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Montana logging machine rates

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Montana's logging industry has changed significantly over the past two decades. Increased operating costs and subsequent diminishing returns, combined with a shifting paradigm in regards to active forest management have had significant impacts on the economic and demographic make-up of the industry. One way to address these changes and mitigate the associated challenges of continued viability is through analysis of the factors and constraints impacting routine operational costs. To provide a resource for comparison between commonly-utilized logging equipment, the hourly owning and operating costs of select mechanical, ground-based machines were calculated using the machine rate method from data supplied by western Montana equipment dealers. The results were compared to historical cost data, and reasons for increased logging expense were studied and discussed. Inflation-adjusted operating costs for ground-based equipment appear to be 32–86% higher than 20 years ago. Reasons include increases in equipment purchase price, fuel, labor wages and benefits, and repair/maintenance expenses as well as a decrease in the number of operational days per year.

Keywords: machine costs; United States; historic cost comparison

Introduction

Forestry has long been one of Montana's foremost industries and the state has played a significant role in the Northwest's forest industry for well over a century. In 2012, Montana's forest products industry harvested 1.8 million m^3 (351 million board feet (MMBF) Scribner log scale), employed 6650 workers, and produced an estimated 1.4 million m^3 (584 MMBF, lumber tally) of lumber with the majority of that activity occurring in the western part of the state (Morgan et al. 2013).

The industry as a whole has changed significantly from its early days, and is very different now to what it was 20 years ago. Harvest volumes have decreased by 64% since 1993 and consequently, so too have employment numbers (44% decrease) along with total sales revenue from finished products (71% decrease) (Morgan et al. 2013). Despite this decline, the average wage in the forest products industry is 16% higher than the average across all sectors in Montana (Department of Natural Resources and Conservation [DNRC] 2013).

In addition to these economic changes, forestry in Montana is undergoing an ecological management paradigm shift. The emphasis on purely production-oriented forestry exists less today than when log prices and annual harvest volumes were higher 20 years ago. As a result of changing ecological objectives and the challenges related to global climate change, more logging contractors are relying on restoration, salvage, and stewardship harvest projects with differing ecological objectives. This brings a new set of challenges and a need for innovation, diversity, and flexibility within the industry. The demographic and economic changes occurring in the state, along with evolving ecological goals have significantly altered Montana's forest industry. To remain relevant, the industry must continually adapt to the changing conditions.

Montana's logging sector has experienced trends similar to the industry at large. In 2012, 575 people were employed in some aspect of logging in Montana, a decline of 96% from 10 years prior (Bureau of Labor Statistics [BLS] 2013). While

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employment has decreased, research suggests that the costs of operating a logging business have increased (Baker et al. 2013). Studies over the past 20 years have illustrated the impacts of increased logging costs, above inflation, across all component cost categories (Cubbage et al. 1988; Hayes et al. 2011). Initial investment levels for new logging equipment have increased, as have fuel, oil, and maintenance costs. Increased concern over the environmental impact of equipment emissions has led to significant advances in engine technology but have also contributed to rising purchase costs. This modern equipment is more powerful and efficient allowing for increased production, decreased fuel usage and emissions, increased reliability and decreased need for human labor. However, the advances and benefits allowed by improved technology have been somewhat stifled by the economic situation that Montana's timber industry faces. Whether or not the improved efficiencies of modern machinery will offset the increased costs of purchasing new equipment is a concern of considerable measure for contemporary logging professionals (Carino et al. 1995).

While total operating costs have largely increased over the past 20 years, delivered prices for logs have experienced a large volatility and in nominal year dollars have generally decreased since mid-1990s levels (Figure 1), thus continuing to decrease the already small profit margins for logging contractors (Cubbage et al. 1988; Bureau of Business and Economic Research [BBER] 2014). Logging costs not only affect a logging business, but also the landowner or agency relying on that contractor as increased operational costs are inevitably passed down from the producer to the consumer and are thus an issue of concern throughout the supply chain.

Figure 1. Mill delivered log prices in nominal year US dollars in Montana for the period 1990–2013 (Source: Bureau of Business and Economic Research 2014).

It is of utmost importance to any business to consider the factors that affect it and find ways to remain competitive. Constant consideration of production levels, operating costs and constraints, and ways to increase the former while minimizing the latter should be a main concern of any business owner, especially in the context of a slowly-recovering economy. While this is largely a matter of the personal motivation of the individual business, generalized resources are available to serve as estimators of start-up and operational costs, a means of comparison between equipment types and logging systems, or as base rates to begin negotiating logging rates.

Specific to the forest products industry, extensive logging cost and production analyses have been produced formally since the early 1940s and even before (Brandstrom 1933; Matthews 1942). Since then, costing research has been ongoing, though mostly in the southern region of the United States (Cubbage et al. 1986; Werblow & Cubbage 1986), but also with recent work in an international constellation (Ackerman et al. 2014). This research has varied in scope and objective, and ranges from offering generalized logging equipment rates to specific costs and productivity rates for one piece of equipment studied in a particular setting.

The methods used to produce these estimates have remained largely unchanged and focus on either (1) the "machine rate analysis" developed by Matthews (1942), and refined by Miyata (1980) and others, or (2) the cash flow analysis utilized more frequently in the accounting or finance industries (Burgess & Cubbage 1989). The predominance of this costing research occurred mostly from 1942 through the 1990s, and has lessened in recent years perhaps due in part to a decline in the industry, and/or increased complexity of costing more advanced equipment. Government agencies, research institutions, and major timber companies have continued to produce cost research into the twenty-first century, though in what seems considerably less volume. The practical consideration of operating costs is one way to improve the long-term survival of an individual operation and is an important facet of active forest management research.

Montana logging cost data have been publicly available since at least the 1950s, and there is evidence that previously-operating regional timber companies kept detailed records prior to that (Roe & Squillace 1953). Since then, it is likely that Montana's major timber companies have kept detailed cost records, most of which are not available publicly as they contain proprietary data. It is unknown, outside of the companies themselves, whether this type of logging cost analysis is on-going to ensure that contract rates reflect actual logging costs, a concept that has been studied in other parts of the country (Cutshall et al. 2000). The increasing challenges of economic viability and continued interest in logging cost work are two significant reasons for maintaining this type of research into the future.

The objectives of this work were to produce a resource for estimating owning and operating costs, independent of production, for the ground-based logging equipment typically encountered in Montana and to compare changes in costs over a 20-year period. The high costs of operating logging equipment that may be familiar to the owner of a logging firm may be less so to the mill, forester, or private landowner contracting with that firm. There has been an identified need (from discussions with various individuals from Montana mills, agencies, and loggers) to produce a set of baseline costs that might serve as a negotiating tool for logging professionals, as well as an informational resource for other interested parties to assess and understand the component parts of logging costs and how these components impact total expenditures. Further, offering a range of equipment costs might assist individuals or businesses that are considering purchasing new equipment in finding the right piece of equipment for their specific operation.

Methods

Equipment costing methods

Logging cost estimation has historically relied on two accounting methods: the machine rate method or cash flow analysis (Burgess & Cubbage 1989). Arguably the most common method is the machine rate approach popularized by Matthews (1942) and further refined and used by others since then (e.g. Miyata 1980; Brinker et al. 2002). The machine rate method compiles and averages fixed and variable costs over the lifespan of a piece of logging equipment so that costs may be calculated per scheduled machine hour (SMH) or productive machine hour (PMH) (Miyata 1980). Fixed cost are those that occur even if the machine is not operating such as depreciation, principal repayment, interest, insurance, and taxes. Variable (or operating) costs are only incurred when the machine is actually operated, such as maintenance and repair, fuel, lube, oil, and labor (Miyata 1980). The machine rate approach is an easy-to-use and easy-to-apply method that also provides a standard format for comparison.

The machine rate method can rely heavily on general “rules of thumb” (ROT), when there is a lack of good machine records, these ROT offer standardized ways to account for fixed and variable costs specific to logging machinery. These ROT have been refined in various published literature (Brinker et al. 2002; Smidt & Gallagher 2013). The simplicity of this method has made it popular for comparison between types of equipment over the years, though it does have obvious limitations. For example, fixed costs will be higher when the equipment is new, and lower as it ages. Conversely, operating costs will be lower when new, and generally higher as the equipment ages (Werblow & Cubbage 1986). The machine rate method doesn’t allow for this sort of analysis, and doesn’t take into account various investment credits or other Federal and State tax laws (Werblow & Cubbage 1986).

While the machine rate analysis is suitable for general cost estimation, its limitations negate it from being a useful tool for individual, machine- and situation-specific cost estimation and tracking. Individual loggers with solid record-keeping might instead choose to employ a second method of cost estimation, cash flow analysis (Burgess & Cubbage 1989; Cutshall et al. 2000). This approach tracks the in-flows and out-flows of cash related to a given piece of machinery on a periodic basis and accounts for the time-value of money. For an individual logging contractor with detailed cost records and an understanding of accounting, this method will prove more intuitive and accurate for cost tracking and will account for changes in costs over the life of equipment. Comparisons of the two methods of cost accounting have found the cash flow analysis to be more accurate, though a more cumbersome method based on the amount of detailed input data required, constantly changing Federal tax laws, and the complexity of calculations (Burgess & Cubbage 1989). In this same comparison, Burgess and Cubbage (1989) also found that the machine rate method generally underestimates actual costs, and that the cash flow analysis was more true to actual costs reported by logging contractors. However, for the sake of comparison and standardization, as well as due to the lack of firm-specific data upon which to base a cash flow analysis, this report produces equipment costs that were computed using the standard machine rate method.

An additional limitation of the method is that all costs are independent of production. Variables such as working days per year and the ratio of scheduled to productive machine hours are needed, however these variables have no direct relation to the volume of timber harvested or processed. It is assumed that the hourly cost of equipment will remain relatively constant for a given contractor from harvest unit to harvest unit. What will change between units is the volume of timber produced per productive hour. This change in production will therefore have an impact on the cost per unit volume.

Machine rate analysis

For this analysis, we relied primarily on local equipment dealers and data in the form of equipment specification and cost sheets, as well as ROT widely accepted from published sources (Table 1) (Matthews 1942; Brinker et al. 2002). There are five dealerships in the Missoula, Montana area that sell new logging equipment to contractors within the study region that combined have distribution rights to all major, commonly-utilized equipment brands. The individual in charge of forestry equipment sales at each dealership was contacted; four out of the five dealerships agreed to directly participate. Direct interviews were conducted and each dealer was asked to provide data for their most frequently sold ground-based logging equipment, including feller-bunchers, skidders, processors, and log loaders. Ultimately, a Manufacturer's Suggested Retail Price (MSRP) (prior to any discounting, delivery, and other associated charges) and specification data were provided for 6–11 pieces of equipment in each category of a ground-based operation, with the exception of skidders (Table 2). The fifth dealership not participating in an interview offers an online tool allowing users to build and price a piece of equipment with associated features such as engine type, cab type, hydraulic package, attachments, etc., that was also used to gather cost and specification data (Caterpillar Tractor Company 2013).

Table 1. Machine rate parameters and assumptions utilized by equipment type.

Equipment type	Life (years)	Salvage value (%)	Utilization (%)	Repair and maintenance (%)
Feller-Buncher	5	15	60	75
Skidder	5	15	65	90
Processor	5	20	90	100
Stroke-Boom Delimber	5	20	90	100
Loader	5	30	65	90

Note: The following rates are constant for all equipment types: Interest 6.50%, Insurance 1.30%, taxes 2%, fuel use 13.35 L/kW-hr (2.63 gal/hp-hr), fuel $0.92/L ($3.50/gal), lube and oil 36.80% of fuel cost.

Specific costs for each piece of equipment were then broken out into fixed and variable costs to produce daily and hourly rates per scheduled and productive machine hours per established machine rate equations (Matthews 1942; Brinker et al. 2002). Equipment depreciation was calculated using the straight-line method and an assumed economic life of 5 years for all equipment. Though logging equipment may realistically be utilized longer than 5 years, this number was chosen based on machine rate method protocol and conversations with local equipment dealers and financiers. Other fixed cost data including interest, insurance, and taxes were collected from Federal, state, city, and private agencies. Labor costs were assembled using Montana-specific wage data from the Bureau of Labor Statistics (BLS 2013) and were based on a 9.5 hour working day. Worker's compensation insurance, Federal unemployment taxes, Social Security taxes, and benefit costs were acquired from Federal, state, and city agencies, local insurance dealers, and the Montana Logging Association. Operating costs were based on a scheduled 180 working days per year (1710 scheduled hours). Mobilization, road building or maintenance, and other contracted services such as slash disposal were not included in this estimate. It should also be noted that production rates have no influence on hourly cost estimates beyond ROT utilization rates. After compilation of cost data (Meek 2014), six local loggers (acting as experts) were contacted and interviewed to validate these costs and make adjustments as applicable.

To identify changes in logging cost over time, current estimates were compared to data produced over 20 years ago in 1993 by one of Montana's former major timber companies and landowners. These data had hourly costs broken down through typical machine rate methods for individual pieces of equipment across different logging systems (ground and cable) and split between fixed and variable costs. The historic costs were based on 200 working days per year. These costs were then adjusted to 2013 dollars using the Consumer Price Index inflator provided by the BLS (2013). Production estimates were not included in the historic data, and consequently are not included in this report.

Results

As evidenced by the machine rate calculations, along with the range of fixed and variable costs by equipment type (Table 3), the cost of purchasing and operating a new piece of logging equipment is significant. For a prospective new logging business, the

Table 2. Logging equipment data acquired from western Montana dealers and calculated total cost (USD) per scheduled machine hour.

Equip. type	Brand	Model	Under-carriage	Weight (kg)	HP	Purchase price	Total $/SMH
Feller-Buncher	John Deere	759J	Track	27,243	241	583,736	169.82
	Cat	511	Track	24,362	247	320,270	114.60
		521	Track	27,084	284	482,660	151.71
		522B	Track	30,409	284	387,110	131.52
	Timbco	XT445L-2	Track	30,416	300	532,341	163.42
		XT430L-2	Track	27,685	300	470,091	150.27
	TimberPro	TL735B	Track	27,070	300	503,443	157.32
	Cat	541	Track	30,191	305	414,000	138.79
		552	Track	35,680	305	513,530	159.83
		551	Track	31,057	308	465,110	149.82
	Tigercat	LX 830	Track	36,287	300	500,000	156.59
Skidder	Cat	535C	Tire	18,044	152	292,562	108.22
		545C	Tire	19,198	219	325,155	121.68
	John Deere	848H Grapple	Tire	17,826	200	369,444	129.97
	Tigercat	620D	Tire	16,443	220	285,000	112.68
Tracked Skidder	Cat	527 GR	Track	17,710	150	405,218	133.53
Processor	John Deere	2454D Logger	Track	14,160	194	428,179	150.02
	Komatsu	PC210LC-10	Track	23,323	160	417,000	149.16
	Pierce	Titan 22	Track	14,160	194	393,000	142.37
		Titan 23	Track	14,160	194	410,514	145.18
	Komatsu	PC290LC-1	Track	30,570	213	540,000	176.77
	Pierce	GP	Track	14,160	194	398,000	142.36
Stroke-Boom Delimber	Denharco	DT 4150	Track	14,160	194	459,364	156.20
		DM 4150	Track	14,160	194	442,853	152.47
	Pierce	PTD2856	Track	14,160	194	521,214	170.14
Loader	John Deere	2154D Logger	Track	12,093	159	371,766	111.78
	Doosan	DX 225 LL	Track	29,499	155	218,998	81.58
	Komatsu	PC210LC-10	Track	23,323	160	325,000	102.68
	Cat	320D FM	Track	26,905	157	257,294	89.22
		325D FM	Track	33,329	204	351,055	110.75
		330D FM	Track	41,433	268	392,310	123.15
		324D	Track	31,231	188	394,885	118.26

Table 3. Estimated hourly costs (USD) for select ground-based equipment categories in Montana. A wage and benefits rate of $27.64/hour, assuming a 9.5-hour day, is used for all machines and included in total machine costs.

		Cost per scheduled machine hour ($/SMH)				Cost per productive machine hour ($/PMH)			Total machine cost	
Category		Depreciation	Interest	Insurance. and tax	Fixed cost	Fuel, Lube, and Oil	Repair and Maint.	Variable cost	$/SMH	$/PMH
Feller-Buncher	Avg.	46.75	11.80	6.36	64.90	36.37	58.43	94.80	149.43	249.04
	Min.	31.84	8.03	4.52	44.39	30.38	39.80	70.93	114.60	190.99
	Max.	58.03	14.64	7.75	80.43	38.82	72.54	103.97	169.82	283.04
Skidder	Avg.	33.35	8.42	4.70	46.47	26.28	46.18	72.46	121.22	152.46
	Min.	28.33	7.15	4.08	39.57	20.95	39.23	61.50	108.22	130.82
	Max.	40.28	10.17	5.56	56.01	30.72	55.78	78.78	133.53	166.49
Processor	Avg.	40.39	11.16	5.99	57.53	26.68	44.88	71.56	149.58	166.20
	Min.	36.77	10.16	5.50	52.43	22.34	40.86	65.69	141.23	156.92
	Max.	50.53	13.96	7.34	71.83	29.74	56.14	85.88	176.77	196.41
Stroke-Boom Delimber	Avg.	44.40	12.26	6.52	63.18	27.09	49.33	76.42	159.60	177.34
	Min.	41.44	11.45	6.13	59.01	27.09	46.04	73.13	152.47	169.41
	Max.	48.77	13.47	7.11	69.35	27.09	54.19	81.28	170.14	189.05
Loader	Avg.	27.03	9.04	4.87	40.94	19.12	37.43	56.55	105.35	162.07
	Min.	17.93	5.99	3.43	27.35	16.07	24.83	40.90	81.58	125.51
	Max.	32.33	10.81	5.71	48.85	27.79	44.76	72.26	123.15	189.46

initial investment of approximately $1.5 million dollars for a complete logging system might preclude entry into the field. For established loggers looking to replace one piece of equipment, careful consideration of operational needs is required to match the right equipment to the right job. For instance, horsepower (HP) needs should be of concern based on the calculated price difference between equipment HP ranges in Table 1. For example, the average purchase price for a feller-buncher with more than 285 HP is 9% (roughly $42,000) more than a feller-buncher with less than 285 HP. Ideally this increase in HP would have a corresponding increase in production; however changes in other variables such as piece size, skidding distance, and harvested and residual volume per unit area confound this comparison. The cost of operating a log processor ranges from $1421 per 9.5-hour day for a dangle-head processor to $1516 per day for a stroke-boom delimber, a difference of 6% or $95 per day. Over the course of a 180-day operating year, this difference equals approximately $17,000. Between equipment and labor, a business owner might expect daily costs to equal roughly $5100 per day if all new equipment is utilized. These costs do not include other necessary costs such as support vehicles to transport the crew or overhead costs such as bookkeeping and sale administration.

Discussion

Comparison to historic cost data

As illustrated by Table 4, the cost of running a mechanical ground-based system in Montana has significantly increased over the past 20 years beyond inflation. Similar results have been found in other regions, dating back to the 1980s where researchers found that "…the costs of logging equipment have increased at rates considerably greater than the prices received by loggers" (Cubbage et al. 1988, p. 9). Based on comparison to past data as well as anecdotal interviews with logging professionals, the main factors contributing to increases in equipment costs purportedly has been in the purchase price of new equipment (and price of steel), diesel fuel prices, and labor costs (Brinker et al. 2002; Hampton 2004; Smidt & Gallagher 2013).

Table 4. Logging cost comparison between 1993 historic data adjusted for inflation (2013 dollars) and 2013 machine rate data assuming a 9.5-hour day.

	Total cost ($/day)		Cost change beyond inflation	
Equipment type	1993	2013	$/Day	%
Feller Buncher	1072	1420	348	+32
Skidder	639	1152	513	+80
Stroke-Boom Delimber	999	1516	517	+52
Loader	714	1001	287	+40

Factors affecting fixed cost changes over time

New equipment might come with added efficiency, power, reliability and consequently productivity, but also with substantial fixed and variable costs. It has been noted that the mere initial investment in a mechanized logging operation can constitute 40–50% of the delivered cost of wood, let alone all other intervening factors (Ashton et al. 2007). This cost is significant and purportedly has been rising over the past 20 years, begging the question of what factors are contributing to escalating logging costs and equipment purchase prices. While this is largely uncontrollable (in contrast to operating costs), it might be of interest and concern to the logging industry to understand the underlying reasons for this trend.

Comparisons between equipment purchase price from our historic data and contemporary data proved challenging based on several factors. Most notably, equipment utilized today is mechanically and technologically very different to 20 years ago. Based on equipment specification data provided by equipment dealers there were observable differences in both weight and horsepower between data sets, with modern equipment having a range of 12–122% more horsepower, thus potentially contributing to increased fuel usage, lube and oil, maintenance, and initial purchase price. The trend with larger and more powerful machines can also be found in the Nordics (Nordfjell et al. 2010). Ideally this increase in power would equate to an increase in productivity or a reduction in complete system bottleneck, a concept validated by research around the country, though the increase in purchase price might offset the production benefits of purchasing new equipment (Cubbage et al. 1986). Ultimately, "…the replacement should be able to generate additional income from increased production (in terms of quantity and/or quality) to offset the additional costs associated with it" (Carino et al. 1995, p. 62).

In addition to increased engine power, changing emission standards have influenced the initial purchase of logging equipment. Federal emission standards have been in place since 1994, with several planned changes occurring since by means of changing generations or "tiers" of standards that new vehicles must meet (Environmental Protection Agency [EPA] 2013). This tiered system implemented a plan to reduce particulate matter and nitrogen oxide from off-road heavy equipment by 50–96% of the current equipment generation in several steps. Essentially, machine manufacturers are charged with adding emission control technology to the exhaust system; this will occur through either exhaust gas recirculation (EGR) or selective catalytic reduction (SCR) (Diesel Technology Forum 2012). While all vehicles in the US are subject to these tiers, heavy equipment will enter Tier 4 standards in 2014, though many manufacturers produced and sold Tier 4 equipment in the US earlier than this (Doosan Equipment 2013). These required engine alterations along with the addition of the DEF system (fluid replenishment) will undoubtedly impact both initial purchase price and operating costs, though the exact impact is unknown and likely manufacturer-dependent. This range is from a 1% increase (Diesel Net 2013) up to 30% based on our interviews with local equipment dealers and published resources. All new equipment is subject to Tier 4 standards, but older equipment will not require retrofitting, a consideration for deciding between purchasing new versus used equipment (Diesel Technology Forum 2012). At some point in the near future Montana's logging professionals will be faced with the decision between continuing to invest in the costly maintenance required to retain older equipment or purchasing new, "greener" equipment. This is a decision that individual business owners must make alone, but one that will have significant cumulative effects on the industry and environment.

While the mechanical side of logging equipment has changed significantly, there has also been substantial improvement in on-board technology. Most modern equipment has advanced computer systems capable of determining and processing different cut log specifications, and then storing production data for future use. Some systems enable mill operators to adjust cutting specifications from the mill without having to implement any changes on the machine, can monitor how the machine is operating mechanically and when maintenance is required, and can set movement boundaries to prevent potential theft or vandalism. These systems ideally enable loggers and mill operators to interact more seamlessly and improve overall efficiency. Yet, similar to cost changes resulting from mechanical advances, there is an underlying cost associated with this improved technology that may be of further consideration when purchasing new equipment.

Another explanation for rising purchase prices is that the price of steel has increased from \$175 per ton (adjusted for inflation) in 1993 to \$216 in 2011, an increase of over 23% beyond inflation, as a result of restricted supply and increased demand overseas (Bleiwas et al. 2013). The cost of steel as a raw material can constitute 60% of the total cost to produce a piece of equipment and a number of equipment manufacturers have stated that as a result of this issue, consumers might see a rise in purchase price from 3 to 5% if there is a continued upward swing in steel prices (Hampton 2004; Electrical Contractor Magazine 2008; Holden-Moss 2012).

Changes to the fixed cost categories of logging equipment are entirely susceptible to forces outside of the owner of a business or operator of a piece of equipment, and thus are personally uncontrollable. Remaining aware of the internal changes impacting fixed cost is crucial, but the one opportunity a business owner does have in this regard is to carefully match specific equipment to individual operational need and capital availability and outlay to assist in continued operational viability.

Factors affecting variable cost changes over time

In addition to increased fixed costs, there has been a notable rise in the variable costs of operation. Volatile fuel costs are an especially influential factor on operational costs, and are a cost that is unlikely to level out in the near future. Debate continues over how Tier 4 standards will impact fuel usage, though from conversations with equipment dealers it appears that with increasing engine sophistication this might also provide increased fuel efficiency. This is especially important to the logging industry, as increased fuel costs can greatly impact an operation's break-even point and erode profit margins (Meek 2014). Estimated fuel costs used here were based on the average price for off-road diesel in Montana at the time of analysis (Mountain West Coop. Missoula 2013) and fuel usage relied on value assumptions produced by Plummer and Stokes (1983); a range of 18.9–30.3 liters (5–8 gallons) per hour was calculated based on the horsepower of the machines. This range was validated as "typical" from our interviews with dealers and contractors and from current research (Green et al. 2014; Kenney et al. 2014), though fuel usage will vary by topography, operator skill, weather, and other factors.

To illustrate the impacts of fuel prices on total daily operating cost, a sensitivity analysis was conducted for a typical mechanical ground-based system. Using machine rate calculations, this equipment combination would use roughly 522 liters (138 gallons) of fuel per day. At \$0.92/L (\$3.50/gallon), daily fuel expenditures would equal \$483; if diesel prices increased to \$1.06/L (\$4.00/gallon) this daily expense would be $552, a difference of $69 or 14%. Contrasted with the average fuel price in 1993 at $0.38/L ($1.44/gallon) adjusted to 2013 dollars (from historic industry cost data), daily fuel expense would only be $199, or 41% of the 2013 daily fuel cost estimate. Varying fuel prices have an impact on daily fuel expenditures and when these prices are extrapolated further, the difference in daily cost becomes increasingly significant. Similar to the issues inherent to the fixed cost categories, changing fuel prices can't be directly controlled, though fuel usage and subsequent expenses can be mitigated by operator skill and consideration of fuel use during downtimes such as breaks or other delays.

The cost of repairs and maintenance for logging equipment is another influential expense though one that is notoriously difficult to track with reliability (Werblow & Cubbage 1986). These costs exist as both routine, expected maintenance and as unplanned, potentially catastrophic breakdowns that can have a significant impact on an operation's monetary situation both in lost productivity and return, as well as cash flow. Repair and maintenance costs vary depending on the type and make/model of machine, operator skill and usage, topography, and planned maintenance routine. This study employed the typical machine rate method of accounting for maintenance as a percentage of depreciation. However, we attempted to acquire local ROT from the equipment dealers that were surveyed for comparison and verification of established ROT. Unsurprisingly, those dealers agreed that average repair and maintenance rates are hard to predict; an estimated range of $35–$50 per operated hour was given anecdotally. Utilizing the machine rate ROT produced a range of $24–$72 per operated hour varying with the type of machine. The calculated average rate was highest for feller-bunchers at $58/PMH, similar for processors and skidders at $46/PMH, and lowest for loaders at $37/PMH. Using the machine rate ROT likely overestimates repair and maintenance costs early in a machine's life, and underestimates them later on. However, assuming a straight-line repair and maintenance cost might allow a business owner to "accumulate a reserve fund in early years to cover the higher costs incurred later in the equipment's life" as noted by Werblow and Cubbage (1986, p. 13).

In our interviews with loggers, foresters, and equipment dealers, maintenance costs were frequently highlighted as a cost that has increased over the past 20 years. Local equipment dealers acknowledged that the price of lubricant and oil, hydraulic hoses, and other parts has increased in recent years though no contemporary research has attempted to quantify this change.

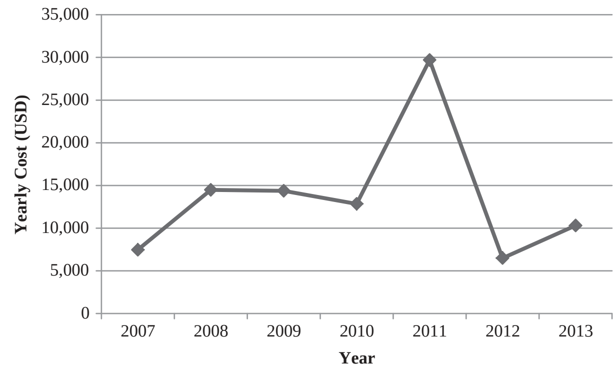

Figure 2. Actual (nominal) yearly maintenance costs of one feller-buncher.

The difficulty in assessing the applicability of machine rate ROT is highlighted by repair and maintenance data acquired from a local logger for one feller-buncher of well-known make and model over the course of 7 years from 2007–2013. As shown in Figure 2, repair and maintenance costs did not increase linearly over the life of this machine but fluctuated widely. Average yearly maintenance costs over the 7 years was $13,660 with an hourly rate of $15.93 based on an average 1295 operated hours per year, but ranged from a low of $5.01/hour in year 6 to a high of $22.93/hour in year 5.

Ultimately, calculating an average repair and maintenance cost to suit the range of equipment and conditions experienced is challenging and assumed values are virtually meaningless in themselves as the volatility of costs is so great. Instead, logging contractors should remain aware of the range of values they can expect over the lifespan of a piece of equipment and should save accordingly.

Like repair and maintenance costs, machine utilization is highly variable. Newer equipment is assumed to be more reliable than older equipment; however machine utilization is influenced by more than mechanical break-downs. Smaller harvest tracts, lower removal volume per unit area, increased average distance to access replacement parts, and increased demands for non-productive machine time such as erosion control or other environmental protection measures all serve to decrease overall machine utilization.

Though the variable costs of a logging operation are significant, they are also more pliable to change than fixed costs, largely based on operator skill and judgment, mitigation of equipment wear from harsh operating conditions, and the type and condition of the equipment itself. There are ways to reduce these daily expenditures, but it will again require thoughtful consideration of operating parameters and conditions to do so.

Other factors affecting operational costs

The mechanical (fixed and variable) costs of running a logging operation account for a large portion of overall cost difference between our historic and contemporary cost data. However, other more general factors exist that routinely impact operational costs. First, the number of annual days a logger works appears to have decreased over the past 20 years. Montana loggers work, on average, between 9 and 10 months a year. This range is due to a variety of factors, most notably market influences on consumer need and the availability of a consistent supply of timber. Yearly weather patterns also influence the amount of operable days with closed forest access due to spring break-up, high amounts of snow, or extreme fire danger. A shorter working year can decrease profit margins by increasing the required hourly contribution to fixed costs and decreasing the volume of timber produced on an annual basis. Based on our machine rate calculations a 10 day increase to 190 days per year changes daily cost by 3.4% or about $175 per day for a mechanical ground-based side. Likewise, if current machine rates are calculated using the 200-day work year that was used to develop the machine rates 20 years ago, daily operating costs decrease 6.5% or $330 per day. It should be noted that even calculated costs assuming a 200-day work year, machine rates are 24–74% higher than inflation-adjusted 1993 costs. This increase puts added strain on an operation to maintain consistent production over the days that are available, thus increasing stress from machine breakdowns, labor recruitment and retention, and other issues. Consistent production is key to mini- mizing costs, a point that is especially salient for loggers with aging equipment, restricted wood sup- plies, and increasingly expensive labor costs (Baker & Greene 2012). Our interviews with local logging professionals indicated that the shorter work year combined with the inability to depend on a consistent wood supply are the two most significant changes that they have seen over the past 20 years, and are a reason that many loggers have gone out of business.

Another influence on general operating cost not included here is the increased driving distance to get to a job site. A consequence of decreased logging employment and mill facilities means the same area is covered by fewer contractors and those remaining must travel further. This results in increased fuel usage, vehicle maintenance, mobilization costs, and down-time for repairs.

A final influence is in regards to the changing demographics of the logging contractor workforce. It's been noted in several recent publications that the average age of the logging sector workforce is increasing. In a 2004 survey of the Inland Northwest, Allen et al. (2008) found that 58% of respondents were over the age of 40, with an average age of 51 years. This is affecting all associated labor costs including hourly wages, worker's compensation (WC) rates, social security, and other personnel costs. According to Bureau of Labor Statistics (2013) data, Montana's average wage for logging equipment operators is $16.75 per hour and $19.53 per hour for timber fallers. Benefit costs including WC, Social Security, Federal and State unemployment, and Medicare rates were compiled from respective Federal and State agencies. We found that excluding WC rates, fringe benefits constitute 23% of the base wage; including WC this percentage can rise to 30–50% of the base wage. While the forest industry sector still commands higher wages than other sectors in Montana, survey respondents reported diminishing wages and revenue each year. Hourly rates have stayed relatively the same over the past 20 years, but the decreasing number of operational days per year amounts to reduced pay over the course of a full year. Base wage rates are controllable; however business owners should expect rising fringe benefit costs to be of increasing significance on total operating expenses.

Worker's compensation insurance (WCI) rates are increasingly important to operational viability. According to a recent article in the *Forest Operations Review*, "The logging profession ranks number one among the most hazardous occupations in terms of fatalities per 100 workers and logging and hauling rank as the top two areas for high severity claims among insurance companies that provide Worker's Compensation" (Lemire 2013, p. 31). In Montana, as in most states, specific WCI rates are based on a logging contractors work experience and history of accidents (Montana State Fund 2012). These rates can vary from $4–6 per hour on average, to upwards of $9 per hour. Some loggers in Montana reported upwards of 78% of the base wage paid in worker's compensation insurance. In a ranking of state-level WCI rates, Montana ranks eighth highest in the nation (Dotter & Manly 2012). There are signs that the situation is improving based on declining rates over the past 10 years, a decline that is based largely on increased safety measures in logging equipment such as enclosed cabs and seatbelt usage and a transition from conventional to mechanized operations. Further, there has been a notable shift in the "safety culture" of the logging industry with greater use of hard hats, saw chaps, radios and cellphones, as well as the addition of the formalized Montana Logging Association Safety Ranger program. Though WC rates have decreased on average, they still remain a significant cost and one that can be somewhat mitigated at the business level.

Changes in Federal health care policies, via the Affordable Care Act, might further increase labor benefit costs though the exact impacts are currently unknown. While health care costs are both significant and unknown, there might be a non-monetary benefit to offering health insurance by way of maintaining employee loyalty.

Though unpredictable, these external factors will continue to have implications on a firm's hourly, daily, and yearly operational costs.

Conclusion

Hourly owning and operating costs for common new logging equipment typically used throughout Montana have been developed as a means to assist logging contractors, foresters, researchers, and others in appropriately assessing costs of logging operations. Hourly machine costs for all categories of equipment were found to have increased beyond inflation over the past 20 years. When costing is completed for equipment not specifically attached to a single contractor, ROT costing approximations must be used. While all ROTs used in this manuscript were verified with equipment dealers and logging contractors to be appropriate, many vary widely and additional research and, for individual firms, cost tracking, is needed to better understand relationships between stand, site, and economic factors and individual cost categories.

Disclosure statement

No potential conflict of interest was reported by the authors.

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