RESEARCH ARTICLE

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Assessing the Economic Viability of Loggers Operating Tree-Length Harvest Systems in the Northeast

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Economic sustainability of logging businesses is critical to successful forest management. Rising expectations and negative market trends can increase logging costs. This study seeks to examine factors influencing logger profitability across a variable forested landscape. Interviews were conducted with loggers across New York and Northern Pennsylvania. Throughput accounting was used to calculate operating expenses, profit margin, and return on investment (ROI) of individual jobs. Regression analysis identified significant variables influencing profit and ROI. Almost half of the logging operations observed were losing money on individual jobs. Loggers required increases in contract rates between 5% and 95% to achieve a positive ROI. The correlation between contract rates and profit margin showed no statistically significant relationship. Total harvest site acreage, total access system distance, harvested volume per acre, and hours spent implementing BMPs were found to be statistically significant when predicting profit.

Keywords: logger viability, economic sustainability, productive machine hour

Logging plays a critical role in managing forests for timber production and is an integral link in the wood supply chain. This makes the financial success of loggers essential to the availability of many goods used daily by the American consumer. However, logging businesses are in decline in the US and are projected to decrease another 2% per year through 2021 (McCormack 2016).

Owning and operating equipment is the biggest expense to logging business owners; therefore, understanding their entire systems cost and productive capacity is essential to making informed purchasing decisions. To operate in the Northeast, loggers typically own some combination of felling, skidding, and processing machines, along with trucks for delivery and excavation equipment for clean-up and BMP compliance. The variety of combinations is evident in the wide range of investment levels, from tens of thousands to millions of dollars.

Common harvesting methods for the ground-based systems used in the Northeast include cut-to-length, tree-length, and whole-tree. Systems composed of older, used equipment have lower initial capital costs, but are subject to frequent breakdowns, drastically decreasing productivity. In contrast, owning new equipment is usually associated with high productivity, but corresponding high capital costs. Low-cost systems are more readily idled during times of low demand, while high-cost systems must have a steady flow of work to be viable.

The variability of harvest conditions associated with timber sale characteristics poses another challenge to logging businesses. This variability and associated lack of predictability is particularly difficult in hardwood and mixed-wood forest cover types of the Northeast (LeDoux 2011). Therefore, productivity can vary from job to job, depending on some critical external variables associated with the harvest, including harvest volume per acre, species, stem size, area of harvest, average skidding distance, topography, access system, and amount of noncommercial timber stand improvement (Germain et al. 2016). Internal factors, such as type of harvest equipment, crew size, and skill levels, can also impact profitability on any given job. Determining the degree to which these external and internal variables impact profitability is critical to long-term logger viability.

Contract rates also influence logger profitability and ideally should fluctuate from job to job depending on market conditions, external, and internal variables. Loggers are commonly paid by a unit cost (e.g., per thousand board feet (MBF), per ton, or per cord) to cut, skid, and land.

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Germain et al. (2016) explored the effects of contract rates on profitability in the Northeast and found that loggers rarely feel that they are positioned to negotiate higher rates for themselves. As price takers, loggers must look for ways to control costs and production rates to make individual jobs profitable.

Most new or semi-new equipment is expensive and subject to steep rates of depreciation (Germain et al. 2016). Many researchers have quantified the cost of running a single machine per hour to help loggers select appropriate machines for their harvesting system and predict their operating costs (Miyata 1980, Werblow and Cubbage 1986, Brinker et al. 2002, Akay et al. 2004, Kizha and Han 2016). Other studies have focused specifically on assessing and comparing costs and productivity of entire harvest systems (Hartsough et al. 1997, Wang et al. 2004, Adebayo et al. 2007, Germain et al. 2016). Knowing machine rates for individual pieces of equipment and entire harvest systems is the first step in determining operating costs for harvests with different site characteristics.

While researchers have attempted to control and isolate the variables affecting productivity, few have taken a holistic approach to assess the degree to which those factors influence harvest profit and expenses. Spreadsheet-based software packages, such as Planning Analysis in Timber Harvesting (PATH) 2.1, Hank Sloan's Logging Cost Calculator, and Auburn Harvester Analyzer, have been instrumental in helping loggers understand their costs, with PATH 2.1 also focusing on profit and return on investment (ROI).

Research focusing on the relationship between contract rates, wages, and profitability is almost non-existent in the Northeast. While it may seem obvious that higher rates would equate to higher levels of profitability, this relationship has not been adequately quantified. Germain et al. (2016) found current contract rates to range from as low as $110/MBF up to $180/MBF (depending on log rule) for sawtimber and from $12 to $22 per ton for pulpwood or chipwood. Their study found that increases in contract rates of $5–$20 per MBF or $3–$5 per ton could make unprofitable jobs become break-even or profitable.

This study seeks to examine factors influencing the profitability of loggers utilizing tree-length harvest systems on individual logging jobs across variable forested landscapes in New York and northern Pennsylvania. This primary goal is supported by the following objectives: (1) assess logger profitability on individual logging jobs and determine optimal productivity and price ranges to ensure economic viability on those specific jobs, and (2) examine how individual harvest characteristics influence logger profitability and create exploratory models for predicting profit based on those variables.

Methods

The study was conducted on logging jobs located primarily in New York, supplemented by two jobs located just across the border in northeastern Pennsylvania. Specifically, in New York, three logging jobs were conducted in the Adirondacks, three were located in the Catskills region, while the bulk were located in the southern and central tier of New York. Working in partnership with procurement and consulting foresters, 31 loggers were identified for scheduled harvesting operations in the summer and fall of 2016. The contractors were contacted by phone and asked to participate in the study. Of these, 23 agreed to participate and provided sufficient information to complete analysis. There was no compensation for participants.

Interviews were conducted at the harvest site at the close-out of each job to ensure that the logger fully reported clean-up costs and number of working days. Questions focused primarily on type of equipment, operating and ownership costs, and special characteristics of the harvest. Following the interview, a global positioning system (GPS) was used to map the landing(s) and skid trails. The associated forester provided important information on each timber sale, including harvest area, maps, number of sawtimber stems marked for harvest (by species), actual sawtimber volume cut, pulpwood/firewood volume cut, and other useful descriptive information. This allowed us to verify volumes provided by the logger and determine profit margins and ROI for each harvest.

The products generated at each harvest included various quantities of sawtimber, pulpwood, and firewood in measurements of board feet, cords, and tons. To estimate total volume from each job, all products were converted to cubic feet. This unit was chosen because it allows for reasonably accurate conversions from original product units as well as conversion to cubic meters for international audiences. Final results are also reported in tons to facilitate interpretation. The conversion factors were based on Hiesl and Benjamin (2013), in which one cord was equal to 85 ft^3 of pulpwood and 128 ft^3 of firewood, one ton (hardwood) was equal to 37.78 ft^3, and 1MBF equaled 83.34 ft^3. Scribner log rule was used by the participating sawmills to estimate sawtimber volumes, making conversions uniform. Since the Scribner log rule is an output-based measurement system, using the lumber conversion rate of 83.34 ft^3 is appropriate given that the final volumes were log-based volumes (Verrill et al. 2004).

Harvest Cost Analysis

PATH 2.1, a spreadsheet software program that calculates and applies costs of the entire production system, was used to

Management and Policy Implications

Understanding the financial success of logging businesses operating on jobs with differing site characteristics is the first step in efforts for logger retention and long-term viability. When assessing a harvesting site, loggers and foresters often rely on an intuitive sense of a job's potential profitability based on previous experience and site characteristics. The results of this study provide empirical evidence to support such assessments in some circumstances and offer tools for future business decisions. Results indicated that almost half of the operations observed lost money on individual jobs. While loggers may be quick to blame sawmills for low contract rates and sawmills will fault loggers for low productivity, both parties need to acknowledge the limitations of the other and the constraints of the industry. Higher contract rates were not correlated with greater levels of profitability; consequently, adjusting rates will not necessarily ensure business success. While contract rates need to be in a suitable range for loggers to cover their costs and make a profit, they are not the final determinant in job profitability. Loggers seldom control contract rates or product prices, but they can control their production rates. Modest increases in productivity may shift break-even jobs to profitable jobs. Loggers need to improve business practices and look internally for ways to improve their productivity to be successful.

Table 1. Variables included in PATH 2.1 calculations.

Input	Description	Assumptions & supplemental sources
Acquisition cost	The original purchase price, including taxes and delivery fees	This will also include the capital costs of any improvements made to a machine at the time of acquisition (e.g., fixing up a used piece of equipment).
Financed amount	The financed portion of the acquisition cost, if any	This rate is used to calculate the alternative return on investment for these funds for a time period equal to the useful life of the machine and then converted into an hourly rate.
Opportunity cost (rate)	The alternative rate of return for any funds used for a down payment on this piece of equipment	
Loan interest rate	The loan interest rate, if financed	
Loan term	The loan term, if financed	
Machine ownership life (hours)	The number of hours this machine can be expected to be in service in its useful life	
Machine hours until significant overhaul or repairs	The machine hours until a significant overhaul or repairs	This information allows calculation of a periodic hourly rate, rather than a lifetime rate. Actual depreciation of machines is steeper at the beginning of their useful life; this information accounts for that. Significant overhauls require recalculation of a new rate as they constitute further investment in the machine.
Percent of cost to depreciation	The percent of the machine's value that will be depreciated between the original acquisition cost and the next significant repair	This input allows calculation of a machine rate for a segment of the machine's life, more closely matching the actual loss of machine value that occurs. PATH 2.1 uses hourly depreciation as the measure of investment in individual harvesting jobs.
Expected annual use (hours)	The number of hours the machine is used in a year on average	This input is used in converting the fixed cost of insurance and the alternative annual return for cash invested in the equipment into hourly rates.
Residual value	This is the salvage value.	This value represents a fixed (non-depreciating) amount of investment in the machine. An annual return on this investment is expected. PATH 2.1 accounts for the return on this investment that is included in individual jobs. Values were sourced from dealership websites and the Northern Logger publication.
Repairs and maintenance cost per PMH	Hourly repairs and maintenance costs	If sufficient information was not provided by the logger, ranges were supplied by Germain et al. (2016) (unpublished data, 2014).
Fuel cost per gallon	The fuel cost per gallon	This was supplied by loggers.
Fuel consumption rate (gallons/hour)	This is the fuel consumption rate (gallons/hour).	This was supplied by loggers.
Lube costs per thousand hours of service	This includes costs of oil changes and grease.	This was supplied by loggers.
Hourly operator costs	This includes the operators' hourly wage, workers' compensation, and benefits.	To calculate hourly operator cost to the employer, we doubled the operator's hourly wage to include benefits. If the owner operator does not know, an hourly wage of $40 was used.
Ratio of machine hours to operator time	This is the percent of the operator's time that is actually spent operating the machine.	This is used to calculate the cost of the labor per productive machine hour. For example, if the hourly operator cost is $30 and the ratio of machine hours to operator's time is 80%; the cost per machine hour is $37.50 ($30 ÷ 0.8).
Annual insurance costs	The cost of replacement insurance on the machine	This only applied if the machine was actually insured (usually as a requirement of the financing).
Daily overhead	This is used to capture other business expenses (e.g., non-productive labor, liability insurance, advertising, pickup truck expenses, legal and professional services, office expenses, and other items typically found in IRS Form 1040 Schedule C).	When loggers did not know, industry averages provided by Steven Bick (2017) were used for the following harvest operation sizes: • Small: 1–2-person cable skidding operation: $200–250/day • Medium: maintenance shop and a mix of older and new equipment: $275–325/day • Larger: maintenance shop and office staff, 3 skidders and newer feller-buncher, loader & slasher combination: $820/day Industry averages were taken from direct consultations with individual loggers from outside this study. Any portion of the owner's time that is not captured as a machine operator is included here.
Job-specific costs	One-time costs directly associated with an individual harvest (e.g., moving costs [one way], road improvements, BMP costs).	
Number of days on the job	This represents all productive days on the job.	This is used to calculate the total overhead associated with the job (i.e. # of days x daily overhead).
Production	This includes product name, total production, and price.	Final production volumes were verified with foresters.

calculate productive machine hour (PMH) for each piece of equipment using throughput accounting (Bick 2017; Goldratt 2004). PMH is defined as the time a machine is performing its scheduled function (Brinker et al. 2002). During the interview, specific equipment information was acquired for each machine the logger used in his business. This allowed us to calculate individual machine rates by determining fixed, operating, and labor costs – expressed in terms of dollars per productive machine hour ($/PMH) in PATH 2.1. Factors affecting variable costs include fuel use and price, oil use and price, maintenance and repair, functional depreciation, and other miscellaneous operating costs. Functional depreciation is the amount of value the equipment uses while producing wood products (Bick 2017; Germain et al. 2016). It is important to note that PATH 2.1 treats depreciation as a variable cost in PMH calculations and uses accumulated actual depreciation over the course of individual harvesting jobs as the primary measurement of investment for each job (Table 1). Furthermore, PATH 2.1 captures costs across the entire harvest system, including machine costs, overhead, and job-specific costs.

After cumulative machine costs, overhead, and job-specific costs were calculated for each piece of equipment, total throughput (net sales – variable expenses), operating expenses, investment, net profit, and ROI were calculated for each harvest operation. Revenue for each job was based on contract rates paid to the loggers to cut-skid and land primarily sawtimber and paid in $/MBF, but included pulpwood and firewood in a few instances. ROI measures the amount of return on an investment relative to the investment's cost and is calculated by dividing profit (total revenue-total costs) by the investment (sum of all hourly equipment costs [along with a pro-rated portion of the depreciation of fixed costs]). ROI can be used to evaluate the efficiency of an individual job or to compare jobs over the course of a year. Tree-length harvesting systems can result in extremely high or low ROIs for individual jobs due to the variable nature of the system and harvest characteristics. To account for this, profit margin (net profit/total revenue) was also calculated. Both ROI and profit margin account for different economies of scale and allow for comparison across jobs of different sizes.

Sensitivity Analysis

Both ROI and profit margin were used to categorize each harvest into three different thresholds: *surviving* (i.e., only partially covering costs while experiencing a loss of equity to uncompensated depreciation), *striving* (i.e., breaking even by meeting operating expenses), or *thriving* (i.e., covering costs and making a profit) (Germain et al. 2016). Since ROI and net profit outcomes will rarely result in a precise breakeven scenario, we used limits of –5% to 5% to quantify the *striving* threshold. Those limits captured jobs with minimal profit or loss that were either in danger of moving into the *surviving* category or capable of advancing into the *thriving* category with slight changes in job characteristics or contract rates.

After each job was categorized, a sensitivity analysis was run on both contract rates and production rates of each harvest in the *surviving* and *striving* categories. Sawtimber contract rates were increased at 5% intervals, while holding other income sources constant (firewood), until each harvest shifted to the *thriving* category. To assess productivity, defined as the ratio of output to PMH, PMH were reduced by percentage intervals until ROI values were 0% (break-even) and between 15% and 20% (*thriving*).

Harvest Site Analysis

ArcGIS 10.4.1 software by ESRI was used to analyze total linear distance of the skid trails and slope data collected on the GPS unit. Digital Elevation Model (DEM) files were obtained from the National Elevation Dataset (NED) clearinghouse. A 1/3 arc-second (10 meters) resolution was available for the entirety of New York and Pennsylvania. Using the ArcGIS 10.4.1 software, the DEM raster data was converted over to percent slope using the *Slope* tool. Average slope and total distance in feet were then calculated for each individual skid trail using the *Calculate Geometry* tool.

Regression Analysis

All statistical analyses were carried out using SAS 9.4® statistical software (SAS Institute, Inc., 2009). Prior to statistical tests and modeling, dependent and independent variables were assessed for normal distribution. Once all variables were determined to have linear relationships, multiple linear regression analyses were conducted to (1) fit ordinary least squares (OLS) regression models with all independent variables as the benchmark, and (2) find "best" models (reduced model) using the stepwise regression method. An analysis was performed to assess the significance of the independent variables on net profit (Y_p). The independent variables include:

X_1 = Acreage: Harvest Acreage
X_2 = Days: Number of Days on the Job
X_3 = Cubic: Cubic Feet per Acre Harvested
X_4 = BMP: Hours Spent on Best Management Practices
X_5 = Total Access System Distance: Skid Trail Length (Feet)
X_6 = Average Skid Distance (Feet)
X_7 = Slope: Average Percent Slope of Skid Trails
X_8 = Years: Number of Years the Owner Operator Has Owned His/Her Business
X_9 = Contract: Contract Rates in $/MBF

The following OLS model was used to determine the full model for predicting net profit:

$$Y_P = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \varepsilon$$

where Y_p, and $X_1 - X_9$ are defined as above, $\beta_0 - \beta_9$ are regression coefficients to be estimated from the data, and ε is the model random error. The final model with each independent variable statistically significant at the $\alpha = 0.05$ level was considered to be the best model for the small sample size and variable nature of the data collected. To determine the "best" model, stepwise selection regression was applied to the dataset. Variables included in the model are determined by two significance levels. The significance level to enter (SLE) is used to set which variables are included in the model. The significance level to stay (SLS) is used to determine which variables ultimately stay in the model. Given the small sample size and social nature of the data, we used an SLE of 0.15 and an SLS of 0.10, which would account for variability. Stepwise selection regression was applied to all seven predictor variables for the response variable. The full and the "best" models were evaluated by model fitting statistics, including the coefficient of determination (R^2), adjusted coefficient of determination (R^2_a), mean squared errors (MSE), Akaike Information Criteria (AIC) (Sakamoto and Kitagawa 1986), predictive sum of squares (PRESS), standardized regression coefficients (STB), and a residual analysis. After the "best" model was selected, model simulations were used to illustrate how well the model predicts net profit. Each simulation used one independent variable against the dependent variable while holding the other remaining independent variables in the model constant at their means.

Results

Demographics and Business Attributes

We interviewed eight single-person operators, eight 2-person crews, four 4-person crews, and three 3-person crews. The sample consisted of veteran loggers, with most contractors (83%) having over a decade of experience as owners of a logging business, and 43% having over two decades of experience. This information is based on the year

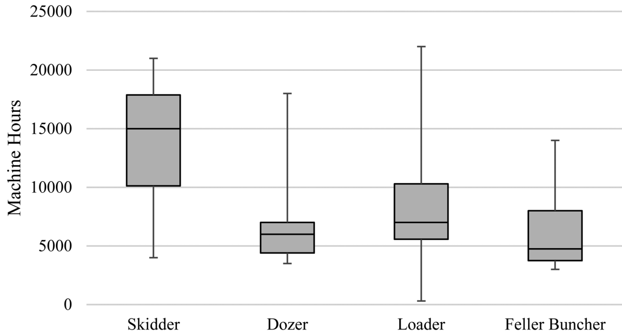

Figure 1. Distribution of total machine hours by equipment type.

they established their business and does not include any previous logging experience for another company.

The loggers participating in this study owned and operated tree-length harvesting systems. Nearly half of the machines being utilized (48%) were made between 1990 and1999, followed by 2000–2009 (33%), 1980–1989 (16%), and 2010–present (3%). Nearly two-thirds of the equipment dated back to the 1980s and 1990s. The age of equipment directly relates to the number of hours each machine has acquired (Figure 1).

Harvest Site Characteristics

Harvest site characteristics included harvest site acreage, total volume harvested, total linear skid distance of access system (feet), average percent slope of each skid trail, and average skid distance for each job (Table 2). The average harvest area was 81 acres, with a range of 5–300 acres. The mean harvest volume was 393 cubic feet (ft^3) (10.4 tons) per acre, ranging from 71ft^3 (1.9 tons) to 920ft^3 (24.4 tons). The average sawtimber volume harvested across the sites was 110MBF, ranging from 16.7MBF to 588.2MBF, and an average of 1.7MBF per acre. The total linear distance of the skid trails averaged 7,423 feet (approximately 1.4 miles), while the average slope of skid trails was 12%. Most jobs had access systems totaling 1.5–2 miles of skid distance. Average skid distance across the harvest sites was 2,811 feet, with a range of 918 to 4,661 feet.

Cost Analysis

The loggers spent an average of 30 days on their respective logging job, with a range of 5 to 75 days. The average cost of operating various logging equipment across the 23 logging jobs was as follows: feller bunchers ($74.80/PMH), skidders ($71.04/PMH), dozers ($68.65/PMH), loaders ($68.12/PMH), and chainsaws ($43.14/PMH). These means include hourly wages with fringe benefits (including workers' compensation) for employees and business owners. The age of the logging equipment was influential in the final cost estimates.

Viability Analysis

ROI and profit margin were chosen to assess the profitability of each job. Average ROI and profit margin values were –33% and –4%, respectively. Per job ROI ranged between –466% and 295%, and profit margin ranged from –38% to 36% (Table 3). It should be emphasized that these values are for individual timber harvesting jobs and do not reflect the logger's yearly investment.

The *surviving*, *striving*, and *thriving* thresholds were then applied to ROI and profit margin values to categorize the profitability of each job. The ROI interpretation shows 12 harvests in the *surviving* category (losing), two in the *striving* (breaking even), and nine in the *thriving* category (making a profit and ROI) (Table 4). The profit margin calculations indicate that 11 of the harvests qualified as *surviving*, four were considered *striving*, and eight were *thriving* (Table 5).

Table 2. Harvest site characteristics by area, volume harvested (sawtimber, pulpwood and firewood) and details of the access system.

ID	Acreage	Total volume sawtimber (MBF)	Total volume pulpwood (tons)	Total volume firewood (cords)	Total linear distance of access system (feet)	Average slope (%)	Average skid distance (feet)
A	33	78	0	0	6776	16	1037
B	11	48.6	0	28	2298	8	1150
C	120	132.2	0	0	8382	12	2095
D	15	33.6	0	13.5	1890	7	945
E	100	85.3	0	0	4019	25	2010
F	35	31.1	0	0	5706	14	2853
G	143	45.5	2717	0	13069	4	2178
H	48	20	939	0	8470	6	4235
I	60	58.3	0	140	9832	11	2458
J	36	113	0	37	1836	7	918
L	40	25	793	0	5395	12	2698
M	30	40	0	84	4959	10	2479
N	85	113	0	153	3702	9	1850
O	90	133.4	0	560	9220	12	4610
P	58	112	0	128	5396	23	2698
Q	35	97.7	0	70	6357	13	3178
R	300	588.2	0	180	28998	10	7249
S	200	200.1	0	70	9323	12	4661
T	80	130.3	0	70	7891	18	3946
U	200	212	0	0	8121	7	4060
V	5	16.7	0	0	3871	33	1935
W	57	98.6	0	220	6583	6	3292
X	77	115	0	70	8851	7	2113

Logger **K** was initially included in the analysis but was later identified and removed from the dataset for not providing sufficient information.

Table 3. Individual harvest financial measurements.

ID	Operating expenses	Total revenue	Net profit	ROI (%)	Profit margin (%)
A	$15,680	$13,260	($2,420)	(88)	(18)
B	$11,815	$10,862	($953)	(39)	(9)
C	$23,277	$23,128	($99)	(2)	(0)
D	$7,711	$6,715	($995)	(233)	(15)
E	$13,611	$14,493	$882	51	6
F	$6,876	$5,372	($1,504)	(451)	(28)
G	$74,359	$99,522	$25,163	295	25
H	$31,264	$34,926	$3,662	86	10
I	$29,370	$21,620	($7,751)	(325)	(36)
J	$17,714	$20,350	$2,636	86	13
L	$31,957	$31,262	($695)	(49)	(2)
M	$10,020	$15,700	$5,680	223	36
N	$31,992	$26,495	($5,497)	(72)	(21)
O	$94,088	$111,517	$17,429	78	16
P	$28,051	$30,197	$2,145	29	7
Q	$35,872	$26,063	($9,809)	(466)	(38%)
R	$143,642	$130,899	($12,743)	(29)	(10)
S	$39,008	$39,423	$416	41%	1%
T	$30,092	$29,748	($344)	(7)	(1)
U	$42,554	$37,100	($5,454)	(61)	(15)
V	$2,213	$2,756	$543	252%	20%
W	$34,858	$31,450	($3,408)	(46)	(11)
X	$30,962	$26,050	($4,912)	(29)	(19)

A sensitivity analysis was applied to the jobs in the *surviving* and *striving* categories to determine the percent increase in contract rates required to shift them into the *thriving* category. It should be noted that firewood income was held constant to focus solely on contract rates. The loggers in the *striving* category only needed modest increases in contract rates (5–10%) to shift to *thriving*. Jobs in the *surviving* category required increases ranging from 20% to 95%.

The sensitivity analysis assessing production rates was also applied to the harvests in the *surviving* and *striving* categories. Harvests in the *striving* category needed modest increases of 1–4%, while jobs in the surviving category needed increases of 11–29%.

The contract rates for the *surviving* threshold averaged $174/MBF (range: $165–195), while the *striving* threshold averaged $172/MBF (range: $165–180). Interestingly, the contract rates for the *thriving* category averaged $163/MBF (range: $150–195). To further assess the impacts of contract rates on profitability two correlations were run with both ROI and profit margin. The correlation between ROI and contract rate was negative, with a Pearson correlation coefficient (ρ = –0.37) and a p-value of 0.079. The correlation between profit margin and contract rates was similar (ρ = –0.39, p-value = 0.065).

Table 4. ROI threshold categorization with contract rates and productivity sensitivity analyses.

ID	Net revenue	Net profit	ROI (%)	Percent contract rate increase to "thrive" (%)	Productivity increase to "thrive" (%)
Striving					
Q	$26,063	($9,809)	(466)	50	29
F	$5,372	($1,504)	(451)	35	24
I	$21,620	($7,751)	(325)	95	19
D	$6,715	($995)	(233)	25	15
A	$13,260	($2,420)	(88)	25	18
N	$26,495	($5,497)	(72)	40	21
U	$37,100	($5,454)	(61)	25	16
L	$31,262	($695)	(49)	10	3
W	$31,450	($3,408)	(46)	30	13
B	$10,862	($953)	(39)	20	11
R	$130,899	($12,743)	(29)	20	13
X	$26,050	($4,912)	(29)	35	24
Surviving					
T	$29,748	($344)	(7)	10	1
C	$23,128	($99)	(2)	10	4
Thriving					
P	$30,197	$2,145	29		
S	$39,423	$416	41		
E	$14,493	$882	51		
O	$111,517	$17,429	78		
J	$20,350	$2,636	86		
H	$34,926	$3,662	86		
M	$15,700	$5,680	223		
V	$2,756	$543	252		
G	$99,522	$25,163	295		

Unit Cost Analysis

A total of 612,157 ft^3 (16,203 tons) was extracted from all the harvests. Firewood comprised 38% of the total volume (233,408 ft^3), followed by sawtimber at 34% (210,650 ft^3) and pulpwood at 28% of the total volume (168,099 ft^3). Roundwood totaled 66% of the volume (401,507 ft^3). The average unit cost to cut, skid, and land the harvested volume was $1.53/ft^3 ($58/ton), with a range of $0.70–2.65/ft^3 ($27–100/ton) (Table 6). A correlation was run to assess the relationship between unit cost and profit margin (ρ = –0.57). Based on the sample size of 23, the results indicate, as expected, that as unit cost increases profit margin decreases. More importantly, the regression line intersects the break-even line at approximately $1.40/ft^3 ($53/ton).

Regression Analysis

OLS with stepwise regression was used to estimate the impact of harvest acreage, days on the job, cubic feet per acre harvested, hours spent on BMPs, skid trail length of access system (feet), average skid distance (feet), average percent slope of skid trails, and the number of years the owner operator has owned his or her business had on net profit. Table 7 lists the descriptive statistics for each dependent and independent variable. Before the best model for net profit could be determined, a full model that included all independent variables was tested. This model was not statistically significant (p-value = 0.077).

Stepwise regression was subsequently conducted to identify which independent variables would produce a statistically significant reduced or best model (p-value = 0.008) with a R^2 of 0.4565, and

Table 5. Net profit threshold categorization with contract rates and productivity sensitivity analyses.

ID	Net revenue	Net profit	Profit margin (%)	Contract rate increase to “thrive” (%)	Productivity increase to “thrive” (%)
Surviving					
Q	$26,063	($9,809)	(38)	50	29
I	$21,620	($7,751)	(36)	95	19
F	$5,372	($1,504)	(28)	35	24
N	$26,495	($5,497)	(21)	40	21
X	$26,050	($4,912)	(19)	35	24
A	$13,260	($2,420)	(18)	25	18
D	$6,715	($995)	(15)	25	15
U	$37,100	($5,454)	(15)	25	16
W	$31,450	($3,408)	(11)	30	13
R	$130,899	($12,743)	(10)	20	13
B	$10,862	($953)	(9)	20	11
Striving					
L	$31,262	($695)	(2)	10	3
T	$29,748	($344)	(1)	10	1
C	$23,128	($99)	0	10	4
S	$39,423	$416	1	5	1
Thriving					
E	$14,493	$882	6		
P	$30,197	$2,145	7		
H	$34,926	$3,662	10		
J	$20,350	$2,636	13		
O	$111,517	$17,429	16		
V	$2,756	$543	20		
G	$99,522	$25,163	25		
M	$15,700	$5,680	36		

R^2_a of 0.3707, and included three variables of acreage (X_1), cubic feet per acre harvested (X_3), and BMPs (X_4). While acreage and cubic feet per acre harvested show a positive relationship with net profit, the number of BMP hours is inversely related to net profit. The standardized model coefficients indicated that cubic feet per acre harvested was the most important variable impacting net profit margin, followed by number of BMP hours and acreage, respectively. The best model is as follows:

$$\check{Y}p = -6954.31 + 50.09\,X_1 + 19.27\,X_3 - 589.55\,X_4$$

To compare the two models, we looked at R^2, R^2_a, MSE, AIC, and PRESS. Table 8 summarizes the model fitting statistics. The best model has a relatively lower R^2 than the full model but a higher R^2_a value. It also has a lower MSE, PRESS, and AIC value. Based on these statistics, the small sample size and variable nature of the data, the best model was selected as most fitting for this study. The best model with better R^2_a, MSE, and PRESS indicated that it would perform better when predicting net profit on logging jobs.

To assess model prediction, model simulations were run with the remaining independent variables and compared to the observed data. Figure 2 demonstrates the best model's ability to predict net profit with cubic feet per acre harvested and harvest site acreage while BMPs were held constant. Although there are three obvious outliers in the graph, many of our observed data points were captured in the simulation.

Discussion

Loggers play a critical role in the wood products supply chain, and therefore their long-term viability is essential to the forest products industry. Understanding the financial success of loggers on jobs with differing site characteristics can help influence management decisions in the industry. For example, foresters can more appropriately assign contract loggers to woodlots that are better suited to their harvest system

Table 6. Logging job total and per acre volumes harvested in cubic feet and tons with associated unit costs.

ID	Acreage	Total volume (ft3)	ft3/acre	Unit cost ($/ft3)	Total volume (tons)	Tons/acre	Unit cost ($/ton)
A	33	6,501	197	$2.41	172	5.2	91
B	11	7,634	694	$1.55	202	18.4	58
C	120	11,018	92	$2.11	292	2.4	80
D	15	4,530	302	$1.70	120	8.0	64
E	100	7,109	71	$1.91	188	1.9	72
F	35	2,592	74	$2.65	69	2.0	100
G	143	106,456	744	$0.70	2,818	19.7	26
H	48	37,142	774	$0.84	983	20.5	32
I	60	22,779	380	$1.29	603	10.1	49
J	36	14,153	393	$1.25	375	10.4	47
L	40	32,043	801	$1.00	848	21.2	38
M	30	14,086	470	$0.71	373	12.4	27
N	85	29,001	341	$1.10	768	9.0	42
O	90	82,798	920	$1.14	2,192	24.4	43
P	58	25,718	443	$1.09	681	11.7	41
Q	35	17,104	489	$2.10	453	12.9	79
R	300	72,061	240	$1.99	1,907	6.4	75
S	200	25,636	128	$1.52	679	3.4	57
T	80	19,816	248	$1.52	525	6.6	57
U	200	17,668	88	$2.41	468	2.3	91
V	5	1,392	278	$1.59	37	7.4	60
W	57	36,378	638	$0.96	963	16.9	36
X	77	18,544	241	$1.67	491	6.4	63

Table 7. Descriptive statistics for all dependent and independent variables.

Variable	*N*	Mean	Std dev	Minimum	Maximum
Net profit	23	85.73	8034.75	−12743	25163.00
Operating expenses	23	34216.78	31691.14	2213.00	142642.00
Acreage	23	80.78	71.55	5.00	300.00
Days on job	23	29.86	20.98	3.00	75.00
Cubic feet per acre	23	393.33	258.52	71.08	919.97
BMP hours	23	7.78	7.95	0	40.00
Total skid distance	23	7432	5479	1836	28998
Average skid distance	23	2811	1486	918	7249
Average percent slope of skid trails	23	0.122	0.069	0.040	0.330
Years of ownership	23	18.95	11.22	3.00	40.00
Contract rates	23	169.65	12.41	150.00	195.00

and independent loggers can better predict potential financial results for various types of jobs. Knowing what variables make individual jobs profitable can make predicting and ensuring overall logger long-term success more achievable.

This study provides a greater understanding of the challenges faced by logging operations in the study region. The sample focused on smaller operations with a heavy representation of single-operators and 2-person crews with tree-length harvest systems. These loggers had a fairly low level of investment, with most having acquired older, used machines. The tree-length harvesting method is used throughout the northeast region, though in many areas whole-tree harvesting is more prevalent. Sixty-four percent of the machines in this study were 15–30 years old, while the remaining 36% were less than 15 years old. The age and condition of these machines mean that there is a fairly low level of investment, but often higher input costs for repairs and maintenance. Consequently, the results of this study will be more representative of loggers with used equipment and relatively high variable costs.

To assess profitability, each individual harvest was categorized using ROI and profit margin according to three thresholds: *surviving*, *striving*, and *thriving*. Almost half of the individual jobs fell in the surviving category. In the short run, loggers, like any small business, will run without making a profit as long as they can cover variable costs, meeting cash flow demands. In the long run, the fortunes of each business can turn with the next job or a change in the weather. Most studies assessing logger profitability have been conducted on a job-by-job basis or through surveys that cannot fully or accurately speak to annual profitability (Blinn et al. 2015, Germain et al. 2016). Annually, loggers will complete jobs across the profitability spectrum. Long-term economic viability requires loggers to be cognizant of potentially problematic, unprofitable jobs and to use them only to bridge the gap between jobs that are profitable, especially when idling the business would result in greater losses.

The sensitivity analysis applied to contract rates of jobs in the *surviving* and *striving* categories revealed a wide range of results. Loggers in the *striving* category needed increases in rates between 5% and 10%, while loggers in the *surviving* category needed increases of 20% to 95%. Moderate increases in contract rates of 5–10% might be feasible; however, increases of 50% or higher are unrealistic in an industry with low profit margins. During the sensitivity analysis, other forms of income from firewood or pulpwood were held constant, which indicates that increases in contract rates may not be the solution to logger profitability or the cause of unprofitability. It should be noted that the contracting sawmills often allowed the loggers to market the firewood and/or pulpwood as they saw fit without charge to the logger. Some loggers took advantage of this supplemental revenue opportunity, while others focused only on the sawtimber.

Table 8. Net profit model comparison.

Model	R2	R2a	MSE	AIC	PRESS
Full OLS	0.5736	0.3299	43257058	410.98	2616036657.4
Best	0.4565	0.3707	40623314	406.56	1312751542.1

Results of this study contradict Germain et al. (2016), who reported that marginal increases in contract rates of \$5–20 per MBF or \$3–5 per ton could shift unprofitable jobs to break-even or profitable scenarios. To further explore the relationship between contract rates and profit margins, a correlation was run that showed a weak relationship with high variation in the data. Consequently, we can infer that if contract rates reside in a realistic range for loggers to cover their costs and make a profit, the key to logger profitability resides more in the productivity of the operation and job characteristics.

While loggers may not have control over their contract rates, they can control their production level and outputs. The results of this study show that modest increases of productivity (1–4%) can lead to profitable jobs for those loggers operating at the break-even point. Larger increases of 11–29% were necessary for loggers in the *surviving* category to turn a profit. Modest productivity increases are achievable by seeking efficiencies in processing and moving, and could come in several forms. Greene et al. (2004) collected weekly production data from 83 logging crews over 20 months in both the US South and Maine. Each crew reported total production as well as any missed production and its cause. Their results showed, on average, that missed production accounted for 20% of potential weekly production. The causes of lost production included market forces, weather, planning, mechanical, labor, stand/tract characteristics, vacation, and regulations. It is quite feasible that the *surviving* and *striving* loggers featured in this study could have lost production due to these causes, and may have been able to shave the number of days on the job. We do not suspect inclement weather conditions played a major role in our sample, as the summer and fall of 2016 was quite dry. Also, although we did not specifically assess operator skill on an equipment-to-equipment basis, we did examine owner/operator experience as a variable within the model. Over 80% of our sample had a decade or more of experience as an owner/operator of a logging business, while nearly half had two decades of experience. The low variability in logging experience across the sample likely contributed to the lack of significance in the model.

Unit cost in dollars per cubic feet was calculated for individual harvests to include all volume and revenue generated

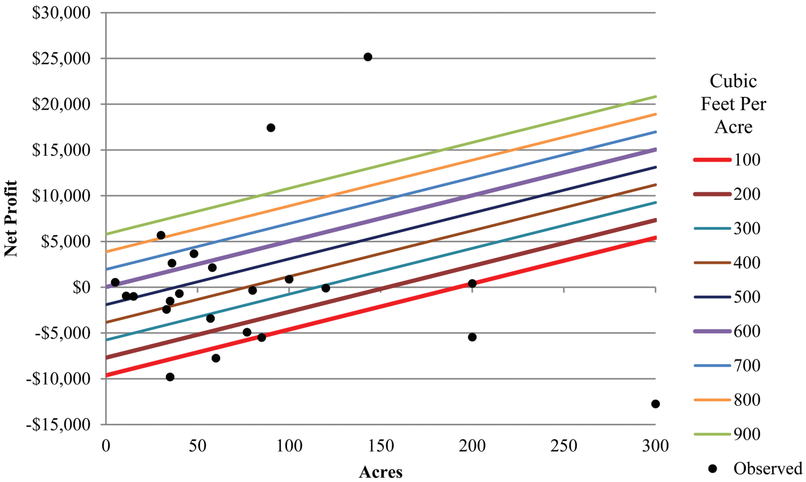

Figure 2. Predicting net profit based on cubic feet per acre harvested and harvest site acreage.

from sawtimber, pulpwood, and firewood. Our results showed an average unit cost of $1.53/ft³ ($58/ton), with a range of $0.70–2.65 ($26–100/ton). The correlation run to assess the relationship between unit cost and profit margin indicated that as unit cost increases, profit margin decreases, with the break-even line at approximately $1.40/ft³ ($53/ton). This threshold may be important in future management decisions. A study conducted in the central hardwoods of Appalachia reported unit harvesting costs for chainsaw and cable skidder systems of $0.38/ft³ when implementing clearcuts and $0.73/ft³ with shelterwood cuts (Li et al. 2004). In a study based in West Virginia, Thompson et al. (2011) reported average costs per ton of $53/ton in hardwood shelterwood cuts and crown thinnings using mechanized harvest systems. Studies conducted in the western US focusing on stump-to-truck costs reported unit cost ranges of $0.42/ft³ to 0.82/ft³ (Han et al. 2004, Adebayo et al. 2007, Harill and Han 2010, Vitorelo et al. 2011). In British Columbia, Renzie and Han (2001) reported harvesting costs of $0.38/ft³ for a chainsaw and cable skidder system conducting group selection cuts in cedar-hemlock forests. A study completed in the Northeast by Kelly et al. (2017) had comparable unit costs with a range of $0.40/ft³ to 1.44/ft³, with a mean of $.91/ft³. While the unit costs reported in the aforementioned studies provide valid comparisons to our study, they do not, however, link unit cost to overall harvest profitability. This study is unique in linking unit harvesting costs to ROI and profit. Based on the above comparisons, it is evident that the logging costs represented in our study are generally on the higher end of the scale. We suspect the age of the equipment, and associated high operating costs, coupled with silvicultural prescriptions dominated by hardwood crown thinnings (versus regeneration cuts), resulted in lower economies of scale, and ultimately higher unit costs.

Loggers need to be cognizant of logging jobs with potentially low productivity and associated high unit costs, and have a good sense whether it will fall into one of three scenarios: *surviving*, *striving*, or *thriving*. When the individual financial results of the study were shared with the participating loggers, the majority were not surprised with their respective ROIs or profit margins. They had a sense of what type of job they were on. Those on *surviving* jobs clearly understood that over the year they would need to balance out their portfolio of jobs with *striving* jobs, as well as *thriving* jobs. What should that balance look like? We offer that Pareto's principle of the "vital few" (often referred to as the 80/20 Rule) might be relevant in assessing the annual financial viability of logging contractors (Juran 1951). In this context, the 80/20 Rule suggests that a majority of the output results from a minority of the input. In the case of logging contractors operating in highly variable conditions in the Northeast, we propose that 80% of a logger's annual profit results from 20% of the logging jobs. In anecdotal conversations with our sample loggers, they agreed that this breakdown could be in the ballpark. When conducting recent logger training workshops, we bounced the same theory off our audiences and they also concurred that a few really profitable jobs (due to harvest characteristics and conditions) throughout the year subsidize the balance of their annual logging jobs. Clearly, the key to long-term economic viability is ensuring that there are enough *thriving* jobs in the annual portfolio. In order to select those jobs, it is important that both logger and foresters know those variables that can impact harvesting costs and productivity.

Isolating the numerous variables impacting harvest operations in the Northeast is challenging. While generally uncontrollable and unpredictable, variables such as weather and breakdowns may be the difference between profits and losses. This study attempted to identify, measure, and predict the impacts of such factors influencing individual harvest operations' net profit. Variables examined were acreage, days on the job, cubic feet per acre harvested, hours spent implementing BMPs, total distance of access system (feet), average skid distance, average percent slope of skid trails, the number of years the owner operator has owned his/her business, and contract rates. Total acreage of a harvest site, cubic feet per acre harvested, and the number of hours spent implementing BMPs on a job were found to be statistically significant when predicting net profit. While acreage and cubic feet were positively associated with total net profit, hours spent implementing BMPs negatively impacted net profit. The simplicity of the model and basic easily estimated inputs allows it to be readily utilized by loggers and foresters.

Conclusion

Harvesting operations in the northeastern US are characterized by challenging site conditions and unpredictable physical environments. Understanding the factors affecting profitability and productivity is important for long-term viability of businesses and future management decisions. Without a skilled and *thriving* logging workforce, most forest management activities cannot be implemented. This study sought to examine those factors that influence logger profitability from job to job across a variable forested landscape. Interviews were conducted during the summer months of 2016, and while this may have controlled for some of the variation in the data due to weather events or market conditions, it did limit the number of interviews. The sample size of 23, while reflective of the current logging community in the study region, is not of a favorable size for statistical analysis. Our model using site conditions and timber sale characteristics to predict profitability could be improved with a larger sample size. Furthermore, a longitudinal study of individual logging businesses throughout a fiscal year would shed light on how individual jobs influence annual profitability, and whether Pareto's principle can be applied to the annual economic viability of logging contractors. Combining this longitudinal approach with comparisons of multiple operations and harvest systems is necessary to better understand the economic viability of loggers in the Northeast.

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