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Machine Rate Estimates and Equipment Utilization – A Modified Approach

John Sessions, Michael Berry, Han-Sup Han

Abstract

As mechanization increases, the percentage of the total cost of the logging operation due to equipment purchase and operation increases. This makes assumptions about machine life, machine maintenance costs, and fuel consumption more critical in understanding the costs of logging operations. For many years machine rate calculations have followed a fixed format based on the concept of scheduled and productive machine hours. When equipment utilization is less than 100%, the traditional machine rate calculation assumes that the machine continues to depreciate and machine wear occurs during the non-productive time at the same rate as during the productive time. This can lead to overestimates of the hourly cost of machine operation by effectively shortening the machine lifetime productive hours as the utilization decreases. The use of inflated machine rates can distort comparisons of logging systems, logging strategies, equipment replacement strategies, and perhaps the viability of a logging operation. We propose adjusting the life of the machine to account for non-productive time: machine life in years should be increased with a decrease in machine utilization, while cumulative machine life in hours remains the same. Once the life has been adjusted, the traditional machine rate calculation procedure can be carried out as is normally done. We provided an example that shows the traditional method at 50% utilization yielded a machine rate per productive hour nearly 30% higher than our modified method. Our sample analysis showed the traditional method consistently provided overestimates for any utilization rate less than 100%, with lower utilization rates yielding progressively increasing overestimates. We believe that our modified approach yields more accurate estimates of machine costs that would contribute to an improved understanding of the machine costs of forest operations.

Keywords: equipment costing, forest operations, mechanization, hourly costs, machine life

1. Introduction

As mechanization increases, the percentage of the total cost of the logging operation due to equipment purchase and operation increases. This makes assumptions about machine life, machine maintenance costs, and fuel consumption more critical in understanding the costs of logging operations. Machine rate calculations have been an important component for evaluating forest stand treatment options (e.g., Bell et al. 2017). Nearly 80 years ago, Donald Matthews (1942) developed the machine rate calculation as a way of estimating equipment operating costs. The method was simple to understand and simple to use. It has been widely adopted by others (e.g., Miyata 1980, Brinker et al. 2002, Ackerman et al. 2014). Less commonly, others have proposed discounted cash flow approaches that sum the discounted costs of equipment purchase, maintenance, fuel and labor costs and then solve for the uniform series cost recovery factor as an estimate of the machine rate (for example, see Bright 2004, Bilek 2009). For similar assumptions about equipment investment, equipment life, interest rates, and maintenance costs, the two approaches give similar machine rates (Bright 2004). Both procedures become problematic in the handling of equipment utilization. Alternatively, others have developed hybrid solutions to equipment costing using a combination of annual workload and economic life assumptions as well as variations when assuming depreciation of fixed assets (Cwiertnia et al. 2014, Forbig 2014) with associated web tools (Triplat and Krajnc 2020, BFW 2020).

Typically, equipment utilization (U) measures the percentage of the scheduled time that equipment is either expected or observed to work. If the machine works its scheduled machine hours (SMH) with no delays, then the utilization is 100%, which means SMH is the same as productive machine hours (PMH). Mathematically, utilization is calculated by dividing PMH by SMH, and then multiplied by 100 to get a percentage utilization rate (i.e. $U = (PMH/SMH) \times 100$). Often, equipment works less than the scheduled operating hours for a variety of reasons including weather, lack of available work, machine breakdowns, and repair & maintenance. Imbalance in harvesting interactions (e.g. between felling and skidding or between skidding and processing) and the supply chain (e.g. harvesting and log transportation) also causes underutilization of machines. Those factors causing underutilization of harvesting machines and trucks are referred to as delays. For example, Han and Han (2020) observed processor utilization rates in the 45–50% range due to imbalance between the yarder and processor productivity rates. In another example, Zamora-Cristales et al. (2013) observed that grinder utilization in three biomass case studies varied between 20% and 60% due to truck availability. Based on the current practices of machine rate estimates, equipment utilization directly affects hourly costs ($/SMH and $/PMH) including key cost factors such as machine life and repair & maintenance.

Table 1 Machine life, salvage value, utilization and repair and maintenance estimators (Brinker et al. 2002)

Machine description	Life, years	Salvage value[1]	Utilization[2]	Repair and maintenance[3]
Tree shear, without carrier	5	50	60	100
Feller buncher, sm., rubber tired	3	20	65	100
Feller buncher, med-lg., rubber tired	4	20	65	100
Feller buncher, lg., tracked, boom	5	15	60	75
Cable skidder, sm., <=80 hp	4	20	65	75
Cable skidder, med., 81–100 hp	4	20	65	90
Cable skidder, med., 101–120 hp	5	15	60	90
Cable skidder, lg., >=120 hp	5	10	60	90
Grapple skidder, 70–90 hp	4	20	65	90
Grapple skidder, >=91 hp	5	25	60	90
Grapple skidder, lg., tracked	5	15	65	100
Forwarder, shortwood	4	20	65	100
Slasher/loader, multi-stem	4	0	65	35
Delimber, iron gate	5	20	90	65
Harvester, combine	4	20	65	110
Loader, bigstick	5	10	65	90
Loader, sm., hydraulic	5	30	65	90
Loader, med., hydraulic	5	30	65	90
Chipper, sm.-med., 12"–18"	5	20	75	100
Chipper, lg., >=22"	5	20	75	100
Crawler tractor, <=100 hp	5	20	25	100
Crawler tractor, 101–200 hp	5	20	60	100
Crawler tractor, >=201 hp	5	20	60	100

[1] Percent of purchase price
[2] Percent of scheduled machine hours
[3] Percent of annual depreciation

The common approach for machine rate calculation (Miyata 1980, Brinker et al. 2002, Ackerman et al. 2014) is to take the straight-line annual depreciation of the machine that would have occurred over its scheduled life and prorate overall depreciation over the productive hours which increases the apparent rate of depreciation (Table 1). The total years of machine life is held constant, and the salvage value is unchanged. Often, equipment repair and maintenance rates are tied to annual equipment depreciation rates, so increasing the depreciation rate can cascade into increased equipment repair and maintenance rates (Brinker et al. 2002). The use of inflated machine rates can distort comparisons of logging systems, logging strategies, equipment replacement strategies, and perhaps the viability of a logging operation. We expand on these concepts with a discussion surrounding machine rate calculation and utilization within the context of equipment life, maintenance costs and fuel consumption and then suggest remedies to create a more accurate machine rate.

1.1 Equipment Life versus Utilization

The life of a piece of equipment is often mentioned by equipment manufacturers, but highly depends upon the working conditions and its preventive maintenance schedule. For example, Caterpillar provides guidance (as cited in FAO 1992) on equipment lives that can vary more than 50% or more depending upon the working conditions, so the first decision is to choose the proper machine life considering the work to be done. Regardless of the machine life, when equipment is turned off, fuel consumption stops, and equipment wear stops. When the equipment resumes its task, fuel consumption and equipment wear resumes. During the time the equipment is not running, its life can be considered suspended. There can be exceptions, such as when equipment is stored for long periods of time and physical deterioration takes place, or when equipment is subject to rapid technological change and obsolescence, such as in the electronics industry. With recent advances in engine idle reduction systems (EIRS), idle time, for even short periods, can be reduced up to 60 percent. Caterpillar (2020) cites excessive idle time as jeopardizing component life, accelerating wear of Tier 4 technologies (emissions treatment components), requiring unnecessary fluid and filter changes, burning through warranty hours and sacrificing resale value. EIRS technologies are being increasingly employed.

The implicit assumption in conventional machine rate calculations is that depreciation never stops, regardless if the machine is operating or not. To account for this in the current machine rate calculation method, the depreciation per productive hour is increased to account for the non-productive time. This effectively says that a machine with a utilization rate of 50% wears out in the same calendar time as a machine with a utilization rate of 100%. Taken to the extreme, a machine with a utilization rate of 1% wears out in the same calendar time as a machine with a utilization rate of 100%.

For machines with high capital attachments, such as heads on processors and cutting/processing heads on feller-bunchers, Ackerman et al. (2014) suggest a separate machine rate calculation for these attachments as they may be replaced on a different cycle as compared to the carrier. In these cases, even if the engine on the carrier is operating during non-productive time, the hydraulic pumps, motors, rollers, cutting chains, and knives of the attachment are not operating. Thus, even during non-productive times, wear is not occurring on the attachment, regardless of the operating mode of the carrier.

Machine rate models represent machine useful or economical equipment life in terms of years (Brinker et al. 2002, Miyata 1980, Ackerman 2014, Bilek 2009), though they note that machine rates are also inherently affected by other factors such as total hours of operation. The Food and Agricultural Organization (FAO) of the United Nations provides guidance on the calculation of machine rates noting that the economic life of agricultural equipment is generally measured in terms of hours and not years (FAO 2020). This logic is further supported by the Caterpillar performance handbook, which indicates that the total number of actual operation hours on a machine along with the ownership period is a key factor in determining operating and owning costs (CAT 2017). Many sectors estimate remaining value (RV) of equipment (a proxy for depreciation and equipment life) based largely on the independent variables of equipment age and hourly usage (Wu and Perry 2004, Cheng 2018). Malinen et al. (2015) found that both age and usage had a similar explanatory value in determining resale price of harvesters and forwarders with older machines showing even higher dependence on age. Other studies suggest age maybe the more important factor (Spinelli 2011). Cwiertnia et al. (2014) reduce economic equipment life by a hypothetically defined functional relationshiop with useful operating hours. Overall, the importance of usage on equipment life and residual value is an established reality.

1.2 Equipment Repair & Maintenance Cost versus Utilization Rate

Machine components are generally scheduled for rebuilds or replacement on an hourly basis of running time. The machine rate models permit the use of experienced or projected repair and maintenance costs, but commonly rules of thumb tie equipment repair and maintenance costs ($/hr) to the rate of depreciation of the equipment ($/hr), e.g., Warren (1977) cited by Miyata (1980), Brinker et al. (2002). The logic is that equipment depreciation is to represent the rate at which the equipment life is being used, so the faster the equipment life is being used, the more frequent the need for repair and maintenance.

However, machine rate models (Brinker et al. 2002, Ackerman et al. 2014) take this a step further and calculate the total repair and maintenance cost that would have occurred if the machine had been operated at 100% utilization and divide that annual cost by the productive hours. The result is that a machine with a 50% utilization rate has the same total projected annual maintenance cost as a machine with a 100% utilization rate. Expressed on a productive hour basis, the machine operated with 50% utilization has a repair and maintenance cost that is twice as high per productive hour as compared to the machine with the 100% utilization rate.

1.3 Fuel Consumption and Wear Rate

Table 2 from Brinker et al. (2002) shows that fuel and oil consumption is only based on productive machine hours. This implies that either the machine is not operating during non-productive time, or perhaps the fuel and oil consumption is assumed negligible during non-productive hours. If the machine is not operating, then wear during non-productive hours is not being incurred. While this approach makes sense, the current machine rate methods do not accurately account for the idea we suggested: equipment life should be increased with decrease of overall machine usage and utilization rates.

Table 2 Traditional machine rate worksheet (Brinker et al. 2002)

Machine Description: ________________	
1. Input Data	
Purchase Price, P	$ ________
Machine Horsepower rating, hp	________ hp
Machine life, n	________ yrs
Salvage value, percent of purchase price, rv %	________ %
Utilization rate, ut %	________ %
Repair and maintenance, percent of depreciation, rm %	________ %
Interest rate, in %	________ %
Insurance and tax rate, it %	________ %
Fuel consumption rate, fcr	________ gal/hp-hr
Fuel cost, fog	$ ________ per gal
Lube and oil, percent of fuel cost, lo %	________%
Operator wage and benefit rate, WB	$ ________ hr
Scheduled machine hours, SMH	________ hrs/yr
2. Calculations	
Salvage value, *S = P*rv %*	$ ________
Annual depreciation, *AD = (P – S)/n*	$ ________
Annual yearly investment *AYI = (((P-S)*(n+1))/(2*n))+S*	$ ________
Productive machine hours *PMH = SMH * ut %*	________ hrs/yr
3. Ownership costs	
Interest cost, *IN = in %*AYI*	$ ________ yr
Insurance and tax cost, *IT = it %*AYI*	$ ________ yr
Yearly ownership cost, *YF$ = AD+IN+IT*	$ ________ yr
Ownership cost per SMH *F$SMH = YF$/SMH*	$ ________ hr
Ownership cost per PMH *F$PMH = YF$/PMH*	$ ________ hr
4. Operating costs	
Fuel cost, *F = hp*fcr*fog*	$ ________ hr
Lube cost, *L = F*lo %*	$ ________ hr
Repair and Maintenance cost *RM = AD*rm %/PMH*	$ ________ hr
Operator labor and benefit cost, *WB/ut %*	$ ________ hr
Operator cost per PMH *V$PMH = F+L+RM+(WB/ut %)*	$ ________ hr
Operator cost per SMH, *V$SMH = V$PMH*ut %)*	$ ________ hr
5. Total machine costs	
Total cost per SMH *T$SMH = F$SMH + V$SMH*	$ ________ hr
Total cost per PMH *T$PMH = F$PMH + V$PMH*	$ ________ hr

2. Modified methods for Machine Rate Calculations

2.1 Adjusting Equipment Life for Utilization

For both the machine rate method and the discounted cash flow method, the most straightforward method to adjust for non-productive time is to adjust the equipment life, while retaining all other rules of the current Miyata-Brinker-Ackerman methodology. For example, if the equipment life under the scheduled hours per year was 5 years, and if the utilization rate is 70%, the adjusted equipment life is 5/.7=7.2 years. If the utilization rate was 50%, the adjusted equipment life is 5/.5=10 years. This recognizes that the total operating machine hours (e.g. 10,000 hours) over the life of the machine is unchanged. Thus, the total number of years of machine life needs to be adjusted to reflect actual working hours of the machine. This approach supports the idea suggested by FAO and Caterpillar handbook that equipment life is measured in terms of actual machine operating (i.e. productive) hours. Of course, depending upon the source of non-productive hours, the adjusted life need not include the full effect of the non-productive hours. The analyst should consider the source of the non-productive hours carefully in deciding upon the appropriate adjusted life. For example, non-productive machine idle time can be even more severe on the engine than full engine operation (Fletcher 2018). In that case the analyst may want to exclude idling time from the extension of equipment life. A detailed example is provided below with results in Table 3.

2.2 Salvage Values

As discussed previously, from a residual value point of view, the salvage value for a machine is the discounted value of its remaining life at the time of disposal or selling of a machine. As such, you would think it should directly reflect its engine hours of usage. However, salvage value seems to have confounding factors not easily separated from the history of a machine. All engine hours are not the same. Engines and power trains operated under heavy loads likely wear at a different rate than engines and power trains at light loads. Also, salvage values are highly subject to adequate machine repair and maintenance. Sundberg and Svanqvist (1987) argued that fuel and oil consumption is not only an input but also represents all other cost items such as depreciation, repairs and maintenance. As such, fuel consumption measures the intensity of use, which adds an additional dimension to operating hours and equipment age in explaining salvage value. Thus, fuel and oil consumption could be considered as a proxy for depreciation, machine conditions, and efficiency in fuel and oil use.

Fortunately, salvage values are usually a less important part of the overall machine rate, compared to the effect of machine life on the machine rate. A sensitivity analysis demonstrates that assuming a lower salvage value, even zero, at the adjusted equipment life for utilization would not significantly change the machine rate.

2.3 Example of Modified Machine Rate Calculations

Consider a piece of equipment costing $500,000 to purchase, with an economic life of 10,000 hours, a combined cost of fuel and lubrication of $12/PMH, a repair and maintenance rate of 87.5% of hourly depreciation cost, the average of the skidder and feller-buncher from Table 1, a labor cost including fringe benefits of $40/SMH, interest rate of 8%, and a salvage value of 20% of the initial cost of the equipment. Insurance and taxes are not considered. If the scheduled machine hours are 2000 hours per year and the utilization rate was 100%, the equipment life in years would be 10,000/2000=5 years. Using the machine rate method of Miyata-Brinker-Ackerman, the hourly cost would be $140.60/PMH (or $140.60/SMH at a 100% U) (Table 3). We also provide the equivalent machine rate resulting from a discounted cash flow analysis to illustrate the traditional machine rate calculation and discounted cash flow methods give similar results for similar assumptions. Using discounted costs from the middle of the year, the hourly cost is $139.05/PMH (or $139.05/SMH at a 100% U).

For the same input, but assuming a utilization of 50% (1000 PMH per year), using the machine rate method of Miyata-Brinker-Ackerman, the hourly cost would be $269.20/PMH hour (Table 3) because the total productive hours over the five-year life was only 5000 hours (1000 hours per year x 5 years=5000 PMH of machine life). Using the discounted cost method, the hourly cost per productive hour is $266.10/PMH with similar assumptions. However, if the equipment life had been increased from 5 to 10 years (1000 hours per year x 10 years=10,000 PMH of machine life), as we suggest to recognize the non-productive time as not affecting equipment wear, then Miyata-Brinker-Ackerman would have yielded $192.60/PMH and the discounted cash flow method would be $192.06/PMH. This assumes that salvage value does not change under the extended life assumption. But, as mentioned

Table 3 Machine rate calculations under using Miyata-Brinker-Ackerman (M-B-A) and the proposed approach that uses the M-B-A approach but increases equipment life with assumption that depreciation and repair and maintenance do not occur during non-productive time. The proposed approach is shown for two salvage value assumptions

	M-B-A		Modified	
	Utilization (U), %			
	100	50	50	50
Equipment purchase price, $	500,000			
Equipment life, hours	10,000			
Equipment life, years	5	5	10	10
Salvage value, $	100,000	100,000	100,000	0
Depreciation (D), $/year	80,000	80,000	40,000	50,000
Interest, %	8			
Average annual investment, $/year	340,000	340,000	320,000	275,000
Scheduled Machine hours SMH/year	2000			
Productive Machine hours PMH/year	2000	1000	1000	1000
Depreciation, $/PMH	40	80	40	50
Interest on investment, $/PMH	13.6	27.2	25.6	22
Fuel and oils, $/PMH	12	12	12	12
Labor including benefits, $/PMH	40	80	80	80
Repair & maintenance $/PMH; 87.5 % of D	35	70	35	43.75
Total hourly cost, $/PMH	140.6	269.2	192.6	207.75

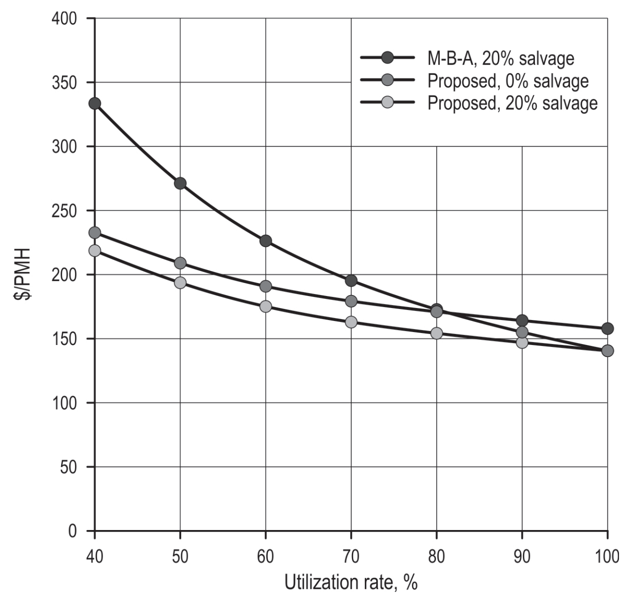

Fig. 1 Comparison of machine rate calculations using M-B-A and two variations of the proposed approach (0% and 20% salvage value). The equipment life is allowed to vary with productive hours and is calculated as 10,000/ productive hours varying from 12.5 years (40% utilization) to 5 years (100% utilization)

earlier, the results are not sensitive to salvage life. If salvage value under the extended life assumption was set to zero, the machine rate would be $207.75/PMH, an increase of 8%. Differences under the discounted cash flow method are even less ($198.7/PMH).

For the stated assumptions, the proposed approach (20% salvage) estimates machine hourly costs to be 35% lower than the M-B-A method at 40% utilization approaching parity at 100% utilization. When the proposed approach (0% salvage) is used, hourly machine costs are estimated to be 30% lower at 40% utilization, reach parity at 80% utilization and exceed M-B-A estimations by 12% at 100% utilization (Fig. 1).

3. Discussion and Conclusions

Although high equipment utilization is a highly desirable management goal, overstating the costs of nonproductive time can lead to incorrect conclusions regarding equipment management strategies. The current method of calculating machine costs that infer equipment wear continues at the same rate during nonproductive hours as during productive hours overstates the cost of non-productive time. The simple procedure of adjusting equipment life suggested in this paper, more accurately estimates machine rates in situations where the machine wear does not occur during non-productive time. Depending upon the source of non-productive hours, the adjusted life need not include the full effect of the non-productive hours. Our discussion and examples have been drawn from new machines. We expect that the same methodology would apply to used machines. Estimating salvage value for the adjusted life is a challenge, but even under assumptions of zero equipment salvage value, the errors in the machine rate calculation are low as compared to errors embedded in current machine rate cost estimates. The approach suggested in this paper is not the only approach to address non-productive time. Zamora-Cristales et al. (2015) differentiated between standing cost and operating cost for trucks and grinders in a decision support model using simulation and mathematical programing. However, the approach in this paper does permit a widely used costing methodology to be adjusted with only a simple change in equipment life. We hope that this paper prompts additional thought and discussion about equipment costing.

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Authors' addresses:

Prof. John Sessions, PhD
e-mail: john.sessions@oregonstate.edu
Oregon state University
College of Forestry
Corvallis OR 97331-5704
USA

Michael Berry, PhD *
e-mail: berry.michaeld@gmail.com
University of the Sunshine Coast
90 Sippy Downs Dr
Sippy Downs QLD 4556
AUSTRALIA

Prof. Han-Sup Han, PhD
e-mail: Han-Sup.Han@nau.edu
Northern Arizona University
Ecological Restoration Institute
Flagstaff AZ 86011
USA

* Corresponding author

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