Proof of Concept: Cumulative Cost Model for NCDOT Equipment Fleet Data

RP-2013-38

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The cumulative cost model can be used to analyze the economics of equipment fleets and estimate the timing and magnitude of economic life. The goal of this project was to assess existing cost data, develop cumulative cost models for four equipment classes, and compare the results with those from previously developed annual cost models. Cost and use data were collected for equipment classes 0201, 0205, 0314, and 0900 from the Business Warehouse and SAP databases. Year by year cumulative cost models were developed for each class based on the established sum of years' digits method to model owning costs and second order polynomial Mitchell curves to model operating costs. The resulting estimates of economic life were:
1. Class 0201 – 197,800 miles at an average life to date total rate of $0.38/mile
2. Class 0205 – 105,000 miles at an average life to date total rate of $1.32/mile
3. Class 0314 – 5,865 hours at an average life to date total rate of $29.43/hour
4. Class 0900 – 6,020 hours at an average life to date total rate of $52.27/hour
Operating cost data for the vast majority of individual machines confirmed the applicability of the second order Mitchell curve and the curves developed fit the cost data better than the exponential models previously fit to the annual cost data. The timing and magnitude of economic lives determined using both methodologies were very similar. The agreement validates the results of both methods and provides additional information that supports the notion that economic life should not be considered a singular point, but rather as a range of machine age.</td></tr>
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Executive Summary

Economic models for estimating the costs associated with owning and operating equipment can be developed and used to identify optimum economic decisions. The previous NCDOT Research Project 2012-07 *Fleet Management Performance Modeling* established the sum of years' digits method for modeling owning costs and modeled operating costs by applying the annual cost methodology. It was noted in that work that data for some equipment classes exhibited variability that masked the increase in operating cost required to predict economic life and recommended that the cumulative cost methodology be explored as a means to overcome the variability. The purpose of this project was to:

1. Evaluate the existing fleet cost data for use with cumulative cost modeling techniques
2. Develop cumulative cost economic models for four NCDOT equipment classes
3. Compare the economic models and economic life resulting from cumulative cost modeling with those from the previous annual cost modeling techniques

Data consisting of annual measures of machine age (in miles or hours) and life to date operating costs were collected from the Business Warehouse and SAP databases for equipment brought into the fleet between 2003 and 2008 for classes 0201, 0205, 0314, and 0900. Consumer Price Index (CPI) data was used to adjust operating costs and purchase price to current (2012) dollars. Operating costs were normalized by purchase price to calculate the cumulative cost index (CCI). The CCI data for the vast majority of individual machines demonstrated that machines experience operating costs over their life that is appropriately represented by the second order polynomial Mitchell curve. Typical least squares regression techniques applied to collective fleet data was not appropriate due to the observed relationship between the Mitchell curve A coefficient and machine age. Therefore, machines in the top quartile by age were used to estimate the Mitchell curve parameters and operating costs over machine age.

Cumulative cost economic models were developed and used to estimate the timing and magnitude of economic life for each class. The total cost models and the economic lives resulting from the models were very similar in terms of timing and magnitude to the results of the previous study based on the annual cost methodology. The agreement between the results validates the results of both methods and provides the Unit with additional information that supports the notion that economic life should not be considered a singular point, but rather as a range of machine age.

The resulting estimates of economic life were:

5. Class 0201 – 197,800 miles at an average life to date total rate of $0.38/mile
6. Class 0205 – 105,000 miles at an average life to date total rate of $1.32/mile
7. Class 0314 – 5,865 hours at an average life to date total rate of $29.43/hour
8. Class 0900 – 6,020 hours at an average life to date total rate of $52.27/hour

The existing fleet cost and use data maintained by NCDOT Fleet Management Unit is sufficient for developing cumulative cost models for several equipment classes. The data for the vast majority of individual machines demonstrated that machines experience operating costs over their life that are appropriately represented by the second order polynomial Mitchell curve used in the cumulative cost model. The Mitchell curves developed fit the operating cost data better than the exponential models fit to the annual cost data in the previous study.

The Mitchell curves developed to model operating costs should be used to establish annual budgets for individual machines. The timing and magnitude estimates of economic life determined from the cumulative cost economic models should be used, along with the results of the previous annual cost analyses, to establish targets for managing the average life to date total cost and life of equipment. Cumulative cost models should be developed for primary equipment classes (those classes with large numbers of equipment and representing large capital investments) and reassessed annually to include the most current data and to expand the number of machines analyzed. The large volumes of available data and targets for timing and magnitude of economic life provide an opportunity that should be seized upon to develop an early warning system to identify individual machines with poor economic performance.

1 Introduction

Economic models for estimating the costs associated with owning and operating equipment can be developed and used to identify optimum economic decisions. Owning costs are modeled largely based on the equipment purchase price and the depreciation schedule set by fleet managers. Operating costs can be modeled by applying either a cumulative cost or period cost modeling methodology. Period cost methods rely on data regarding costs experienced over a set period of time, which is often more readily available but does not allow for consideration of the effect of repair costs experienced prior or subsequent to the study period. Cumulative cost methods require data for costs experienced over the entire life of the machine, but does provide consideration of effects beyond a set time period.

1.1 Research Need

Economic models for NCDOT equipment have been previously developed using period (annual) cost data maintained in the SAP and Business Warehouse (BW) databases. For some equipment classes, variability within the NCDOT annual data masked the increase in operating cost required to predict economic life. Annual cost data is inherently noisy because:

1. Machine performance varies from year to year – A machine may incur high maintenance/repair costs and a corresponding low usage, which drives up the average annual cost rate (cost/mile or cost/hr) of the equipment. Yet in the following year, this same machine may continue to reap the benefits of repair and experience a low cost rate.

2. Data reflects all possible economic variability resulting from differences in equipment makes/models, operator skills, geographic locations, and applications – In some instances, the makes/models of older machines are no longer produced and the nominal horsepower of newer machines is greater. These changes and others may make it desirable to carefully select the data from which the economic models are developed.

Cost data maintained in the SAP and BW databases has not been evaluated for use with cumulative cost modeling methods. Where the necessary data is available, cumulative cost models can be compared to the previously developed period cost models.

1.2 Research Scope and Objectives

The purpose of this project was to address the following objectives:

1. Evaluate the existing fleet cost data for use with cumulative cost modeling techniques
2. Develop cumulative cost economic models for four NCDOT equipment classes
3. Compare the economic models and economic life resulting from cumulative cost modeling with those from the previous annual cost modeling techniques

The specific work tasks through which these objectives were achieved are:

Objective 1 – Study Classes and Data Evaluation (Task 1)

Four equipment classes were identified for inclusion in this study. Cost data within the SAP and BW databases for the four selected classes was evaluated with respect to availability and applicability for developing cumulative cost models.

Objective 2 – Model Development (Task 2)

Economic models to estimate the total cost of equipment were developed by applying cumulative cost modeling techniques to the existing data for the four classes identified in Task 1. Total cost included both owning costs and operating costs. The models were used to estimate the economic life of equipment in each class.

Objective 3 – Comparison of Models and Results (Tasks 3 and 4)

The cumulative cost models and resulting estimated economic life were compared to those previously developed using period cost methods to assess the level of agreement between the two methods.

2 Overview of the Cumulative Cost Model

Equipment managers are tasked with making difficult economic decisions regarding the purchase, operation, repair, and disposal of equipment. These decisions require managers to forecast costs, determine feasible economic lives for machines, and evaluate acquisition strategies. The cumulative cost model (CCM), first introduced by Vorster (1980), is a cost minimization model developed to aid the decision making process. The model provides an easily understood graphical representation of the complex equipment economics issue.

The CCM is structured with the ordinate (y-axis) representing cumulative costs, often referred to as the sum or net present value of all cost transactions to date. The abscissa (x-axis) represents equipment age, which can be in units of calendar years, cumulative use, or units of production. Cumulative costs are usually not time dependent and units of production are difficult to track, therefore, the preferred method of reporting age is in units of cumulative use (hours worked or miles driven). This can be easily recorded from meter readings on individual pieces of equipment in either hours or miles (Mitchell et al., 2011). The cumulative cost curve within the model appears to experience an exponential increase in cumulative cost as the age of the equipment increases. The curve intersects with the ordinate at the point representing the purchase price (P_p) of the equipment. Figure 2.1, adapted from (Vorster, 1980), provides the graphical representation of the CCM.

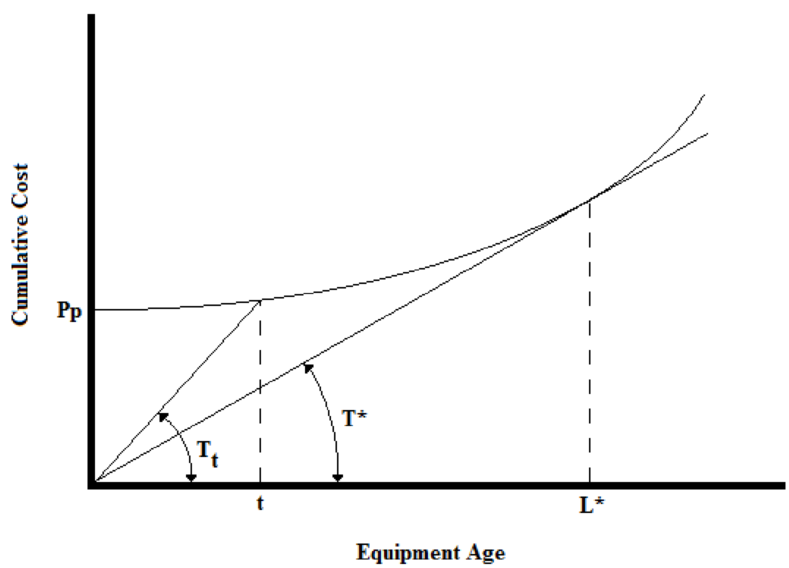

Figure 2.1: Cumulative Cost Model [adapted from Vorster (1980)]

The cumulative cost at any time *t* is the sum of the purchase price and operating costs experienced up to time *t*. The average cumulative cost for a machine at any time *t* is defined by the slope a line (T_t) drawn through the origin and the point on the curve at time *t*. This slope T_t is calculated by dividing cumulative cost by machine age *t*. Due to the increasing rate of operating cost accrual, there exists a minimum value T_t that defined as T* and occurs when the line through the origin is tangent to the cumulative cost curve, which is at a machine age L*. The economic life for a machine, defined as the period that ends when the average life to date rate reaches a minimum (Vorster, 2009), is L*.

Mitchell (1998) furthered the work by developing a mathematical model to describe the accrual of repair costs as a machine ages. Repair costs were the focus of the study because they are a significant portion of operating costs and cause the increasing rate of operating cost accrual as the machine ages. Field data from 260 machines in 17 different fleets was used to evaluate 19 equation forms. A second order polynomial, provided as Equation 1, was found most appropriate for predicting cumulative repair costs:

$$CC_{p\&l} = A{*}H_w^{\,2} + B{*}H_w \qquad (1)$$

where $CC_{p\&l}$ = cumulative cost of repair parts and labor from 0 hours to H_w hours;
H_w = life to date hours worked by the machine; and
A and *B* are coefficients.

An average coefficient of determination, R^2, for all fleets was found to be 0.72. While this value may appear too low for the model to adequately describe the phenomena, it was determined appropriate given the use of field data from a variety of operating conditions (Mitchell et al., 2011). In the model, the *A* coefficient represents the linear portion of growth in costs over time and the *B* coefficient represents how costs accumulate more quickly as the equipment ages.

While Mitchell found the second order polynomial appropriate to describe the accural of repair costs, it can also be used to model the more comprehensive operating costs. Vorster (2009) notes that costs associated with preventative maintenance, tires or tracks, wear parts, and fuel consumption are accrued at a predictable rate and and can be forecast in a linear fashion. Modeling these costs along with repair costs does alter the form of the model, but rather influences the coefficient values.

The cumulative cost methodolgy is best applied to data collected from machines of a similar type, size, and working under similar conditions. Nunnally (2000) notes that operating conditions have an impact on repair costs, and thus operating costs. The methodolgy does have limitations related to the availablity of quality data. Life to date (cumulative) cost data must be available for a sufficient number of machines. Machine ages should be be varying and it is best if some analyzed machines are at, or beyond, economic life.

3 Assessment of Existing Data

3.1 Data Collection

The data required for the cumulative cost methodology are machine age, measured as life to date use and life to date operating costs by for individual machines. Data was collected from the Production Business Warehouse and Equipment Rental Income SAP reports. The Equipment ID sets for the analyses were established by retrieving data with period from and to dates of December 31, 2012 per the procedure outlined in *NCDOT Report RP-2012-07.* Life to date data was then retrieved by leaving period from date blank and setting the period to date to the last date of the desired year. Data was collected from years 2003 to 2012 for machines brought into the fleet between the years 2003 and 2008 in equipment classes 0201, 0205, 0314, and 0900.

To ensure sufficient data, only equipment model years ranging from 2003 to 2008 were analyzed for each of the four classes. This resulted in up to 10 data points for 2003 models and 5 data points for 2008 models.

3.2 Data Validation

Data for each machine was validated to ensure the quality of the data and to confirm the applicability of the second order polynomial Mitchell curve used in the cumulative cost methodology to model operating costs. Of the 1,959 machines for which data was collected, data for only 3 machines was of suspect quality. Data for one machine indicated the machine worked more hours in a year than are in a year (8,760 hours), another accumulated cost over a period of years without associated use, and another accumulated use without associated cost. These machines were removed from the analysis.

Life to date operating cost was plotted against machine age for each piece of equipment in Excel and a second order polynomial trendline was added to determine how well the Mitchell curve fit the cost and use data. Figure 3.1 shows the cumulative operating costs as a function of usage for a 2003 class 0201 vehicle. The coefficient of determination (R^2) of 0.99 indicates that the data fit the proposed model very well. High coefficients of determination (greater than 0.90) were observed on a vast majority of the equipment across all four classes indicating that the available data appears to be valid for use in this analysis.

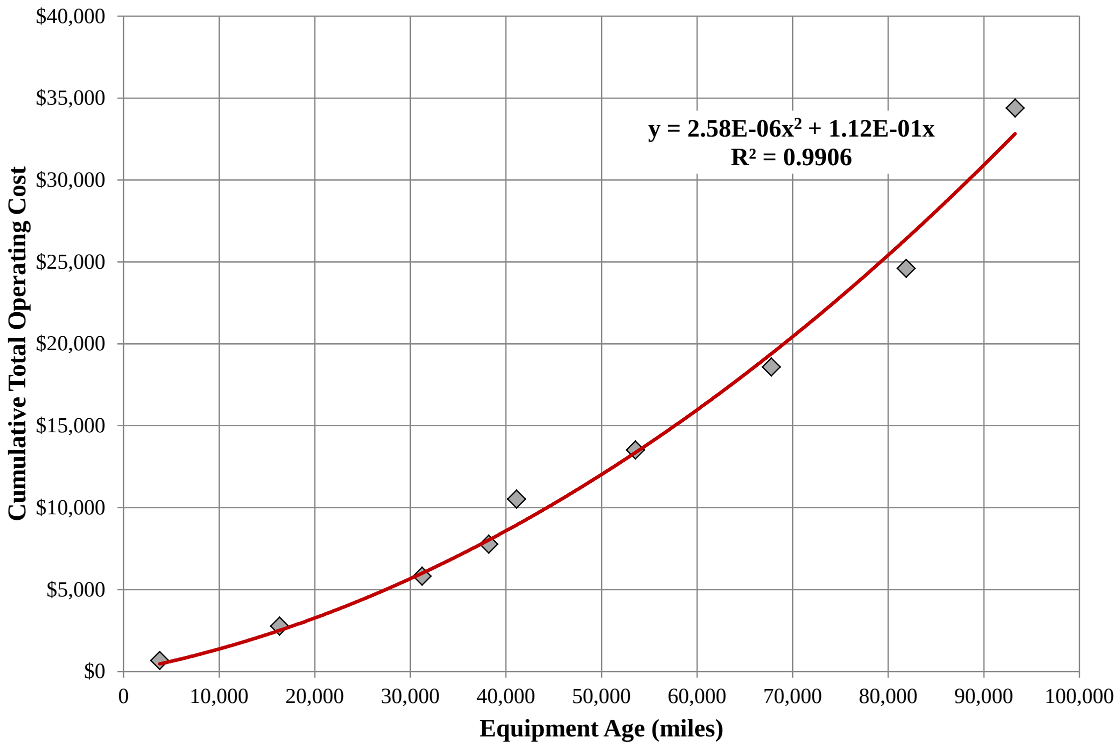

Figure 3.1: Typical Cumulative Costs for Individual NCDOT Equipment

3.3 Data Reduction

Prior to developing models for each equipment class, the operating cost and purchase price data was adjusted for inflation and the cumulative cost was normalized by the purchase price.

Adjustment for inflation was accomplished by using Consumer Price Index (CPI) data to adjust annual operating costs and purchase price to current (2012) dollars. The inflation adjusted annual costs were summed year-by-year to determine the inflation adjusted cumulative costs. The inflation adjusted cumulative costs were then divided by the inflation adjusted purchase price to yield a normalized cumulative cost index (CCI) for each piece of equipment. Figure 3.2 shows the normalized cumulative cost as a function of usage for the same class 0201 machine used for Figure 3.1. The normalized cumulative cost represents the cumulative cost as a fraction of purchase price. For the machine illustrated in Figure 3.2, cumulative operating cost was approximately 80 percent of the purchase price at a machine age of 50,000 miles.

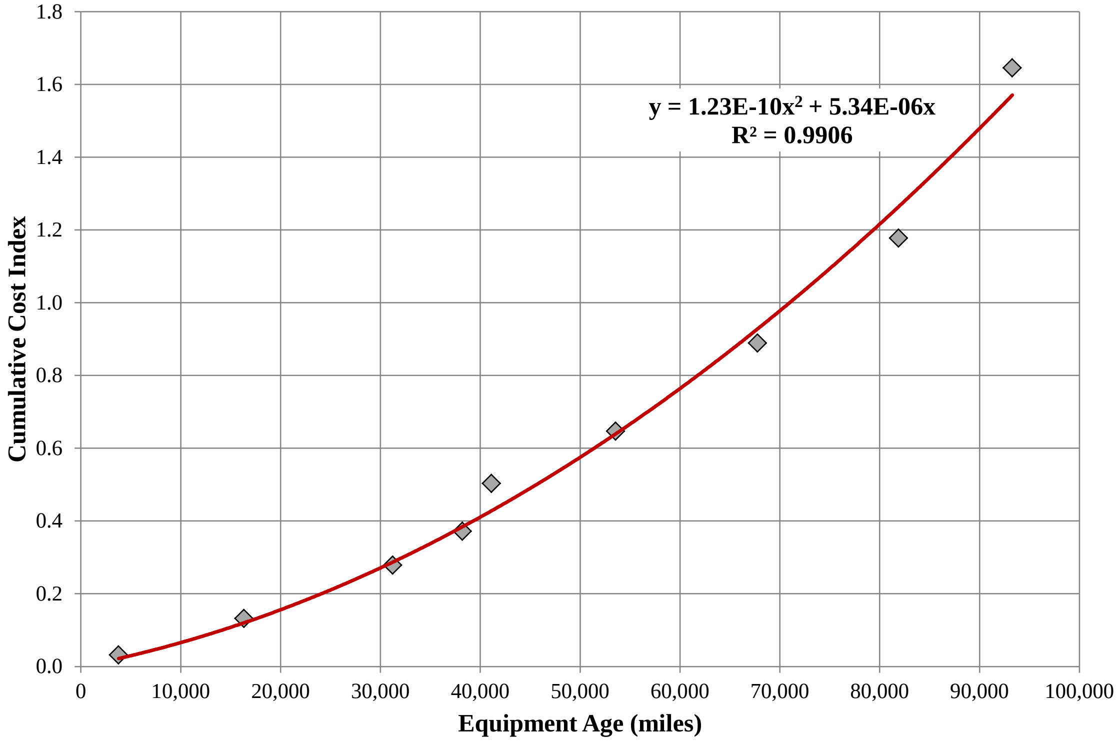

Figure 3.2: Typical Normalized Cumulative Cost for Individual NCDOT Equipment

4 Model Development

Economic models were developed for each equipment class to include both owning costs and operating costs. The owning cost portion of the model accounts for the decrease in machine value as it ages. The sum of years' digits method of depreciation was applied using the depreciation term and minimum resale value for each class established in the previous study. The operating cost portion of the model accounts for the costs of fuel, preventive maintenance, and repairs. The second-order polynomial Mitchell curve was used to estimate the operating costs for each equipment class.

4.1 Mitchell Curves

To define the Mitchell curve for each class, the typical method is to use least squares regression techniques to estimate the curve coefficients (A and B values) from pairs of equipment age (in hours or miles) and cumulative cost collected from the machine within an equipment class. This is the same methodology that was applied to annual data from individual machines and described in the previous section. Data pairs can be either a single point from each machine representing the current machine status or multiple data points from each machine typically representing the machine status at the end of each year.

For each of the 4 equipment classes, both sets of data pairs were used to develop the Mitchell curve and examples are provided as Figures 4.1 and 4.2. Mitchell curves for the remaining classes are provided in Appendix A. The estimated A and B coefficient values are provided in Table 4.1. The A coefficient values were negative for 3 equipment classes based on the 2012 data and 2 equipment classes based on the 2003 to 2012 data. Negative values indicate a decrease in the rate of change in costs as machines age, which prevents a point of minimum total cost and economic life. Negative A coefficient values were also counter to the positive values observed for the large majority of individual machines.

Table 4.1: Mitchell Curve Parameters for Equipment Classes

Equipment Class	2012 Data Pairs		2003 to 2012 Data Pairs	
	A Coefficient	**B Coefficient**	**A Coefficient**	**B Coefficient**
0201	$-1.06\text{x}10^{-11}$	$1.30\text{x}10^{-5}$	$-9.61\text{x}10^{-12}$	$1.18\text{x}10^{-5}$
0205	$-5.53\text{x}10^{-11}$	$2.30\text{x}10^{-5}$	$-1.29\text{x}10^{-11}$	$1.70\text{x}10^{-5}$
0314	$-1.08\text{x}10^{-8}$	$2.57\text{x}10^{-4}$	$3.66\text{x}10^{-10}$	$2.06\text{x}10^{-4}$
0900	$7.36\text{x}10^{-9}$	$1.76\text{x}10^{-4}$	$8.61\text{x}10^{-9}$	$1.60\text{x}10^{-4}$

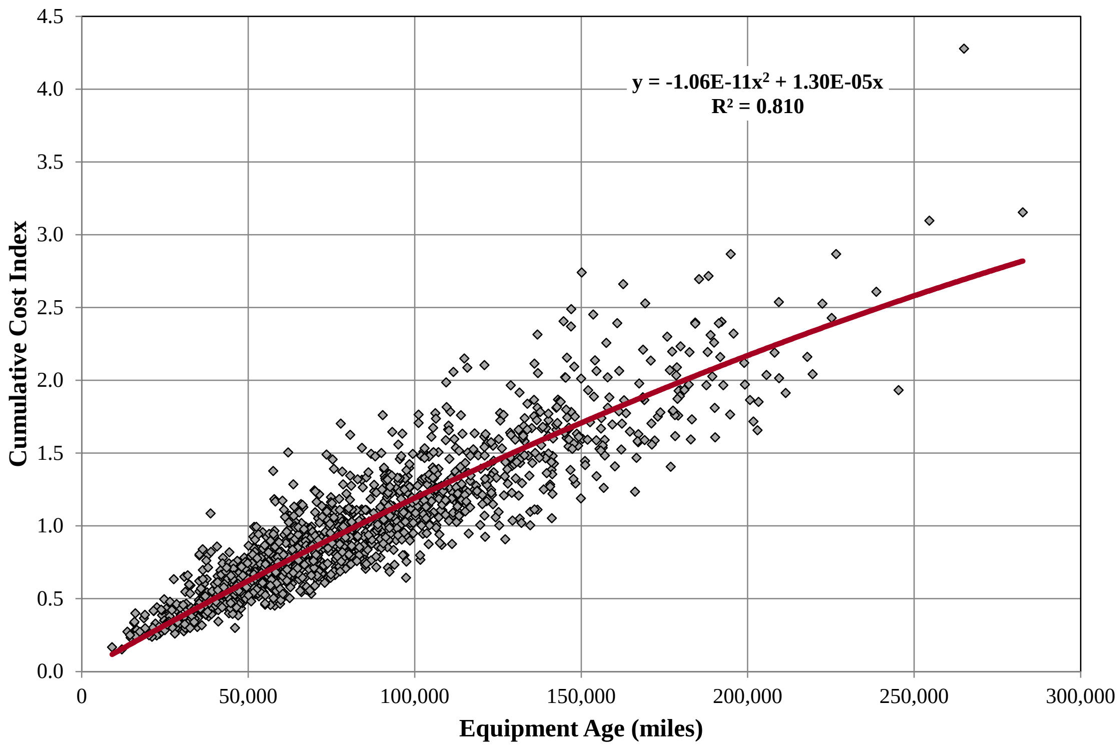

Figure 4.1: Cumulative Cost Index and Best Fit Curve for Class 0201 from 2012 Data

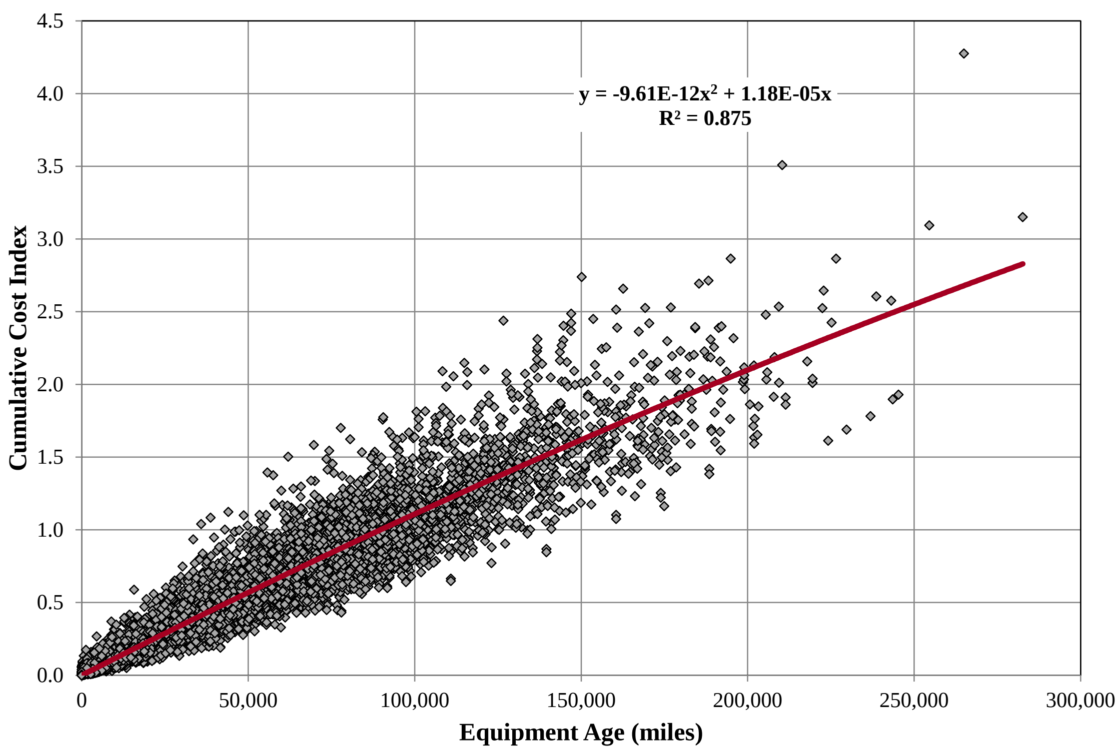

Figure 4.2: Cumulative Cost Index and Best Fit Curve for Class 0201 from 2003 to 2012 Data

A relatively large variability in cumulative cost index values was observed at young machine ages for each equipment class. This coupled with the large number of data points at young machine ages appears to strongly influence the value of the A coefficients, and thus the shape of the Mitchell curves. Investigation revealed a relationship between machine age and A coefficient values. Values of the A coefficient were highly variable at young machine ages and converge to a consistent value at older ages. This relationship was observed for each of the 4 equipment classes. Values of the B coefficient, while highly variable at very young machine ages, remained variable and did not converge to a common value. Examples of the relationships between the A and B coefficient values and machine age are provided as Figures 4.3 and 4.4, respectively. Similar figures for the remaining equipment classes are provided in Appendix B.

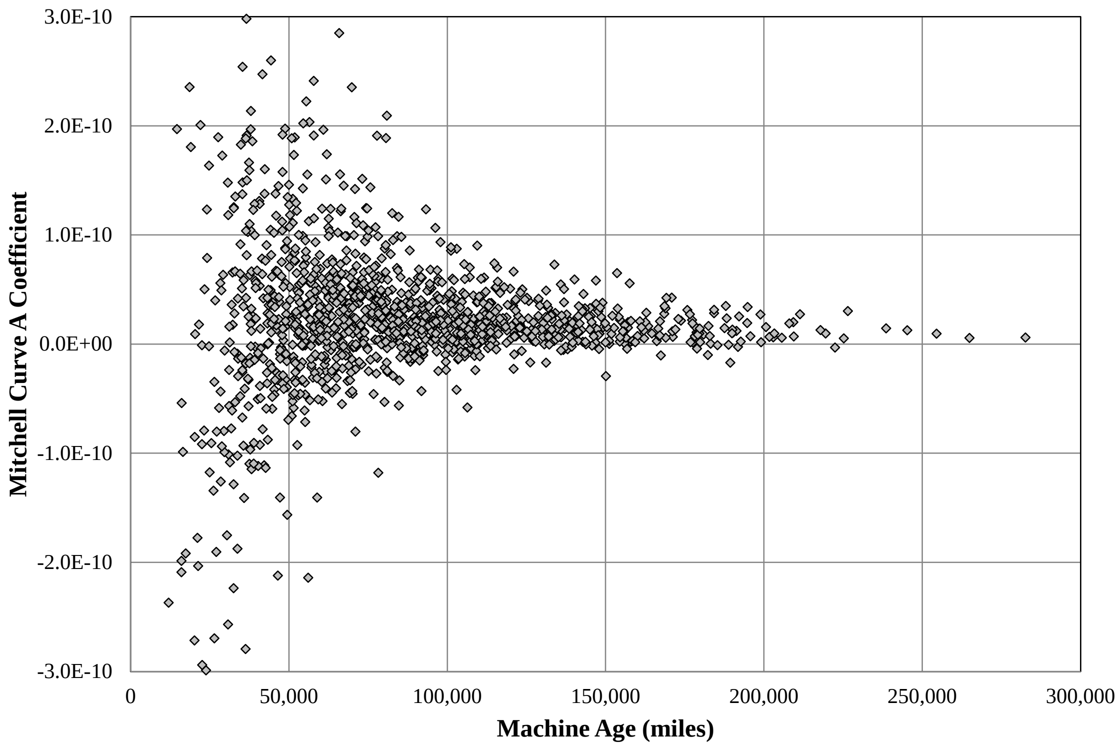

Figure 4.3: Relationship between A Coefficient Value and Machine Age for 0201 Class

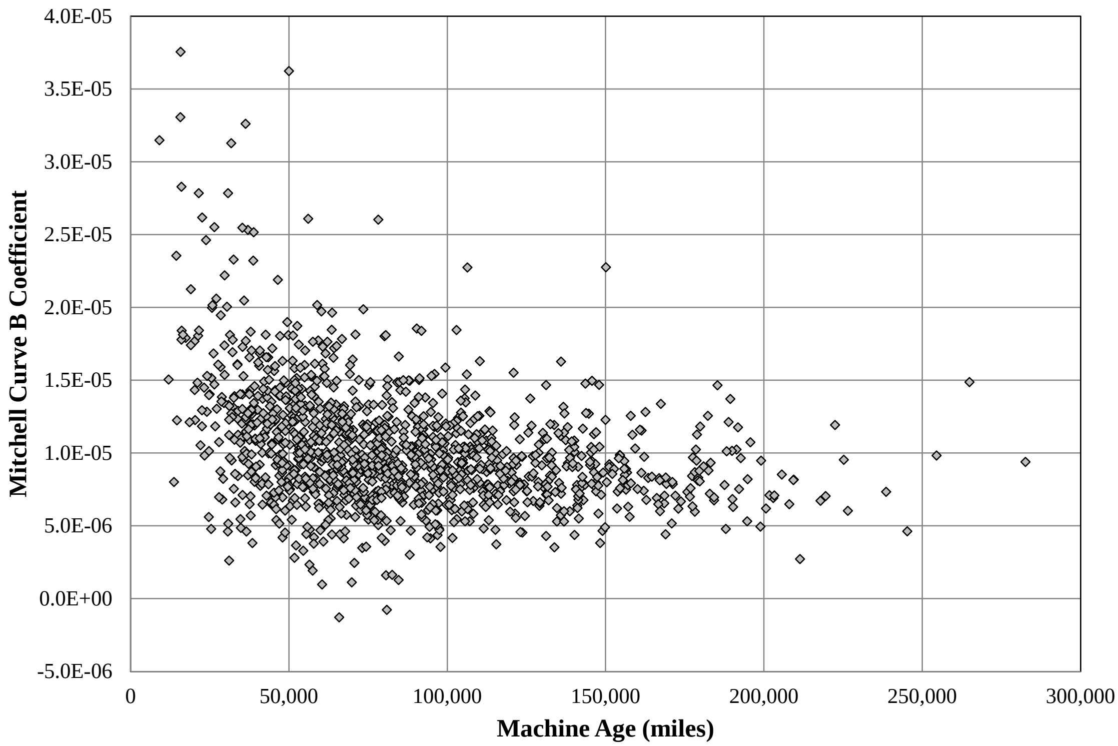

Figure 4.4: Relationship between B Coefficient Value and Machine Age for 0201 Class

It was apparent from the individual machine data that the second order polynomial Mitchell curve was applicable for modeling operating costs, but that least squares regression of equipment class data was not appropriate for estimating the coefficients due to the observed relationship between the A coefficient values and machine age. It was also apparent that relatively older machines exhibited much less variability in the A coefficient values. Therefore, the Mitchell curve coefficients for each equipment class were estimated using machines in the top quartile (25 percent) by age and having positive A coefficients. The few machines with negative A coefficients were not representative of the fleet and were neglected.

Using the 0201 equipment class as an example, the 75th percentile of machine age was 109,565 miles and there were 328 machines at or above this age. Of those 328, there were 298 machines with positive A coefficients. These 298 machines are represented in blue in Figure 4.5 and were used to develop the model the operating costs.

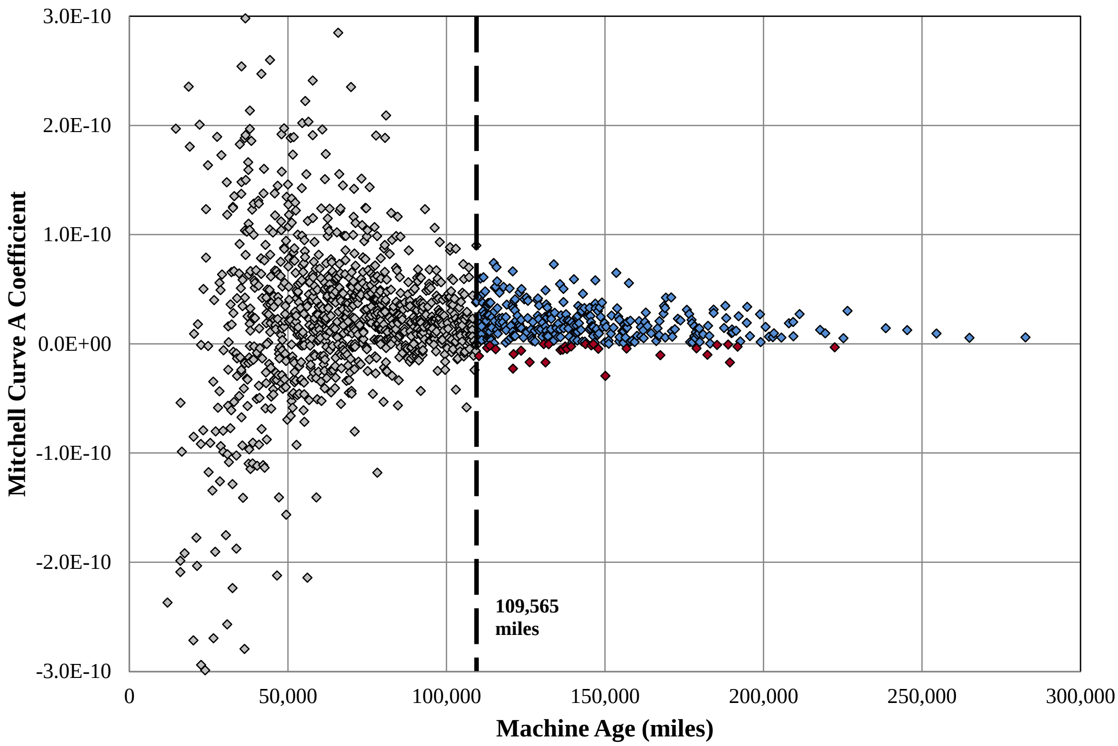

Figure 4.5: A Coefficient Values of 0201 Class with Top Quartile by Age Highlighted

To make an appropriate estimate of the A and B coefficients representing each equipment class, the distributions of coefficient values were investigated. The Kolmogorov-Smirnov (KS) test was applied at the 95 percent confidence level to evaluate whether the values were normally distributed. With the exception of the A coefficients for the 0201 equipment class, all coefficients were determined to be normally distributed. The most likely estimate for normally distributed data is the average. The average coefficient values for each equipment class are provided in Table 4.2 and were incorporated into the economic models for each equipment class.

Table 4.2: Mitchell Curve Coefficients by Equipment Class

Equipment Class	Average A Coefficient	Average B Coefficient
0201	2.04×10^{-11}	8.31×10^{-6}
0205	7.61×10^{-11}	8.46×10^{-6}
0314	2.25×10^{-8}	1.32×10^{-4}
0900	1.97×10^{-8}	1.05×10^{-4}

The cumulative cost data for the top quartile by machine age and the Mitchell curve for each equipment class are provided as Figures 4.6 to 4.9.

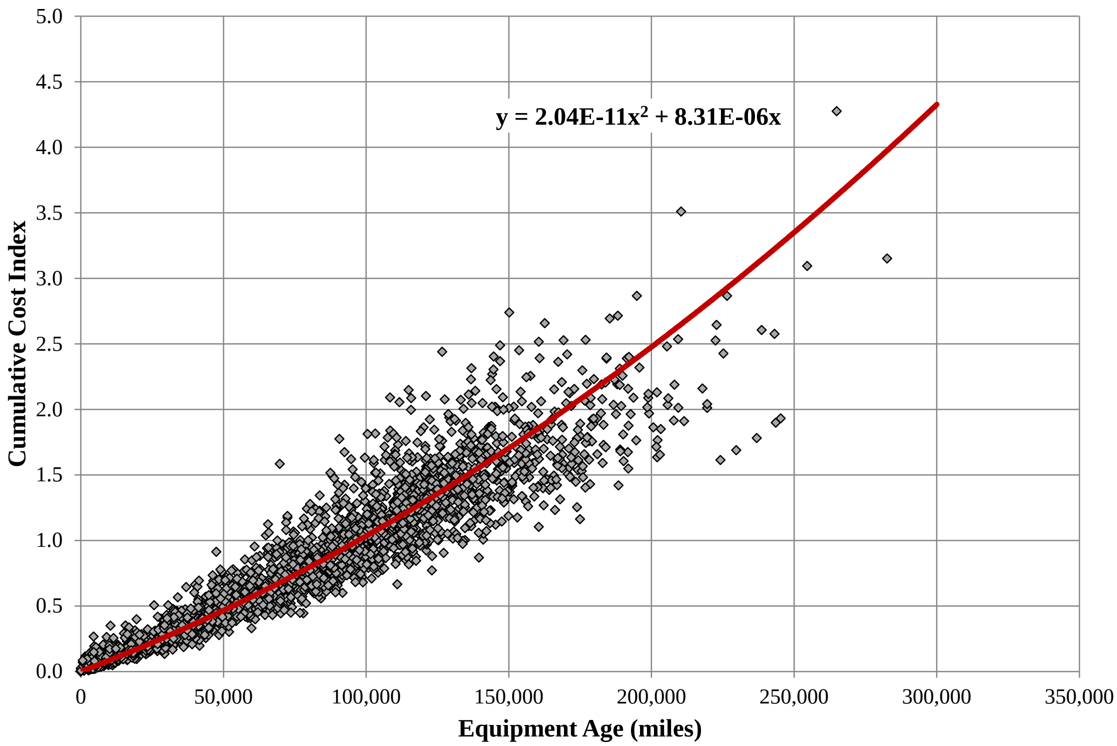

Figure 4.6: Cumulative Cost Index and Mitchell Curve for Top Quartile of Class 0201

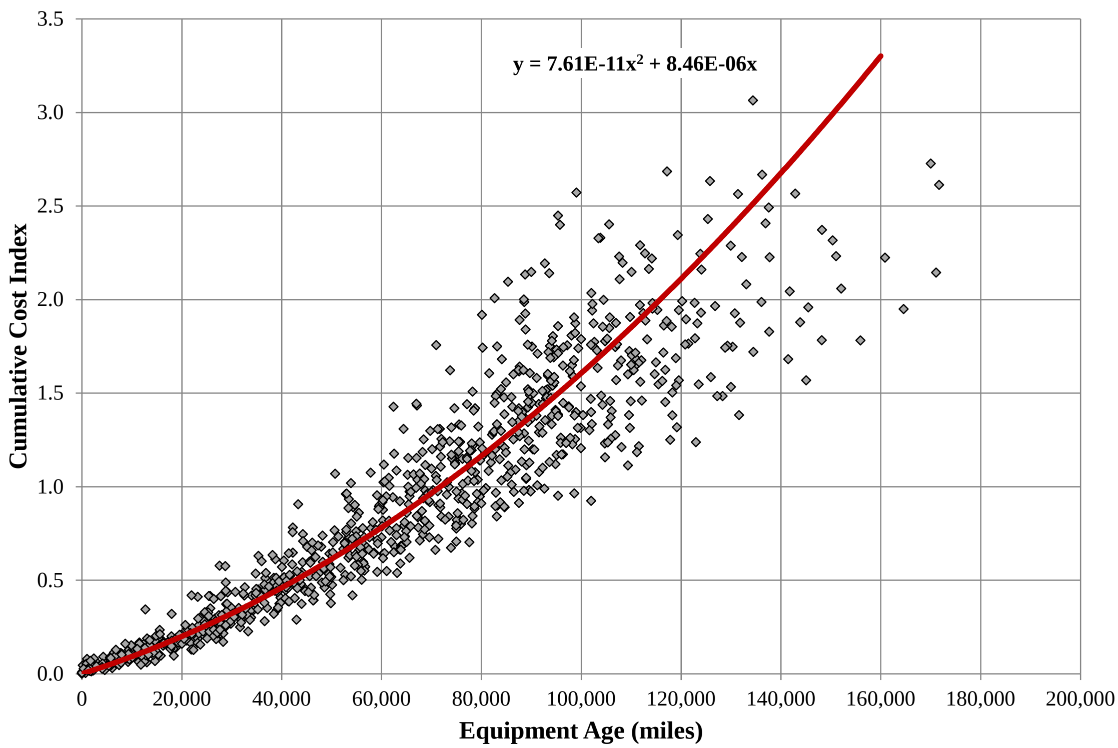

Figure 4.7: Cumulative Cost Index and Mitchell Curve for Top Quartile of Class 0205

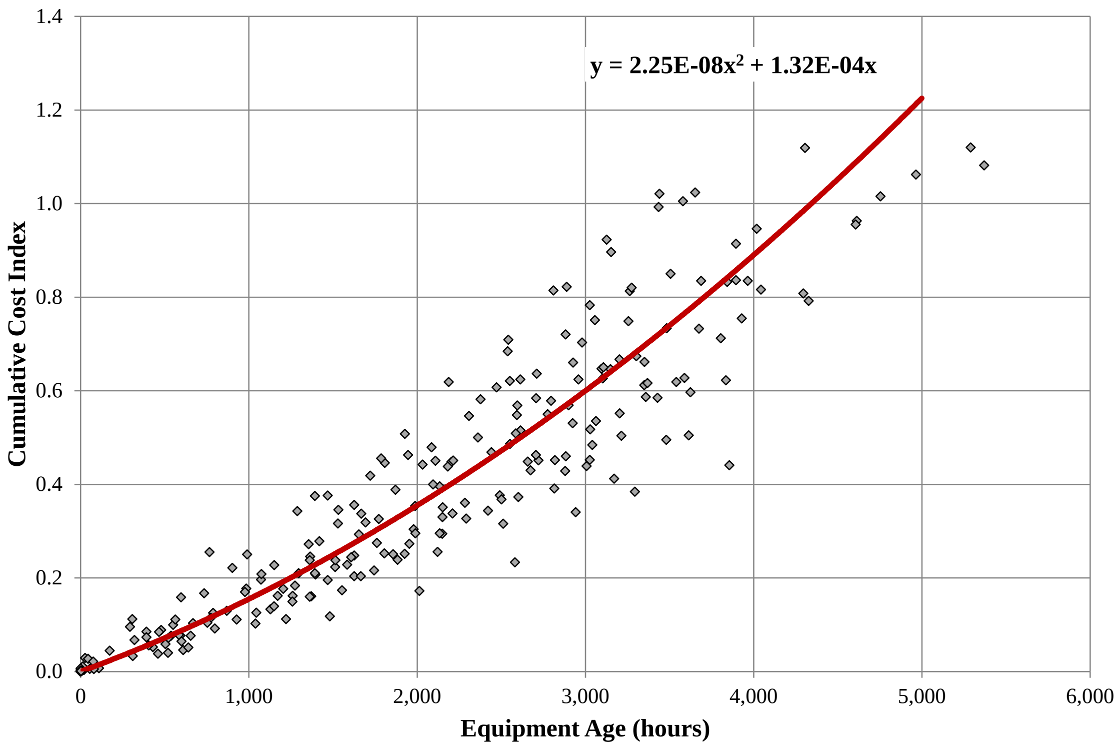

Figure 4.8: Cumulative Cost Index and Mitchell Curve for Top Quartile of Class 0314

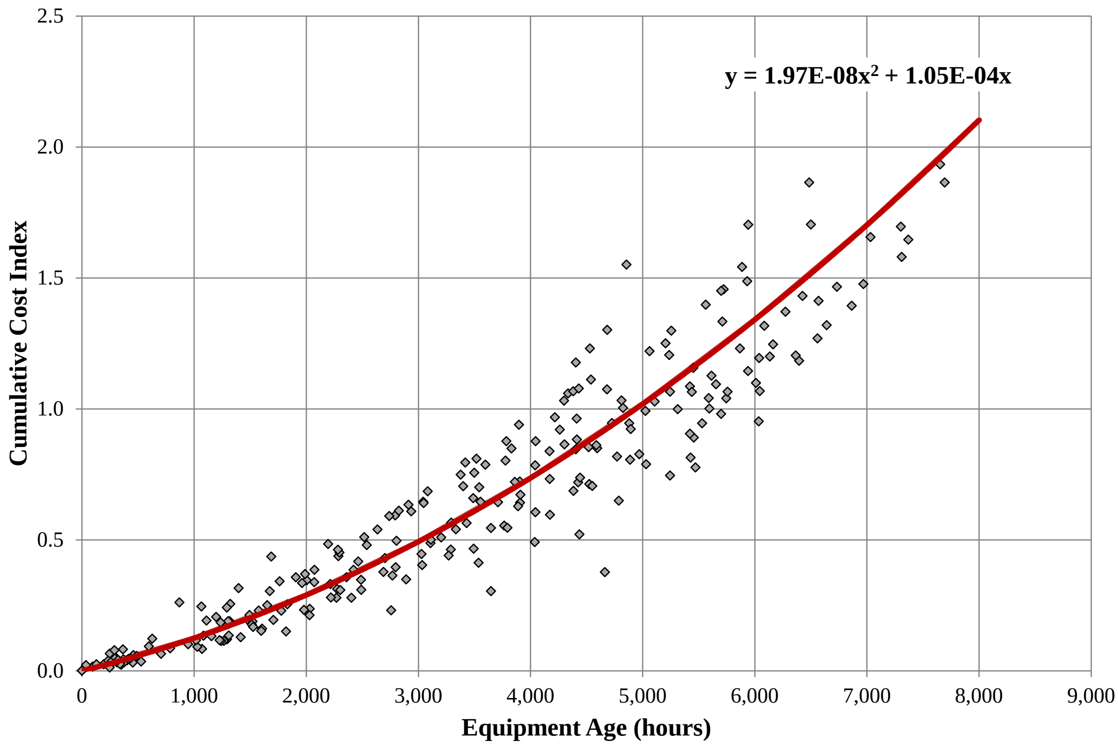

Figure 4.9: Cumulative Cost Index and Mitchell Curve for Top Quartile of Class 0900

4.2 Economic Models

An economic model was developed for each equipment class and used to estimate economic life, which is the point at which the average total rate reaches a minimum. It was necessary to estimate the purchase price and annual use for each equipment class to develop the economic models. Purchase price was estimated based on the prices paid for equipment in 2012. Annual use was estimated based on the average annual use of machines used to estimate the Mitchell curve coefficients for each equipment class. These estimated values are provided in Table 4.3.

Table 4.3: Purchase Price and Annual Use by Equipment Class

Equipment Class	Purchase Price	Annual Use
0201	$23,000	8,600 miles
0205	$55,000	7,000 miles
0314	$75,000	345 hours
0900	$150,000	430 hours

Owning costs is present in the model as the annual depreciation charge, and is calculated using the sum of years' digits method as previously described. In addition to the annual charge applied during the depreciation term, the average life to date rate for owning was calculated by dividing the life to date depreciation amount by the life to date machine age. The Mitchell curve was used to estimate the life to date operating cost at the end of each year in the model. Also, the annual operating cost and life to date operating rate was calculated. The owning and operating rates were summed to calculate the average life to date total rate for the equipment.

The economic models are provided as Tables 4.4 to 4.7 and Figures 4.10 to 4.13. The economic life, defined by the minimized average life to date total rate, is highlighted in each table.

Table 4.4: Class 0201 Economic Model of Cumulative Costs

Year	Age (mi)	Annual Depreciation Charge	End of Year Machine Value	Life to Date Owning Rate ($/mi)	Annual Operating Cost	Life to Date Operating Cost	Life to Date Operating Rate ($/mi)	Life to Date Total Rate ($/mi)
0			$ 23,000					
1	8,600	$ 6,133	$ 16,867	$ 0.71	$ 1,679	$ 1,679	$ 0.20	$ 0.91
2	17,200	$ 4,907	$ 11,960	$ 0.64	$ 1,748	$ 3,427	$ 0.20	$ 0.84
3	25,800	$ 3,680	$ 8,280	$ 0.57	$ 1,817	$ 5,245	$ 0.20	$ 0.77
4	34,400	$ 2,453	$ 5,827	$ 0.50	$ 1,887	$ 7,131	$ 0.21	$ 0.71
5	43,000	$ 1,227	$ 4,600	$ 0.43	$ 1,956	$ 9,087	$ 0.21	$ 0.64
6	51,600		$ 4,600	$ 0.36	$ 2,025	$ 11,113	$ 0.22	$ 0.57
7	60,200		$ 4,600	$ 0.31	$ 2,095	$ 13,207	$ 0.22	$ 0.53
8	68,800		$ 4,600	$ 0.27	$ 2,164	$ 15,371	$ 0.22	$ 0.49
9	77,400		$ 4,600	$ 0.24	$ 2,233	$ 17,605	$ 0.23	$ 0.47
10	86,000		$ 4,600	$ 0.21	$ 2,303	$ 19,907	$ 0.23	$ 0.45
11	94,600		$ 4,600	$ 0.19	$ 2,372	$ 22,279	$ 0.24	$ 0.43
12	103,200		$ 4,600	$ 0.18	$ 2,441	$ 24,720	$ 0.24	$ 0.42
13	111,800		$ 4,600	$ 0.16	$ 2,510	$ 27,231	$ 0.24	$ 0.41
14	120,400		$ 4,600	$ 0.15	$ 2,580	$ 29,810	$ 0.25	$ 0.40
15	129,000		$ 4,600	$ 0.14	$ 2,649	$ 32,459	$ 0.25	$ 0.39
16	137,600		$ 4,600	$ 0.13	$ 2,718	$ 35,178	$ 0.26	$ 0.39
17	146,200		$ 4,600	$ 0.13	$ 2,788	$ 37,965	$ 0.26	$ 0.39
18	154,800		$ 4,600	$ 0.12	$ 2,857	$ 40,822	$ 0.26	$ 0.38
19	163,400		$ 4,600	$ 0.11	$ 2,926	$ 43,749	$ 0.27	$ 0.38
20	172,000		$ 4,600	$ 0.11	$ 2,996	$ 46,744	$ 0.27	$ 0.38
21	180,600		$ 4,600	$ 0.10	$ 3,065	$ 49,809	$ 0.28	$ 0.38
22	189,200		$ 4,600	$ 0.10	$ 3,134	$ 52,943	$ 0.28	$ 0.3771
23	**197,800**		**$ 4,600**	**$ 0.09**	**$ 3,203**	**$ 56,147**	**$ 0.28**	**$ 0.3769**
24	206,400		$ 4,600	$ 0.09	$ 3,273	$ 59,419	$ 0.29	$ 0.3770
25	215,000		$ 4,600	$ 0.09	$ 3,342	$ 62,761	$ 0.29	$ 0.377
26	223,600		$ 4,600	$ 0.08	$ 3,411	$ 66,173	$ 0.30	$ 0.38
27	232,200		$ 4,600	$ 0.08	$ 3,481	$ 69,653	$ 0.30	$ 0.38
28	240,800		$ 4,600	$ 0.08	$ 3,550	$ 73,203	$ 0.30	$ 0.38
29	249,400		$ 4,600	$ 0.07	$ 3,619	$ 76,823	$ 0.31	$ 0.38
30	258,000		$ 4,600	$ 0.07	$ 3,689	$ 80,511	$ 0.31	$ 0.38

Note: Based on 8,600 miles per year; $23,000 purchase price; and 80 percent depreciation over 5 years

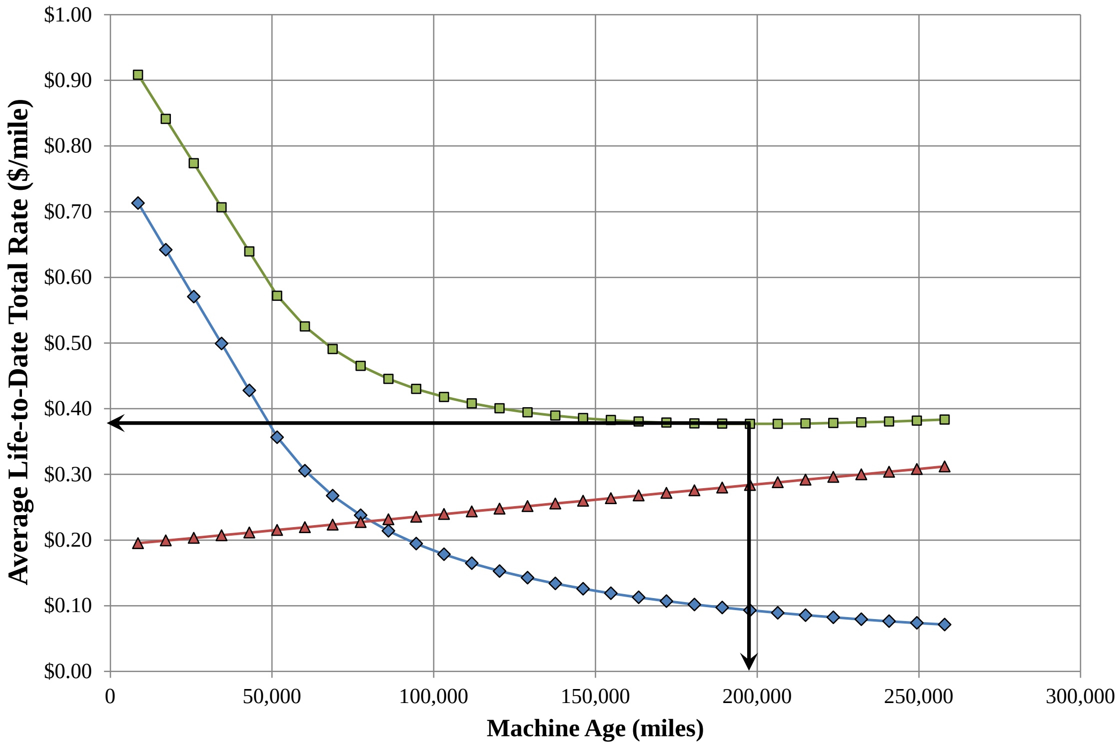

Figure 4.10: Class 0201 Graphical Economic Model of Cumulative Owning and Operating Costs

Table 4.5: Class 0205 Economic Model of Cumulative Costs

Year	Age (mi)	Annual Depreciation Charge	End of Year Machine Value	Life to Date Owning Rate ($/mi)	Annual Operating Cost	Life to Date Operating Cost	Life to Date Operating Rate ($/mi)	Life to Date Total Rate ($/mi)
0			$ 55,000					
1	7,000	$ 11,000	$ 44,000	$ 1.57	$ 3,461	$ 3,461	$ 0.49	$ 2.07
2	14,000	$ 9,429	$ 34,571	$ 1.46	$ 3,872	$ 7,333	$ 0.52	$ 1.98
3	21,000	$ 7,857	$ 26,714	$ 1.35	$ 4,282	$ 11,616	$ 0.55	$ 1.90
4	28,000	$ 6,286	$ 20,429	$ 1.23	$ 4,693	$ 16,308	$ 0.58	$ 1.82
5	35,000	$ 4,714	$ 15,714	$ 1.12	$ 5,103	$ 21,411	$ 0.61	$ 1.73
6	42,000	$ 3,143	$ 12,571	$ 1.01	$ 5,514	$ 26,925	$ 0.64	$ 1.65
7	49,000	$ 1,571	$ 11,000	$ 0.90	$ 5,924	$ 32,849	$ 0.67	$ 1.57
8	56,000		$ 11,000	$ 0.79	$ 6,334	$ 39,183	$ 0.70	$ 1.49
9	63,000		$ 11,000	$ 0.70	$ 6,745	$ 45,928	$ 0.73	$ 1.43
10	70,000		$ 11,000	$ 0.63	$ 7,155	$ 53,084	$ 0.76	$ 1.39
11	77,000		$ 11,000	$ 0.57	$ 7,566	$ 60,649	$ 0.79	$ 1.36
12	84,000		$ 11,000	$ 0.52	$ 7,976	$ 68,625	$ 0.82	$ 1.34
13	91,000		$ 11,000	$ 0.48	$ 8,387	$ 77,012	$ 0.85	$ 1.33
14	98,000		$ 11,000	$ 0.45	$ 8,797	$ 85,809	$ 0.88	$ 1.325
15	**105,000**		**$ 11,000**	**$ 0.42**	**$ 9,207**	**$ 95,017**	**$ 0.90**	**$ 1.324**
16	112,000		$ 11,000	$ 0.39	$ 9,618	$ 104,634	$ 0.93	$ 1.327
17	119,000		$ 11,000	$ 0.37	$ 10,028	$ 114,663	$ 0.96	$ 1.33
18	126,000		$ 11,000	$ 0.35	$ 10,439	$ 125,101	$ 0.99	$ 1.34
19	133,000		$ 11,000	$ 0.33	$ 10,849	$ 135,951	$ 1.02	$ 1.35
20	140,000		$ 11,000	$ 0.31	$ 11,260	$ 147,210	$ 1.05	$ 1.37

Note: Based on 7,000 miles per year; $55,000 purchase price; and 80 percent depreciation over 7 years

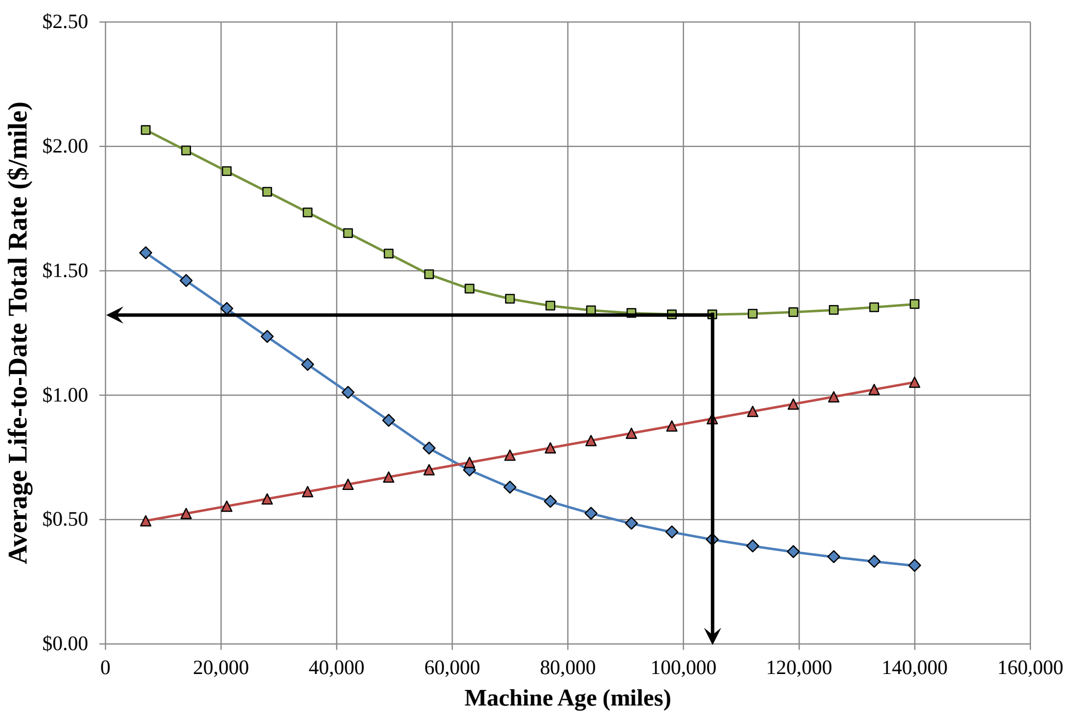

Figure 4.11: Class 0205 Graphical Economic Model of Cumulative Owning and Operating Costs

Table 4.6: Class 0314 Economic Model of Cumulative Costs

Year	Age (hrs)	Annual Depreciation Charge	End of Year Machine Value	Life to Date Owning Rate ($/mi)	Annual Operating Cost	Life to Date Operating Cost	Life to Date Operating Rate ($/hr)	Life to Date Total Rate ($/hr)
0			$75,000					
1	345	$14,063	$60,938	$40.76	$3,626	$3,626	$10.51	$51.27
2	690	$12,054	$48,884	$37.85	$4,029	$7,655	$11.09	$48.94
3	1,035	$10,045	$38,839	$34.94	$4,431	$12,086	$11.68	$46.62
4	1,380	$8,036	$30,804	$32.03	$4,834	$16,920	$12.26	$44.29
5	1,725	$6,027	$24,777	$29.11	$5,236	$22,156	$12.84	$41.96
6	2,070	$4,018	$20,759	$26.20	$5,638	$27,794	$13.43	$39.63
7	2,415	$2,009	$18,750	$23.29	$6,041	$33,835	$14.01	$37.30
8	2,760		$18,750	$20.38	$6,443	$40,278	$14.59	$34.97
9	3,105		$18,750	$18.12	$6,845	$47,123	$15.18	$33.29
10	3,450		$18,750	$16.30	$7,248	$54,371	$15.76	$32.06
11	3,795		$18,750	$14.82	$7,650	$62,021	$16.34	$31.16
12	4,140		$18,750	$13.59	$8,052	$70,073	$16.93	$30.51
13	4,485		$18,750	$12.54	$8,455	$78,528	$17.51	$30.05
14	4,830		$18,750	$11.65	$8,857	$87,386	$18.09	$29.74
15	5,175		$18,750	$10.87	$9,260	$96,645	$18.68	$29.54
16	5,520		$18,750	$10.19	$9,662	$106,307	$19.26	$29.45
17	**5,865**		**$18,750**	**$9.59**	**$10,064**	**$116,371**	**$19.84**	**$29.43**
18	6,210		$18,750	$9.06	$10,467	$126,838	$20.42	$29.48
19	6,555		$18,750	$8.58	$10,869	$137,707	$21.01	$29.59
20	6,900		$18,750	$8.15	$11,271	$148,978	$21.59	$29.74

Note: Based on 345 hours per year; $75,000 purchase price; and 75 percent depreciation over 7 years

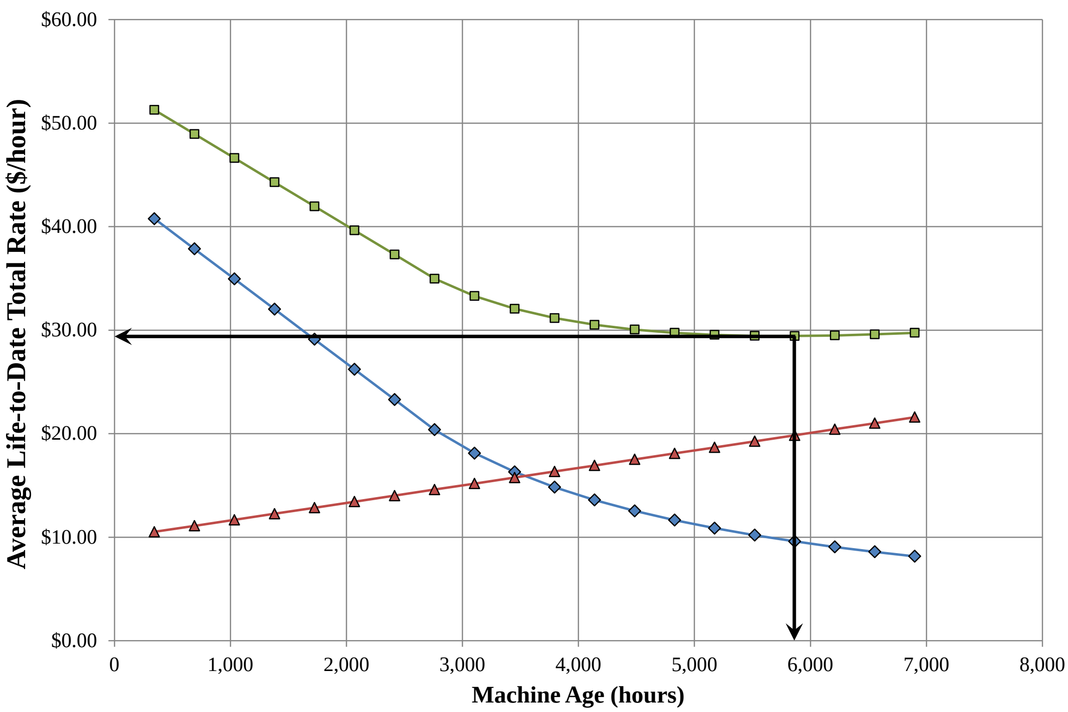

Figure 4.12: Class 0314 Graphical Economic Model of Cumulative Owning and Operating Costs

Table 4.7: Class 0900 Economic Model of Cumulative Costs

Year	Age (hrs)	Annual Depreciation Charge	End of Year Machine Value	Life to Date Owning Rate ($/mi)	Annual Operating Cost	Life to Date Operating Cost	Life to Date Operating Rate ($/hr)	Life to Date Total Rate ($/hr)
0			$150,000					
1	430	$22,500	$127,500	$52.33	$7,333	$7,333	$17.05	$69.38
2	860	$20,000	$107,500	$49.42	$8,427	$15,760	$18.33	$67.74
3	1,290	$17,500	$90,000	$46.51	$9,520	$25,280	$19.60	$66.11
4	1,720	$15,000	$75,000	$43.60	$10,614	$35,894	$20.87	$64.47
5	2,150	$12,500	$62,500	$40.70	$11,707	$47,601	$22.14	$62.84
6	2,580	$10,000	$52,500	$37.79	$12,800	$60,401	$23.41	$61.20
7	3,010	$7,500	$45,000	$34.88	$13,894	$74,295	$24.68	$59.57
8	3,440	$5,000	$40,000	$31.98	$14,987	$89,282	$25.95	$57.93
9	3,870	$2,500	$37,500	$29.07	$16,080	$105,362	$27.23	$56.30
10	4,300		$37,500	$26.16	$17,174	$122,536	$28.50	$54.66
11	4,730		$37,500	$23.78	$18,267	$140,803	$29.77	$53.55
12	5,160		$37,500	$21.80	$19,361	$160,164	$31.04	$52.84
13	5,590		$37,500	$20.13	$20,454	$180,618	$32.31	$52.44
14	**6,020**		**$37,500**	**$18.69**	**$21,547**	**$202,165**	**$33.58**	**$52.27**
15	6,450		$37,500	$17.44	$22,641	$224,805	$34.85	$52.30
16	6,880		$37,500	$16.35	$23,734	$248,539	$36.12	$52.48
17	7,310		$37,500	$15.39	$24,827	$273,367	$37.40	$52.79
18	7,740		$37,500	$14.53	$25,921	$299,288	$38.67	$53.20
19	8,170		$37,500	$13.77	$27,014	$326,302	$39.94	$53.71
20	8,600		$37,500	$13.08	$28,107	$354,409	$41.21	$54.29

Note: Based on 430 hours per year; $150,000 purchase price; and 75 percent depreciation over 9 years

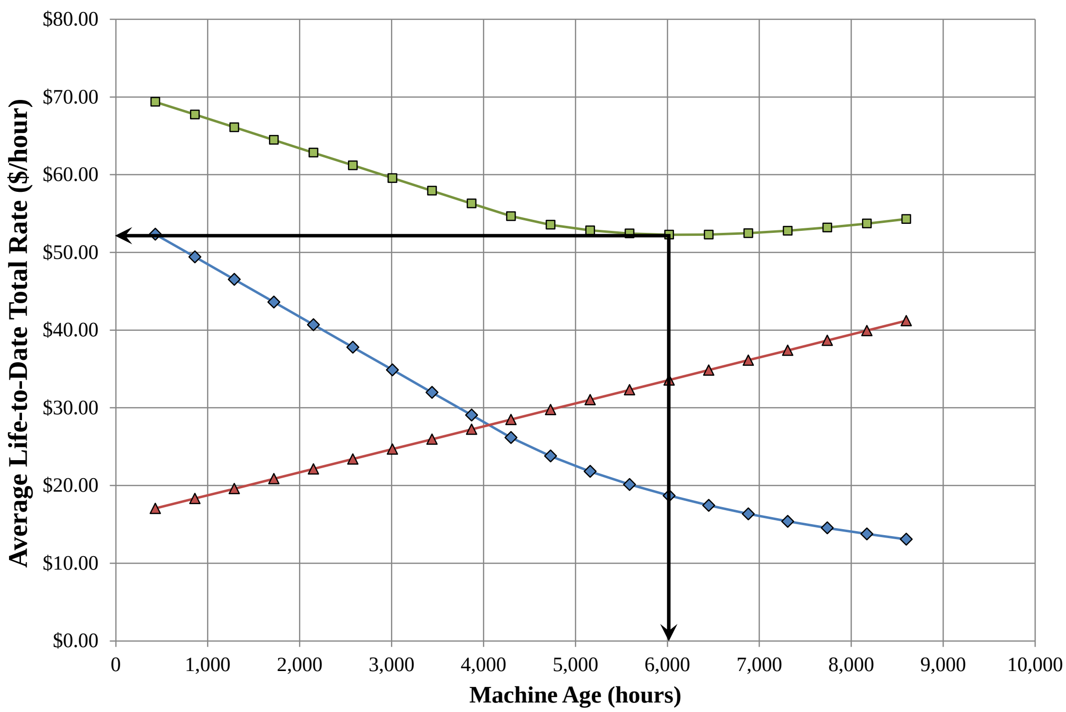

Figure 4.13: Class 0900 Graphical Economic Model of Cumulative Owning and Operating Costs

5 Comparison of Results

The timing and magnitude of economic life estimated using the annual cost methodology during the previous study were compared to the results of this cumulative cost study. The results compare well for each class and are provided in Table 5.1.

In terms of machine age at economic life, or the timing economic life, the cumulative cost methodology resulted in longer lives for classes 0201 and 0314, and shorter lives for classes 0205 and 0900. The differences were small and represent 1 to 2 years of use, which is within the "sweet spot" where the changes in average life to date total rate is very small from year to year.

The average life to date owning and operating rates resulting from the cumulative cost model were nearly all less than the corresponding rates from the annual cost methodology. Only the owning rate for the 0900 equipment class was greater from the cumulative cost methodology. The cumulative cost methodology based on the Mitchell curves resulted in average life to date operating rates lower than those from the previous study.

The average life to date total rates, or the magnitude of economic life, estimated using both methods were similar. The cumulative cost methodology resulted in a slightly greater total rate for the 0900 class, and lower total rates for the remaining classes.

Table 5.1: Comparison of Economic Life Estimates

	Economic Life Estimates based on Annual Cost Methodology				Economic Life Estimates based on Cumulative Cost Methodology			
Equipment Class	**Age**	**Owning Rate**	**Operating Rate**	**Total Rate**	**Age**	**Owning Rate**	**Operating Rate**	**Total Rate**
0201	186,379	$ 0.11	$ 0.31	$ 0.42	197,800	$ 0.09	$ 0.28	$ 0.38
0205	113,525	$ 0.43	$ 1.17	$ 1.60	105,000	$ 0.42	$ 0.90	$ 1.32
0314	5,197	$ 12.68	$ 21.66	$ 34.33	5,865	$ 9.59	$ 19.84	$ 29.43
0900	6,568	$ 15.92	$ 36.28	$ 52.20	6,020	$ 18.69	$ 33.58	$ 52.27

6 Conclusions and Recommendations

The project was successful in achieving the research objectives, which were to:

1. Evaluate the existing fleet cost data for use with cumulative cost modeling techniques
2. Develop cumulative cost economic models for four NCDOT equipment classes
3. Compare the economic models and economic life resulting from cumulative cost with those from the previous period cost modeling techniques

The existing fleet cost and use data maintained by NCDOT Fleet Management Unit is sufficient for developing cumulative cost models for several equipment classes. Cumulative cost and age data are currently available for machines brought into the fleet over the past 10 years. While not explicitly evaluated as part of this project, it appears based on the results of the previous study that some equipment classes likely lack a sufficient number of machines to develop reliable cumulative cost models. This is not a shortcoming resulting from the cumulative cost methodology or the data maintenance efforts of the Unit, but rather a reality resulting from the need for only small number of some equipment types.

The data for the vast majority of individual machines demonstrated that machines experience operating costs over their life that is appropriately represented by the second order polynomial Mitchell curve used in the cumulative cost model to estimate operating costs. Typical least squares regression techniques applied to collective fleet data was not appropriate due to the observed relationship between the Mitchell curve A coefficient and machine age. The methods used to estimate the A and B coefficients resulted in operating cost models that adequately and appropriately represented the costs experienced. The Mitchell curves developed as part of the cumulative cost methodology fit the cost data better than the exponential models fit to the annual cost data in the previous study. Because the cumulative cost data reflects both maintenance/repair costs and the subsequent beneficial use of the action, the data is not as inherently variable as the annual cost data and cost models with significantly greater R^2 values can be developed.

Cumulative cost economic models were developed for the 0201, 0205, 0314, and 0900 equipment classes and used to estimate the timing and magnitude of economic life for each class. The total cost models and the economic lives resulting from the models were very similar in terms of timing and magnitude to the results of the previous study based on the annual cost methodology. The agreement between the results validates the results of both methods and provides the Unit with additional information that supports the notion that economic life should not be considered a singular point, but rather as a range of machine age.

The following recommendations are made based on the results of the analysis and conclusions drawn:

1. Operating costs should be modeled in terms of cumulative cost using Mitchell curves for additional appropriate equipment classes within the NCDOT fleet. The curves can be used to establish annual budgets for individual machines.
2. The timing and magnitude estimates of economic life determined from the cumulative cost economic models should be used, along with the results of the previous annual cost

analyses, to establish targets for managing the average life to date total cost and life of equipment.

3. Cumulative cost models should be developed for primary equipment classes (those classes with large numbers of equipment and representing large capital investments) and reassessed annually to include the most current data and expand the number of machines analyzed.
4. The large volumes of available data and targets for the timing and magnitude of economic life provide an opportunity that should be seized upon to develop an early warning system to identify individual machines with poor economic performance. Research should be performed to identify the "traits" of machines with poor economic performance, as well as those with good economic performance. The identified traits are likely to be in the form of magnitude of cumulative operating costs experienced by a certain machine age, or ratios of operating cost components.

7 References

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Appendix A Cumulative Cost Index by Equipment Age

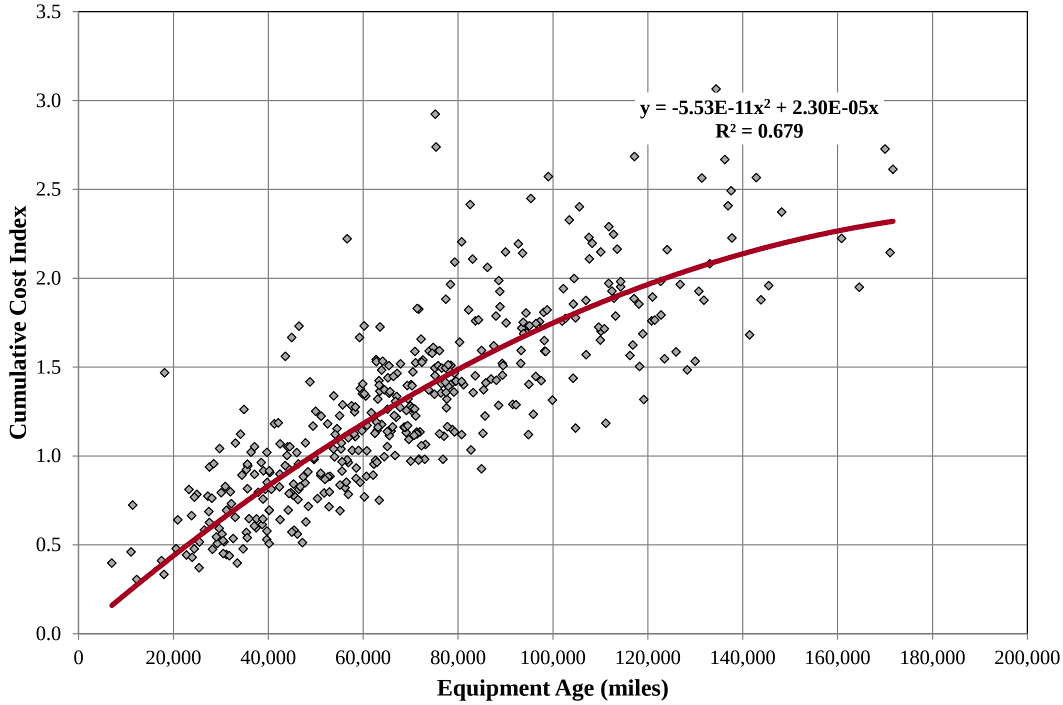

Figure A.1: Cumulative Cost Index and Best Fit Curve for Class 0205 from 2012 Data

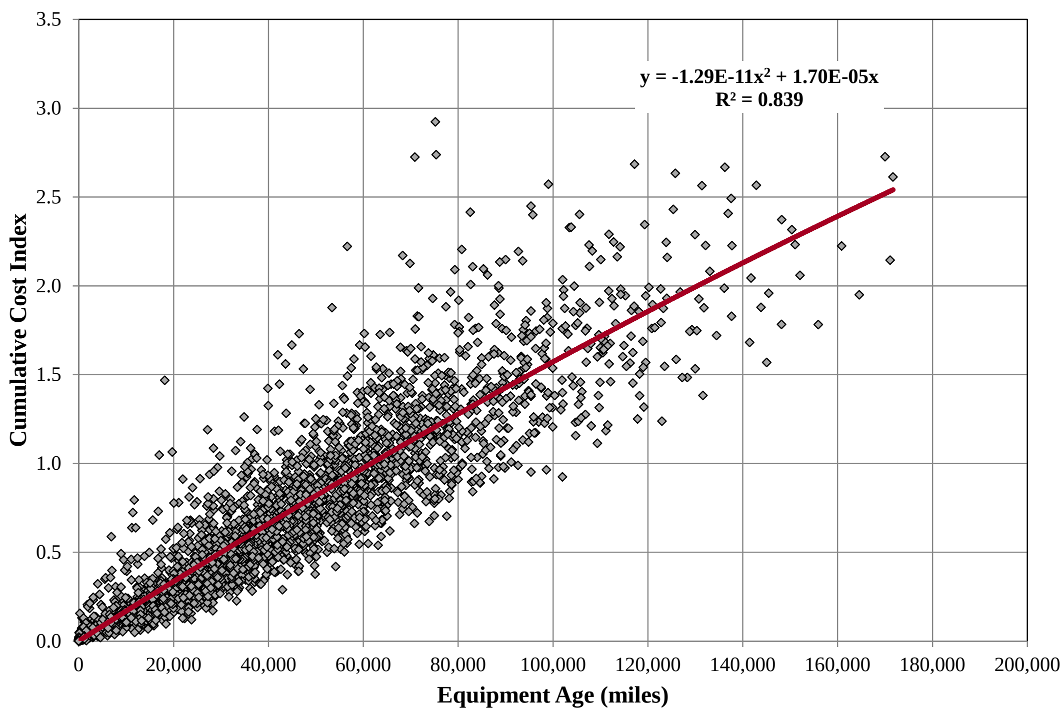

Figure A.2: Cumulative Cost Index and Best Fit Curve for Class 0205 from 2003 to 2012 Data

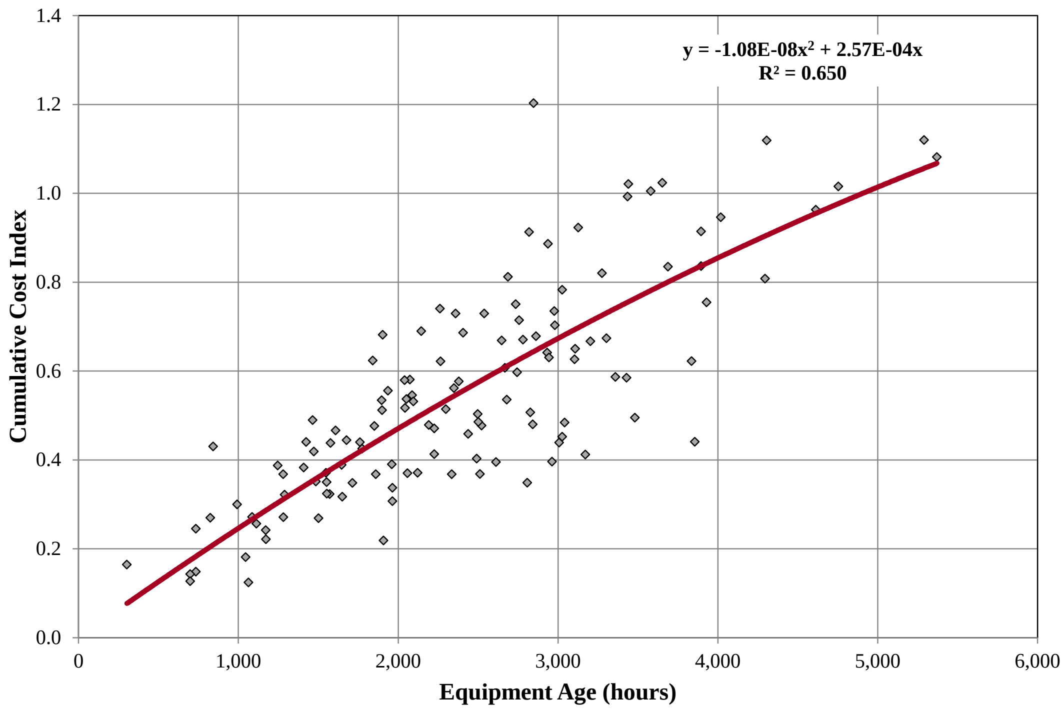

Figure A.3: Cumulative Cost Index and Best Fit Curve for Class 0314 from 2012 Data

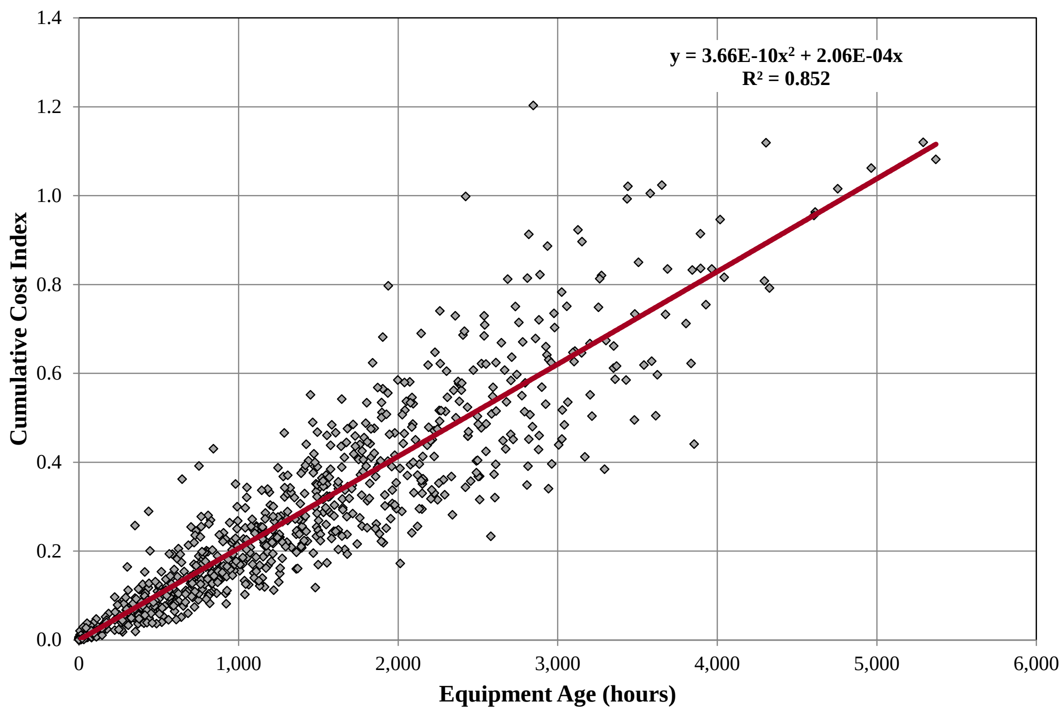

Figure A.4: Cumulative Cost Index and Best Fit Curve for Class 0314 from 2003 to 2012 Data

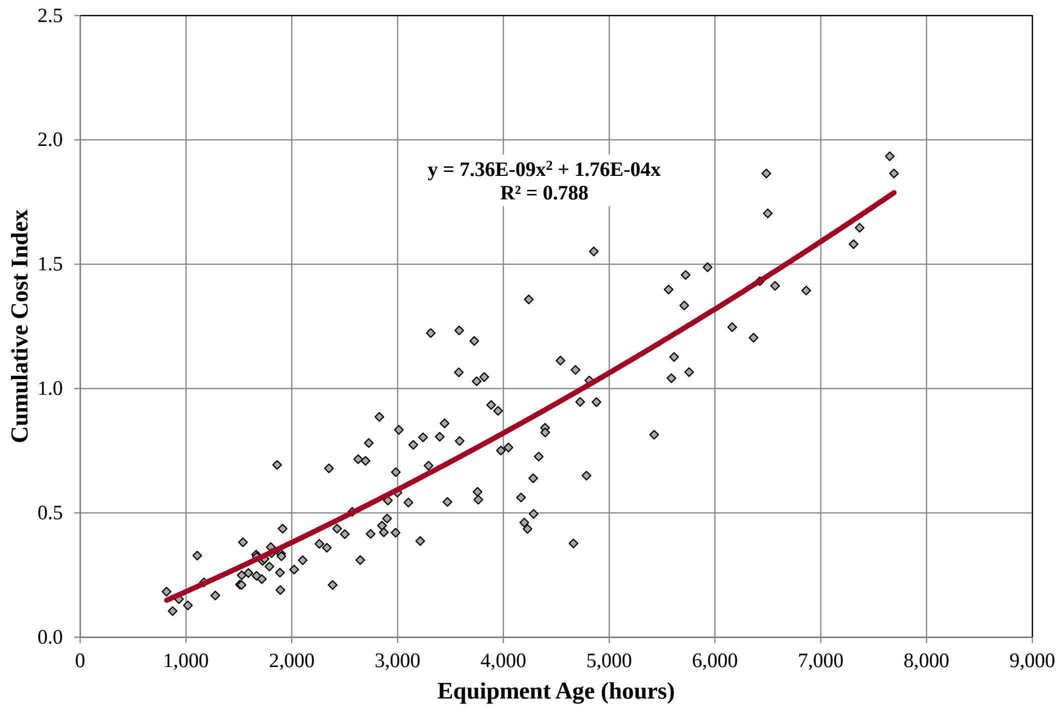

Figure A.5: Cumulative Cost Index and Best Fit Curve for Class 0900 from 2012 Data

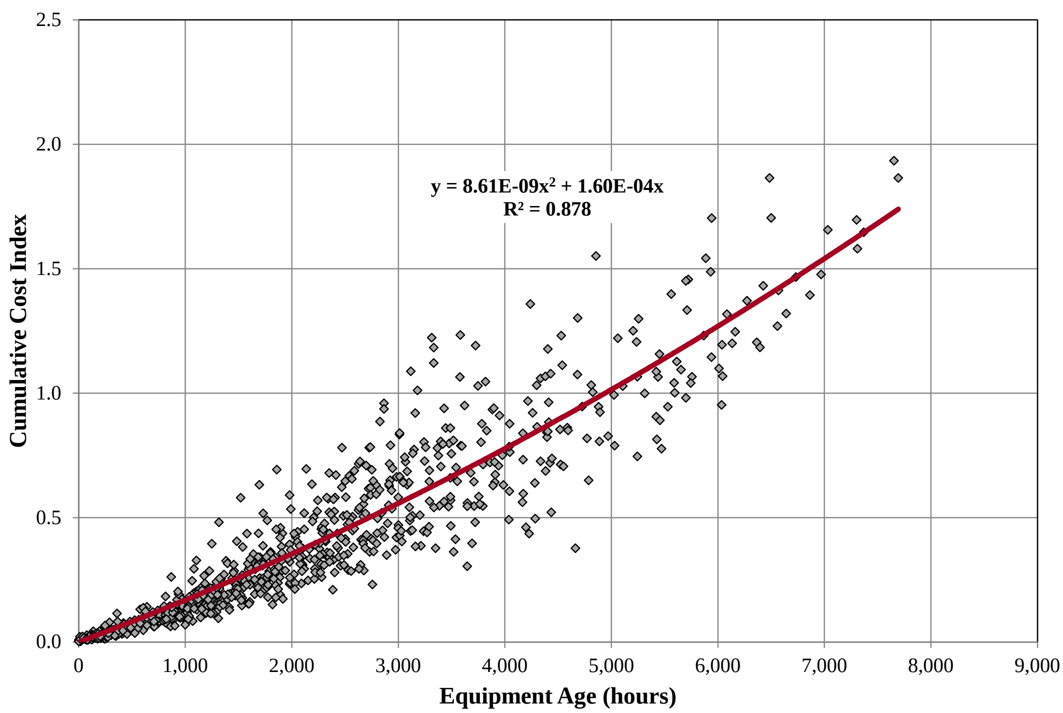

Figure A.6: Cumulative Cost Index and Best Fit Curve for Class 0900 from 2003 to 2012 Data

Appendix B Mitchell Curve Coefficients by Equipment Age

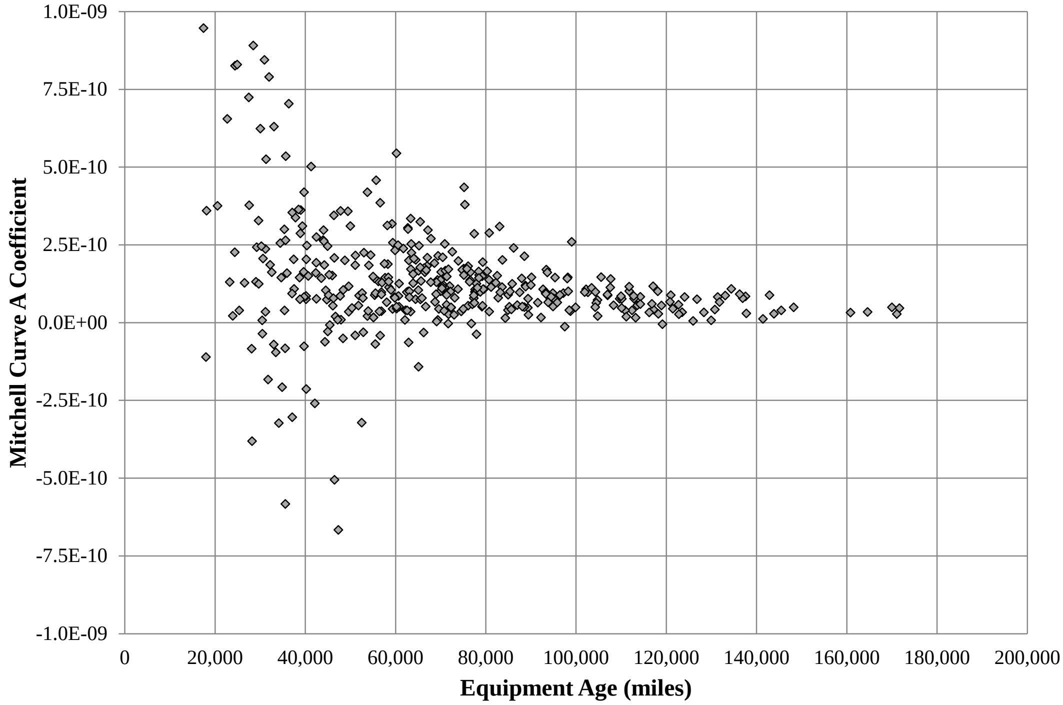

Figure B.1: Relationship between A Coefficient Value and Machine Age for 0205 Class

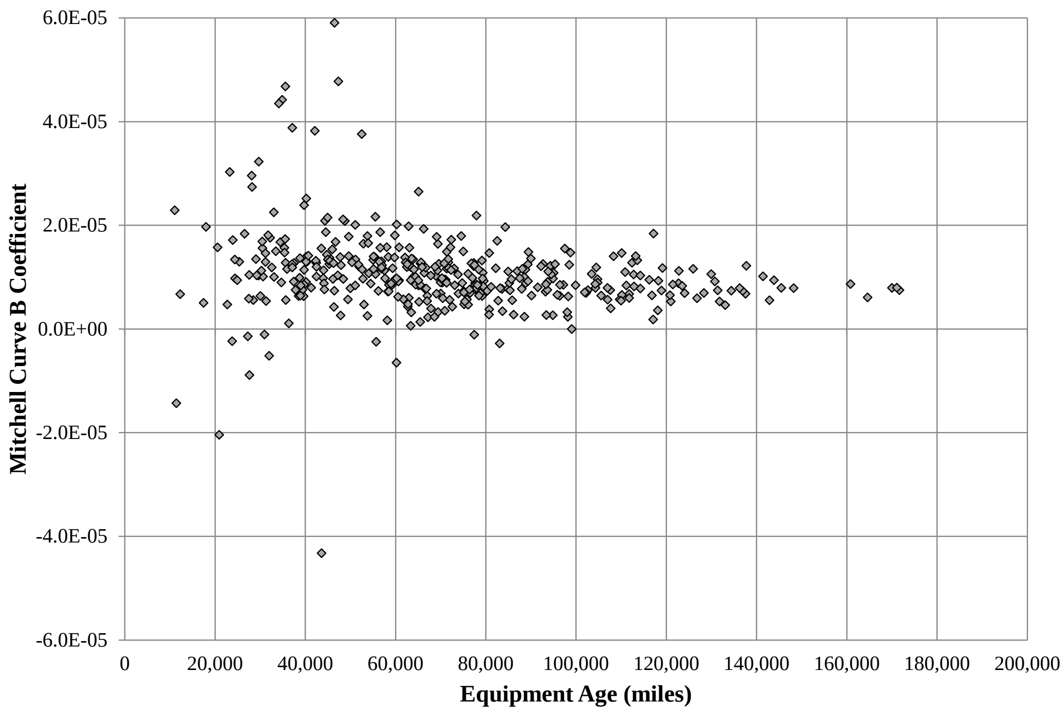

Figure B.2: Relationship between B Coefficient Value and Machine Age for 0205 Class

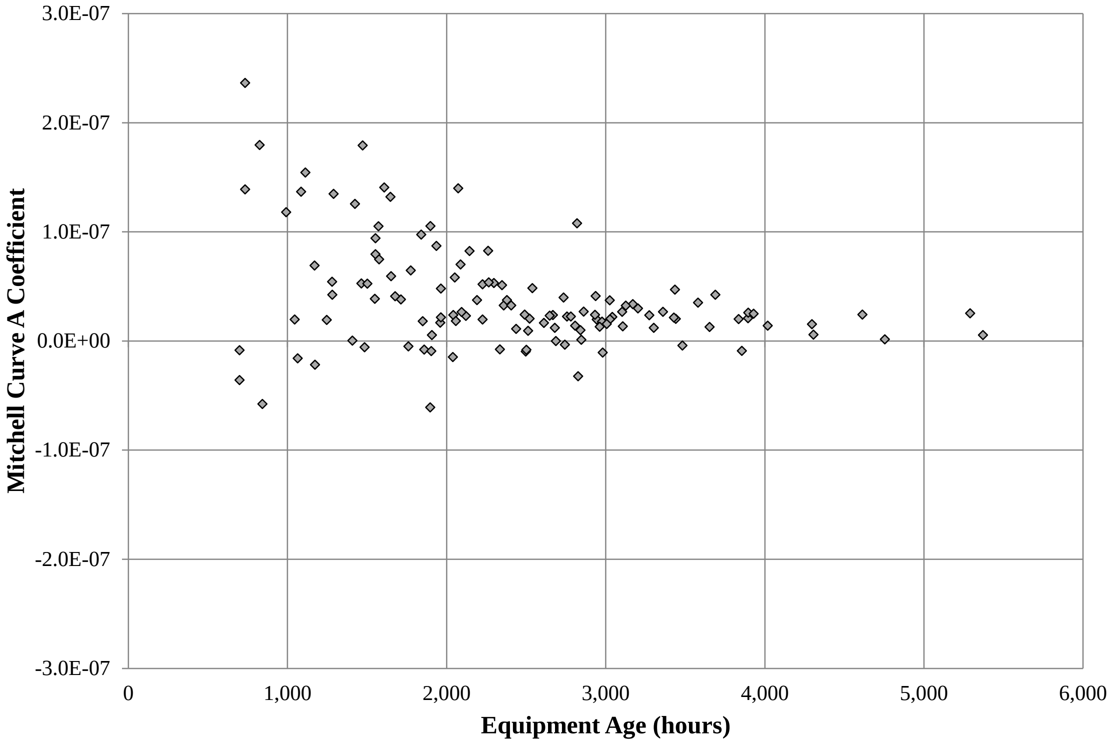

Figure B.3: Relationship between A Coefficient Value and Machine Age for 0314 Class

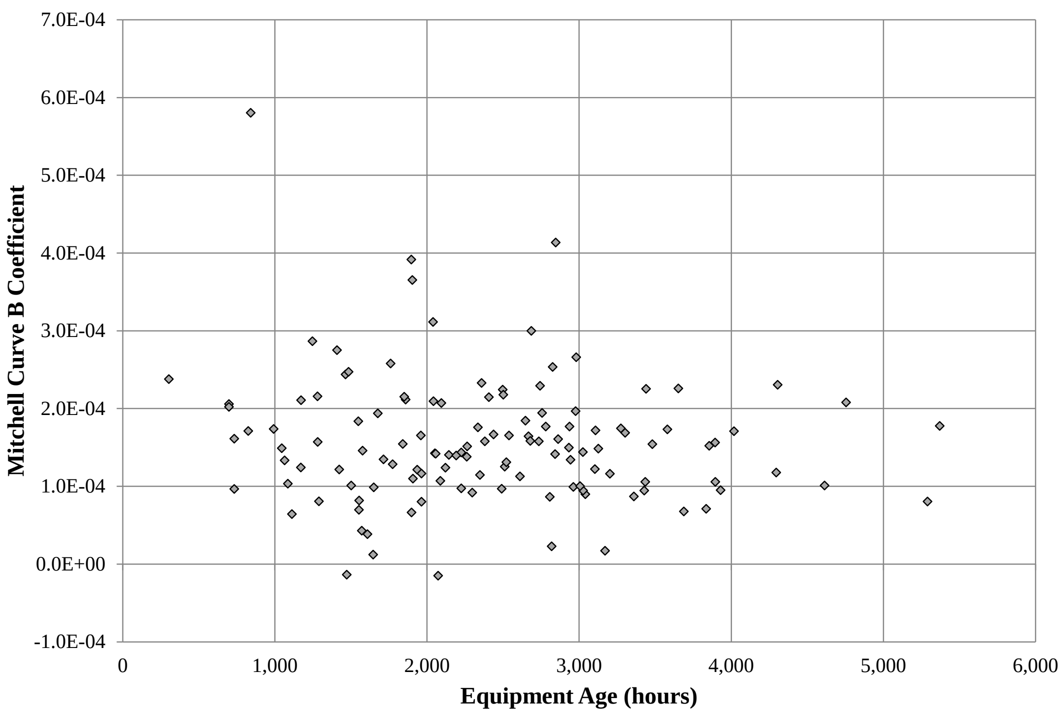

Figure B.4: Relationship between B Coefficient Value and Machine Age for 0314 Class

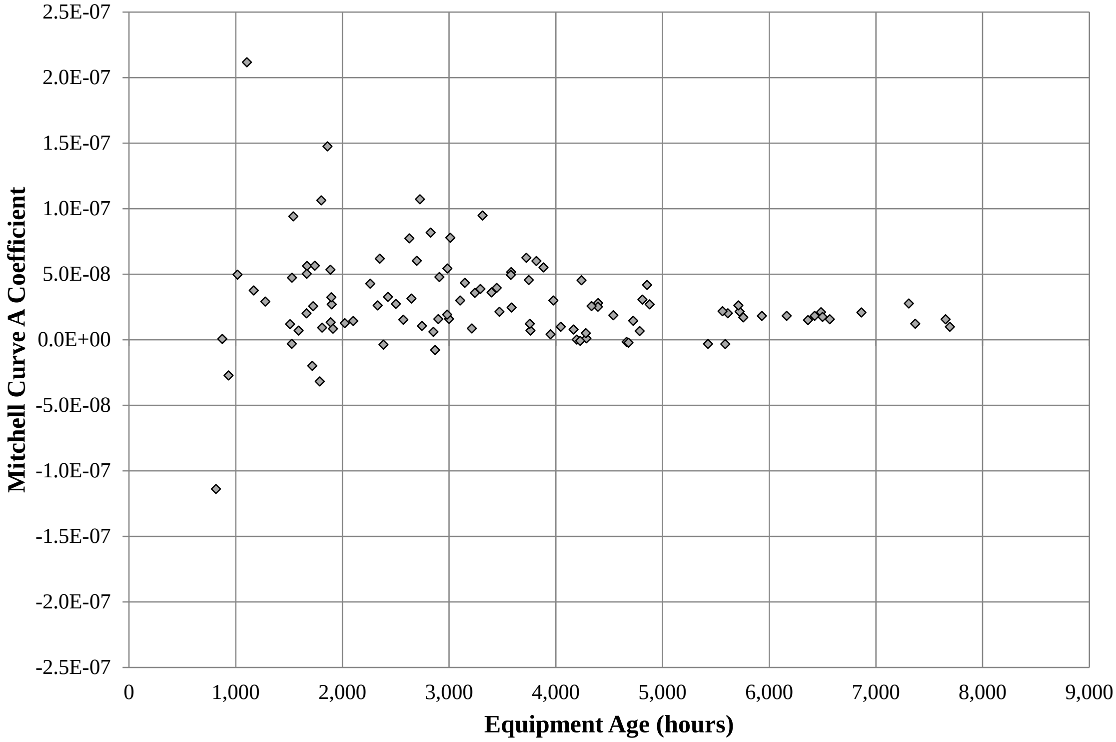

Figure B.5: Relationship between A Coefficient Value and Machine Age for 0900 Class

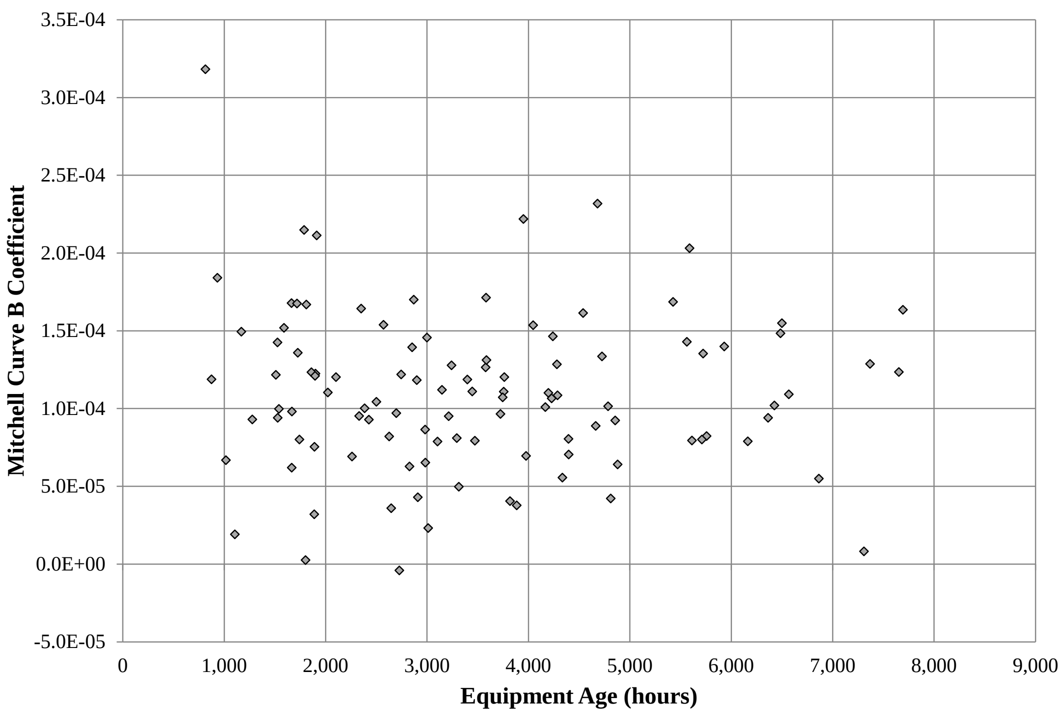

Figure B.6: Relationship between B Coefficient Value and Machine Age for 0900 Class