

Flat Cars

Using a weight of 2830 pounds per MBF and car capacity of 100 tons

200,000/2850 = 70 MBF per car or .01429 cars per MBF

Chip Cars

Using a weight of 38 pounds per cubic foot with 71 feet of solid wood per Unit.

37 Unit per rail car capacity

1/37 = 47.85 Units per Car or .0270 cars per Unit

Box Cars

150,000 Msqft 3/8" per car and car capacity of 75 tons

150,000/150 = .0067 cars per Msqft 3/8"

APPENDIX B

Derivation of Machine Rates for Rail Cars and Locomotives

Engine cost:

Purchase Price = 1,000,000

Economic Life = 30 years

Number of day utilized per year = 365

Number of hours utilized per day = 18

Interest = 4%

Taxes (% of AAI) = 3

Cost per hour $10.59

Maintenance Cost $4.16

Total Hourly cost: $14.75

Rail Car Cost:	Flat Car	Box Car	Chip Car
Purchase Cost	29,305	40,065	34,320
Economic Life (years)	25	25	25
Days utilized/year	365	264	165
Hours utilized per day	24	24	24
Interest	4	4	4
Taxes (% of AAI)	3	3	3
Cost Per Hour	.26	.49	.66

APPENDIX C

Cost Prediction Equations for Lumber

Worden - Springfield

	Intercept	Slope	R2
Worden - Klamath Falls	1164.0	0.035	0.2421
Klamath Falls - Chiloquin	1183.0	0.100	0.6818
Chiloquine - Chemault	8645.4	0.160	0.7344
Chemault - Gilchrist Jct.	2819.0	0.080	0.9819
Gilchrist Jct.- Oakridge	1882.0	0.189	0.9696
Oakridge - Springfield	1108.0	0.032	0.3800

Santiam Branch

	Intercept	Slope	R2
Foster - Sweet Home	6970.4	0.029	0.9898
Sweet Home - Lebanon	6120.8	0.045	0.9671

Astoria Line

	Intercept	Slope	R2
Hammon - Warrenton	5176.6	0.151	0.7266
Warrenton - Astoria	8416.7	0.180	0.6166
Astoria - Clatskanie	2785.9	0.100	0.9612
Clatskanie - St. Helens	1405.0	0.067	0.9515
St. Helens - Portland	3191.9	0.068	0.9506

Forest Grove Branch

	Intercept	Slope	R2
Forest Grove - Hilsboro	3214.5	0.056	0.9039

Oregon Electric

	Intercept	Slope	R2
Junction City - Albany	9383.6	0.379	0.6933
Albany - Independence	3660.8	0.242	0.6061
Independence - Salem	3409.4	0.074	0.7942
Salem - Brooks	4265.3	0.038	0.9508
Brooks - Beaverton	1721.7	0.062	0.9546
Beaverton - United Jct.	3024.8	0.048	0.9656

Mt Hood Railway

	Intercept	Slope	R2
Hood River - Odell	7552.1	0.051	0.9900
Odell - Park Dale	7532.8	0.049	0.9919

Chemult - Celio

	Intercept	Slope	R2
Chemult - Bend	2360.0	0.501	0.2842
Bend - Redmond	1185.0	0.074	0.9794
Redmond - Prineville Jct.	6813.0	0.040	0.9983
Prineville Jct.- Madras	9388.7	0.080	0.9723
Madras - Maupin	6728.9	0.104	0.9600
Maupin - Celio	8348.9	0.125	0.9537

City of Prinevile

	Intercept	Slope	R2
City of Prineville	4208.7	0.051	0.9612

Gilchrist JCT

	Intercept	Slope	R2
Gilchrist - Gilchrist Jct.	3741.2	0.038	0.9745

Shelburn - Mill City

	Intercept	Slope	R2
Shelburn - Lyon	1052.0	0.353	0.7701
Lyon - Mill City	7710.5	0.113	0.7380

Monroe - Hillsboro

	Intercept	Slope	R2
Monroe - Corvallis	7721.1	0.785	0.9337
Corvallis - Independence	3350.8	0.163	0.8491
Independence - McMinnville	1102.0	0.072	0.0033
McMinnville - Yamhill	7288.0	0.052	0.4551
Yamhill - Forest Grove	7250.2	0.045	0.8771
Forest Grove - Hillsboro	3214.5	0.056	0.9039

Portland - Idahoe

	Intercept	Slope	R2
Portland - Hood River	2138.0	0.222	0.4328
Hood River - Dalles	8393.0	0.057	0.9613
Dalles - Celio	3671.4	0.073	0.4708
Celio - Biggs	3213.0	0.078	0.7395
Biggs - Arlington	1094.0	0.243	0.4090
Arlington - Heppner Jct.	2038.7	0.064	0.8634
Heppner Jct.- Broadman	1006.0	0.118	0.7014

Broadman - Echo	9136.2	0.187	0.5639
Echo - Pendleton	1011.0	0.175	0.6722
Pendleton - LaGrande	2953.0	0.511	0.3001
LaGrande - Union	8328.1	0.296	0.7519
Union - North Power	1119.0	0.373	0.7471
North Power - Haines	6970.2	0.141	0.8536
Haines - Baker	7703.0	0.221	0.7950
Baker - Durkee	5887.7	0.563	0.7073
Durkee - Idahoe	6347.0	0.563	0.7007

Monroe - Dawson

	Intercept	Slope	R2
Monroe - Dawson	3808.6	0.337	0.7757

Geer - Salem

	Intercept	Slope	R2
Geer - Salem	2939.2	0.120	0.6029

Theilsen - Dallas

	Intercept	Slope	R2
McMinnville - Dallas	4687.0	0.455	0.8718
Thielsen - Dallas	2839.0	1.338	0.8924

Alturas - Lakeview

	Intercept	Slope	R2
Lakeview - California Bdr.	6636.1	0.046	0.9686

Condor - Arlington

	Intercept	Slope	R2
Condor - Arlington	1313.0	0.236	0.7158

Heppner - Heppner JT

	Intercept	Slope	R2
Heppner - Heppner Jct.	1309.0	0.133	0.9656

Klammath - Bly

	Intercept	Slope	R2
Klammath Falls - Olean	8216.6	0.074	0.7836
Olean - Dary	5915.0	0.036	0.9779
Dary - Beaty	4257.4	0.084	0.9462

Beaty - Bly	3013.4	0.042	0.9704

Oregon - East

	Intercept	Slope	R2
Culp Creek - Cottage Grove	6988.4	0.550	0.9557

Springfield - Shelburn

	Intercept	Slope	R2
Springfield - Coburg	8808.2	0.405	0.6286
Coburg - Lebanon	8324.1	0.952	0.7570
Lebanon - Scio	9066.1	0.585	0.8761
Scio - Shelburn	7178.4	0.076	0.9554

Portland Traction Co.

	Intercept	Slope	R2
Portland - Milwaukie	5710.9	0.098	0.7706
Milwaukie - Gresham	4079.0	0.029	0.7537
Gresham - Boring	4346.7	0.053	0.3891

Oregon & Northwest Railroad

	Intercept	Slope	R2
Seneca - Burns	4529.6	0.100	0.9401
Burns - Hines	1526.4	0.021	0.9958

Woodburn - Stayton

	Intercept	Slope	R2
Woodburn - Silverton	1315.0	0.937	0.9611
Silverton - Stayton	3166.4	0.795	0.9612

Wilsonia - Jefferson

	Intercept	Slope	R2
Wilsonia - Jefferson	7080.6	0.507	0.9267

Eugene - Portland

	Intercept	Slope	R2
Eugene - Junction City	3249.4	0.131	0.7397
Junction City - Halsey	1287.0	0.062	0.9850
Halsey - Albany	9053.7	0.119	0.5705
Albany - Salem	6339.1	0.091	0.9365
Salem - Brooks	4265.3	0.038	0.9508

Brooks - Woodburn	4043.5	0.035	0.9483
Woodburn - Canby	4163.0	0.076	0.9644
Canby - Oregon City	3403.0	0.030	0.4740
Oregon City - Milwaukie	1286.0	0.043	0.9632
Milwaukie - Portland	5710.9	0.098	0.7706

Canby - Molalla

	Intercept	Slope	R2
Canby - Molalla	1465.9	0.924	0.9766

Mohawk Jct. - Marcola

	Intercept	Slope	R2
Springfield - Marcola	3559.6	0.000	0.2000

Medford - White City

	Intercept	Slope	R2
Medford - White City	4422.0	0.090	0.9135

Whiteson - Willamina

	Intercept	Slope	R2
Whiteson - Sheridan	1373.0	0.072	0.9302
Sheridan - Willamina	5800.1	0.147	0.5836

West Stayton - Stayton

	Intercept	Slope	R2
West Stayton - Stayton	7818.3	0.035	0.2751

Wallual Branch

	Intercept	Slope	R2
Wallual - Branch	1161.0	0.081	0.9711

California - Springfield

	Intercept	Slope	R2
Cal Border - Ashland	1104.0	0.071	0.9540
Ashland - Medford	4136.9	0.069	0.6384
Medford - Goldhill	998.0	0.265	0.9619
Goldhill - Rogue River	3150.1	0.025	0.6318
Rogue River - Grants Pass	5770.7	0.309	0.9850
Grants Pass - Glendale	1961.0	0.084	0.8126
Glendale - Correct	1354.0	0.582	0.7374

Correct - Dillard	7812.0	0.252	0.4604
Dillard - Roseburg	3494.7	0.033	0.3700
Roseburg - Sutherline	995.0	0.008	0.2650
Sutherline - Anlauf	1066.0	0.192	0.7640
Anlauf - Cottage Grove	6930.7	0.076	0.7435
Cottage Grove - Creswell	3036.1	0.044	0.8602
Creswell - Goshen	2139.0	0.002	0.0439
Goshen - Springfield	3661.1	0.056	0.2362

Portland - Boring

	Intercept	Slope	R2
Portland - Line Jct.	1178.0	0.269	0.5825
Line Jct.- Boring	985.0	0.275	0.5724

Eugene - Myrtle Point

	Intercept	Slope	R2
Eugene - Noti	4346.7	0.414	0.8099
Noti - Swiss Home	1125.0	1.004	0.7519
Swiss Home - Mapleton	6972.6	0.193	0.7508
Mapleton - Florence	5368.2	0.313	0.4286
Florence - Gardner	4600.1	0.460	0.7605
Gardner - Reedsport	1211.0	0.049	0.9787
Reedsport - Lakeside	6240.4	0.123	0.2574
Lakeside - North Bend	8403.3	0.186	0.4585
North Bend - Coos Bay	4620.6	0.052	0.1735
Coos Bay - Coquille	8432.4	0.099	0.0805
Coquille - Myrtle Point	3419.9	0.270	0.8395

Portland - Tillamook

	Intercept	Slope	R2
Portland - Lake Oswego	8127.7	0.254	0.8672
Lake Oswego - Beaverton	6081.1	0.051	0.9869
Beaverton - Hillsboro	8734.9	0.065	0.9742
Hillsboro - Tillamook	2616.0	1.386	0.8692

St. Joseph - Cook

	Intercept	Slope	R2
St. Joseph - Cook	9143.7	0.167	0.4511

Boardman - Perrydale

	Intercept	Slope	R2
Boardman - Perrydale	1343.7	0.072	0.0688

Page - Tallman

	Intercept	Slope	R2
Page - Tallman	1332.0	0.887	0.7905

California - Klamath Falls

	Intercept	Slope	R2
CA OR - Klamath Falls	6324.1	0.079	0.2400

Albany - Toledo

	Intercept	Slope	R2
Albany - Corvallis	4024.5	0.092	0.8229
Corvallis - Philomath	2262.2	0.045	0.9806
Philomath - Edyville	1852.0	0.935	0.8653
Edyville - Toledo	7702.3	0.498	0.6772

Gardner - Gardner Jct

	Intercept	Slope	R2
Gardner - Gardner Jct.	4697.6	0.022	0.0953

Joseph Branch

	Intercept	Slope	R2
Lagrand - Island City	4765.3	0.038	0.9986
Island City - Elgin	7561.1	0.102	0.5418
Elgin - Walla	9372.6	0.066	0.9807
Walla - Enterprise	8990.4	0.377	0.7716
Enterprise - Joseph	2197.0	0.087	0.1398

Oregon Eastern Branch

	Intercept	Slope	R2
Ontario - Vale	6664.8	0.062	0.9811
Vale - Burns	3331.0	0.300	0.9355

Pilot Rock - Pendleton

	Intercept	Slope	R2
Pilot Rock - Pendleton	5275.4	0.043	0.9691

Umatila - Pendleton

	Intercept	Slope	R2
Umatila - Pendleton	9007.2	0.041	0.9752

Line Jct. - Gresham

	Intercept	Slope	R2
Line Jct.- Gresham	6654.7	0.208	0.6921

APPENDIX D

Cost Prediction Equations for Plywood

Worden - Springfield

	Intercept	Slope	R2
Worden - Klamath Falls	1134.0	0.026	0.1989
Klamath Falls - Chiloquin	1063.0	0.145	0.9113
Chiloquine - Chemault	8770.5	0.210	0.9394
Chemault - Gilchrist Jct.	4522.5	0.055	0.0890
Gilchrist Jct.- Oakridge	1867.0	0.228	0.9758
Oakridge - Springfield	979.0	0.198	0.8394

Santiam Branch

	Intercept	Slope	R2
Foster - Sweet Home	6970.2	0.042	0.9961
Sweet Home - Lebanon	6203.5	0.092	0.7722

Astoria Line

	Intercept	Slope	R2
Hammon - Warrenton	4254.7	0.250	0.9516
Warrenton - Astoria	6988.0	0.320	0.9352
Astoria - Clatskanie	2772.3	0.120	0.9786
Clatskanie - St. Helens	1393.2	0.074	0.9689
St. Helens - Portland	3179.7	0.075	0.9680

Forest Grove Branch

	Intercept	Slope	R2
Forest Grove - Hilsboro	2819.7	0.124	0.9185

Oregon Electric

	Intercept	Slope	R2
Junction City - Albany	7119.7	0.554	0.9135
Albany - Independence	2520.7	0.317	0.9132
Independence - Salem	3168.4	0.099	0.9469
Salem - Brooks	4036.0	0.076	0.9010
Brooks - Beaverton	1711.3	0.070	0.9719
Beaverton - United Jct.	3018.2	0.058	0.9815

Mt Hood Railway

	Intercept	Slope	R2
Hood River - Odell	7551.6	0.078	0.9966
Odell - Park Dale	7532.9	0.076	0.9974

Chemult - Celio

	Intercept	Slope	R2
Chemult - Bend	1807.0	1.137	0.6930
Bend - Redmond	6362.3	0.064	0.1846
Redmond - Prineville Jct.	5360.9	0.059	0.7329
Prineville Jct.- Madras	1281.0	0.132	0.6449
Madras - Maupin	1760.0	0.208	0.3311
Maupin - Celio	8330.4	0.141	0.9712

City of Prinevile

	Intercept	Slope	R2
City of Prineville	7050.4	0.118	0.5528

Gilchrist JCT

	Intercept	Slope	R2
Gilchrist - Gilchrist Jct.	3737.9	0.049	0.9882

Shelburn - Mill City

	Intercept	Slope	R2
Shelburn - Lyon	8982.4	0.473	0.9648
Lyon - Mill City	7210.0	0.196	0.9298

Monroe - Hillsboro

	Intercept	Slope	R2
Monroe - Corvallis	7097.8	0.575	0.9452
Corvallis - Independence	2859.9	0.132	0.9277
Independence - McMinnville	7886.9	0.403	0.8067
McMinnville - Yamhill	6545.4	0.159	0.8164
Yamhill - Forest Grove	6578.5	0.124	0.7225
Forest Grove - Hillsboro	2819.7	0.124	0.9185

Portland - Idahoe

	Intercept	Slope	R2
Portland - Hood River	1598.0	0.860	0.6846
Hood River - Dalles	9284.5	0.077	0.8379
Dalles - Celio	2883.8	0.176	0.7539
Celio - Biggs	2848.9	0.158	0.8924
Biggs - Arlington	8402.8	0.570	0.7446
Arlington - Heppner Jct.	1612.4	0.159	0.9290
Heppner Jct.- Broadman	8930.6	0.291	0.8185
Broadman - Echo	6929.9	0.481	0.7591
Echo - Pendleton	7690.8	0.496	0.7563

Pendleton - LaGrande	2406.0	1.156	0.7050
LaGrande - Union	7010.7	0.408	0.9561
Union - North Power	9335.4	0.519	0.9503
North Power - Haines	6492.6	0.209	0.9769
Haines - Baker	6690.2	0.322	0.9627
Baker - Durkee	3088.4	0.753	0.9433
Durkee - Idahoe	3603.0	0.748	0.9434

Monroe - Dawson

	Intercept	Slope	R2
Monroe - Dawson	1870.6	0.477	0.9356

Geer - Salem

	Intercept	Slope	R2
Geer - Salem	1947.4	0.216	0.8632

Theilsen - Dallas

	Intercept	Slope	R2
McMinnville - Dallas	4718.2	0.263	0.7790
Thielsen - Dallas	2906.0	1.600	0.9594

Alturas - Lakeview

	Intercept	Slope	R2
Lakeview - California Bdr.	5657.3	0.077	0.7836

Condor - Arlington

	Intercept	Slope	R2
Condor - Arlington	1233.0	0.483	0.8182

Heppner - Heppner JT

	Intercept	Slope	R2
Heppner - Heppner Jct.	1307.0	0.165	0.9824

Klammath - Bly

	Intercept	Slope	R2
Klammath Falls - Olean	8538.0	0.092	0.8202
Olean - Dary	4819.9	0.057	0.7789
Dary - Beaty	9118.5	0.197	0.5037
Beaty - Bly	3316.0	0.080	0.7870

Oregon - East

	Intercept	Slope	R2
Culp Creek - Cottage Grove	6224.8	0.434	0.9430

Springfield - Shelburn

	Intercept	Slope	R2
Springfield - Coburg	8905.2	0.309	0.4868
Coburg - Lebanon	4749.5	1.076	0.9563
Lebanon - Scio	7646.2	0.562	0.9557
Scio - Shelburn	7110.3	0.117	0.9953

Portland Traction Co.

	Intercept	Slope	R2
Portland - Milwaukie	5691.6	0.079	0.8646
Milwaukie - Gresham	3781.6	0.077	0.7859
Gresham - Boring	4114.8	0.090	0.7500

Oregon & Northwest Railroad

	Intercept	Slope	R2
Seneca - Burns	4510.1	0.102	0.9551
Burns - Hines	1527.0	0.035	0.9988

Woodburn - Stayton

	Intercept	Slope	R2
Woodburn - Silverton	1093.0	0.809	0.9263
Silverton - Stayton	3114.0	0.444	0.8838

Wilsonia - Jefferson

	Intercept	Slope	R2
Wilsonia - Jefferson	6776.2	0.344	0.9271

Eugene - Portland

	Intercept	Slope	R2
Eugene - Junction City	2515.5	0.219	0.9229
Junction City - Halsey	7017.4	0.051	0.0946
Halsey - Albany	8377.1	0.198	0.9360
Albany - Salem	6406.4	0.104	0.9740
Salem - Brooks	4036.0	0.076	0.9010
Brooks - Woodburn	3068.0	0.025	0.3444
Woodburn - Canby	1404.0	0.117	0.0101

	Intercept	Slope	R2
Canby - Oregon City	2712.6	0.053	0.9046
Oregon City - Milwaukie	1285.0	0.055	0.9854
Milwaukie - Portland	5691.6	0.079	0.8646

Canby - Molalla

	Intercept	Slope	R2
Canby - Molalla	1424.9	0.528	0.9070

Mohawk Jct. - Marcola

	Intercept	Slope	R2
Springfield - Marcola	3282.1	0.046	0.9585

Medford - White City

	Intercept	Slope	R2
Medford - White City	3915.6	0.134	0.8993

Whiteson - Willamina

	Intercept	Slope	R2
Whiteson - Sheridan	1182.0	0.188	0.7324
Sheridan - Willamina	5562.9	0.144	0.9700

West Stayton - Stayton

	Intercept	Slope	R2
West Stayton - Stayton	8170.3	0.019	0.1536

Wallual Branch

	Intercept	Slope	R2
Wallual - Branch	1161.0	0.103	0.9861

California - Springfield

	Intercept	Slope	R2
Cal Border - Ashland	1103.0	0.077	0.9694
Ashland - Medford	3440.2	0.144	0.7571
Medford - Goldhill	9237.6	0.283	0.9298
Goldhill - Rogue River	3325.1	0.044	0.8430
Rogue River - Grants Pass	6219.4	0.162	0.8841
Grants Pass - Glendale	1506.0	0.140	0.4941
Glendale - Correct	963.0	0.864	0.9388
Correct - Dillard	5746.2	0.404	0.9336
Dillard - Roseburg	2225.5	0.153	0.9010

Roseburg - Sutherline	7463.3	0.164	0.8355
Sutherline - Anlauf	1049.0	0.408	0.8302
Anlauf - Cottage Grove	3446.2	0.146	0.6375
Cottage Grove - Creswell	2673.0	0.104	0.7881
Creswell - Goshen	2377.8	0.002	0.0111
Goshen - Springfield	3135.2	0.114	0.9603

Portland - Boring

	Intercept	Slope	R2
Portland - Line Jct.	1005.0	0.426	0.9363
Line Jct.- Boring	8125.5	0.442	0.8792

Eugene - Myrtle Point

	Intercept	Slope	R2
Eugene - Noti	2854.4	0.472	0.9591
Noti - Swiss Home	7239.8	1.135	0.9563
Swiss Home - Mapleton	6085.6	0.269	0.9516
Mapleton - Florence	4994.5	0.233	0.9140
Florence - Gardner	2750.9	0.547	0.9592
Gardner - Reedsport	1195.0	0.075	0.9914
Reedsport - Lakeside	5402.2	0.205	0.9718
Lakeside - North Bend	8051.7	0.179	0.6693
North Bend - Coos Bay	4598.5	0.075	0.7490
Coos Bay - Coquille	6148.4	0.353	0.8110
Coquille - Myrtle Point	3490.9	0.172	0.7937

Portland - Tillamook

	Intercept	Slope	R2
Portland - Lake Oswego	8081.3	0.184	0.9265
Lake Oswego - Beaverton	5722.9	0.115	0.8687
Beaverton - Hillsboro	3215.2	0.055	0.1329
Hillsboro - Tillamook	2738.0	1.655	0.9532

St. Joseph - Cook

	Intercept	Slope	R2
St. Joseph - Cook	7805.5	0.311	0.8006

Boardman - Perrydale

	Intercept	Slope	R2
Boardman - Perrydale	454.2	0.177	0.9775

Page - Tallman

	Intercept	Slope	R2

Page - Tallman	1008.0	0.965	0.9517

California - Klamath Falls

	Intercept	Slope	R2
CA OR - Klamath Falls	5517.2	0.190	0.9302

Albany - Toledo

	Intercept	Slope	R2
Albany - Corvallis	3667.0	0.142	0.9036
Corvallis - Philomath	2036.4	0.096	0.9298
Philomath - Edyville	1470.0	1.023	0.9449
Edyville - Toledo	4632.6	0.705	0.9368

Gardner - Gardner Jct

	Intercept	Slope	R2
Gardner - Gardner Jct.	4662.9	0.037	0.7757

Joseph Branch

	Intercept	Slope	R2
Lagrand - Island City	4197.0	0.064	0.9553
Island City - Elgin	6600.3	0.239	0.7918
Elgin - Walla	9372.4	0.090	0.9919
Walla - Enterprise	7363.1	0.458	0.9626
Enterprise - Joseph	1556.6	0.160	0.9682

Oregon Eastern Branch

	Intercept	Slope	R2
Ontario - Vale	960.0	0.112	0.6542
Vale - Burns	5609.0	0.482	0.3541

Pilot Rock - Pendleton

	Intercept	Slope	R2
Pilot Rock - Pendleton	5270.3	0.054	0.9843

Umatila - Pendleton

	Intercept	Slope	R2
Umatila - Pendleton	5984.2	0.055	0.3664

Line Jct. - Gresham

	Intercept	Slope	R2
Line Jct.- Gresham	5882.9	0.269	0.9761

APPENDIX E

Cost Prediction Equations for Wood Chips

Worden - Springfield

	Intercept	Slope	R2
Worden - Klamath Falls	1076.0	0.056	0.9803
Klamath Falls - Chiloquin	1098.0	0.100	0.9754
Chiloquine - Chemault	9389.8	0.161	0.9716
Chemault - Gilchrist Jct.	3305.7	0.040	0.9792
Gilchrist Jct.- Oakridge	1914.0	0.240	0.9739
Oakridge - Springfield	1071.0	0.079	0.9775

Santiam Branch

	Intercept	Slope	R2
Foster - Sweet Home	6961.5	0.035	0.9926
Sweet Home - Lebanon	6513.7	0.055	0.9756

Astoria Line

	Intercept	Slope	R2
Hammon - Warrenton	6092.6	0.022	0.9905
Warrenton - Astoria	9484.2	0.029	0.9898
Astoria - Clatskanie	2741.2	0.114	0.9677
Clatskanie - St. Helens	1373.7	0.083	0.9654
St. Helens - Portland	3159.7	0.084	0.9645

Forest Grove Branch

	Intercept	Slope	R2
Forest Grove - Hilsboro	3277.0	0.031	0.9841

Oregon Electric

	Intercept	Slope	R2
Junction City - Albany	1145.0	0.118	0.9752
Albany - Independence	5023.9	0.073	0.9752
Independence - Salem	3727.2	0.028	0.9793
Salem - Brooks	4316.0	0.032	0.9791
Brooks - Beaverton	1693.6	0.075	0.9670
Beaverton - United Jct.	3005.5	0.056	0.9735

Mt Hood Railway

	Intercept	Slope	R2
Hood River - Odell	7536.3	0.040	0.9832
Odell - Park Dale	7518.6	0.036	0.9852

Chemult - Celio

	Intercept	Slope	R2
Chemult - Bend	2683.0	0.289	0.9777
Bend - Redmond	6098.3	0.069	0.9805
Redmond - Prineville Jct.	5280.9	0.014	0.9917
Prineville Jct.- Madras	1302.0	0.101	0.9793
Madras - Maupin	1821.0	0.164	0.9783
Maupin - Celio	8287.9	0.156	0.9679

City of Prinevile

	Intercept	Slope	R2
City of Prineville	7518.4	0.072	0.9757

Gilchrist JCT

	Intercept	Slope	R2
Gilchrist - Gilchrist Jct.	3726.3	0.042	0.9780

Shelburn - Mill City

	Intercept	Slope	R2
Shelburn - Lyon	1249.0	0.065	0.9777
Lyon - Mill City	8029.6	0.038	0.9823

Monroe - Hillsboro

	Intercept	Slope	R2
Monroe - Corvallis	1253.0	0.224	0.5637
Corvallis - Independence	3870.6	0.076	0.7806
Independence - McMinnville	1096.0	0.104	0.9768
McMinnville - Yamhill	7251.4	0.045	0.9816
Yamhill - Forest Grove	7255.3	0.042	0.9797
Forest Grove - Hillsboro	3277.0	0.031	0.9841

Portland - Idahoe

	Intercept	Slope	R2
Portland - Hood River	2273.0	0.222	0.9774
Hood River - Dalles	9359.9	0.081	0.9784
Dalles - Celio	4054.2	0.043	0.9801
Celio - Biggs	3292.3	0.036	0.9850
Biggs - Arlington	1226.0	0.135	0.9794
Arlington - Heppner Jct.	2117.3	0.027	0.9877
Heppner Jct.- Broadman	1051.0	0.062	0.9819
Broadman - Echo	1006.0	0.111	0.9799
Echo - Pendleton	1094.0	0.115	0.9798

Pendleton - LaGrande	3271.0	0.288	0.9780
LaGrande - Union	999.0	0.056	0.9822
Union - North Power	1339.0	0.072	0.9808
North Power - Haines	7572.8	0.028	0.9871
Haines - Baker	8856.4	0.044	0.9840
Baker - Durkee	9400.4	0.104	0.9797
Durkee - Idahoe	986.0	0.103	0.9796

Monroe - Dawson

	Intercept	Slope	R2
Monroe - Dawson	5954.2	0.081	0.8958

Geer - Salem

	Intercept	Slope	R2
Geer - Salem	3602.1	0.032	0.9827

Theilsen - Dallas

	Intercept	Slope	R2
McMinnville - Dallas	6881.9	0.373	0.6956
Thielsen - Dallas	4305.0	0.678	0.9118

Alturas - Lakeview

	Intercept	Slope	R2
Lakeview - California Bdr.	5837.6	0.053	0.9764

Condor - Arlington

	Intercept	Slope	R2
Condor - Arlington	1402.0	0.168	0.9789

Heppner - Heppner JT

	Intercept	Slope	R2
Heppner - Heppner Jct.	1302.0	0.152	0.9721

Klammath - Bly

	Intercept	Slope	R2
Klammath Falls - Olean	8743.1	0.123	0.9326
Olean - Dary	4905.4	0.035	0.9779
Dary - Beaty	1001.0	0.136	0.9746
Beaty - Bly	3544.4	0.049	0.9767

Oregon - East

	Intercept	Slope	R2
Culp Creek - Cottage Grove	1020.0	0.202	0.6373

Springfield - Shelburn

	Intercept	Slope	R2
Springfield - Coburg	1034.0	0.367	0.6486
Coburg - Lebanon	1451.0	0.174	0.8928
Lebanon - Scio	1259.0	0.133	0.6783
Scio - Shelburn	7336.2	0.015	0.9353

Portland Traction Co.

	Intercept	Slope	R2
Portland - Milwaukie	6152.2	0.050	0.8700
Milwaukie - Gresham	4063.3	0.033	0.9792
Gresham - Boring	4478.7	0.040	0.9788

Oregon & Northwest Railroad

	Intercept	Slope	R2
Seneca - Burns	4477.0	0.134	0.9638
Burns - Hines	1520.9	0.013	0.9893

Woodburn - Stayton

	Intercept	Slope	R2
Woodburn - Silverton	1872.0	0.415	0.6758
Silverton - Stayton	7799.9	0.413	0.6140

Wilsonia - Jefferson

	Intercept	Slope	R2
Wilsonia - Jefferson	1002.0	0.203	0.5821

Eugene - Portland

	Intercept	Slope	R2
Eugene - Junction City	3811.2	0.052	0.9782
Junction City - Halsey	6727.1	0.045	0.9799
Halsey - Albany	9382.2	0.075	0.9775
Albany - Salem	6334.2	0.100	0.9743
Salem - Brooks	4316.0	0.032	0.9791
Brooks - Woodburn	2858.7	0.036	0.9790
Woodburn - Canby	1250.0	0.065	0.9874

Canby - Oregon City	2745.5	0.038	0.9772
Oregon City - Milwaukie	1284.0	0.067	0.9889
Milwaukie - Portland	6152.2	0.050	0.8700

Canby - Molalla

	Intercept	Slope	R2
Canby - Molalla	7161.6	0.355	0.5853

Mohawk Jct. - Marcola

	Intercept	Slope	R2
Springfield - Marcola	3410.3	0.009	0.9852

Medford - White City

	Intercept	Slope	R2
Medford - White City	4826.1	0.035	0.9516

Whiteson - Willamina

	Intercept	Slope	R2
Whiteson - Sheridan	1270.0	0.066	0.9813
Sheridan - Willamina	6465.1	0.056	0.6618

West Stayton - Stayton

	Intercept	Slope	R2
West Stayton - Stayton	7541.6	0.107	0.7875

Wallual Branch

	Intercept	Slope	R2
Wallual - Branch	1158.0	0.090	0.9755

California - Springfield

	Intercept	Slope	R2
Cal Border - Ashland	1100.0	0.109	0.9788
Ashland - Medford	4275.4	0.049	0.9787
Medford - Goldhill	1104.0	0.207	0.8654
Goldhill - Rogue River	2976.1	0.034	0.9649
Rogue River - Grants Pass	7378.5	0.135	0.6483
Grants Pass - Glendale	1540.0	0.145	0.9755
Glendale - Correct	1731.0	0.156	0.9579
Correct - Dillard	9154.3	0.101	0.9669
Dillard - Roseburg	3620.3	0.041	0.9387

Roseburg - Sutherline	8520.2	0.061	0.9827
Sutherline - Anlauf	1361.0	0.116	0.9808
Anlauf - Cottage Grove	4327.0	0.046	0.9795
Cottage Grove - Creswell	3187.3	0.037	0.9790
Creswell - Goshen	1964.4	0.019	0.9218
Goshen - Springfield	3883.6	0.023	0.9822

Portland - Boring

	Intercept	Slope	R2
Portland - Line Jct.	1306.0	0.101	0.7876
Line Jct.- Boring	1123.0	0.063	0.9831

Eugene - Myrtle Point

	Intercept	Slope	R2
Eugene - Noti	6857.1	0.091	0.9412
Noti - Swiss Home	1785.0	0.163	0.8855
Swiss Home - Mapleton	8017.0	0.040	0.9816
Mapleton - Florence	6917.8	0.162	0.6410
Florence - Gardner	7441.9	0.086	0.9337
Gardner - Reedsport	1298.6	0.010	0.9879
Reedsport - Lakeside	6788.6	0.034	0.9264
Lakeside - North Bend	8643.8	0.299	0.8799
North Bend - Coos Bay	4591.9	0.057	0.7123
Coos Bay - Coquille	8471.1	0.121	0.9138
Coquille - Myrtle Point	4321.4	0.323	0.8576

Portland - Tillamook

	Intercept	Slope	R2
Portland - Lake Oswego	9318.9	0.146	0.7415
Lake Oswego - Beaverton	6053.0	0.036	0.9820
Beaverton - Hillsboro	3009.4	0.041	0.9845
Hillsboro - Tillamook	4188.0	0.678	0.9119

St. Joseph - Cook

	Intercept	Slope	R2
St. Joseph - Cook	993.0	0.052	0.9836

Boardman - Perrydale

	Intercept	Slope	R2
Boardman - Perrydale	1574.0	0.015	0.9737

Page - Tallman

	Intercept	Slope	R2

	Intercept	Slope	R2
Page - Tallman	1877.0	0.228	0.8525

California - Klamath Falls

	Intercept	Slope	R2
CA OR - Klamath Falls	6403.6	0.077	0.9766

Albany - Toledo

	Intercept	Slope	R2
Albany - Corvallis	4126.7	0.082	0.8966
Corvallis - Philomath	2232.0	0.028	0.9835
Philomath - Edyville	2437.0	0.259	0.7487
Edyville - Toledo	1069.0	0.170	0.9615

Gardner - Gardner Jct

	Intercept	Slope	R2
Gardner - Gardner Jct.	4681.4	0.015	0.9853

Joseph Branch

	Intercept	Slope	R2
Lagrand - Island City	4161.8	0.013	0.9916
Island City - Elgin	8023.5	0.054	0.9816
Elgin - Walla	9344.3	0.074	0.9843
Walla - Enterprise	1121.0	0.084	0.9157
Enterprise - Joseph	2485.4	0.032	0.9491

Oregon Eastern Branch

	Intercept	Slope	R2
Ontario - Vale	977.0	0.067	0.9802
Vale - Burns	5747.0	0.562	0.9770

Pilot Rock - Pendleton

	Intercept	Slope	R2
Pilot Rock - Pendleton	5258.2	0.050	0.9746

Umatila - Pendleton

	Intercept	Slope	R2
Umatila - Pendleton	6027.8	0.041	0.9786

Line Jct. - Gresham

	Intercept	Slope	R2
Line Jct.- Gresham	7672.5	0.042	0.7811

APPENDIX F

Cost Prediction Equations for All Wood Products

Worden - Springfield

	Intercept	Slope	R2
Worden - Klamath Falls	1121.0	0.043	0.0889
Klamath Falls - Chiloquin	1123.0	0.103	0.2625
Chiloquine - Chemault	8928.3	0.180	0.6204
Chemault - Gilchrist Jct.	1450.0	0.378	0.0005
Gilchrist Jct.- Oakridge	1897.0	0.205	0.7592
Oakridge - Springfield	1052.0	0.110	0.2964

Santiam Branch

	Intercept	Slope	R2
Foster - Sweet Home	6944.2	0.039	0.8749
Sweet Home - Lebanon	6237.5	0.073	0.4010

Astoria Line

	Intercept	Slope	R2
Hammon - Warrenton	5218.0	0.143	0.5660
Warrenton - Astoria	8397.9	0.171	0.4732
Astoria - Clatskanie	2735.5	0.117	0.9481
Clatskanie - St. Helens	1393.8	0.074	0.9443
St. Helens - Portland	3180.7	0.075	0.9444

Forest Grove Branch

	Intercept	Slope	R2
Forest Grove - Hilsboro	3042.1	0.084	0.7235

Oregon Electric

	Intercept	Slope	R2
Junction City - Albany	963.0	0.317	0.4494
Albany - Independence	3932.5	0.188	0.4254
Independence - Salem	3447.3	0.068	0.7291
Salem - Brooks	4187.9	0.053	0.8053
Brooks - Beaverton	1707.5	0.069	0.9490
Beaverton - United Jct.	3003.4	0.056	0.9478

Mt Hood Railway

	Intercept	Slope	R2
Hood River - Odell	7465.0	0.071	0.7102
Odell - Park Dale	7443.7	0.069	0.6815

Chemult - Celio

	Intercept	Slope	R2
Chemult - Bend	2336.0	0.595	0.3044
Bend - Redmond	8643.4	0.016	0.0632
Redmond - Prineville Jct.	5872.9	0.030	0.0053
Prineville Jct.- Madras	1133.0	0.171	0.0493
Madras - Maupin	1300.0	0.347	0.0184
Maupin - Celio	8324.2	0.140	0.9439

City of Prinevile

	Intercept	Slope	R2
City of Prineville	5928.4	0.135	0.0379

Gilchrist JCT

	Intercept	Slope	R2
Gilchrist - Gilchrist Jct.	3712.3	0.047	0.9145

Shelburn - Mill City

	Intercept	Slope	R2
Shelburn - Lyon	1082.0	0.286	0.5645
Lyon - Mill City	7562.0	0.136	0.7152

Monroe - Hillsboro

	Intercept	Slope	R2
Monroe - Corvallis	993.0	0.406	0.3125
Corvallis - Independence	3556.8	0.094	0.3234
Independence - McMinnville	1017.0	0.173	0.1717
McMinnville - Yamhill	6987.1	0.097	0.6092
Yamhill - Forest Grove	7044.3	0.072	0.5306
Forest Grove - Hillsboro	3042.1	0.084	0.7235

Portland - Idahoe

	Intercept	Slope	R2
Portland - Hood River	2046.0	0.398	0.2756
Hood River - Dalles	8922.2	0.086	0.1509
Dalles - Celio	3567.8	0.098	0.4572
Celio - Biggs	2997.9	0.115	0.6454
Biggs - Arlington	1065.0	0.317	0.4328
Arlington - Heppner Jct.	1793.7	0.110	0.6275
Heppner Jct.- Broadman	978.0	0.175	0.6140
Broadman - Echo	8769.7	0.267	0.4801

Echo - Pendleton	965.0	0.268	0.4731
Pendleton - LaGrande	2923.0	0.616	0.3310
LaGrande - Union	8569.0	0.247	0.5696
Union - North Power	1153.0	0.302	0.5042
North Power - Haines	6954.3	0.142	0.7551
Haines - Baker	7794.1	0.199	0.6475
Baker - Durkee	6562.2	0.428	0.4273
Durkee - Idahoe	7036.9	0.426	0.4281

Monroe - Dawson

	Intercept	Slope	R2
Monroe - Dawson	4195.3	0.263	0.3976

Geer - Salem

	Intercept	Slope	R2
Geer - Salem	2912.2	0.117	0.4454

Theilsen - Dallas

	Intercept	Slope	R2
McMinnville - Dallas	6180.8	0.239	0.1785
Thielsen - Dallas	3463.0	1.058	0.2323

Alturas - Lakeview

	Intercept	Slope	R2
Lakeview - California Bdr.	6121.3	0.048	0.0926

Condor - Arlington

	Intercept	Slope	R2
Condor - Arlington	1291.0	0.349	0.6502

Heppner - Heppner JT

	Intercept	Slope	R2
Heppner - Heppner Jct.	1300.0	0.160	0.9364

Klammath - Bly

	Intercept	Slope	R2
Klammath Falls - Olean	8536.1	0.090	0.2935
Olean - Dary	5294.6	0.031	0.0217
Dary - Beaty	7275.0	0.225	0.0341
Beaty - Bly	3226.6	0.069	0.2749

Oregon - East

	Intercept	Slope	R2
Culp Creek - Cottage Grove	8440.2	0.300	0.3063

Springfield - Shelburn

	Intercept	Slope	R2
Springfield - Coburg	979.0	0.287	0.3160
Coburg - Lebanon	1009.0	0.622	0.3601
Lebanon - Scio	1029.0	0.356	0.3931
Scio - Shelburn	7076.0	0.094	0.5920

Portland Traction Co.

	Intercept	Slope	R2
Portland - Milwaukie	5918.9	0.066	0.5392
Milwaukie - Gresham	3955.1	0.052	0.6853
Gresham - Boring	4305.4	0.064	0.5967

Oregon & Northwest Railroad

	Intercept	Slope	R2
Seneca - Burns	4545.6	0.105	0.8738
Burns - Hines	1479.0	0.032	0.6069

Woodburn - Stayton

	Intercept	Slope	R2
Woodburn - Silverton	1558.0	0.522	0.2435
Silverton - Stayton	5888.4	0.357	0.1681

Wilsonia - Jefferson

	Intercept	Slope	R2
Wilsonia - Jefferson	8574.7	0.256	0.2636

Eugene - Portland

	Intercept	Slope	R2
Eugene - Junction City	3206.2	0.139	0.6798
Junction City - Halsey	9434.7	0.035	0.0503
Halsey - Albany	8961.2	0.132	0.6930
Albany - Salem	6321.9	0.105	0.9212
Salem - Brooks	4187.9	0.053	0.8053
Brooks - Woodburn	3409.5	0.018	0.0015

	Intercept	Slope	R2
Woodburn - Canby	2575.0	0.478	0.0016
Canby - Oregon City	2991.6	0.035	0.0878
Oregon City - Milwaukie	1286.0	0.054	0.8543
Milwaukie - Portland	5918.9	0.066	0.5392

Canby - Molalla

	Intercept	Slope	R2
Canby - Molalla	4586.6	0.406	0.1917

Mohawk Jct. - Marcola

	Intercept	Slope	R2
Springfield - Marcola	3379.0	0.026	0.0857

Medford - White City

	Intercept	Slope	R2
Medford - White City	4439.9	0.082	0.5910

Whiteson - Willamina

	Intercept	Slope	R2
Whiteson - Sheridan	1285.0	0.099	0.1584
Sheridan - Willamina	6021.0	0.106	0.5388

West Stayton - Stayton

	Intercept	Slope	R2
West Stayton - Stayton	7822.3	0.054	0.3699

Wallual Branch

	Intercept	Slope	R2
Wallual - Branch	1156.0	0.099	0.9232

California - Springfield

	Intercept	Slope	R2
Cal Border - Ashland	1106.0	0.079	0.8145
Ashland - Medford	3986.3	0.086	0.5338
Medford - Goldhill	1039.0	0.206	0.4570
Goldhill - Rogue River	3031.2	0.054	0.3690
Rogue River - Grants Pass	6728.9	0.158	0.3960
Grants Pass - Glendale	1719.0	0.044	0.3090
Glendale - Correct	1415.0	0.456	0.3460
Correct - Dillard	7891.6	0.213	0.3188

Dillard - Roseburg	3256.2	0.058	0.0642
Roseburg - Sutherline	8831.6	0.054	0.0215
Sutherline - Anlauf	1161.0	0.247	0.2290
Anlauf - Cottage Grove	5236.5	0.041	0.0458
Cottage Grove - Creswell	2955.4	0.066	0.6341
Creswell - Goshen	2074.8	0.019	0.1051
Goshen - Springfield	3581.1	0.065	0.4548

Portland - Boring

	Intercept	Slope	R2
Portland - Line Jct.	1180.0	0.251	0.5140
Line Jct.- Boring	984.0	0.258	0.5159

Eugene - Myrtle Point

	Intercept	Slope	R2
Eugene - Noti	5032.6	0.283	0.4270
Noti - Swiss Home	1311.0	0.641	0.3337
Swiss Home - Mapleton	7103.2	0.163	0.5792
Mapleton - Florence	6146.6	0.176	0.2297
Florence - Gardner	5311.4	0.320	0.4149
Gardner - Reedsport	1141.3	0.062	0.5631
Reedsport - Lakeside	6187.2	0.120	0.4287
Lakeside - North Bend	8698.9	0.165	0.2789
North Bend - Coos Bay	4559.1	0.069	0.4902
Coos Bay - Coquille	7825.6	0.180	0.3207
Coquille - Myrtle Point	4205.4	0.176	0.2317

Portland - Tillamook

	Intercept	Slope	R2
Portland - Lake Oswego	8766.0	0.154	0.4075
Lake Oswego - Beaverton	5885.3	0.081	0.6986
Beaverton - Hillsboro	5512.4	0.028	0.0688
Hillsboro - Tillamook	3290.0	1.102	0.2245

St. Joseph - Cook

	Intercept	Slope	R2
St. Joseph - Cook	9025.2	0.177	0.4679

Boardman - Perrydale

	Intercept	Slope	R2
Boardman - Perrydale	1112.4	0.097	0.3062

Page - Tallman

	Intercept	Slope	R2

	Intercept	Slope	R2
Page - Tallman	1498.0	0.571	0.3479

California - Klamath Falls

	Intercept	Slope	R2
CA OR - Klamath Falls	6080.2	0.121	0.6015

Albany - Toledo

	Intercept	Slope	R2
Albany - Corvallis	3935.6	0.109	0.8320
Corvallis - Philomath	2095.5	0.072	0.6602
Philomath - Edyville	2033.0	0.585	0.3001
Edyville - Toledo	8244.1	0.388	0.3532

Gardner - Gardner Jct

	Intercept	Slope	R2
Gardner - Gardner Jct.	4642.7	0.032	0.3724

Joseph Branch

	Intercept	Slope	R2
Lagrand - Island City	4332.5	0.047	0.1240
Island City - Elgin	7389.1	0.141	0.5509
Elgin - Walla	9312.9	0.086	0.8879
Walla - Enterprise	9508.9	0.269	0.4264
Enterprise - Joseph	2081.4	0.098	0.3865

Oregon Eastern Branch

	Intercept	Slope	R2
Ontario - Vale	8298.9	0.143	0.0477
Vale - Burns	4680.0	0.790	0.0218

Pilot Rock - Pendleton

	Intercept	Slope	R2
Pilot Rock - Pendleton	5250.0	0.052	0.9381

Umatila - Pendleton

	Intercept	Slope	R2
Umatila - Pendleton	7299.9	0.000	0.0654

Line Jct. - Gresham

	Intercept	Slope	R2
Line Jct.- Gresham	6789.4	0.173	0.6217

APPENDIX G

Programming Notes and User's Guide

The Train Simulator is written in FORTRAN 77. The command TRAIN executes the program. There are two input files for the train model. The first is a fixed format file call TRACKS.ALL. This file contains the list of all of track segments to be processed. The next files are the track segments to be processed.

There are ten subroutines in the program. The main subroutine is TRAIN. This program increments the loops for the three products and calls the remainder of the subroutine. At the beginning of the subroutine the interest rate is defined. The first subroutine called from TRAIN is DATENT. DATENT reads the TRACKS.ALL file for the list of links to be processed. The subroutine then opens each link file and reads the track description file. The first line of the file contains the number of track segments, the number of trains per week, and the beginning mile post. The format for this line is I4, I4, F7.3. The remainder of the file is the track description file. The variables are ending segment mile post, grade, curvature, rail weight, maximum velocity, tons of ballast, ballast life, number of tunnels, and number of bridges. The format is 9(F7.2).

The next subroutine called from the train subroutine is

BUILD. Build creates the train by calculating the number and type of rail cars and the number of engines. The total weight of the train is calculated.

The next set of subroutines calculates the total resisting forces, the velocity, and the travel time for the train. The first subroutine is MOTION. It calls RESIST, which calculates the forces acting upon the train. The velocity is calculated by the secant method in the subroutine SECANT. Once the final velocity has been calculated, the travel time is calculated in subroutine MOTION.

The next subroutine, TRACKS, calculates the track cost. TRACKS calculates the vegetation removal cost along the track, ballast cost, the rail tie cost, and the rail wear increase due to the curvature and grade resistance.

The next subroutine, OPCOST, calculates the operation cost. The OPCOST subroutine calculates the engine cost, car cost and the fuel cost.

The last cost subroutine is SUMCST. It calculates the total cost for each segment in the link. This subroutine calculates the train operation labor cost. The output from this file is written to a temporary file.

The final subroutine is WRITER. It creates a fixed format with the link name, product code (1 for lumber, 2 for plywood and 3 for wood chips), the tonnage shipped, the distance traveled in feet, and the total cost. The format is 1X,A10,I5,1X,F11.3, 1X,F11.3. The output from WRITER provides the input for statistical analysis.

APPENDIX H

Source Code

```
C
C******************************************************************* C*
   MM/DD/YY    WHO    STER              DESCRIPTION
C*      07/07/88    KDB    ----          ORIGINAL DEVELOPMENT
C*******************************************************************
C
       PROGRAM TRAIN
       CHARACTER * 2 ENDO
       INTEGER TKT,PROD
$INCLUDE: 'TRAIN.INC'

       ENDO = 'NO'
C
5      RATRTN=.04
C
       TKT=6
       OPEN(UNIT=TKT,FILE='TRACKS.ALL',STATUS='UNKNOWN',
     1 ACCESS='SEQUENTIAL',FORM='FORMATTED',RECL=20)

       DO WHILE (ENDO .EQ. 'NO')
       CALL DATENT(ENDO,TKT)
C
       DO 40 P=1,3
          IF(P .EQ. 1)THEN
             UNITS=7000
             RATE=100
             PROD=1500
          END IF
          IF(P .EQ. 2)THEN
             UNITS=7000
             RATE=100
             PROD=1500
          END IF
          IF(P .EQ. 3)THEN
             UNITS=7000
             RATE=100
             PROD=1500
          END IF
          DO 30 K=PROD,UNITS,RATE
             DO 20 L=1,2
                CALL BUILD
                DO 10 I=1,NSEC
                   CALL MOTION
                   CALL TRACK
                   CALL OPCOST
10              CONTINUE
                CALL SUMCST
20           CONTINUE
30        CONTINUE
40     CONTINUE
       REWIND OUT
       CALL WRITER
       GOTO 5
       CLOSE(TKT,STATUS='KEEP')
```

```
      END DO
500   FORMAT(1X,'*****',A2,'*****')
1000  FORMAT(1X,'ENTER FILE NAME')
2000  FORMAT(A20)
      END
```

```
C*****************************************************************
C*     MM/DD/YY     WHO     STER                DESCRIPTION
C*     07/07/88     KDB     ----           ORIGINAL DEVELOPMENT
C*
C*****************************************************************
       SUBROUTINE OPCOST
$INCLUDE: 'TRAIN.INC'
C
       FC=.65
       ENGCOS=14.75
       ENGCST(I)=ENGCOS/60*TIMTOT(I)*NE
       IF(P .EQ. 1)THEN
          CARPUR=29303
          NTUY=365
          TCRCOS = .26 /60
       END IF
       IF(P .EQ. 2)THEN
          CARPUR=40065
          NTUY=264
          TCRCOS = .49 /60
       END IF
       IF(P .EQ. 3)THEN
          CARPUR=34320
          NTUY=165
          TCRCOS = .66 /60
       END IF
       CARMAN=0.015
       CMANCS=CARMAN*LENSEC(I)/5280
       TCRCSS=TCRCOS*TIMTOT(I)
       TCRCST=(TCRCSS+CMANCS)*NC
       OPRCST(I)=TCRCST+ENGCST(I)
C
C      FUEL COST
C
       FULCON(I) = 3.2 * LENSEC(I)/5280*NE
       FULCST(I) = FULCON(I) * .65
       VCOST(I)=TRKWAR(I)+OPRCST(I)+FULCST(I)
       RETURN
       END
```

```
C
C*****************************************************************
C*    MM/DD/YY    WHO    STER              DESCRIPTION
C*    07/07/88    KDB    ----          ORIGINAL DEVELOPMENT
C*
C****************************************************************C
      SUBROUTINE MOTION
$INCLUDE: 'TRAIN.INC'
C
      VEND0=0
      IF(I .EQ. 1)THEN
         VB(I)=VEND0
      ELSE
         VB(I)=VB(I-1)
      END IF
      CALL RESIST
      IF(VEND(I) .GT. VMAX(I))THEN
         PD(I)=1
         DIS=ABS(VB(I)**2-VEND(I)**2)*70*(WTOT/2000)/RTOT
         IF(DIS .LT. LENSEC(I))THEN
            DIS=ABS(VB(I)**2-VEND(I)**2)*70*(WTOT/2000)/RTOT
            DISACC=DIS
            DISCON=LENSEC(I)-DIS
            TIMEAC(I)=ABS(VEND(I)-VB(I))*95.6*(WTOT/2000)/RTOT/60
            TIMCON(I)=DISCON/(VEND(I)*88)
            TIMTOT(I)=TIMEAC(I)+TIMCON(I)
         ELSE
            DISACC=DIS
            DISCON=LENSEC(I)-DIS
            TIMEAC(I)=ABS(VEND(I)-VB(I))*95.6*(WTOT/2000)/RTOT/60
            TIMCON(I)=DISCON/(VEND(I)*88)
            TIMTOT(I)=TIMEAC(I)+TIMCON(I)
         END IF
      ELSE
         DISACC=DIS
         DISCON=LENSEC(I)-DIS
         TIMEAC(I)=ABS(VEND(I)-VB(I))*95.6*(WTOT/2000)/RTOT/60
      END IF
      RETURN
      END
```

```
C*************************************************************C*
C*     MM/DD/YY     WHO     STER              DESCRIPTION
C*     07/07/88     KDB     ----          ORIGINAL DEVELOPMENT
C*
C*************************************************************C
       SUBROUTINE DATENT(ENDO,TKT)
       CHARACTER EXIST
       INTEGER TKT
$INCLUDE: 'TRAIN.INC'
C
C       WRITE(*,1000)
        READ(TKT,2000,END=15)FILNAM
        EXIST='N'
C       WRITE(*,1100)
C       READ(*,2100)EXIST
C
       COL=INDEX(FILNAM,'.')
       FILTRK=FILNAM(1:COL)//'TRK'
       J=0
       NSEC=0
       INP=2
       IF(EXIST .EQ. 'N')THEN
          OPEN(UNIT=INP,FILE=FILTRK,STATUS='UNKNOWN',
     1    ACCESS='SEQUENTIAL',FORM='FORMATTED',RECL=80)
          READ(INP,3000)NSEC,NTRW,MP0
          DO 10 J=1,NSEC
             READ(INP,3100)MP(J),GR(J),CURVE(J),RAIL(J),VMAX(J),
     1       BALAST(J),BALIFE(J),NTNEW(J),NBNEW(J)
10        CONTINUE
       ELSE
          OPEN(UNIT=INP,FILE=FILTRK,STATUS='UNKNOWN',
     1    ACCESS='SEQUENTIAL',FORM='FORMATTED',RECL=80)
          WRITE(*,1400)
          READ(*,1500)MP0
20        WRITE(*,1600)
          J=J+1
          NSEC=NSEC+1
          READ(*,4000)MP(J),GR(J),CURVE(J),RAIL(J),VMAX(J),
     1    BALAST(J),BALIFE(J),NTNEW(J),NBNEW(J)
          IF(MP(J) .LT. 0)THEN
             NSEC=NSEC-1
             J=J+1
             WRITE(*,1200)
             READ(*,1300)NTRW
          ELSE
             GOTO 20
          END IF
          WRITE(INP,3000)NSEC,NTRW,MP0
          DO 30 J=1,NSEC
         WRITE(INP,3100)MP(J),GR(J),CURVE(J),GR(J),RAIL(J),
     1    VMAX(J),BALAST(J),BALIFE(J),NTNEW(J),NBNEW(J)
30        CONTINUE
       END IF
       DO 40 J=1,NSEC
```

```
          IF(J .EQ. 1)THEN
             LENSEC(J)=ABS((MP(J)-MP0))*5280
             BALLST(J)=ABS((MP(J)-MP0))*BALAST(J)
             NT=NT+NTNEW(J)
             NB=NB+NBNEW(J)
          ELSE
             LENSEC(J)=ABS((MP(J)-MP(J-1)))*5280
             BALLST(J)=ABS((MP(J)-MP(J-1)))*BALAST(J)
             NT=NT+NTNEW(J)
             NB=NB+NBNEW(J)
          END IF
40     CONTINUE
       DO 50 J=1,NSEC
          GR(J)=ABS(GR(J))
50     CONTINUE
       RETURN
15     ENDO='ED'
500    FORMAT(1X,'*****',A2,'*****')
1000   FORMAT(1X,'ENTER FILENAME ',$)
1100   FORMAT(1X,'IS THIS A NEW FILE')
1200   FORMAT(1X,'NUMBER OF TRAINS PER WEEK ',$)
1300   FORMAT(I4)
1400   FORMAT(1X,'BEGINING MILE POST ',$)
1500   FORMAT(F7.3)
1600   FORMAT(1X,'MILE POST CURVE GRADE RAIL VMAX BALLAST LIFE TUN BRD')
2000   FORMAT(A20)
2100   FORMAT(A1)
2200   FORMAT(1X,I4,I4,F7.3)
2300   FORMAT(1X,9(F7.3))
3000   FORMAT(1X,I4,I4,F7.3)
3100   FORMAT(1X,9(F7.3))
4000   FORMAT(9(F7.3))
       RETURN
       END
```

```
C***************************************************************
C*     MM/DD/YY    WHO    STER              DESCRIPTION
C*     07/07/88    KDB    ----          ORIGINAL DEVELOPMENT
C*
C**************************************************************C
       SUBROUTINE TRACK
$INCLUDE: 'TRAIN.INC'
C
       RC=190
       VEGCOS=160
       RTON=2*1760*RAIL(I)/2000
       BALCOS=52.00
       BALFE=BALIFE(I)
       NTRY=NTRW*52
       MTONY=WTOT/(2000*1000000)*NTRY
       BALCST=BALAST(I)*BALCOS
       BCAPRC=BALCST*(RATRTN*(1+RATRTN)**BALFE/((1+RATRTN)**BALFE-1))
       BALWAR=BCAPRC/NTRY
C
C      TIE WEAR
C
       TIECST=150*46*LENSEC(I)/5280
       TCAPRC=TIECST*(RATRTN*(1+RATRTN)**30/((1+RATRTN)**30-1))
       TIEWAR=TCAPRC/NTRY
C
C      SURFACE WEAR
C
       SURWAR=(160*LENSEC(I)/5280)/NTRY
       VEGCST=(VEGCOS*LENSEC(I))/5280/NTRY
C
C      RAIL WEAR
C
       TON=WTOT/(2000*1000000)
       RAILOD=(TON*NTRY)**.565*.92*RAIL(I)
       RAILCS=RC*RTON
       RCAPRC=RAILCS*(RATRTN*(1+RATRTN)**RAILOD/((1+RATRTN)**RAILOD-1))
       RAILWR=RCAPRC/NTRY
C
C      INCREASE RAIL WEAR DUE TO GRADE
C
       GRADE=ABS(GR(I))
       IF(GRADE .GE. 0 .AND. GRADE .LE. .5)THEN
          RALWRG=0
       END IF
       IF(GRADE .GT. .5 .AND. GRADE .LE. 1)THEN
          RALWRG=0
       END IF
       IF(GRADE .GT. 1 .AND. GRADE .LE. 1.5)THEN
          RALWRG=0.035
       END IF
       IF(GRADE .GT. 1.5 .AND. GRADE .LE. 2.0)THEN
          RALWRG=0.107
       END IF
       IF(GRADE .GT. 2.0 .AND. GRADE .LE. 2.5)THEN
```

```
         RALWRG=0.248
      END IF
      IF(GRADE .GT. 2.5)THEN
         RALWRG=0.466
      END IF
C
C     INCREASE FOR CURVITURE
C
      IF(CURVE(I) .GE. 0 .AND. CURVE(I) .LT. .5)THEN
         RALWRC=0
      END IF
      IF(CURVE(I) .GE. .5 .AND. CURVE(I) .LT. 1.5)THEN
         RALWRC=0
      END IF
      IF(CURVE(I) .GE. 1.5 .AND. CURVE(I) .LT. 2.5)THEN
         RALWRC=0.136
      END IF
      IF(CURVE(I) .GE. 2.5 .AND. CURVE(I) .LT. 3.5)THEN
         RALWRC=0.260
      END IF
      IF(CURVE(I) .GE. 3.5 .AND. CURVE(I) .LT. 4.5)THEN
         RALWRC=0.429
      END IF
      IF(CURVE(I) .GE. 4.5 .AND. CURVE(I) .LT. 5.5)THEN
         RALWRC=0.613
      END IF
      IF(CURVE(I) .GE. 5.5 .AND. CURVE(I) .LT. 6.5)THEN
         RALWRC=0.818
      END IF
      IF(CURVE(I) .GE. 6.5 .AND. CURVE(I) .LT. 7.5)THEN
         RALWRC=1.083
      END IF
      IF(CURVE(I) .GE. 7.5 .AND. CURVE(I) .LT. 8.5)THEN
         RALWRC=1.273
      END IF
      IF(CURVE(I) .GE. 8.5 .AND. CURVE(I) .LT. 9.5)THEN
         RALWRC=1.500
      END IF
      IF(CURVE(I) .GE. 9.5)THEN
         RALWRC=1.703
      END IF
      TRKWAR(I)=(1+RALWRG+RALWRC)*RAILWR+BALWAR+TIEWAR+SURWAR+VEGCST
      TWEAR=TRKWAR(I)*5280/LENSEC(I)
C
      RETURN
      END
```

```
C*****************************************************************
C*     MM/DD/YY     WHO     STER                DESCRIPTION
C*     07/07/88     KDB     ----           ORIGINAL DEVELOPMENT
C*
C*****************************************************************C
       SUBROUTINE SECANT(VO,RR,V)
$INCLUDE: 'TRAIN.INC'
C
       FRONT=120
C
C       RRU=17.9+(1.39*VO-10.2+0.002*FRONT*VO**2)/(WTOT/(2000*6))
C
       RRU=.6+20/(WTOT/2000)+.01*VO+.07*VO**2/(WTOT*2/2000)
       RR=RRU*(WTOT/2000)
       V=308*HPTOT/(RODRES(I)+RR)
       RR=RODRES(I)+RR
       RETURN
       END
```

```
C***************************************************************
C*    MM/DD/YY    WHO    STER              DESCRIPTION
C*    07/07/88    KDB    ----         ORIGINAL DEVELOPMENT
C***************************************************************C
       SUBROUTINE BUILD
$INCLUDE: 'TRAIN.INC'
C
       IF(P .EQ. 1)THEN
          LUMBER(L)=K
          PLYWD(L)=0
          CHIP(L)=0
       END IF
       IF(P .EQ. 2)THEN
          LUMBER(L)=0
          PLYWD(L)=K
          CHIP(L)=0
       END IF
       IF(P .EQ. 3)THEN
          LUMBER(L)=0
          PLYWD(L)=0
          CHIP(L)=K
       END IF
       NOFLAT(L)=INT(LUMBER(L)*.0142+.5)
       NOBOX(L)=INT(PLYWD(L)*.0067+.5)
       NOHOP(L)=INT(CHIP(L)*.0270+.5)
       NC=NOFLAT(L)+NOBOX(L)+NOHOP(L)
       IF(L .EQ. 1)THEN
          CARGO=1.415*LUMBER(L)+1.35*CHIP(L)+1.70*PLYWD(L)
       ELSE
          CARGO=0
       END IF
       TCARWT=30*NOFLAT(L)+35*NOHOP(L)+40*NOBOX(L)+CARGO
       NE=INT(.75*TCARWT/2500)
       IF(NE .LT. 1)THEN
          NE=1
       END IF
       HPTOT=2500*NE
       BRAK=3500*NE
       BRAKE=3500*NE
       WTOT=(TCARWT+NE*175)*2000
       IF(L .EQ. 2)THEN
          WTOT=(NOFLAT(L)*30+NOBOX(L)*40+NOHOP(L)*35+NE*175)*2000
       ELSE
          WTOT=(NOFLAT(L)*30+NOBOX(L)*40+NOHOP(L)*35+
     1          NE*175+CARGO)*2000
       END IF
       VALUE=40*CHIP(L)+225*LUMBER(L)+500*PLYWD(L)
       IF(L .EQ. 2)THEN
          VALUE=0
       END IF
       RETURN
       END
```

```
C*****************************************************************
C*    MM/DD/YY    WHO    STER              DESCRIPTION
C*    07/07/88    KDB    ----          ORIGINAL DEVELOPMENT
C*
C****************************************************************C
       SUBROUTINE RESIST
$INCLUDE: 'TRAIN.INC'
       REAL M
C
       GRDRES(I)=WTOT*SIN(ATAN(GR(I)/100))
       IF(GRDRES(I) .LT. 0)THEN
          GRDRES(I)=0
       END IF
       ROLERR(I)=WTOT*8/2000
       IF(CURVE(I) .EQ. 0)THEN
          CURES(I)=0
       ELSE
          CURES(I)=WTOT/2000*.8/CURVE(I)
       END IF
       IF(PD(I) .EQ. 3)THEN
          BRAKF(I)=BRAK
       ELSE
          BRAKF(I)=O
       END IF
       RODRES(I)=GRDRES(I)+ROLERR(I)+CURES(I)+BRAKF(I)
       VO=VB(I)
       CALL SECANT(VO,RR,V)
       RR1=RR
       V1=V
       VO=VMAX(I)
       CALL SECANT(VO,RR,V)
10     RR2=RR
       V2=V
       M=(RR2-RR1)/(V2-V1)
       RR1=RR2
       V1=V2
       VO=V2+RR2/M
       CALL SECANT(VO,RR,V)
       IF(ABS(V-V1) .GT. 2.5)THEN
          GOTO 10
       ELSE
          VEND(I)=V
          RTOT=RR+RODRES(I)
       END IF
       RETURN
       END
```

```
C
C***************************************************************
C*     MM/DD/YY     WHO     STER               DESCRIPTION
C*     07/07/88     KDB     ----          ORIGINAL DEVELOPMENT
C*
C***************************************************************C
       SUBROUTINE WRITER
       CHARACTER * 20 FIL1DT,FIL2DT,FIL3DT
$INCLUDE: 'TRAIN.INC'
C
       COL=INDEX(FILNAM,'.')
       FIL1DT=FILNAM(1:COL)//'1DT'
       FIL2DT=FILNAM(1:COL)//'2DT'
       FIL3DT=FILNAM(1:COL)//'3DT'
       IN1=7
       IN2=8
       IN3=9
       OPEN(UNIT=IN1,FILE=FIL1DT,STATUS='UNKNOWN',
     1 ACCESS='SEQUENTIAL',FORM='FORMATTED')
C
10     READ(OUT,1000,END=20)P,L,K,CARGO1,TOTSC1,CPTM1,SUMCS1
       READ(OUT,1000,END=20)P,L,K,CARGO2,TOTSC2,CPTM2,SUMCS2
       TOTCOS=(SUMCS1+SUMCS2)
       WRITE(IN1,2000)FILNAM(1:8),P,CARGO1,TOTSC1,TOTCOS
       GOTO 10
C
1000   FORMAT(3(I5,2X),4(F11.3,2X))
2000   FORMAT(1X,A10,I3,F11.3,1X,F11.3,1X,F11.3)
20     CLOSE(IN1,STATUS='KEEP')
       CLOSE(IN2,STATUS='KEEP')
       CLOSE(IN3,STATUS='KEEP')
       CLOSE(OUT,STATUS='KEEP')
       RETURN
       END
```

```
C*****************************************************************
C*    MM/DD/YY    WHO    STER              DESCRIPTION
C*    07/07/88    KDB    ----          ORIGINAL DEVELOPMENT
C*
C****************************************************************C
       SUBROUTINE SUMCST
       INTEGER B,T
$INCLUDE: 'TRAIN.INC'
C
       TOTSEC=0
       TOTIME=0
       TOTTRK=0
       TOTFUL=0
       TCOST=0
       TOPERC=0
       DO 10 I=1,NSEC
          TOTSEC=TOTSEC+LENSEC(I)
          TOTIME=TOTIME+TIMTOT(I)
          TOTTRK=TOTTRK+TRKWAR(I)
          TOTFUL=TOTFUL+FULCST(I)
          TCOST=TCOST+VCOST(I)
          TOPERC=TOPERC+OPRCST(I)
10     CONTINUE
       TOTBC=0
       TOTTC=0
       TOTBM=0
       TOTTM=0
       BANMAN=7900
       BCNSCT=5000
       XXX=1.15**30-1
       IF(NB .GT. 0)THEN
          DO 20 B=1,NB
             BRIDGE(B)=BCNSCT*(.15*(1.15)**30)/XXX
             TOTBC=TOTBC+BRIDGE(B)
             TOTBM=TOTBM+BANMAN
20        CONTINUE
       END IF
       TUNMAN=8500
       TUNCST=5000
       IF(NT .GT. 0)THEN
          DO 30 T=1,NT
             TUNNEL(T)=TUNCST*(.15*(1.15)**30)/XXX
             TOTTC=TOTTC+TUNNEL(T)
             TOTTM=TOTTM+TUNMAN
30        CONTINUE
       END IF
       TOTSTR=(TOTTC+TOTTM+TOTBC+TOTBM)/NTRY
       INVDAY=7/NTRW+TOTIME/(60*24)
       INVENC=VALUE*RATRTN*INVDAY/365
       CREWC=25*3*TOTIME
       SUMCOS=TCOST+TOTFUL+TOTSTR+INVENC+CREWC
       IF(L .EQ. 1)THEN
          CPTM=SUMCOS/(TOTSEC/5280*CARGO)
       ELSE
```

```
         CPTM=0
      END IF
      COL=INDEX(FILNAM,'.')
      FILOUT=FILNAM(1:COL)//'OUT'
      OUT=5
      OPEN(UNIT=OUT,FILE=FILOUT,STATUS='UNKNOWN',
     1 ACCESS='SEQUENTIAL',FORM='FORMATTED')
      WRITE(OUT,1000)P,L,K,CARGO,TOTSEC,CPTM,SUMCOS,TOTIME
1000  FORMAT(3(I5,2X),5(F11.3,2X))
      RETURN
      END
```

```
C     TRAIN INCLUDE FILE
C
C
      INTEGER NC,NE,NSEC,NTRW,NTRY,COL,OUT,P,L,K,I,RATE,UNITS
      CHARACTER * 20 FILOUT,FILNAM,FILTRK
      REAL LUMBER(25),PLYWD(25),CHIP(25),NOFLAT(25),NOBOX(25),
     1 CARGO,TCARWT,HPTOT,BRAK,BRAKE,WTOT,VALUE,MP0,MP(25),
     2 CURVE(25),GR(25),RAIL(25),VMAX(25),BALAST(25),BALIFE(25),
     3 NTNEW(25),NBNEW(25),LENSEC(25),BALLST(25),NT,NB,VEND0,
     4 VEND(25),VB(25),PD(25),DIS,DISACC,DISCON,TIMEAC(25),
     5 TIMCON(25),TIMTOT(25),ENGCST(25),CARPUR,NTUY,OPRCST(25),
     6 FULCON(25),FULCST(25),VCOST(25),GRDRES(25),ROLERR(25),
     7 CURES(25),BRAKF(25),RODRES(25),RTOT,TOTSEC,TOTIME,TOTTRK,
     8 TOTFUL,TCOST,TOPERC,BRIDGE(25),TUNNEL(25),TOTBC,TOTBM,TOTTM,
     9 TOTSTR,INVENC,CREWC,SUMCOS,TWEAR,TRKWAR(25),NOHOP(25)
C
C
C
      COMMON/VARIBL/NC,NE,NSEC,NTRW,NTRY,COL,OUT,P,L,K,I,RATE
     1 FILOUT,FILNAM,UNITS,FILTRK,RATRTN,
     2 LUMBER,PLYWD,CHIP,NOFLAT,NOBOX,
     3 NTNEW,NBNEW,LENSEC,BALLST,NT,NB,VEND0,
     4 VEND,VB,PD,DIS,DISACC,DISCON,TIMEAC,
     5 TIMCON,TIMTOT,ENGCST,CARPUR,NTUY,OPRCST
C
      COMMON/ARRAY/FULCON,FULCST,VCOST,GRDRES,
     1 CARGO,TCARWT,HPTOT,BRAK,BRAKE,WTOT,VALUE,MP0,MP,
     2 CURVE,GR,RAIL,VMAX,BALAST,BALIFE,TRKWAR,
     4 CURES,BRAKF,RODRES,RTOT,TOTSEC,TOTIME,TOTTRK,
     5 TOTFUL,TCOST,TOPERC,BRIDGE,TUNNEL,TOTBC,TOTBM,TOTTM,
     6 TOTSTR,INVENC,CREWC,SUMCOS,TWEAR,ROLERR
```