

Effect of Data Collection Period Length on Marginal Cost Models for Heavy Equipment

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Equipment managers can apply either the cumulative cost or period cost based (PCB) methodology to estimate operating costs of heavy equipment, both of which rely on historical data. Cumulative cost methodology requires data to be available over the entire life of the machine, while period cost based methodology requires data available only over a period of time. A fleet of material handlers were studied to investigate the impact of period length when applying the PCB methodology. Cost data were collected and period lengths of ½, 1, 2 and 3 calendar years were analyzed to develop marginal repair and maintenance cost models, which were in turn used to develop total cost models. The period length must be sufficiently large for equipment to experience failure, realize repair, and mitigate the impact of the downtime associated with the repair. A minimum period length to produce a realistic total cost model was found to be 1 year. While period lengths of 1, 2, and 3 years resulted in reasonably accurate results, a tendency to overestimate repair and maintenance costs relative to the results based on a longer full dataset was noted. Estimates of economic life agreed with published estimates.

Key Words: Heavy Equipment, Equipment Economics, Economic Life, Equipment Management

Introduction

An essential part of many construction operations is the equipment utilized to perform required tasks and adequately managing the cost of equipment is an important ability of the construction industry. Though, it is important to estimate the cost of all equipment used in construction operations, this research is limited to heavy, off-road mobile equipment used in the construction, agricultural, mining, and other processing industries. Properly estimating operating costs, specifically repair parts and labor (RPL) costs is a difficult task and requires the availability of historical equipment cost data. Currently, equipment managers can apply either the cumulative cost or period cost based (PCB) methodology to estimate operating costs of heavy equipment, both of which rely on historical data. Cumulative cost methodology requires data to be available over the entire life of the machine, while period cost based methodology requires data available only over a period of time. A fleet of Liebherr material handlers were studied to investigate the minimum amount of historical data to be used within the PCB methodology. Cost data were collected and period lengths of 1/2, 1, 2 and 3 calendar years were analyzed to quantify the impact of limited period lengths on the forecasted repair costs. The cumulative cost minimization model was used to estimate the economic life of the material handlers based on the full and limited data sets.

Background

Equipment costs can be categorized as either owning or operating costs, which are characterized by their nature. Owning costs are the costs to have and keep a machine in the fleet and are experienced regardless of whether the machine is used to perform work. Owning costs include the loss in machine value as it ages; the costs of licenses, insurance, and taxes; and the cost of providing capital to acquire the machine (Nunnally, 2006). The majority of owning costs are experienced early in the life of the machine, and the average hourly owning costs decrease as the costs are distributed over machine hours accumulated with machine age (Vorster, 2009). Operating costs are experienced with every hour the machine is operated. Operating costs include the cost of preventive maintenance, wear parts, fuel, tires or tracks, and repair parts and labor (RPL) (Vorster, 1980). All operating costs except those for repair parts and labor, are easily estimated, and relatively constant throughout the life of the machine. The cost of RPL increases with age as the required repair actions increase in frequency and magnitude (Douglas, 1975). It is RPL costs that cause the average hourly operating cost to increase with machine age.

Total cost is the sum of owning and operating costs. Decreasing owning costs combined with increasing operating costs produce a minimum average hourly total cost and optimum age at which it is economically advantageous to replace the machine. This optimum age is known as the economic life, which is defined as the time period when the average hourly cost to date reaches a minimum (Vorster, 2009). As shown in Figure 1, the total average hourly cost decreases early in machine life due to a rapid loss in equipment value and increases later in life as operating costs continually increase. The minimum cost is the point at which if the machine is sold, the cumulative average hourly cost of the machine is minimized. Minimum cost is denoted in Figure 1 as the junction of dashed lines. Owning and operating the machine past this point will result in an increase in total average hourly cost due to continually increasing operating costs.

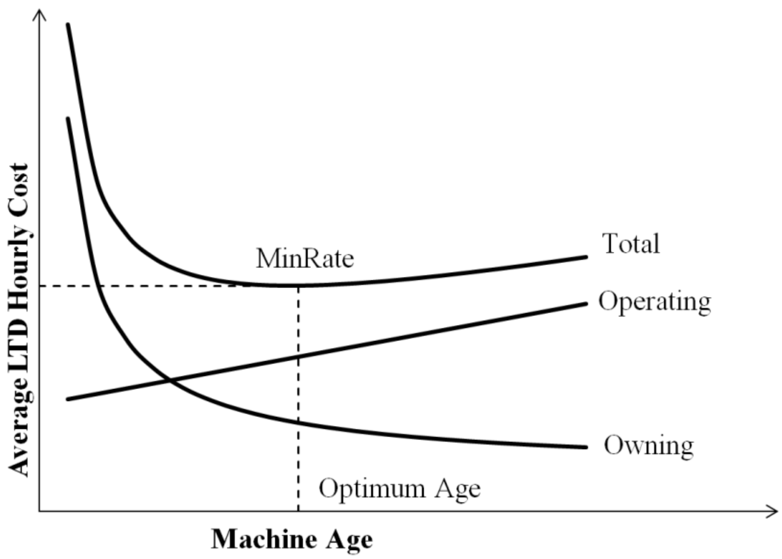

Figure 1: Cumulative Cost Minimization , adapted from (Mitchell, 1998)

An analysis to estimate economic life requires operating costs to be forecast. Mitchell (1998) analyzed field records or RPL costs for construction equipment and found that the relationship between cumulative RPL cost and machine age is best modeled as a second order polynomial, which is provided as Equation 1.

$y = Ax + Bx^2$ Equation 1

In Equation 1, y = cumulative RPL costs, x = cumulative machine age (hrs), A = essential expenditure coefficient, and B is the growth coefficient (Mitchell, 1998). Coefficients A and B are determined through regression analysis of machine age and cumulative RPL cost. This analysis based on cumulative cost data requires accurate records of RPL costs from the time of purchase to the current age. This is a serious limitation, as many companies lack complete cost data.

The period cost based (PCB) methodology to model RPL costs was introduced by Mitchell et al. (2011) to overcome the need for complete cumulative cost data. In the PCB methodology, the average hourly rate experienced by a machine over a fixed period of time is used to estimate the parameters (A and B coefficients) of the Mitchell curve. The PCB methodology is an application of the mean value theorem where the average hourly cost of RPL experienced over the period is equal to the marginal costs of RPL at a machine age contained within the period. The derivative of the Mitchell curve, provided as Equation 2, represents the marginal cost and is defined using the same A and B coefficients of the Mitchell curve.

$y' = 2Bx + A$ Equation 2

In Equation 2, y'= marginal cost ($/hr), x = machine age (hrs), and A and B are the coefficients of the Mitchell curve (Mitchell et al., 2011). It can be shown that for a second order polynomial, the slope of a line through two points (H_s and H_e) on the curve is equal to the slope of the line tangent to the curve at the point (H_m) midway between H_s and H_e. This concept is shown in Figure 2. The average hourly cost of RPL over a fixed time period is used as an estimate of the marginal cost of RPL at the average machine age over the period. Multiple estimates of marginal cost for varying machine ages are then used to estimate the A and B coefficients through linear regression analysis.

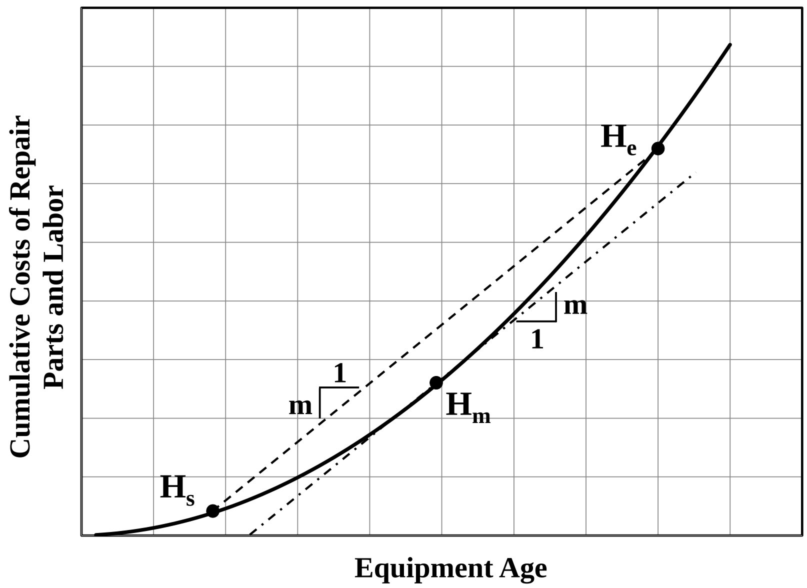

Figure 2: Concept of Period Cost Based Method (Mitchell et al., 2011)

While the principal advantage of PCB methodology is the ability to include machines in the analysis without cumulative cost data, the method is not without shortcomings. Mitchell et al. (2011) noted that the period cost data tended to be less stable than data gathered over the entire life of the machine. For this reason it was recommend that analysis be performed using as much data as is practical. However the amount of that data determined to be practical was not established. The impact of period length on the Mitchell curve is illustrated in Figure 3. The actual cost experienced by machines is a step function, where the true marginal cost of RPL is either zero or infinite. Details A and B illustrate how the timing of those expenditures relative to the period bounds impact the marginal cost calculation.

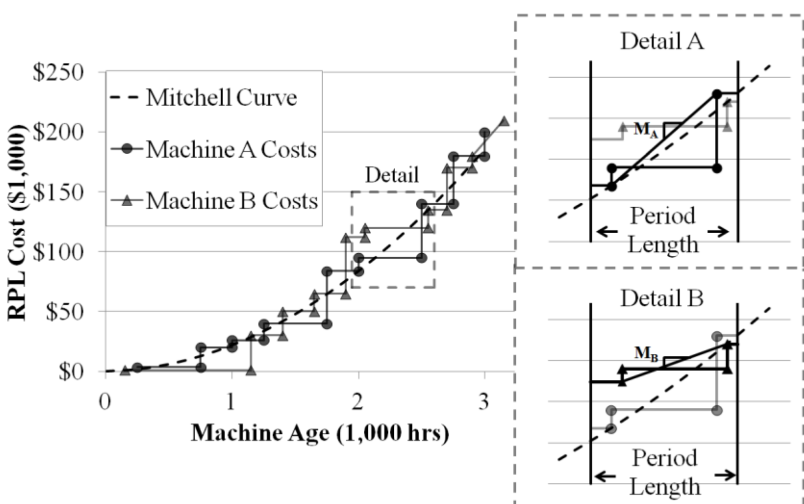

Figure 3: Effect of period length on marginal cost estimates

The costs experienced by a machine are determined by tracking individual expenditures and associating those expenditures with an estimate of machine age. This is denoted in Figure 3 by the vertical lines in the step functions. Expenditures are followed by a grace period where no RPL costs are experienced. This is denoted by the horizontal lines. The Mitchell curve is an approximation of this negative cash flow. Details A and B are simplistic representations of the manner in which marginal cost is calculated from expenditures. As shown in Detail A, during the collection period the machine has undergone a significant repair that results in the marginal cost exceeding the expected value for that machine during its costing period. The average hourly cost during the period (M_A) exceeds the slope of the tangent line to the Mitchell curve at the midpoint of the period length. Conversely, shown in Detail B, is a machine that only experienced maintenance during the collection period. Thus the marginal cost (M_B) is below what would be expected during the period. The average hourly cost (M_B) is less than the slope of the tangent line to the Mitchell curve at the midpoint of the period length. If the period lengths, shown in Details A and B, were larger, then the potential to capture significant expenditures and grace periods increases. Machine B experienced signification repairs just prior to the start of the period, and extending the period to include this major expenditure results in an estimate of marginal cost that is much closer to the expected value. Thus the impact of period length on marginal cost estimates must be understood to allow the PCB methodology to be appropriately applied to model and forecast the costs of RPL.

Methodology

A fleet of 48 Liebherr material handlers were studied to determine the impact of period length on the forecasted costs. The fleet consisted of machines with 30, 40, 60 and 80 ton operating weights and the age of machines extended to 20,000 hours. Of the 48 machines in the fleet, 21 machines were selected to produce a sample population representative of the fleet in terms of both the age and operating weight, as machine age and size influence the timing and magnitude of operating costs. The distribution of machines by age and size is provided in Table 1.

Table 1
Age and Size of Analyzed Equipment

Age (1,000 hours)	**Operating Weight**				
	30 ton	**40 ton**	**60 ton**	**80 ton**	**Total**
0-5	3	0	2	0	5
5-10	0	1	2	3	6
10-15	0	1	2	3	6
15-20	1	0	1	2	4
Total	4	2	7	8	21

Data regarding operating costs and equipment age were collected for each machine. The operating cost data consisted of charges for labor and parts associated with routine maintenance and periodic repairs. The magnitude of these costs was determined based on the invoiced amount. Following the recommendations of Mitchell et al. (2011), data was collected from multiple sources in an effort to develop a comprehensive cost record for each machine. Both electronic and hardcopy data sources were utilized in data collection efforts. The company specific accounting software provided equipment costs electronically, while archives of hardcopy paper invoices at both the operating yard were the machine is housed and at the location of the primary repair and service vendor were manually collected.

The period of time for which cost records were available varied for each machine and ranged from 3 years to 6 years. This full data set was modeled using the PCB methodology and the parameters (A and B coefficients) of the Mitchell curve were estimated. The Mitchell curve was developed and used to estimate the cumulative repair and maintenance costs curve and to develop a cumulative cost minimization model. The economic life and minimum average hourly rate were estimated to be 17,000 hours and $91.54 per hour, respectively.

To investigate the effect of period length, datasets of machine costs and age were developed for periods of ½, 1, 2, and 3 calendar years. Period lengths measured in calendar years were preferred over hours of use due to the high variability in machine utilization, particularly in short data collection periods. The PCB methodology was applied to each dataset to estimate the parameters of the Mitchell curve for the fleet, which was used to estimate the cumulative repair and maintenance costs and to develop a cumulative cost minimization model. The economic life and minimum average hourly rate were estimated for each period length.

Total cost models were developed to include estimates of owning costs and operating costs. Owning costs included an estimated annual cost of licenses, taxes, and insurance; the cost of capital as a fixed percentage of machine value; and an annual estimate of the loss in machine value based on a method similar to that presented by Lucko et al. (2006). Operating costs included the costs of repair and maintenance resulting from analysis of each period dataset and an estimated fixed hourly cost of fuel consumed.

Results

A period length of ½ year resulted in a repair and maintenance marginal cost model that differed substantially from the other studied periods and full data. The resulting marginal cost models are provided as Figure 4. The estimated Mitchell curve parameters, economic life, and minimum average hourly cost results are provided in Table 2. Costs experienced in the ½ year period were predominantly associated with maintenance actions as the period was too short for most machines to experience a repair action. Variance within the ½ year period marginal cost estimates was greatest, as some machines experienced repairs and realized marginal costs significantly larger than those machines only experiencing maintenance costs. As a result of minimal repair costs, the slope of the marginal cost model (twice the B coefficient of the Mitchell curve) was smallest and the intercept (A coefficient) was greatest relative to the other period lengths. The small rate of increase in estimated marginal cost of repair and maintenance resulted in the largest estimate of economic life and smallest estimated minimum average hourly cost.

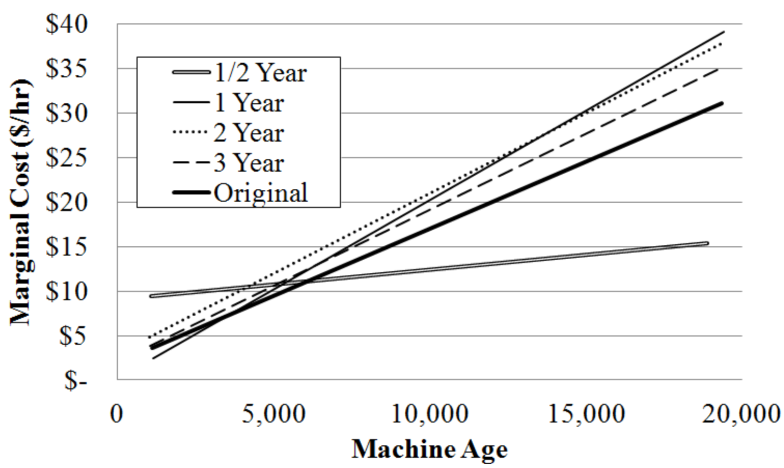

Figure 4: Marginal cost models

Table 2

Marginal cost model parameters and economic life

Period	A	B	R^2	Economic Life (hrs)	Minimum Average Hourly Cost ($/hr)
1/2 Year	9.087	0.00016	0.03	39,000	$ 84.44
1 Year	0.182	0.00100	0.31	14,000	$ 93.66
2 Years	2.942	0.00090	0.32	15,000	$ 94.93
3 Years	2.034	0.00085	0.43	16,000	$ 93.25
All data	1.912	0.00075	0.60	17,000	$ 91.54

The marginal cost models resulting from the 1, 2, and 3 year periods agreed well with the results from the full data. While there was not an apparent relationship between period length and the estimated A coefficient, the results did reflect an inversely proportional relationship between period length and the estimated B coefficient. Increased period length also resulted in marginal cost models that better fit the collected data, as evidenced by the increased R^2 values provided in Table 2. The results indicated that the B coefficient greatly influences the timing (machine age) at which the average hourly cost reaches a minimum value, while the magnitude of the minimum average hourly cost was influenced by other factors in addition to the costs of repairs and maintenance.

The marginal cost model parameters for each period length were used to estimate the cumulative repair and maintenance costs, which were then compared to the estimate resulting from the marginal cost model developed from the full data. The results are provided as Figure 5, in which the estimated cumulative cost of repair and maintenance for each period length is presented as the percentage of the cost estimated from the full data. Early in machine life the magnitude of the repair and maintenance costs are dominated by the value of the A coefficient and the B coefficient has a lesser influence. As the machine ages, the value of the B coefficient exhibits greater influence on the magnitude of costs due to the proportionality to the square of the machine age and the relative influence of the A coefficient is decreased. This is most evident in the results for the ½ year period in Figure 5. The large A coefficient caused extremely large estimated costs early in machine life, while the small B coefficient caused estimated costs later in machine life that were significantly less than all other models.

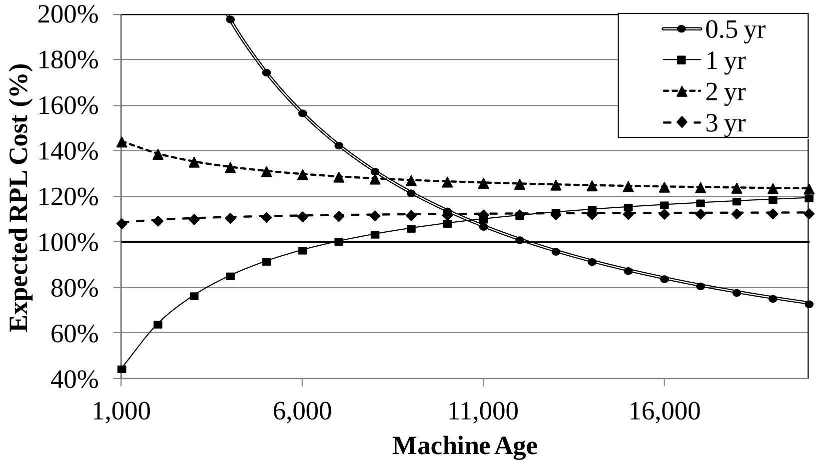

Figure 5: Comparison of estimated cumulative repair and maintenance cost

It is interesting to note from Figure 5, that while the estimated costs based on a 1 year data collection period were significantly lower early in machine life than estimates based on longer periods, the estimated costs for the 1, 2, and 3 year periods reasonably agreed at and beyond a machine age of approximately 8,000 hours. Published estimates of the length of machine life for similar machines range from 12,000 hours to 16,000 hours, depending on machine size and operating conditions (USACE, 2011). Thus, the estimates of repair and maintenance costs based on data collection periods 1 year and greater in length exhibited a reasonable level of agreement within the range of ages in which the economic life is expected to occur.

Conclusion

The PCB methodology is a viable alternative to the cumulative cost methodology for forecasting heavy equipment operating costs that vary with machine age. The requirement for cumulative cost data that limits the applicability of the cumulative cost methodology is overcome within the PCB methodology by the use of historical cost data from a limited period of time. The length of the period was found to significantly influence and be directly proportional to the reliability of the resulting marginal cost model. An increase in period length increased the opportunity to realize repair and maintenance actions, as well as the subsequent grace period resulting from the actions.

For the fleet of material handlers studied, the minimum period length to produce a realistic total cost model was 1 year. The period length must be sufficiently large for equipment to experience failure, realize repair, and mitigate the impact of the downtime associated with the repair. A period length of ½ year was not sufficient to consistently capture the costs of repair and maintenance actions and grace periods.

Period lengths greater than or equal to 1 year were sufficiently long for the machine to experience failure and realize the repair. While period lengths of 1, 2, and 3 years resulted in reasonable accurate results, a tendency to overestimate repair and maintenance costs relative to the results based on a longer full dataset was noted. The estimated B value decreased as the period length increased, which may be a result of more adequately capturing the full grace period resulting from repair actions. Furthermore, there was a clear correlation between period length and the goodness of fit for the marginal cost models.

Estimates of economic life resulting from total cost models developed using analysis results from period lengths of 1 year and greater agree with published estimates. For the studied material handlers, an increase of one year in the data collection period resulted in an increase in the estimated economic life of 1,000 hours, or approximately a half year of machine use. The estimated economic life is an estimate, or target, value and the actual cost performance of a machine should be monitored and evaluated as the machine age nears the economic life. Additionally, the slope of the total cost curve at the economic life is zero and varies gradually before and after the economic life. Thus, there exists a range of machine ages, termed the machine sweet spot, for which the average total hourly rate varies only slightly. A difference of 2,000 hours, or approximately one year of machine use, in the estimated economic life does not represent a significant change in the average total hourly cost of the machine.

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