Techniques for Preparing Alternative Road Access Policies for Steep and Mountainous Terrain

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ABSTRACT - The theoretical balance between yarding with cable logging systems and expanding road access in steep and mountainous terrain may be influenced by the uncertainty of expected logging production for longer yarding distances. Intuitively speaking, shorter yarding distances provide higher production with less uncertainty but require more roads. Risk assessment techniques are presented, which may be useful for comparing feasible and cost competitive yarding alternatives.

Keywords: Logging, Weibull, cable, time and motion studies.

INTRODUCTION

Forest practices have changed considerably in Western Washington State over the last decade. For example, harvest densities from lands managed by the Washington State Department of Natural Resources have steadily decreased and at the same time, standards and approved activities for roads have rapidly increased1. Longer yarding distances and reduced road dependencies seem to be intuitive policy alternatives based on economic assessments of published regression equations for logging production studies.

Several authors have presented techniques for estimating preferred ranges of yarding distances. Mathews published one of the earliest references, (Mathews, 1942). Studier & Binckley presented examples of “optimal” yarding distances based on highlead cable systems and old-growth logging, (Studier & Binckley, 1974**)**, and Peters provided an equation for cost surfaces based on lateral and external yarding distances (Peters, 1974). Adamovich illustrated similar cost surfaces, (Adamovich, 1974). These techniques have been commonly applied to cable logging systems for improving on-site production.

Schiess and Jaross applied these techniques to several studies of cable yarding systems and reported that the long-span alternatives may be cost competitive with conventional yarding distances in situations indicative of harvest density reductions, (Schiess, P., Jaross W, 1999). However, road dependencies for the Washington State Department of Natural Resources continue to increase. Schiess and Jaross speculated that the referenced regression equations and techniques might not have adequately represented the uncertainty of logging production. For demonstration purposes, different regression methods are presented for comparing workable yarding alternatives.

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1 This information is derived from approved Forest Practice Applications and Timber Notice of Sale for harvest activities since 1989 and may be requested from the Washington State Department of Natural Resources’, Forest Practices and Product Sales & Leasing Divisions respectively.

DATA SOURCES

Consistent production data for cable logging operations in Washington State were difficult to procure for the purposes presented in this paper. As a result, Brian Boswell, R.P.F. of the Forest Engineering Research Institute of Canada, graciously provided time and motion observations for six case studies of cable logging systems in Northwestern British Columbia, referred to hereinafter as TR-127, (Boswell, Brian, 1999). The cable systems in his study included medium to large skyline, swing, and modified-highlead yarders with standing, live and north bend rigging configurations. Figure 1 illustrates the collection of his 1,044 cycle observations.

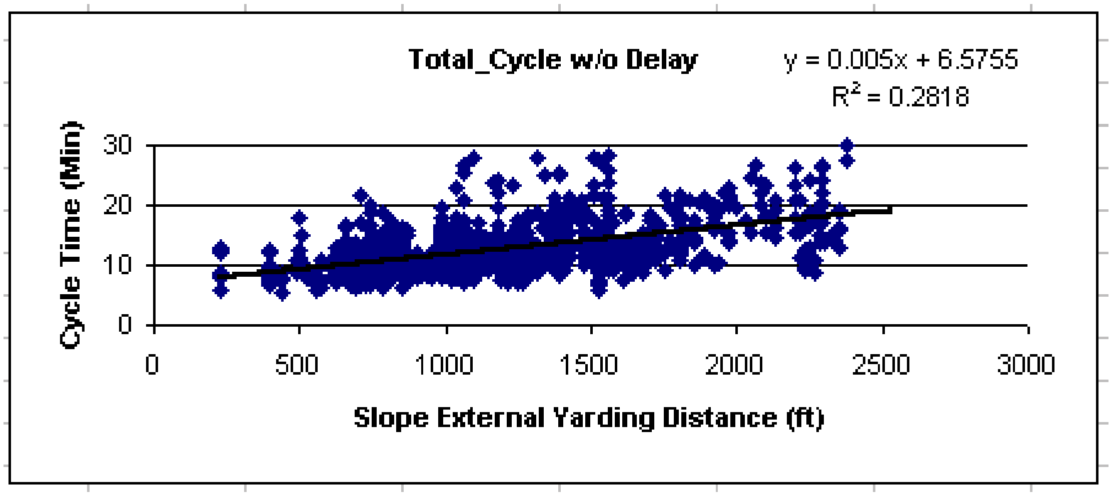

Figure 1. Delay free cycle time for 1,044 observations.

Figure 1 illustrates a single linear regression with a coefficient of determination (R^2) of 0.28. Based on an unrelated collection of 33 independent studies of medium to large cable systems in the early 1980's, (Aubuchon, R.A., 1982), R^2 values ranged from 0.13 to 0.68 with an average of 0.33 weighted by the respective cycles. The R^2 value is an indication of how well the regression accounts for the variance (uncertainty) of the observations, with a value of one being a perfect representation.

The R^2 values presented in the TR-127 publication were estimated using a multiple regression analysis for six strata of 973 total cycle observations; one stratum for each case study. The R^2 values ranged from 0.15 to 0.49 with an average of 0.41 weighted by the numbers of stratified cycles. A methodology is presented that substantially improves the R^2 to more than 0.87.

FORMULATION OF A SIMULATION MODEL

Data from 1,044 cycle observations of the six case studies from TR-127 are converted from metric units and summarized using the following ten (10) elements presented in Table 1. These abbreviations will be used from hereon.

During this investigation, the summarized cycle elements were stratified by Slope Yarding Distances. The groups included all distances, then 0-500 feet, 501-1,000 feet, 1,001-2,000 feet, and finally yarding cycles with SYD greater than 2,000 feet. For demonstration purposes of the proposed regression methods, this paper focuses on the collection of all yarding distances.

Table 1. Summarized Cycle Elements

#	Cycle Element	Abbreviation	Units
1	Slope Yarding Distance	SYD	Feet
2	Lateral Yarding Distance	LYD	Feet
3	External Outhaul Speed	EOS	Feet /Minute
4	External Inhaul Speed	EIS	Feet /Minute
5	Lateral Outhaul Speed	LOS	Feet /Minute
6	Lateral Inhaul Speed	LIS	Feet /Minute
7	Constant	C	Minutes
8	Delays	DEL	Minutes
9	P{Lateral Yarding}	P_LAT	%
10	P{Delay}	P_DEL	%

WEIBULL PARAMETER ESTIMATION

The formulation of the simulation model includes estimating parameters of Weibull and exponential distributions, as well as using Microsoft EXCEL™ spreadsheet functions for building random sampling routines and illustrating results.

Rank regression using median ranks and Bernard's approximation (ReliaSoft Corporation, 2001) is used to estimate three Weibull distribution parameters for the first eight cycle elements, presented in Table 1. Table 2 provides statistics of the cycle elements and the parameter estimates including shape, scale, and location.

As an assumption, elements nine and ten presented in Table 1 are exponentially distributed. The mean rates are estimated by dividing the number of observed occurrences by the total number of cycles. P_LAT and P_DEL are the cumulative probabilities of these mean rates. Table 3 provides an example of the total number of observations and R^2 values for each summarized cycle element. Next, the simulation model is presented.

The desired confidence interval of the estimated population mean of cycle times is used to determine how many simulated samples are necessary2. In this case, for an arbitrarily desired precision within +/- 30 seconds, 4,000 cycles are simulated. Each simulated cycle consists of random observations for the elements presented in Table 3. Half of the simulated cycles use computer generated uniform pseudo-random numbers (0<=x<1), while the remaining cycles utilize a complimentary random number (x =1-x) based on the first 2,000 cycles.

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2 The confidence interval is inversely proportional to the square root of the number of simulated samples; therefore quadrupling the simulated samples reduces the width by half.

Table 2. Weibull Simulation Parameters and Distribution Statistics.

	Weibull Parameters			Simulated Stats			TR-127 Stats		
Cycle Element	**Shape (A)**	**Scale (B)**	**Loc. (G)**	**Mean**	**Stdev**	**Skew**	**Mean**	**Stdev**	**Skew**
SYD	2.26	1140.82	172.63	1183.1	472.8	0.5	1184.6	459.7	0.6
LYD	1.48	76.64	8.463	77.7	47.5	1.2	83.2	46.4	0.9
EIS	3.02	1160.66	76.28	1113.1	374.4	0.2	1107.0	411.7	1.6
EOS	2.36	621.18	72.13	622.6	247.8	0.4	624.0	271.0	1.5
LIS	1.44	127.74	5.633	121.5	81.3	1.1	121.6	117.1	4.8
LOS	1.78	46.59	2.14	43.6	24.0	0.8	43.5	27.7	1.8
C	1.68	6.07	2.07	7.5	3.3	0.9	6.4	2.8	2.1
DEL	0.71	7.85	0.19	10.0	14.2	5.5	10.7	11.9	7.0
P_LAT	0.46								
P_DEL	0.21								

Table 3. Coefficients of Determination for the Weibull.

Element	R^2	Freq
SYD	0.97	1044
LYD	0.99	629
EIS	0.98	1044
EOS	0.99	1044
LIS	0.97	614
LOS	0.98	609
C	0.98	1044
DEL	0.91	259
Observation w/ Delay	0.87	1044
Simulation w/ Delay	0.97	4000

This complimentary method increases precision and reduces computation time of the simulation, (Hillier, F. and G. Lieberman, 2001). Each random observation utilizes a unique pseudo-random number to avoid biased sampling. The simulated precision is presented in Table 6 of the RESULTS section. Cycle elements one through eight, presented in Table 1, are estimated as random observations from the Weibull distributions defined in Table 4. Equation 1.1 and pseudo-random numbers (described above) are used to generate the samples.

Weibull_Random_Observation = G-A*Ln(x)^(1/B)   1.1

The variables for Equation 1.1 were presented in Table 2, and x represents a uniformly distributed pseudo-random number, as described above.

Of the observed 1,044 cycles from TR-127, 629 and 259 have lateral yarding and delays respectively. To account for these observations, two additional uniform random numbers are generated for each cycle to determine if lateral yarding and/or delay(s) occurred in a simulated cycle. This is a simple application of Queuing Theory for simulating breakdowns and repairs, (Thierauf, R. and R. Klekamp, 1975). For example, if a uniform random number is less than the estimated probability for P_DEL, then the simulator samples a random observation for DEL

For each simulated cycle, the sampled elements are combined to estimate total cycle time with and without delay using Equations 1.2 and 1.3 (Microsoft EXCEL™ formats). The variables presented in Equations 1.2 and 1.3 were defined in Table 1. The results of a simulation for all yarding distances are presented next.

Cycle_Time = SYD/EOS + SYD/EIS + C **1.2**

+ IF(RAND() < P_LAT, LYD/LIS +LYD/LES, 0)

With_Delay = Cycle_Time + IF(RAND() < P_DEL, DEL, 0) **1.3**

RESULTS

The simulated and observed cycles were summarized with histograms and statistics. These results were used for model validation. Figures 2 and 3 illustrate the histograms for cycle times (min/cycle) and production levels respectively[3].

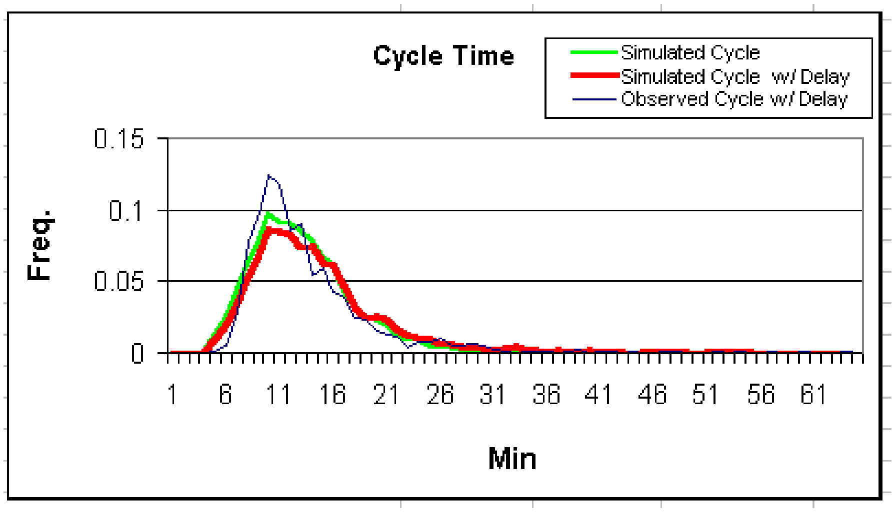

Figure 2. Simulated and observed cycle times.

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[3] TR-127 average turn ~ 3.4 m^3 or 7456 lbs, assuming, 5.7 m^3/mbf and 12.5 lbs/bdft.

Production estimates are based on a 25-ton (US) Truck Payload and 8.5 hrs per day.

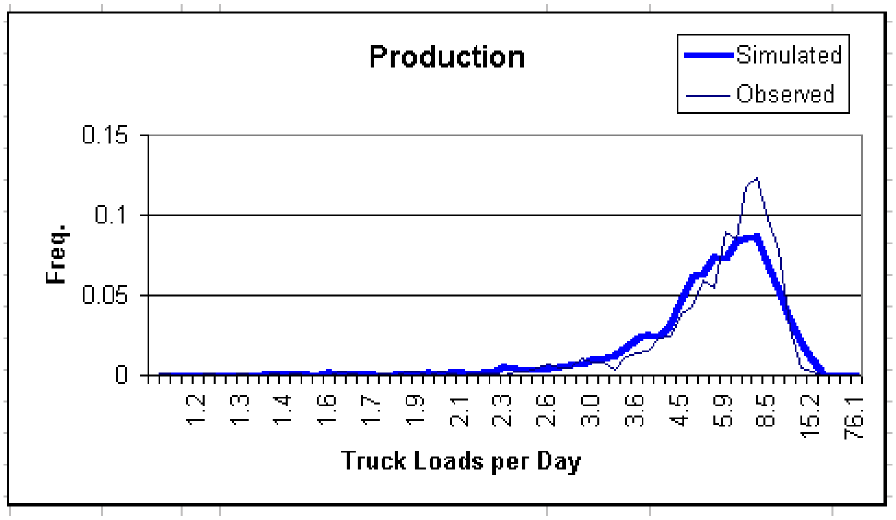

Figure 3. Simulated and observed production rates[2]

Summary statistics, the results of a non-parametric analysis, and common statistical tests are presented. Table 4 provides the summary statistics for the simulated and observed total cycle times with delay.

Table 4. Summary Statistics

Statistic	Simulated	Observed
Mode =	9.3	9.2
Mean =	14.6	14.3
Stdev =	9.0	11.4
Skew =	4.2	6.1
Count =	4000	1044

With a 95% confidence interval, the simulation estimated the population mean of cycle times with delay to be 14.65 +/- 0.46 minutes. The summary statistics presented in Table 4 suggested similar populations. However, it is important to point out that a one-minute difference in cycle time can affect total production cost by as much as ten percent (10%), within preferred economic yarding distances, (Jaross, Weikko S., 2001). Table 5 presents a risk analysis of simulated and observed cycle times based on arbitrary production categories.

Table 5. Non-Parametric Analysis Comparing Simulation and Observations.

P{Cycle Time w/ Delay} is	Simulated	Observed	Production Risk
Less than 6 minutes?	1%	0%	Low
Between 6 and 8 minutes?	11%	11%	Medium
Greater than 8 minutes?	88%	89%	High

With a 95% confidence interval, the Student-t test could not reject a null hypothesis with a probability of 1.8% that the simulations and observations came from the same population. The single factor ANOVA test results are presented in Table 6. With the significance value at 0.01 and 0.05 the $F_{critical}$ is 6.64 and 3.84 respectively.

Table 6. Single Factor ANOVA

Source of Variation	**SS**	**DF**	**MS**	**F**	**P-value**
Level	80.206	1	80.21	0.8831	0.3474
Error	457910	5042	90.82		
Total	457990	5043			
Summary					
Count	**Sum**	**Mean**	**Stdev**	**95% C.I.**	
1044 observations	14969.5	14.34	11.43		
4000 simulations	58599.4	14.65	8.97	+/- 0.46	

The Kolmogorov-Smirnov test estimated an absolute maximum difference of 8% between the two distributions. During the investigation, further validation was performed by adjusting distribution parameters and by re-stratifying the cycle observations by slope yarding distances. Similar results were obtained. Factors other than yarding distances such as yarder types, contractors, etc. may be studied in the future. The conclusions to this investigation are presented next.

CONCLUSIONS

Forest practices have changed considerably in Western Washington State over the last decade. Rapid increases in road dependencies for the Department of Natural Resources seem counterintuitive to steady decreases in harvest densities and to policies advocating longer yarding distances. These trends are the consequence of choices made for individual timber sales, perhaps because of uncertainty in long-span logging production, or completely unrelated reasons.

Linear regression analyses are traditionally published with time and motion studies of logging systems and have typically resulted in low coefficients of determination. This investigation demonstrated an improved representation of uncertainty for logging production studies in general. A non-parametric analysis was presented as well, demonstrating that risk assessments for comparing yarding systems were possible. Further investigations of the proposed methodology are recommended for refining alternative road access policies in steep and mountainous terrain.

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