Acknowledgments

The authors would like to thank Andy Sivanich for his work on calculating the life cycle for Class 330 snowplows in Mn/DOT's districts 1 and 6, along with the assistance of Nirish Dhruv. Your work laid the foundation for this research and allowed the comparison of results using the M4 system and the MAPS system.

The authors greatly appreciate the advising and assistance of the many great people at Mn/DOT, including Bob Ellingsworth, Kerry Monson, John Cavanaugh, Jim Lilly, Roberta Dwyer, John Scharfbillig. Bob and Kerry were especially helpful with interfacing with the M4 system.

Also of great assistance were the members of the Fleetrio senior design team in the Department of Mechanical and Industrial Engineering at the University of Minnesota Duluth. John Cirilli, Adam Marksteiner, and Sarah Trainor supplemented the project with gaining valuable insights into the intangible factors associated with fleet assets.

Last, we appreciate the patience and assistance of Carol Wolosz and Jeanne Hartwick as we worked on the project. Thanks for the answers, suggestions, and support.

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1 Introduction

Determining the optimal life cycle of an asset is a key goal for fleet management. The life cycle includes everything from acquisition to disposal, maintenance, operations, training, and improvements. The chief aim of life cycle costing is to minimize the total cost of ownership.

This research has been a continuation of the life cycle cost analysis done in 2003-04, which concentrated on Class 330 snowplows in District 1 and District 6. The objective of this research project is to expand the analysis done last year to develop a model to evaluate the life cycle costs of more classes of vehicles and more districts. That year's research focused on the literature review and analyzed class 330 vehicles (single-axle snowplows/dump trucks), belonging to District 1 and District 6 of the Minnesota Department of Transportation (Mn/DOT). The information used was primarily extracted from the Minnesota Accounting Procurement System (MAPS). From that work, the average optimal life of these assets was found to be 9 years in District 1 and 11 years in District 6.

The research for this year, on the other hand, has expanded the analysis to include all districts of Mn/DOT for cars, pickups, and medium-duty vehicles (vehicle classes 80, 90, 180, 190, 250), single-axle snowplows/dump trucks (class 330), and dual-axle snowplows/dump trucks (class 350). Another objective is to switch the data input from MAPS over to M4, which is the current system used by Mn/DOT. An additional objective is to identify the types of intangible factors that should be considered but are often neglected in life cycle analysis.

A brief summary of last year's bibliography research is presented in Section 2. It is expanded with new literature found relative to the topic.

New requirements for this year forced a change in the methodology to gather and process data. The new methodology is presented and analyzed in Section 3.

Sections 4 and 5 present the analysis done implementing the new methodology using data from the MAPS and M4 systems, respectively. The purpose of the analysis of MAPS data were to verify the results of the new methodology.

Sections 6 discusses the results of this report, including the effectiveness of the model, the quality of the data used, and the potential role of intangible factors in fleet management decisions.

Section 7 concludes the report and presents recommendations for implementation and further work.

2 Literature Review

This section contains a brief summary of the previous year's research literature review and an overview of parallel replacement analysis.

2.1 Summary of Previous Research

The actual cost of an asset contains not only the purchase price but also operation, maintenance, training, fuel and other consumables, staff costs including overheads, support equipment (special tools), transportation and handling, and asset disposal (PCPU, 1992). It is a common mistake to only consider purchase prices in the decision making. Life Cycle Cost (LCC) analysis, on the other hand, recognizes the entire cost of an asset during its life cycle to determine the most economic way to operate the asset. A pictorial representation of the situation is shown in Figure 2-1.

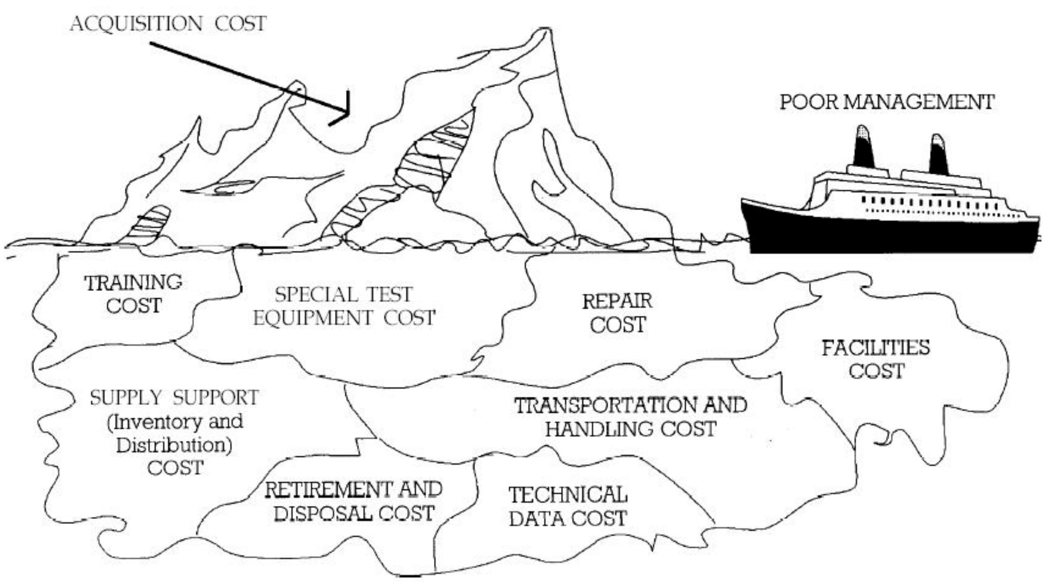


Figure 2-1 Total Cost of Visibility - The Iceberg Effect. Source: PCPU, 1992

The following cost elements were selected to be used in the life cycle cost analysis of Mn/DOT's fleets:

- Purchase Price: The cost of acquisition is simply the cost of purchasing the vehicle (chassis) plus the cost of all of the ancillary equipment (such as plows and sanders). The purchase price data were extracted from the M4 information system.
- Maintenance: The maintenance costs play a large role in the LCC analysis. For this study, the maintenance cost is composed of three separate cost elements. These elements are Shop Labor, Field Labor, and Parts
- Fuel: Fuel can be a large cost in the LCC of a vehicle. This can especially be the case when the vehicle is large and is used to haul heavy loads of material.
- Salvage Value: The vehicle salvage value is the dollar amount that Mn/DOT can expect to receive when the unit can be sold. The salvage value plays an important role in the LCC analysis. In the cost breakdown of a snowplow owned and operated by a government agency, the salvage value represents the only positive cash flow in the life cycle of the plow.
- Discount Factor: When conducting an economic analysis with an evaluation period of more than one year, it is necessary to take into account the time value of money (FHWA, 2003). The buying power of the dollar in year zero is not equal to the buying power in year ten. In order to equate cash flows in the base year (year zero) to future cash flows, a discount factor must be applied. Application of the discount factor brings the cash flow in question back to the base year, resulting in the present value of the cash flow.
  Choosing the proper discount factor for the LCC analysis is essential for producing accurate results. Mn/DOT's recommendation towards the value of the discount factor was a 5% annual discount rate. This value falls in line with the recommendations of the FHWA. According to that agency, the discount factor for conducting a LCC analysis should be within the range of 3%-5%. Thus, 5% was selected for the study.

(Sivanich, 2005)

The lack of resale values, as found by Sivanich (2005), forced us to use a double declining depreciation model to simulate this. Under this model, the value of the asset at the end of each year is given by:

$$B_t = P(1 - \frac{2}{n})^t \quad [2.1]$$

where

B_t = Remaining value

P = Initial asset value

n = Total number of depreciation periods in asset life

t = Time period

(White et al, 1998)

One of the most common methods to compare different cash flows, as when doing life cycle costing analysis, is the present worth model. In this case, all the future cash flows are discounted to the present time and summed. The resulting value represents the worth of the total cash flow in today's money. In the case of an investment to maximize gains, the higher the present value the better. In the case of life cycle costing analysis to minimize costs, the lower the present value the better.

One of the problems with this methodology is that it does not work when comparing two different cash flows with different time periods. The amortized cost method (or leveled cost method) is better in those cases. In this model, the present worth is distributed equally over the entire time period. In this report the model is going to be referred to as Equivalent Uniform Annual Cost (EUAC.)

Under the EUAC model, as shown in Figure 2-2, acquisition costs decrease as the vehicle life extends because the cost is spread over more years. At the same time, operational expenses rise over the years. There is one point in time where the total cost of ownership is minimized and that defines the optimal life cycle.

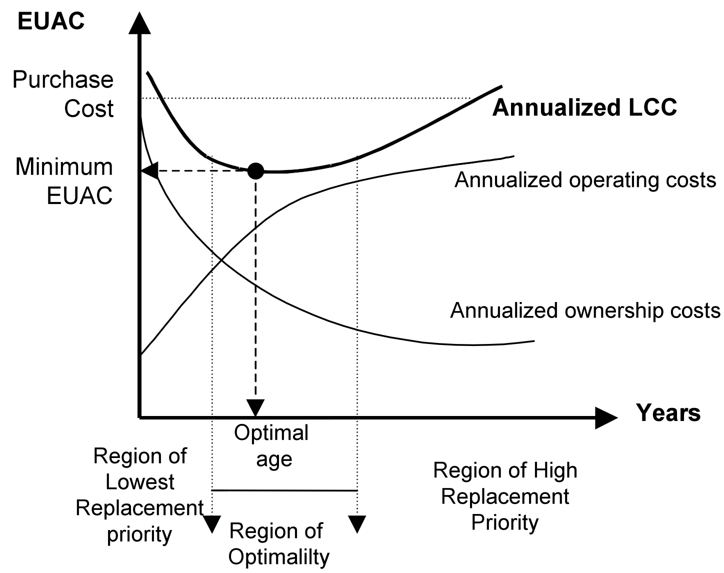


Figure 2-2 Equivalent Uniform Annual Cost Model. Source: Weissman (2003)

The methodology to calculate the EUAC for the different life cycles is:

1. Gather the appropriate cost data (ex. first four years of data for a four year life cycle, five years for a five years life cycle.)

2. Discount all the costs to year zero using Equation 2.2.

$$P = F\,(1+i)^{-n} \qquad [2.2]$$

where

P = Present value of expenditure

F = Expenditure n years away from P

i = Annual interest rate

3. Distribute the costs equally over the entire life cycle using Equation 2.3.

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad [2.3]$$

where

$A =$ Uniform annual cashflow

$P =$ Present value

$i =$ Annual interest rate

$n =$ Number of year in life cycle

4. Repeat the procedure for all the life cycles to be evaluated

(Sivanich, 2005)

Life cycle calculations are fairly simple to implement using Microsoft Excel spreadsheet software. This was the methodology used to analyze all the data.

Sivanich (2005) found the optimal life cycle for single-axle snowplows in Mn/DOT's District 1 and District 6. He used this approach for individual units in these two districts and found the average optimal life cycle to be 9 years in District 1 and 11 years in District 6.

2.2 Parallel Replacement Analysis

Hartman and Lohmann (1997) described parallel replacement analysis as:

> Parallel replacement deals with the replacement of a multitude of economically interdependent assets which operate in parallel. Reasons for this economic interdependence include: (1) demand is generally a function of the assets as a group, such as when a fleet of assets are needed to meet a customer's demands; (2) economies of scale may exist when purchasing assets, promoting large quantity of purchases; (3) dis-economies of scale may exist with maintenance costs because assets purchased together tend to fail at the same time; and (4) budgeting constraints may require that assets compete for available funds. These characteristics, either alone or together, can cause the assets to be economically interdependent.

The main difference between parallel replacement analysis and serial replacement analysis is that the former takes into consideration how any option exercised over one particular asset affects the rest of the assets of the same fleet.

Serial replacement analysis assumes a certain utilization level for an asset throughout its life cycle. Hartman (1999) says that "as utilization levels influence operating and maintenance (O&M) costs and salvage values, which in turn influence replacement schedules, a replacement solution is not truly optimal unless utilization levels are also maximized." An asset utilization level depends on the demand requirements, number of assets available, and capacity of each asset. For example, if a certain asset can be used for 5,000 miles per month, there are 4 units of that asset, and the demand is only 15,000 miles, there is more than one combination of utilization levels that can be used. There is a decision to be made that affects the utilization of the different assets, thus their costs and replacement policy.

Hartman (2004 and 1999) and Hartman and Lohmann (1997) provide an optimum solution procedure for the parallel replacement problem. This procedure is not as simple as the ones used in serial replacement analysis. The mathematical model is more complex and their data requirements are more exhaust. The methodology was not used in this research due to data quality problems, but the general problem was taken into account.

3 Methodology

The methodology developed, and explained below, was primarily chosen because of the data restrictions imposed and the amount of information required to process.

In consultation with Mn/DOT personnel, it was decided to only use data from the M4 system due to the State of Minnesota seeking to move toward a common information system. This is different than the research in 2003-04 where most of the information came from MAPS. The M4 system, being relatively new, only had information for the last 4 or 5 years. In comparison, last year's research was based on information from MAPS which contained up to 10 years of data for each unit. The most thorough discussion of the initial life cycle costing research is documented in the MSEM thesis by Sivanich (2005).

It was possible for last year's research to develop a life cycle cost analysis per unit without incurring large forecast errors because almost every unit had 10 years of real data. The optimal life cycle policy was calculated as the most probable result obtained from each unit. This analysis was not possible having only data from M4 as was requested.

Having only 4 or 5 years of data from M4 information system, it was too risky and error prone to forecast the cost of each unit to have enough information to do a life cycle cost analysis for each unit. For example, it is required to have close to 15 years of data in the case of snowplows to do the analysis. With this difficulty at hand, the focus was on how to develop a cost curve that would be representative of the whole fleet and do the life cycle cost analysis directly for the whole fleet.

Another issue with the previous research methodology was that it did not escalate easily. That research focused only on two different Mn/DOT districts and only analyzed one class of vehicle. The objective of this research was to expand the analysis to all the districts and seven different classes of vehicles (80, 90, 180, 190, 250, 330, and 360). The amount of information required to do this analysis increased considerably from one research to the other, making the manual calculation of optimal life cycle for each unit almost impossible and too prone to error.

The solution was to average the cost of each unit based on each unit's age. This approach allows us to utilize different units to simulate different parts of the fleet's standard cost structure. New units simulate the first years of the typical unit and old vehicles the last year's. Figure 3-1 shows graphically how it works. The combination of many different units with different ages permits developing a cost structure curve representing the whole fleet.

Of course, this representation of the whole fleet only makes sense when units are of the same class. The study also considered to analyze independently units from each district in order to find out if there were different usage and maintenance patterns.

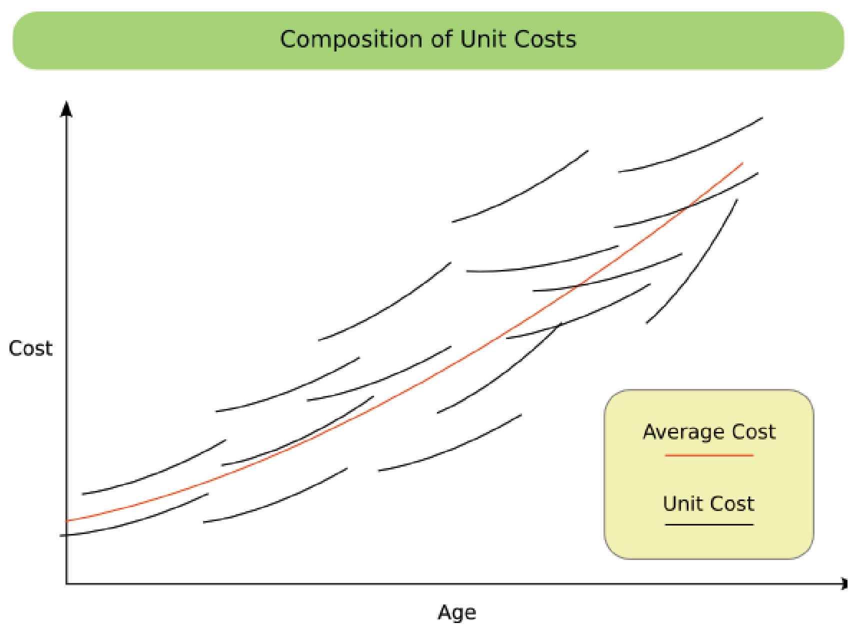


Figure 3-1 Units Cost Composition

Once the cost structure of the fleet is known, a life cycle cost analysis is performed as it was done in last year's research.

The methodology requires having the following information available:

- Unit class and district where it has been used
- Purchase costs and date
- Fuel consumption or mileage per month
- Labor and parts costs with date

With the previous information at hand, the general cost structure of the fleet for one type of class and possible for one particular district is generated as follows:

- Move all costs and purchase prices to a specify date using index prices (see Section 3.1). This allows operating with cost information without considering inflation and different value of money during a period of time.
- Calculate the average purchase cost.
- Calculate how old the unit was for each cost entry.
- Calculate the total cost per unit for each type of cost (fuel, parts, and labor) based on unit age. From now on all the information is managed based on unit's age and it is just going to be referenced as "year."
- Calculate the average cost per year for each district and class of vehicle.
- Use regression techniques to smooth cost structure. In general, a linear regression has been applied with good fit.
- Use that information with the model to calculate the optimal life cycle.

The actual LCC analysis is done with a spreadsheet similar to the one shown in Figure 4-7. The values in that spreadsheet are just an example. The parameters of the spreadsheets are the average purchase cost, number of years in which the units are depreciated, interest rate to consider on the cash-flow analysis, and maintenance costs. The average purchase price and maintenance cost calculation was explained before. In this example, the maintenance cost regression resulted in an intercept of $2,804 and a slope of $583. This means that the initial cost is $3,387 ($2,804 + $583) and it will increase $583 annually for each year of usage. It was chosen to use double-declining depreciation, as last year's research, because it follows closely how vehicles lose value according to their age. At the same time, the interest rate used for the calculations was 5 percent as was used in the previous research.

Purchase:	$ 76,429			Interest Rate:	5%
Maintenance Linear Regression					
Slope:	$ 583			Depreciation (years):	13
Intercept:	$ 2,804				
Correlation:	97.86%				
Years used:	1 - 9				
EOY	**Purchase**	**Selling**	**Maintenance**	**NPV**	**UAC**
0	$ 76,429	$ 76,429			
1		$ 64,671	$ 3,386	$ 18,063	$ 18,966
2		$ 54,721	$ 3,969	$ 33,620	$ 18,081
3		$ 46,303	$ 4,551	$ 47,187	$ 17,328
4		$ 39,179	$ 5,134	$ 59,176	$ 16,688
5		$ 33,152	$ 5,717	$ 69,913	$ 16,148
6		$ 28,051	$ 6,299	$ 79,656	$ 15,694
7		$ 23,736	$ 6,882	$ 88,611	$ 15,314
8		$ 20,084	$ 7,464	$ 96,937	$ 14,998
9		$ 16,994	$ 8,047	$ 104,764	$ 14,739
10		$ 14,380	$ 8,629	$ 112,188	$ 14,529
11		$ 12,167	$ 9,212	$ 119,288	$ 14,361
12		$ 10,296	$ 9,795	$ 126,123	$ 14,230
13		$ 8,712	$ 10,377	$ 132,739	$ 14,131
14		$ 7,371	$ 10,960	$ 139,172	$ 14,060
15		$ 6,237	$ 11,542	$ 145,447	$ 14,013
16		$ 5,278	$ 12,125	$ 151,584	$ 13,987
17		$ 4,466	$ 12,708	$ 157,597	$ 13,979
18		$ 3,779	$ 13,290	$ 163,498	$ 13,987
19		$ 3,197	$ 13,873	$ 169,293	$ 14,008
20		$ 2,705	$ 14,455	$ 174,986	$ 14,041
21		$ 2,289	$ 15,038	$ 180,582	$ 14,085
22		$ 1,937	$ 15,620	$ 186,081	$ 14,137
23		$ 1,639	$ 16,203	$ 191,485	$ 14,196
24		$ 1,387	$ 16,786	$ 196,794	$ 14,262
25		$ 1,174	$ 17,368	$ 202,006	$ 14,333
		Min	**$13,979**		
		Year	**17**		

Figure 3-2 LCC Analysis Spreadsheet Example

The spreadsheet calculates the Net Present Value (NPV) of the cash flow that would be incurred in if the units are sold at the end of the year (EOY) 1 through 25 respectively. This EOY represents the life cycle chosen for the fleet. The NPV is calculated using equation 3.2 as follows:

$$NPV = PurchasePrice + \frac{SellingPrice_N}{(1 + InterestRate)^N} + \sum_{n=1}^{N} \frac{Maintenance_n}{(1 + InterestRate)^n} \qquad [3.2]$$

where:

N: number of years considered

Finally, the Uniform Annual Cost (UAC) is calculated based on the NPV and the number of years the units are used. The UAC is the annual cost it would be incurred if the unit is kept for a given number of years. The optimal life cycle is that which minimizes the UAC; in this example it would be year 14.

In order to see if the model would work as it was supposed to, a simulation spreadsheet was developed. The particularities of the simulation are discussed on Section 3.2 and a sensitivity analysis of the methodology is presented in Section 3.3. A sensitivity analysis of the life cycle cost methodology was also performed and its results are discussed on Section 3.4.

3.1 Cost – Time Corrections

There are two main price indexes produced by the U. S. Department of Labor (USDL), Bureau of Labor Statistics: Producer Price Index (PPI) and Consumer Price Index (CPI). "The Consumer Price Index (CPI) is a measure of the average change over time in the prices paid by urban consumers for a market basket of consumer goods and services" (USDL, 2004a). On the other hand, the USDL defines the PPI (USDL, 2004b) as:

> The Producer Price Index (PPI) is a family of indexes that measures the average change over time in selling prices received by domestic producers of goods and services. PPIs measure price change from the perspective of the seller. This contrasts with other measures, such as the Consumer Price Index (CPI), that measure price change from the purchaser's perspective. Sellers' and purchasers' prices may differ due to government subsidies, sales and excise taxes, and distribution costs.

The usage of PPI over CPI in this research is because the latter reflects the spending patterns of U.S. population in urban areas, not reflecting price changes for organizations such as Mn/DOT.

Usage of price indexes is important when two expenditures for the same type of good were made in different time periods and there is a need to compare both. During this research, expenditures have been collected for fuel, parts, and labor. All of these types of costs have been made during a 10- or 5-year period depending on the source of information (MAPS and M4, respectively).

The PPI has two types of indexes: industry data and commodity data. Each one of them is organized in different groups, each one grouping different type of items. The current major groups for commodities are:

group_code	group_name
00	All commodities
01	Farm products
02	Processed foods and feeds
03	Textile products and apparel
04	Hides, skins, leather, and related produ
05	Fuels and related products and power
06	Chemicals and allied products
07	Rubber and plastic products
08	Lumber and wood products
09	Pulp, paper, and allied products

group_code	group_name
10	Metals and metal products
11	Machinery and equipment
12	Furniture and household durables
13	Nonmetallic mineral products
14	Transportation equipment
15	Miscellaneous products
DUR	Durability of product
ILF	Industrial Commodities less fuels
IND	Industrial Commodities
PFF	Farm products, processed foods and feeds
RP	Regional Refined Petroleum
SI	Special indexes
SOP	Stage of processing

Table 3-1. PPI Group Codes. Source: ftp://ftp.bls.gov/pub/time.series/wp/wp.group

From Table 3-1, groups 5 and 14 are useful for the current analysis. Group 5 will be used for fuel costs and group 14 will be used for purchase prices and parts' costs. The list of subgroups for each of those major groups is shown under the Appendix 9.1 and 9.2, respectively.

According to the different type of costs used in this research, such as purchase, parts, and fuel, the following PPI groups will be used:

- Fuel

- Gasoline (classes 80, 90, 180, 190, and 250): group WPU057104 (Unleaded regular gasoline)
- Diesel (classes 330 and 360): group WPU057303 (#2 diesel fuel)

- Purchase Costs
    - All classes: group WPU1411 (Motor vehicles)
- Parts
    - All classes: group WPU1412 (Motor vehicle parts)

It was desired to use the following groups to use with purchase prices:

- Sedans (classes 80, 90, 180, and 190): group WPU141101 (Passenger cars)
- Trucks (classes 250, 330, and 350): group WPU141102 (Motor trucks and truck tractors)

However, the second group has been discontinued and it was decided use the group WPU1411 for all the vehicle classes.

Since there is no PPI for labor costs, they are treated differently. Wages closely follow the cost of living, making the CPI a reasonable estimator of the variances in labor costs.

The most up-to-date indexes used in this research were accessed at:

- WPU05: ftp://ftp.bls.gov/pub/time.series/wp/wp.data.6.Fuels
- WPU14: ftp://ftp.bls.gov/pub/time.series/wp/wp.data.15.Transportation
- CPI: ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

It is also possible to access the indexes through the Bureau of Labor Statistics website at http://www.bls.gov/data/home.htm and selecting the corresponding method and time series.

The index values used during this research are shown in the Appendix, Sections 9.3 through 9.7.

3.2 Model Testing by Simulation

A model simulation spreadsheet was developed to verify that the methodology used worked as expected.

The objective of the simulation spreadsheet was to randomly generate units and their particular cost data based on a general cost structure, analyze that data with the methodology described before, and finally compare the results with the original information. If the result of the methodology applied to the randomly generated information is close to the originating data, the model would be shown to work correctly.

Figure 3-3 shows the model's spreadsheet with all its parameters. The values used in Figure 3-3 are just an example.

Units		
Number of Units	50	
Maximum Age	20	years
Years of Data	10	years
Purchase Value Base	77000	dollars
Purchase Value Variation	15%	

Other Model Parameters

Use Fuel?	FALSE	
Interest Rate	5%	
Depreciation		
Type	double	(double or linear)
Years	13	
Linear Final Value	10%	(only used in linear depreciation)
Type of Variation	normal	(normal or linear)
Fuel Variation	5%	
Maintenance Variation	15%	
Fuel Year Increase	0%	
Maintenance Year Increase	20%	

Maintenance Costs

	Fuel		Maintenance	
Years Old	Percent	Value	Percent	Value
0	100%	$ 1,500	100%	$ 5,000
1	100%	$ 1,500	120%	$ 6,000
2	100%	$ 1,500	140%	$ 7,000
3	100%	$ 1,500	160%	$ 8,000
4	100%	$ 1,500	180%	$ 9,000
5	100%	$ 1,500	200%	$ 10,000
6	100%	$ 1,500	220%	$ 11,000
7	100%	$ 1,500	240%	$ 12,000
8	100%	$ 1,500	260%	$ 13,000
9	100%	$ 1,500	280%	$ 14,000
10	100%	$ 1,500	300%	$ 15,000
11	100%	$ 1,500	320%	$ 16,000
12	100%	$ 1,500	340%	$ 17,000
13	100%	$ 1,500	360%	$ 18,000
14	100%	$ 1,500	380%	$ 19,000
15	100%	$ 1,500	400%	$ 20,000
16	100%	$ 1,500	420%	$ 21,000
17	100%	$ 1,500	440%	$ 22,000
18	100%	$ 1,500	460%	$ 23,000
19	100%	$ 1,500	480%	$ 24,000
20	100%	$ 1,500	500%	$ 25,000

Figure 3-3 Model Simulation Spreadsheet Example

The model parameters are:

- Fleet Parameters and Data Availability:
    - Number of Units: Represents the number of units that are going to be generated.
    - Maximum Age: Represents how old each unit can be.
    - Years of Data: Represents the maximum number of years of data that are available for each unit. This tries to simulate the situation where data are available for the last 5 years, for example, but units have different age. So, if a unit was bought 10 years ago, the data available is from year 5 to 10. If the unit was bought 4 years ago instead, the available data goes from year 1 to 4.
- Cost Information:

- Purchase Value Base: Average purchase price for these units.
- Maintenance and Fuel Costs: Costs incurred in average for each unit depending on its age. Maintenance cost represents both parts and labor.
- Fuel and Maintenance Year Increase: Annual increase of fuel and maintenance cost expressed as percentages. It is not necessarily the only option; yearly costs can be set up one by one.
- Use Fuel: Describes if fuel is considered as part of the operating cost or not.

- Life Cycle Parameters
    - Interest Rate: Interest rate used for cash flow analysis.
    - Depreciation Type: Type of depreciation used on the units. It can be either "linear" or "double" declining.
    - Depreciation Years: Number of years used with the depreciation formula.
    - Depreciation Final Value: Value of the unit after being completely depreciated expressed as percentage of the purchase price. This is only used with linear depreciation.
- Variation
    - Variation Type: Represents the form of variation for every cost data. It can be either linear or normal (normally distributed).
    - Costs Variation: Allowed variation expressed as percentage of the average cost. If variation type is linear, the percent represent both maximum and minimum allowed variations. If variation type is normal, the percentage represents the point with one standard deviation.

The simulation model tries to represent the situation where there are many vehicles in the fleet that has an average cost structure, each one with a certain cost structure that differs from the "normal" one, and the data available does not contain every possible year for each unit.

The model generates a given number of units and randomly chooses their ages and purchase prices. The number of years with data for each unit is the minimum between their age and the parameter *Years of Data*. The purchase prices, as all the other cost information, are generated randomly taking into consideration the base value, the distribution type, and its variability. Fuel cost and maintenance cost are generated randomly for each unit and year of data. The generation method is similar to the one described before for purchase prices.

Once all the information has been generated, the methodology explained in Section 3 is applied. The life cycle cost analysis of both randomly generated fleet and the base unit is displayed graphically and in table form in order to be able to compare results between them. An example of the UAC results is shown in Figure 3-4. It shows the values of the randomly generated units with and without applying linear regression as well as the fleet "true" UAC.

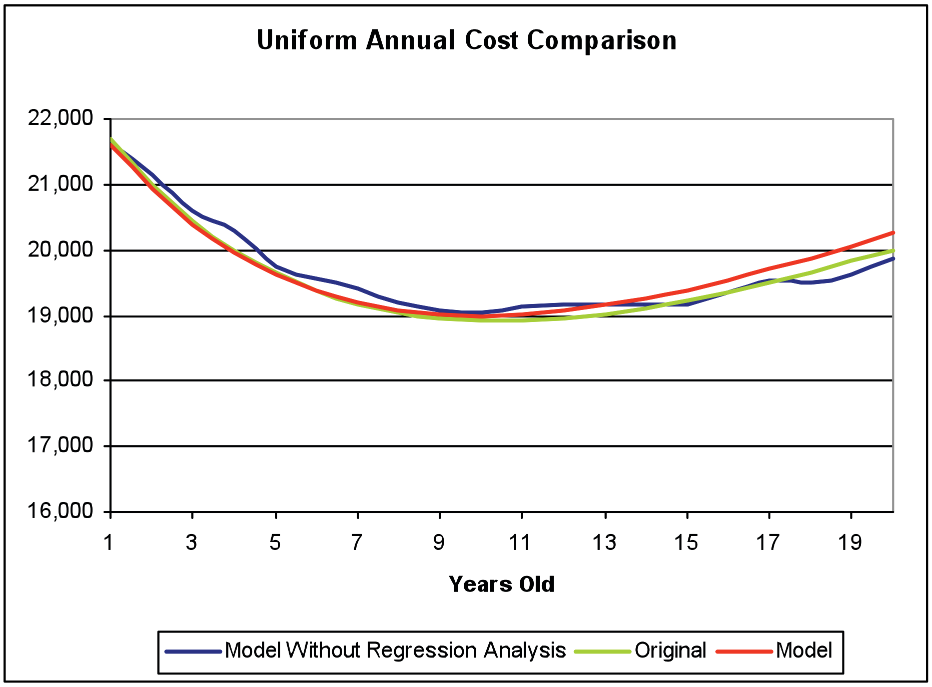


Figure 3-4 Model Simulation Graphical Result Example

The example presented here shows that the result of the life cycle cost analysis over the raw data may generate local minimums. A detailed analysis should be performed before those results are chosenas optimal life cycles. After seeing this type of behavior in almost every analysis, a regression analysis was added to the methodology in order to mitigate possible errors due to deviations from the fleet standard.

Figure 3-4 also shows some differences between the smoothed random sample and the true fleet UAC. The model was run many times, many of them providing similar results. The simulated curve might be higher or lower than the original one depending on how numbers were generated. Even though there are differences in the minimum year cost, the optimum life cycle is generally close to the original one.

Figure 3-5 shows the result of repeated simulation with the same model parameters. The model was run 30 times. In this example, all of the optimum life cycle results are in the range of

9 to 12 years. Each of those optimal life cycles got 3, 12, 13, and 2 hits respectively. The optimal life cycle of the fleet, represented by values without any variation, is 10 years tending to be closer to 11 years rather than 9 years. The dispersion of the results is influenced by the cost structure of the fleet and its variations. In this example, it is clear that the frequency of each result approximately represents reality and that some variation in the individual vehicles shifts the optimal life cycle to either side.

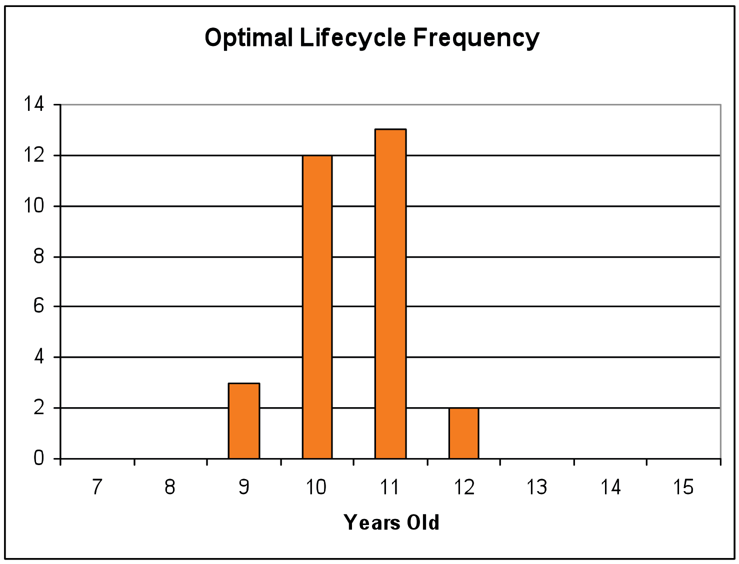


Figure 3-5 Example Model Multi-Simulation Result Frequency

The results of the many simulations run validate the model in the sense that it does not introduce any additional noise into the system. Many things should be considered after seeing these deviations, however.

The deviations presented with the previous example are one of the reasons for performing two different sensitivity analyses. The first sensitivity analysis was done over the variations within individual units and it is presented in Section 3.3. The second one was done to study the sensitivity of the life cycle cost analysis methodology and it is presented in Section 3.4.

3.3 Sensitivity Analysis of the Methodology

The simulation of the methodology presented in the previous section includes many variables representing the possible variations found on each particular vehicle compared to the fleet as a whole.

The variables that affect the result when applying the methodology are:

- Cost Variations:
  - Purchase Price
  - Fuel
  - Maintenance
- Information
  - Number of Units
  - Years of Data Available

The effects of cost variation are easy to understand. The higher the variation of any of those variables, the higher the dispersion of the results obtained. A new simulation was done maintaining all the parameters of the spreadsheet as shown in Figure 3-3 except for Purchase Price, Fuel, and Maintenance variations. Those parameters were changed to 25, 15, and 25 percent respectively. The result of this new simulation is shown in Figure 3-6.

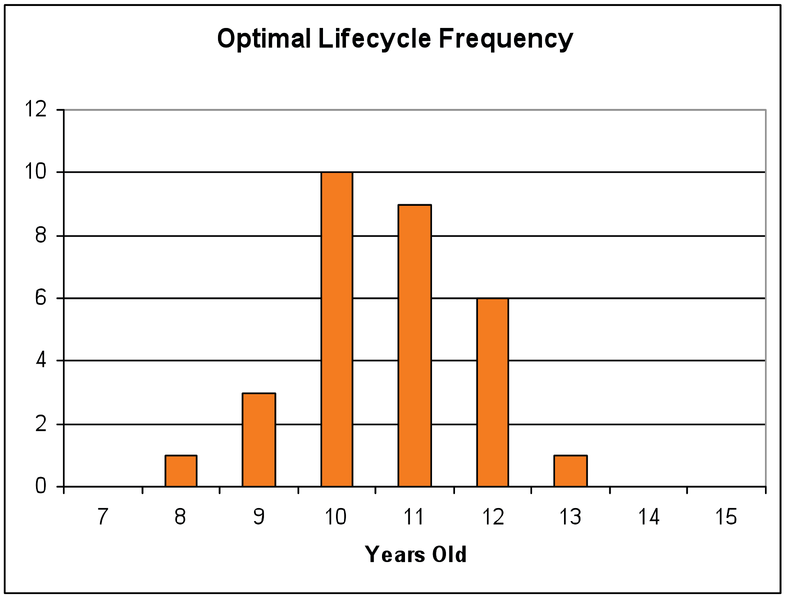


Figure 3-6 Multi-Simulation with Higher Cost Variations

Comparing the results presented in Figure 3-6 with those of Figure 3-3, it is clear that increasing the variation of these three costs increases the dispersion of results.

At the same time, the increase of the data available to analyze decreases the variation of the results if the variability of the costs of each unit are kept constant. To graphically show the effects of information over the results, another simulation was run changing only the number of units available and the number of years of information available for each unit. In this example, the number of units was set to 80 instead of 50 as shown in Figure 3-3 and the number of years of data were changed from 10 to 15. The results of this new simulation are shown in Figure 3-7.

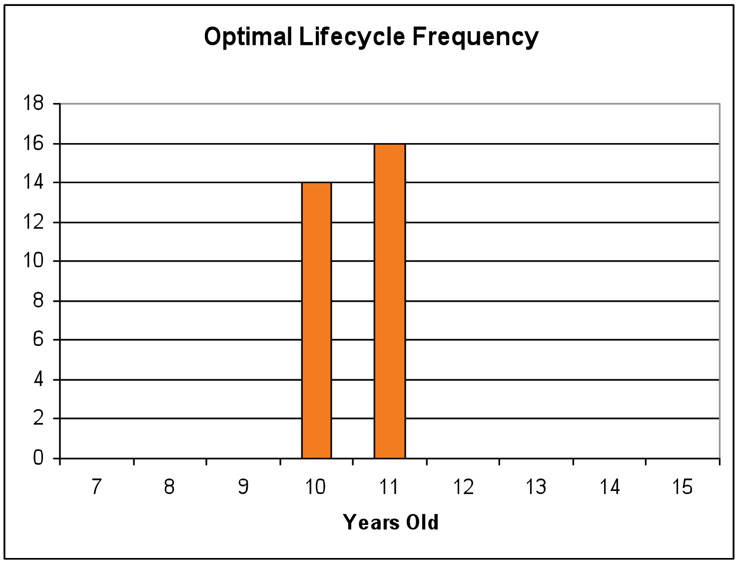


Figure 3-7 Multi-Simulation with More Information Available

The variability each unit's costs cannot be controlled. It is what it is and nothing would change this. On the other hand, the accuracy of the methodology results will increase with more information available as shown in Figure 3-3 and Figure 3-7. This means that if Mn/DOT keeps gathering more cost data, which are accurate, the accuracy of the analysis will improve alone.

3.4 Life Cycle Cost Sensitivity Analysis

The result of the LCC analysis is sensitive to the values used for every parameter of the model. An analysis of the sensitivity of the result to those parameters is presented in this section. The objective of this analysis is to find out where is more important to be sure the data are correct and focus on them.

The sensitivity analysis was performed considering 5 parameters: purchase price, interest rate, number of years used for depreciation, initial maintenance cost, and yearly maintenance increase.

The base scenario had the following parameter values:

- Purchase Price: $77,000
- Interest Rate: 5 %
- Depreciation Years: 13 (using double depreciation)
- Initial Maintenance Cost: $5,000
- Yearly Maintenance Increase: 20 %

The basic scenario was taken from the values calculated for class 330 vehicles used in District 1. The interest rate, depreciation years, and type were selected as they were used in last year's research.

3.4.1 Purchase Price

The first change analyzed was the purchase price. The values used were $65,000, $70,000, $75,000, $80,000, $85,000, and $90,000.

Figure 3-8 shows how the UAC change depending on how expensive is to buy a new vehicle. As the purchase price increases, the annual cost and optimum life cycle increases too.

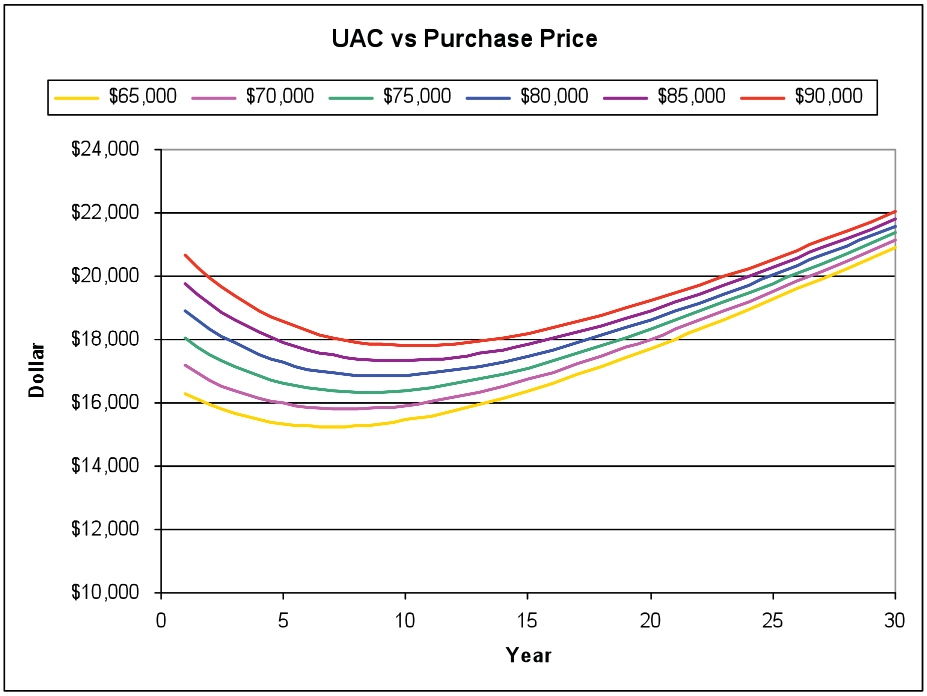


Figure 3-8 UAC vs Purchase Price

Purchase Price	$ 65,000	$ 70,000	$ 75,000	$ 80,000	$ 85,000	$ 90,000
Cost	$ 15,249	$ 15,809	$ 16,338	$ 16,846	$ 17,339	$ 17,810
Life Cycle	7	8	8	9	10	10

Table 3-2 Effects of different purchase prices over life cycle

Higher purchase cost increases the cost of ownership of that asset. Thus, the operating costs balance ownership costs later in the life cycle.

The effect of an increase in the purchase price is not too large because, using double depreciation, the highest penalty is during the first years due. This means that the incremental increase of the cost of ownership decreases with the age of the vehicle.

3.4.2 Interest Rate

The second change was done over the interest rate used for the cash flow analysis. The values used were 2, 5, 8, 11, 14, and 17 percent. As a public entity, the interest rate proposed by Mn/DOT is 5 percent; for-profit organizations generally apply higher values.

Figure 3-9 shows how the UAC changes depending on the interest rate used. As the interest rate increases, the annual cost and optimum life cycle also increase, and the UAC curve flattens out.

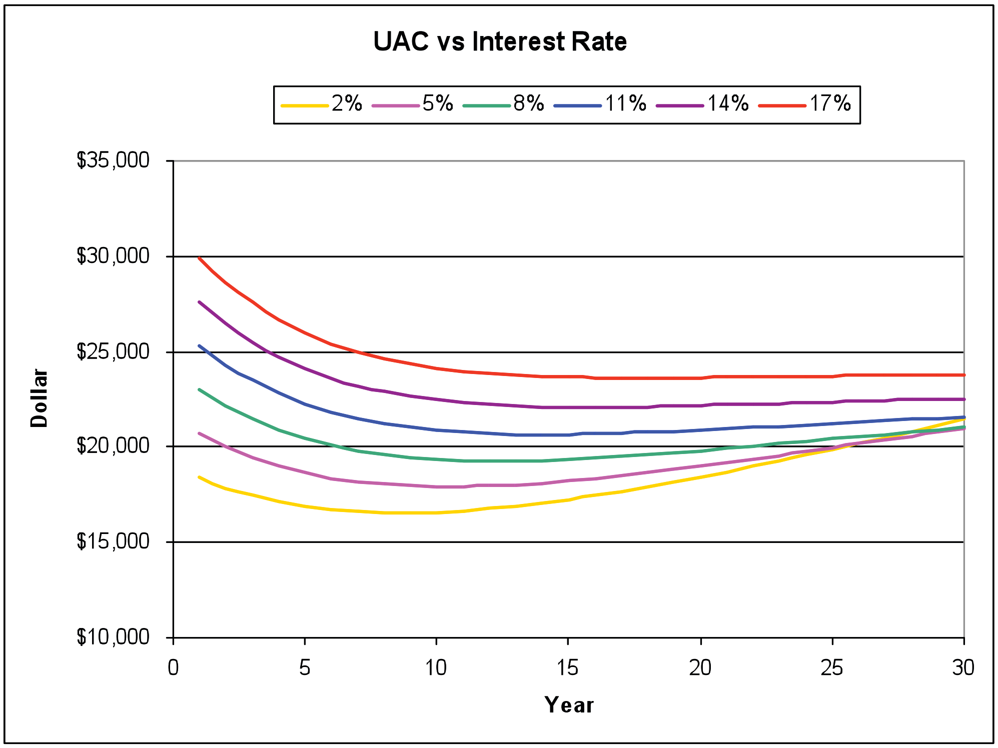


Figure 3-9 UAC vs Interest Rate

Interest Rate	2%	5%	8%	11%	14%	17%
Cost	$ 16,547	$ 17,919	$ 19,267	$ 20,644	$ 22,087	$ 23,622
Life Cycle	9	10	12	14	16	18

Table 3-3 Effects of different interest rates over life cycle

There are two effects if the interest rate increases:

- The increasing rate of maintenance cost decreases
- The positive effect of the selling value in the cash flow decreases

The decrease in the positive cash flow from selling the asset means that depreciation of the asset accelerates. Thus, the cost of ownership in the first years increases during these years. If the maintenance costs stayed the same, the optimum life cycle would also decrease because the cost of maintaining the asset would be higher than its depreciation earlier. Actually, the normal increase of operating costs decreases with higher interest rates. It seems that in the tradeoff of these two effects, the operating cost increase cannot balance the higher ownership costs and that is why the asset should not be replaced until later.

The different interest rates used in this analysis have a relatively high variation. The reason of this is this variation reflects the interest rates used in different types of companies or organizations.

3.4.3 Depreciation Years

Another change analyzed was the number of years used to depreciate vehicles using a double depreciation technique. The values used were 7, 9, 11, 13, 15, and 17 years, respectively. The number of years used in last year's research was 13.

Figure 3-10 shows how the UAC changes depending on how many years a vehicle takes to be depreciated. As the number of years a vehicle takes to be depreciated increases, the life cycle decreases.

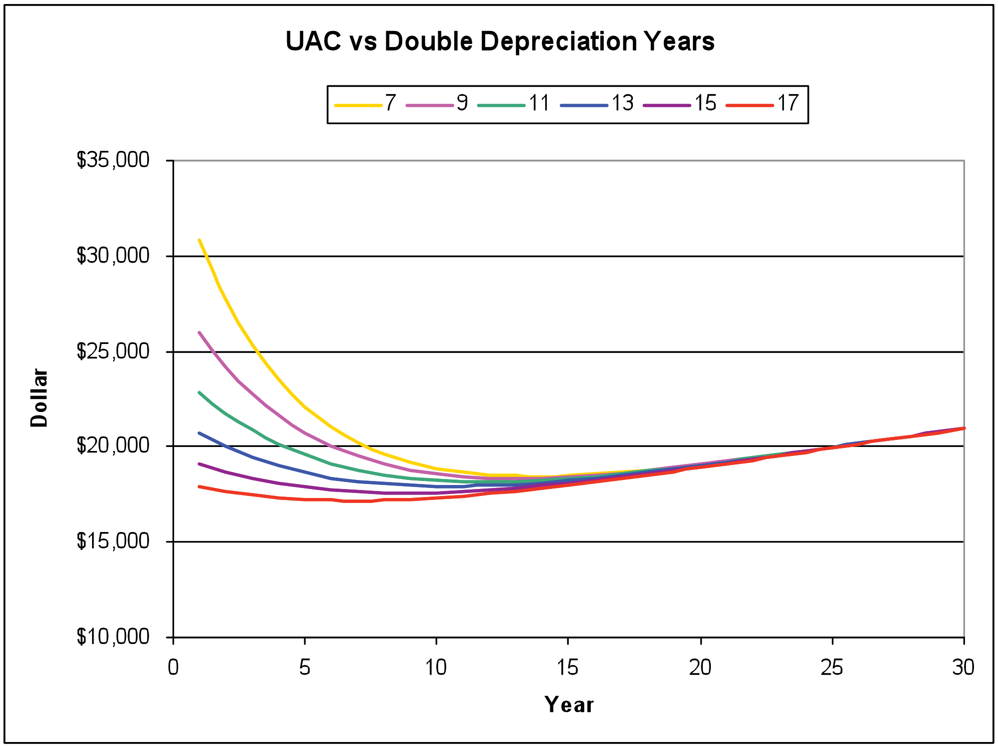


Figure 3-10 UAC vs Depreciation Years

Double Depreciation Years	7	9	11	13	15	17
Cost	$ 18,457	$ 18,353	$ 18,174	$ 17,919	$ 17,583	$ 17,175
Life Cycle	14	13	12	10	9	7

Table 3-4 Effects of different depreciation periods over life cycle

Increasing the depreciation period of the asset decreases the cost of ownership during the first years. This can be seen in Figure 3-10 where the beginning of each UAC curve decreases as the number of years of depreciation increases. Once the asset has been almost fully depreciated, the UAC only changes because of the operating expenses, making all UAC curves almost identical.

The reason the optimum life cycle decreases as the depreciation period increases is that operating expenses become greater than ownership cost earlier in the life cycle of the asset.

The effect of the number of years in which the asset is depreciated greatly affects the optimum life cycle. If the number of years used for depreciation is relatively high, there is not a big difference between yearly costs but a big difference in the optimum life cycle. This might be a problem when there is not enough information about selling prices or, even if there is a lot of information, they have a high degree of variability.

3.4.4 Initial Maintenance Cost

Another change analyzed was the initial maintenance cost. The values used were \$3,500, \$4,000, \$4,500, \$5,000, \$5,500, and \$6,000 respectively. The initial maintenance cost in the base case is \$5,000. This includes labor and parts, but not fuel.

Figure 3-11 shows how the UAC changes depending on the initial maintenance cost. There are three main effects with those changes. First, the optimum life cycle decreases as the initial maintenance cost is increased. The reason is that operating expenses balance ownership costs earlier in the life cycle. Second, the UAC curve grows quicker with an increase in the initial cost. This is due, in part, to how the maintenance cost is set up in the example. In this case, the annual cost is set to grow at a given percentage; thus, an increase of the initial cost generates an increase of all the subsequent costs. The net effect of this indirect effect is that it also helps to decrease the optimum life cycle. Finally, an increase of the initial maintenance cost, thus all the maintenance costs, makes the UAC increase for any given life cycle.

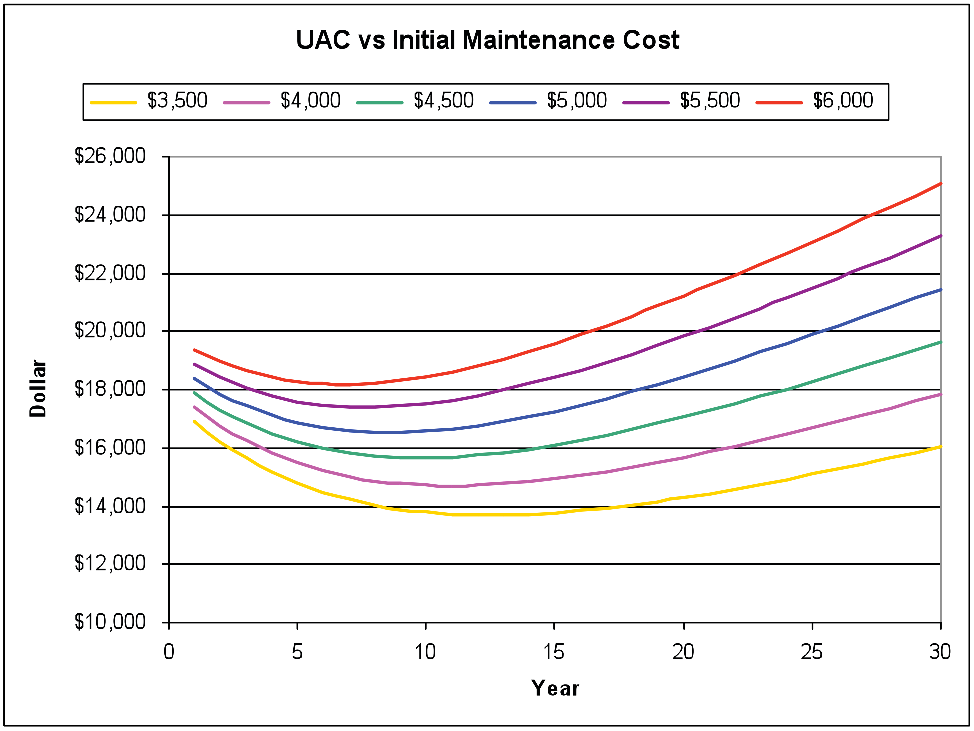


Figure 3-11 UAC vs Initial Maintenance Cost

Initial Maintenance Cost	$ 3,500	$ 4,000	$ 4,500	$ 5,000	$ 5,500	$ 6,000
Cost	$ 13,693	$ 14,702	$ 15,652	$ 16,547	$ 17,389	$ 18,186
Life Cycle	12	11	10	9	8	7

Table 3-5 Effects of different initial maintenance costs over life cycle

3.4.5 Maintenance Year Increase

Finally, an analysis was done to see how UAC and optimum life cycle change when there are changes in the maintenance cost yearly increase. The values used are 14, 16, 18, 20, 22, and 24 percent and the results are shown in Figure 3-12. The original value was 20 percent.

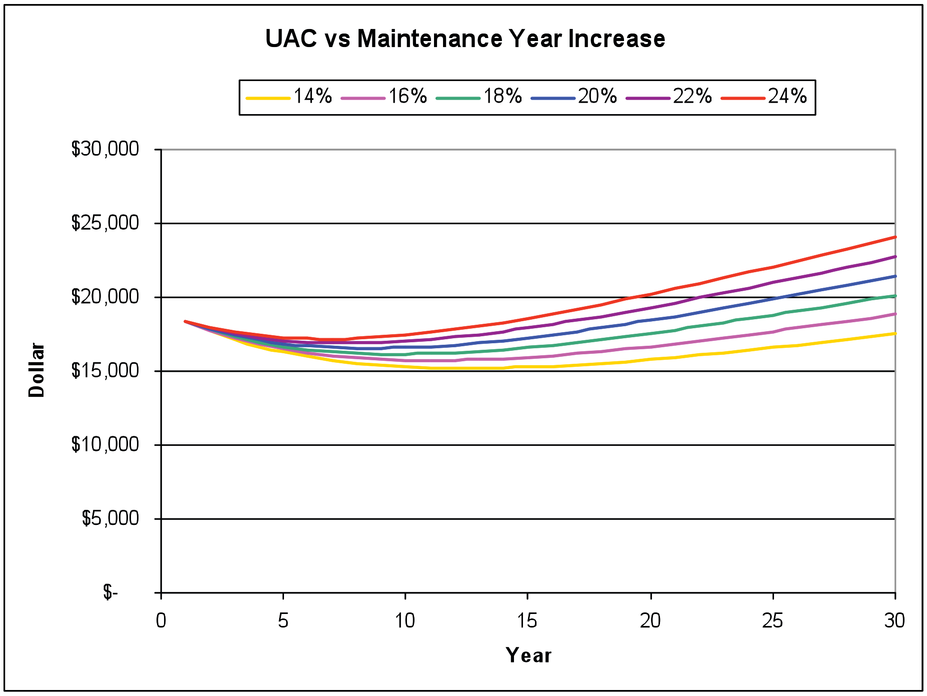


Figure 3-12 UAC vs Maintenance Year Increase

Maintenance Year Increase	14%	16%	18%	20%	22%	24%
Cost	$ 15,193	$ 15,702	$ 16,152	$ 16,547	$ 16,889	$ 17,186
Life Cycle	12	11	10	9	8	7

Table 3-6 Effects of different maintenance cost year increase over life cycle

There are two main effects when increasing the maintenance cost yearly increase. The first one is that the UAC curve grows quicker if there is an increase in that variable. Obviously, if maintenance costs increase more quickly, so does the UAC. A direct effect of this is that the optimum life cycle decreases as the variable increases. Increasing operating costs while having the cost of ownership fixed makes both balance each other earlier in the life cycle of the asset.

4 Analysis of MAPS Data

In order to validate the new methodology developed in this research, last year's research data were used so that results could be compared. These data included only class 330 vehicles used in Districts 1 and 6 of the Minnesota Department of Transportation.

The yearly average cost for this class of vehicles used in Districts 1 and 6, after fixing some obvious problems with the data, are shown in Figure 4-1 and Figure 4-2, respectively.

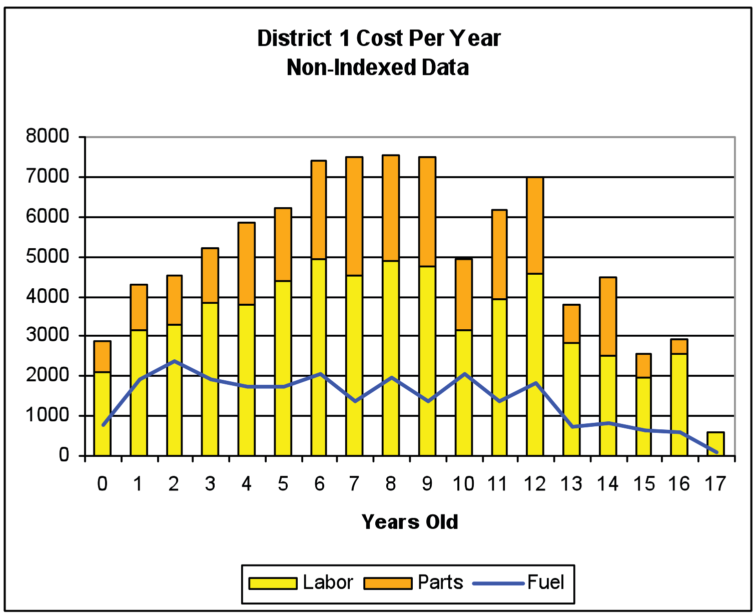


Figure 4-1 Cost of Class 330 - District 1 (MAPS Data)

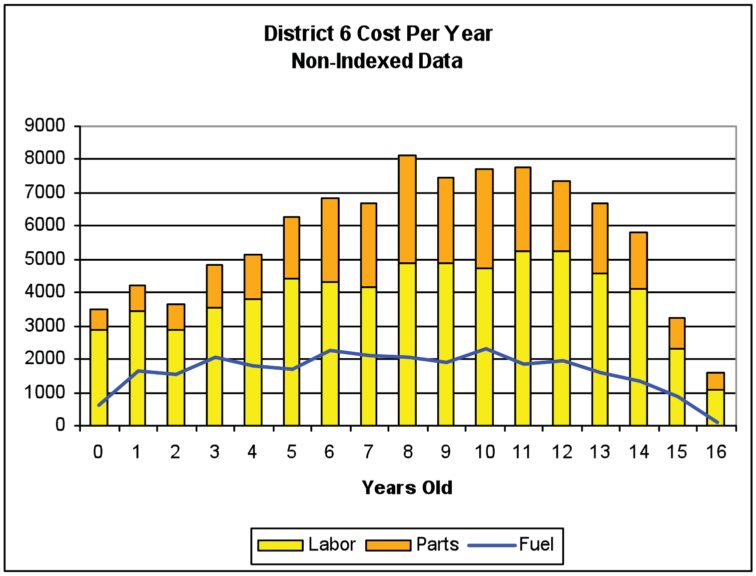


Figure 4-2 Cost of Class 330 - District 6 (MAPS Data)

After using the different price indexes to convert costs from nominal to current dollars as of December 2004, as explained in Section 3.1, the previous cost structures were changed as shown in Figure 4-3 and Figure 4-4, respectively.

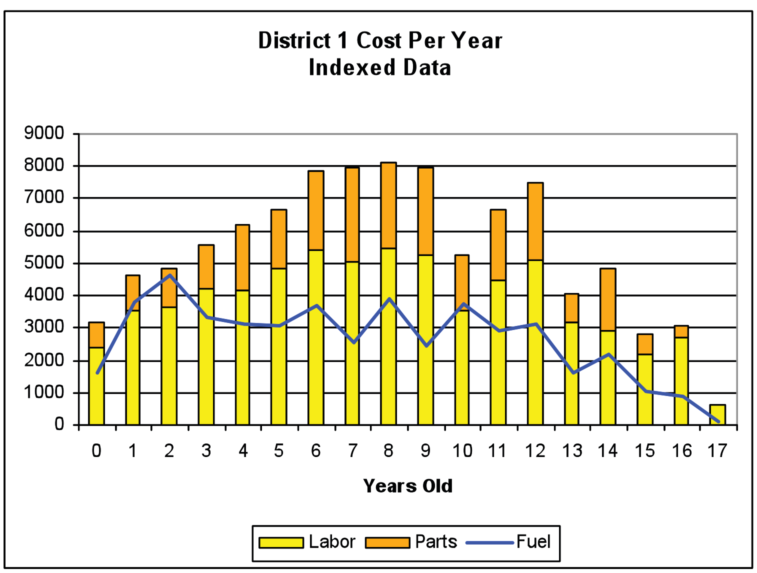


Figure 4-3 Cost of Class 330 - District 1 - Indexes (MAPS Data)

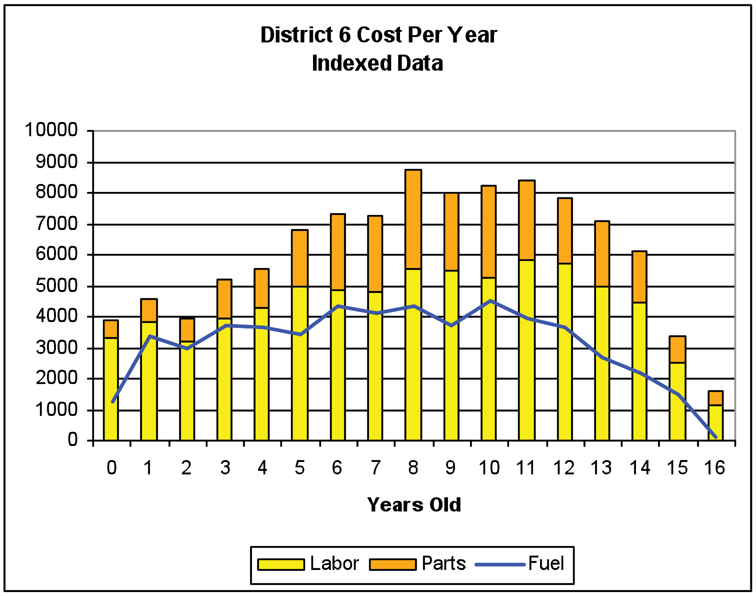


Figure 4-4 Cost of Class 330 - District 6 - Indexes (MAPS Data)

Finally, Figure 4-5 and Figure 4-6 show the cost structure when using both price indexes and overhead.

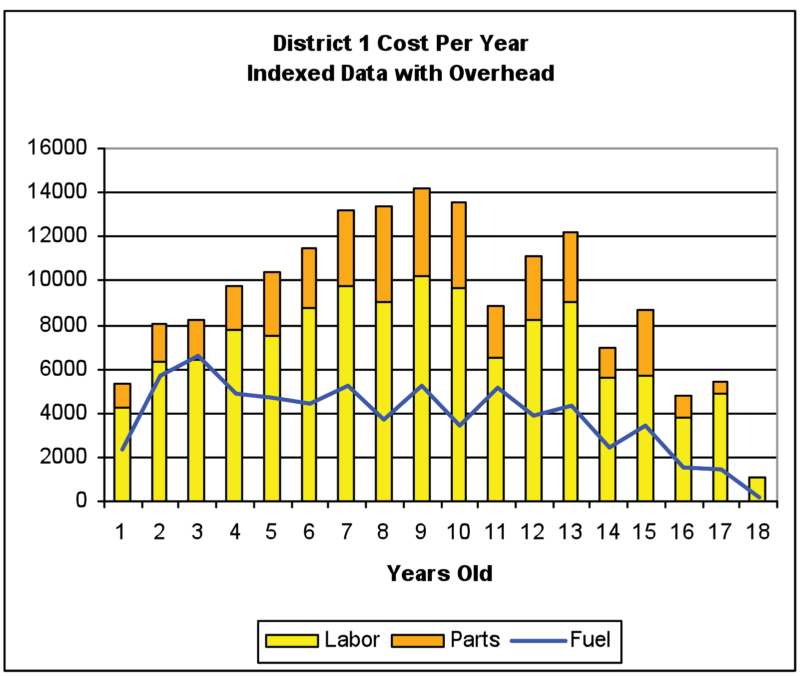


Figure 4-5 Cost of Class 330 - District 1 - Indexes and Overhead (MAPS Data)

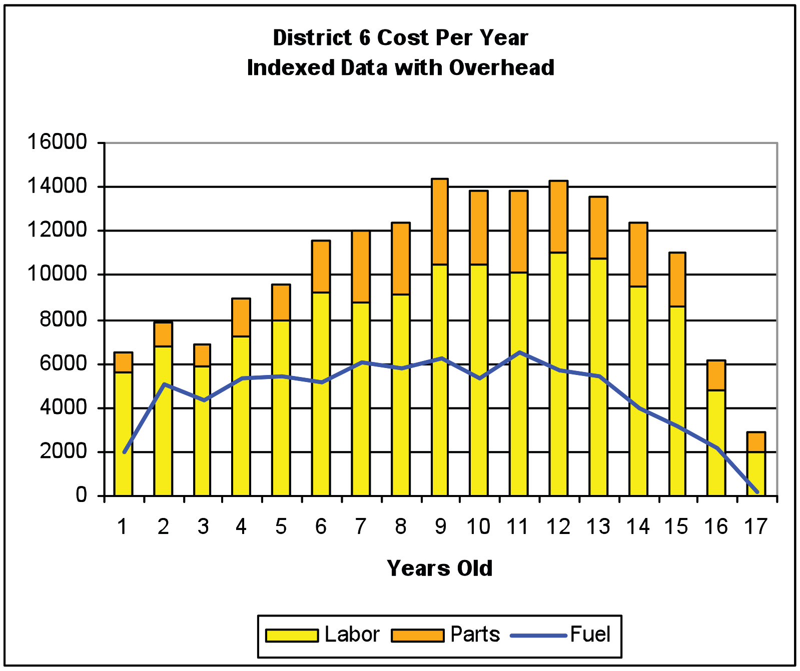


Figure 4-6 Cost of Class 330 - District 6 - Indexes and Overhead (MAPS Data)

The analysis of the previous cost structures showed an interesting behavior. For both districts, fuel consumption stays almost constant from year 1 to approximately year 12 and then it decreases constantly as the life of the vehicle increases. Fuel consumption can be considered an indirect measure of vehicle utilization. The pattern seen is congruent with Mn/DOT's life cycle policy. Currently, Mn/DOT utilizes a 12 year life cycle for class 330 vehicles. After that threshold, vehicles are either sold or put into reserve mode in order to be used only during peak demand periods.

On the other hand, parts and labor costs increase constantly through years 0 to 9-10, then they stabilize for a couple more years, and finally they decrease as the vehicle's age increases. Using the fuel cost information as a measurement of utilization, maintenance costs increase almost linearly as vehicles get older for the same utilization rate until they reach year 9 or 10.

From there to year 12, maintenance costs stall while vehicles are still used at the same pace. Finally, from that point on, maintenance costs decrease as fuel or utilization also decrease.

An explanation for the behavior of the 9 to 12 year old units is that some big maintenance items are not done when vehicles reach this age because Mn/DOT's people know they are close to the 12-year-old limit. It looks like a reasonable behavior. The behavior would be different if they would plan to keep those units until they are 20 years old, for example. The same behavior of not doing major maintenance can be extrapolated to the 12+ years lifetime. At the very moment an old unit experiences major breakdowns, it would put up for sale.

The behavior seen in those graphs complicates the LCC analysis. The reality is that if Mn/DOT's policy were different, the cost from year 9 on would have been different too. LCC analysis requires yearly cost data based on the same utilization level and it does not consider the human factor behavior explained before. For this reason, maintenance costs were simulated as if they change linearly with the age of the vehicle. A regression analysis was used on the total cost of maintenance for only the first 8-10 years, depending on how the pattern was observed.

The following sections contain the results of the analysis done considering different combinations of factors. Those factors are linear regression of total costs (parts and labor) or independent regression for each type of cost, usage of price indexes, and usage of overhead.

4.1 Simple Regression Analysis

This section contains the results of the analysis when using linear regression of the total maintenance costs.

4.1.1 Non-Indexed Data and No Overhead

Figure 4-7 and Figure 4-8 show the results of these regression analyses done for District 1 and District 6 class 330 vehicles with data taken from MAPS system. The correlation was done over the total maintenance costs. In this first initial analysis, the data were not indexed using PPI and CPI and did not contain overhead costs because that was how it was done in last year's research. More analyses were done taking into account indexed values and also overhead.

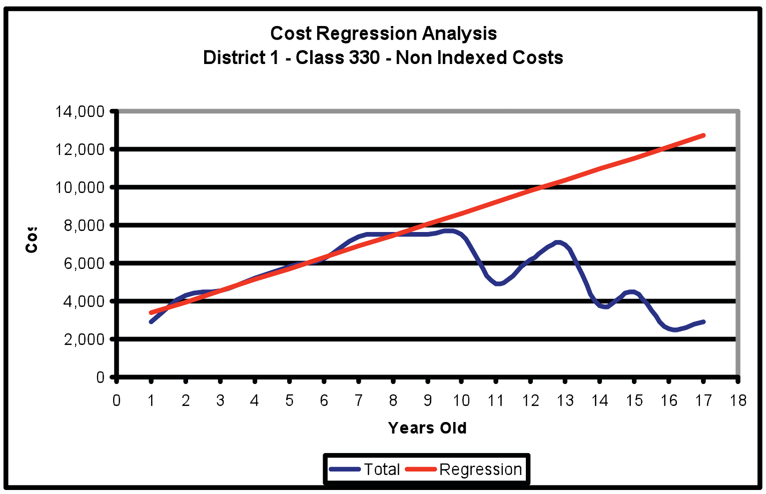


Figure 4-7 Cost Regression Analysis Result - District 1 – Non-Indexed Costs and No Overhead

The linear regression analysis for District 1 data generated the following results:

- Years used for correlation: 1 - 9
- Intercept: $2,804
- Yearly maintenance increase: $583
- Regression correlation: 97.86 %

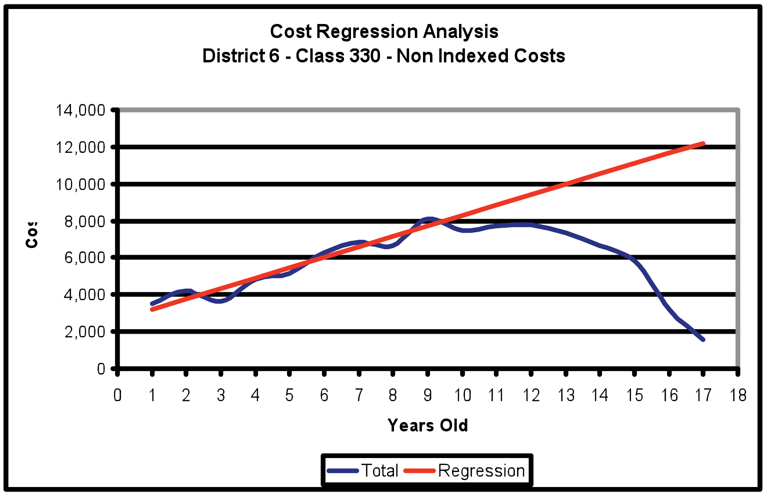


Figure 4-8 Cost Regression Analysis Result - District 6 – Non-Indexed Costs and No Overhead

The linear regression analysis for District 6 data generated the following results:

- Years used for correlation: 1 - 9
- Intercept: $2,665
- Yearly maintenance increase: $561
- Regression correlation: 96.50 %

Both linear regression analyses have a high correlation factor. More than 95 percent of the variation of the maintenance costs can be explained with the vehicle's increased age. At the same time, initial cost and yearly increases are very similar in both districts.

The calculated purchase cost for District 1 and 6, without using price indexes, were $76,429 and $67,622 respectively. A LCC analysis was done using these costs, double depreciation over 13 years, and 5 percent of interest rate. The results of these analyses are shown in Figure 4-9 and Figure 4-10 for District 1 and District 6, respectively.

District 1 Using cost without overhead and without indexes

Purchase:	$ 76,429	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 583	Depreciation (years):	13
Intercept:	$ 2,804		
Correlation:	97.86%		
Years used:	1 - 9		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 76,429	$ 76,429			
1		$ 64,671	$ 3,386	$ 18,063	$ 18,966
2		$ 54,721	$ 3,969	$ 33,620	$ 18,081
3		$ 46,303	$ 4,551	$ 47,187	$ 17,328
4		$ 39,179	$ 5,134	$ 59,176	$ 16,688
5		$ 33,152	$ 5,717	$ 69,913	$ 16,148
6		$ 28,051	$ 6,299	$ 79,656	$ 15,694
7		$ 23,736	$ 6,882	$ 88,611	$ 15,314
8		$ 20,084	$ 7,464	$ 96,937	$ 14,998
9		$ 16,994	$ 8,047	$ 104,764	$ 14,739
10		$ 14,380	$ 8,629	$ 112,188	$ 14,529
11		$ 12,167	$ 9,212	$ 119,288	$ 14,361
12		$ 10,296	$ 9,795	$ 126,123	$ 14,230
13		$ 8,712	$ 10,377	$ 132,739	$ 14,131
14		$ 7,371	$ 10,960	$ 139,172	$ 14,060
15		$ 6,237	$ 11,542	$ 145,447	$ 14,013
16		$ 5,278	$ 12,125	$ 151,584	$ 13,987
17		$ 4,466	$ 12,708	$ 157,597	$ 13,979
18		$ 3,779	$ 13,290	$ 163,498	$ 13,987
19		$ 3,197	$ 13,873	$ 169,293	$ 14,008
20		$ 2,705	$ 14,455	$ 174,986	$ 14,041
21		$ 2,289	$ 15,038	$ 180,582	$ 14,085
22		$ 1,937	$ 15,620	$ 186,081	$ 14,137
23		$ 1,639	$ 16,203	$ 191,485	$ 14,196
24		$ 1,387	$ 16,786	$ 196,794	$ 14,262
25		$ 1,174	$ 17,368	$ 202,006	$ 14,333

Min	**$13,979**
Year	**17**

Figure 4-9 Life Cycle Cost Analysis - District 1 – Non-Indexed and No Overhead

District 6 Using cost without overhead and without indexes

Purchase	$ 67,622	Interest Rate: 5%

Maintenance Linear Regression

Slope	$ 561	Depreciation (years): 13
Intercept	$ 2,665	
Correlation:	96.50%	
Years used:	1 - 11	

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 67,622	$ 67,622			
1		$ 57,218	$ 3,227	$ 16,201	$ 17,011
2		$ 48,416	$ 3,788	$ 30,217	$ 16,251
3		$ 40,967	$ 4,350	$ 42,499	$ 15,606
4		$ 34,664	$ 4,911	$ 53,410	$ 15,062
5		$ 29,331	$ 5,473	$ 63,235	$ 14,606
6		$ 24,819	$ 6,034	$ 72,199	$ 14,224
7		$ 21,001	$ 6,595	$ 80,482	$ 13,909
8		$ 17,770	$ 7,157	$ 88,223	$ 13,650
9		$ 15,036	$ 7,718	$ 95,534	$ 13,441
10		$ 12,723	$ 8,280	$ 102,498	$ 13,274
11		$ 10,765	$ 8,841	$ 109,184	$ 13,145
12		$ 9,109	$ 9,403	$ 115,641	$ 13,047
13		$ 7,708	$ 9,964	$ 121,910	$ 12,978
14		$ 6,522	$ 10,525	$ 128,020	$ 12,933
15		$ 5,519	$ 11,087	$ 133,992	$ 12,909
16		$ 4,670	$ 11,648	$ 139,844	$ 12,903
17		$ 3,951	$ 12,210	$ 145,586	$ 12,913
18		$ 3,343	$ 12,771	$ 151,228	$ 12,937
19		$ 2,829	$ 13,333	$ 156,774	$ 12,972
20		$ 2,394	$ 13,894	$ 162,228	$ 13,018
21		$ 2,025	$ 14,456	$ 167,591	$ 13,071
22		$ 1,714	$ 15,017	$ 172,866	$ 13,133
23		$ 1,450	$ 15,578	$ 178,052	$ 13,200
24		$ 1,227	$ 16,140	$ 183,148	$ 13,273
25		$ 1,038	$ 16,701	$ 188,154	$ 13,350

Min	**$12,903**
Year	**16**

Figure 4-10 Life Cycle Cost Analysis District 6 – Non-Indexed and No Overhead

The optimum life cycle cost for District 1 is obtained when vehicles are replaced after 17 years, resulting in an estimated annual cost of $13,979. Vehicles from District 6, on the other hand, should be replaced when they are 16 years old and their annual cost is $12,903.

4.1.2 Indexed Data and No Overhead

Price indexes have to be used in order to avoid comparing absolute costs without taking into account the difference in the value of money and inflation factors. For a detailed explanation, refer to Section 3.1.

Figure 4-11 and Figure 4-12 show the results of these regression analyses done for District 1 and District 6 class 330 vehicles with data taken from MAPS system after applying PPI and CPI indexes to the different cost data. The indexed costs are expressed as December 2004 values. The correlation was done over the total maintenance costs. In this analysis, the data do not contain overhead costs.

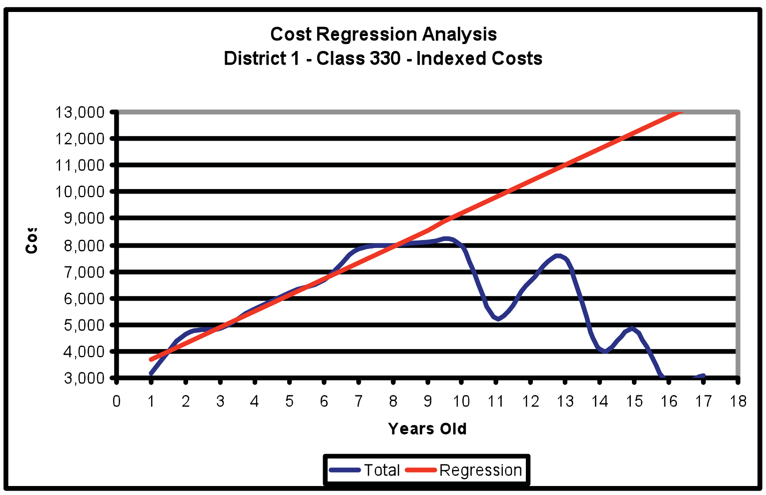


Figure 4-11 Cost Regression Analysis Result - District 1 – Indexed Costs and No Overhead

The linear regression analysis for District 1 data generated the following results:

- Years used for correlation: 1 - 9
- Intercept: $3,061
- Yearly maintenance increase: $611
- Regression correlation: 98.15 %

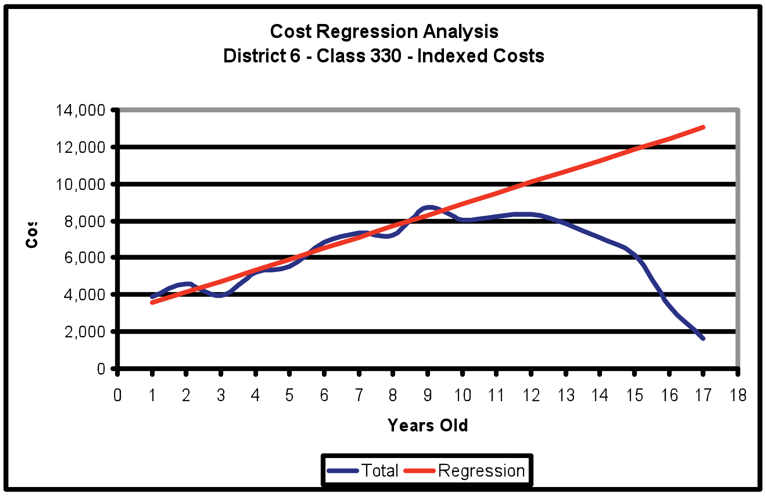


Figure 4-12 Cost Regression Analysis Result - District 6 - Indexed Costs and No Overhead

The linear regression analysis for District 6 data generated the following results:

- Years used for correlation: 1 - 9
- Intercept: $2,961
- Yearly maintenance increase: $593
- Regression correlation: 96.37 %

Again, both linear regression analyses have a correlation factor greater than 95 percent. At the same time, initial cost and yearly increases are very similar in both districts.

The calculated purchase cost for District 1 and 6, without using price indexes, were $77,908 and $73,800 respectively. A LCC analysis was done using these costs, double depreciation over 13 years, and 5 percent of interest rate. The results of these analyses are shown in Figure 4-13 and Figure 4-14 for District 1 and District 6, respectively.

District 1 Using indexes and cost without overhead

Purchase:	$ 77,908	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 611	Depreciation (years):	13
Intercept:	$ 3,061		
Correlation:	98.15%		
Years used:	1 - 9		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 77,908	$ 77,908			
1		$ 65,922	$ 3,672	$ 18,622	$ 19,553
2		$ 55,780	$ 4,283	$ 34,695	$ 18,659
3		$ 47,199	$ 4,894	$ 48,745	$ 17,900
4		$ 39,937	$ 5,505	$ 61,190	$ 17,256
5		$ 33,793	$ 6,116	$ 72,361	$ 16,713
6		$ 28,594	$ 6,727	$ 82,521	$ 16,258
7		$ 24,195	$ 7,338	$ 91,879	$ 15,878
8		$ 20,473	$ 7,949	$ 100,597	$ 15,565
9		$ 17,323	$ 8,560	$ 108,805	$ 15,308
10		$ 14,658	$ 9,171	$ 116,604	$ 15,101
11		$ 12,403	$ 9,782	$ 124,070	$ 14,937
12		$ 10,495	$ 10,394	$ 131,266	$ 14,810
13		$ 8,880	$ 11,005	$ 138,236	$ 14,716
14		$ 7,514	$ 11,616	$ 145,017	$ 14,650
15		$ 6,358	$ 12,227	$ 151,635	$ 14,609
16		$ 5,380	$ 12,838	$ 158,110	$ 14,589
17		$ 4,552	$ 13,449	$ 164,456	$ 14,587
18		$ 3,852	$ 14,060	$ 170,684	$ 14,601
19		$ 3,259	$ 14,671	$ 176,800	$ 14,629
20		$ 2,758	$ 15,282	$ 182,811	$ 14,669
21		$ 2,334	$ 15,893	$ 188,717	$ 14,719
22		$ 1,975	$ 16,504	$ 194,522	$ 14,778
23		$ 1,671	$ 17,115	$ 200,225	$ 14,844
24		$ 1,414	$ 17,726	$ 205,827	$ 14,916
25		$ 1,196	$ 18,337	$ 211,327	$ 14,994

Min	**$14,587**
Year	**17**

Figure 4-13 Life Cycle Cost Analysis - District 1 - Indexed and No Overhead

District 6 Using indexes and cost without overhead

Purchase	$ 73,800	Interest Rate:	5%

Maintenance Linear Regression

Slope	$ 593	Depreciation (years):	13
Intercept	$ 2,961		
Correlation:	96.37%		
Years used:	1 - 11		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 73,800	$ 73,800			
1		$ 62,446	$ 3,554	$ 17,712	$ 18,597
2		$ 52,839	$ 4,147	$ 33,019	$ 17,758
3		$ 44,710	$ 4,740	$ 46,418	$ 17,045
4		$ 37,831	$ 5,333	$ 58,303	$ 16,442
5		$ 32,011	$ 5,926	$ 68,989	$ 15,935
6		$ 27,086	$ 6,519	$ 78,723	$ 15,510
7		$ 22,919	$ 7,112	$ 87,701	$ 15,157
8		$ 19,393	$ 7,705	$ 96,079	$ 14,865
9		$ 16,410	$ 8,298	$ 103,976	$ 14,628
10		$ 13,885	$ 8,891	$ 111,488	$ 14,438
11		$ 11,749	$ 9,484	$ 118,688	$ 14,289
12		$ 9,941	$ 10,078	$ 125,634	$ 14,175
13		$ 8,412	$ 10,671	$ 132,367	$ 14,091
14		$ 7,118	$ 11,264	$ 138,922	$ 14,034
15		$ 6,023	$ 11,857	$ 145,324	$ 14,001
16		$ 5,096	$ 12,450	$ 151,589	$ 13,987
17		$ 4,312	$ 13,043	$ 157,733	$ 13,991
18		$ 3,649	$ 13,636	$ 163,765	$ 14,009
19		$ 3,087	$ 14,229	$ 169,690	$ 14,041
20		$ 2,612	$ 14,822	$ 175,513	$ 14,084
21		$ 2,211	$ 15,415	$ 181,238	$ 14,136
22		$ 1,870	$ 16,008	$ 186,864	$ 14,196
23		$ 1,583	$ 16,602	$ 192,393	$ 14,263
24		$ 1,339	$ 17,195	$ 197,825	$ 14,337
25		$ 1,133	$ 17,788	$ 203,158	$ 14,415

Min	**$13,987**
Year	**16**

Figure 4-14 Life Cycle Cost Analysis - District 6 - Indexed and No Overhead

The optimum life cycle cost for District 1 is obtained when vehicles are replaced after 17 years, resulting in an estimated annual cost of $14,587. Vehicles from District 6, on the other hand, should be replaced when they are 16 years old and their annual cost is $13,987.

4.1.3 Indexed Data and Overhead

Figure 4-15 and Figure 4-16 show the results of these regression analyses done for District 1 and District 6 class 330 vehicles with data taken from MAPS system after applying price indexes to the different cost data and taking into account overhead costs. The indexed costs are expressed as December 2004 values. The correlation was done over the total maintenance costs.

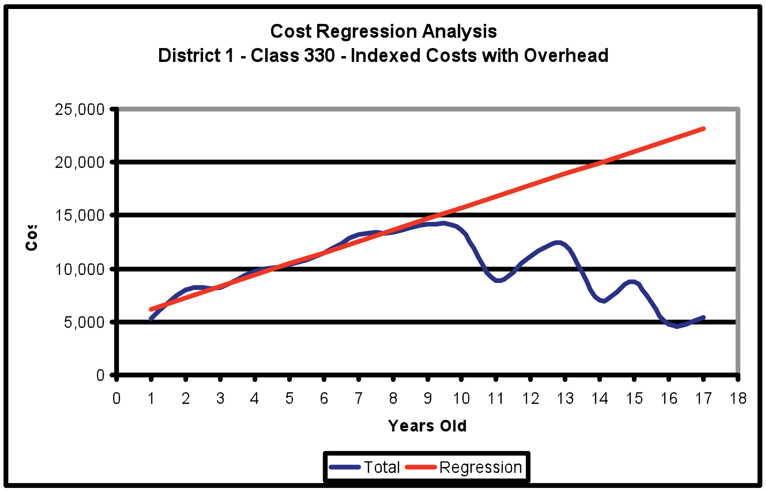


Figure 4-15 Cost Regression Analysis Result - District 1 – Indexed Costs and Overhead

The linear regression analysis for District 1 data generated the following results:

- Years used for correlation: 1 - 9
- Intercept: $5,161
- Yearly maintenance increase: $1,057
- Regression correlation: 98.44 %

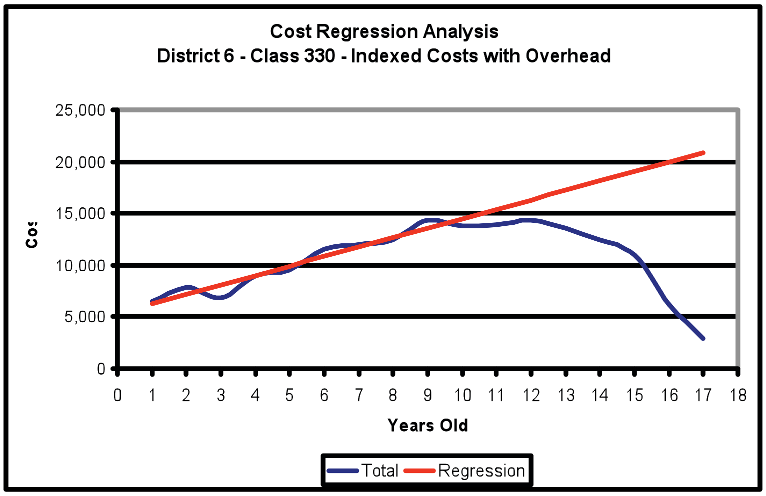


Figure 4-16 Cost Regression Analysis Result - District 6 – Indexed Costs and Overhead

The linear regression analysis for District 6 data generated the following results:

- Years used for correlation: 1 - 10
- Intercept: $5,366
- Yearly maintenance increase: $911
- Regression correlation: 97.30 %

Again, both linear regression analyses have a high correlation factor. Also, initial cost and yearly increases are very similar in both districts.

The calculated purchase cost for District 1 and 6, without using price indexes, were $77,908 and $73,800 respectively. A life cycle cost analysis was done using these costs, double depreciation over 13 years, and 5 percent of interest rate. The results of these analyses are shown in Figure 4-17 and Figure 4-18 for District 1 and District 6, respectively.

District 1 Using indexes and cost with overhead

Purchase:	$ 77,908	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 1,057	Depreciation (years):	13
Intercept:	$ 5,161		
Correlation:	98.44%		
Years used:	1 - 9		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 77,908	$ 77,908			
1		$ 65,922	$ 6,218	$ 21,047	$ 22,099
2		$ 55,780	$ 7,275	$ 39,835	$ 21,423
3		$ 47,199	$ 8,333	$ 56,855	$ 20,878
4		$ 39,937	$ 9,390	$ 72,496	$ 20,445
5		$ 33,793	$ 10,447	$ 87,060	$ 20,109
6		$ 28,594	$ 11,505	$ 100,785	$ 19,857
7		$ 24,195	$ 12,562	$ 113,855	$ 19,676
8		$ 20,473	$ 13,619	$ 126,412	$ 19,559
9		$ 17,323	$ 14,676	$ 138,562	$ 19,494
10		$ 14,658	$ 15,734	$ 150,389	$ 19,476
11		$ 12,403	$ 16,791	$ 161,954	$ 19,497
12		$ 10,495	$ 17,848	$ 173,300	$ 19,553
13		$ 8,880	$ 18,906	$ 184,461	$ 19,637
14		$ 7,514	$ 19,963	$ 195,458	$ 19,746
15		$ 6,358	$ 21,020	$ 206,306	$ 19,876
16		$ 5,380	$ 22,078	$ 217,013	$ 20,024
17		$ 4,552	$ 23,135	$ 227,586	$ 20,187
18		$ 3,852	$ 24,192	$ 238,024	$ 20,362
19		$ 3,259	$ 25,249	$ 248,326	$ 20,548
20		$ 2,758	$ 26,307	$ 258,491	$ 20,742
21		$ 2,334	$ 27,364	$ 268,515	$ 20,943
22		$ 1,975	$ 28,421	$ 278,394	$ 21,150
23		$ 1,671	$ 29,479	$ 288,122	$ 21,360
24		$ 1,414	$ 30,536	$ 297,696	$ 21,574
25		$ 1,196	$ 31,593	$ 307,111	$ 21,790

Min	**$19,476**
Year	**10**

Figure 4-17 Life Cycle Cost Analysis - District 1 - Indexed and Overhead

District 6 Using indexes and cost with overhead

Purchase	$ 73,800	Interest Rate:	5%

Maintenance Linear Regression

Slope	$ 911	Depreciation (years):	13
Intercept	$ 5,366		
Correlation:	97.30%		
Years used:	1 - 10		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 73,800	$ 73,800			
1		$ 62,446	$ 6,277	$ 20,305	$ 21,321
2		$ 52,839	$ 7,188	$ 38,371	$ 20,636
3		$ 44,710	$ 8,099	$ 54,672	$ 20,076
4		$ 37,831	$ 9,010	$ 69,582	$ 19,623
5		$ 32,011	$ 9,921	$ 83,398	$ 19,263
6		$ 27,086	$ 10,832	$ 96,351	$ 18,983
7		$ 22,919	$ 11,744	$ 108,621	$ 18,772
8		$ 19,393	$ 12,655	$ 120,348	$ 18,621
9		$ 16,410	$ 13,566	$ 131,641	$ 18,521
10		$ 13,885	$ 14,477	$ 142,582	$ 18,465
11		$ 11,749	$ 15,388	$ 153,234	$ 18,448
12		$ 9,941	$ 16,299	$ 163,644	$ 18,463
13		$ 8,412	$ 17,210	$ 173,845	$ 18,507
14		$ 7,118	$ 18,121	$ 183,864	$ 18,575
15		$ 6,023	$ 19,032	$ 193,717	$ 18,663
16		$ 5,096	$ 19,944	$ 203,416	$ 18,769
17		$ 4,312	$ 20,855	$ 212,968	$ 18,890
18		$ 3,649	$ 21,766	$ 222,377	$ 19,024
19		$ 3,087	$ 22,677	$ 231,646	$ 19,168
20		$ 2,612	$ 23,588	$ 240,773	$ 19,320
21		$ 2,211	$ 24,499	$ 249,758	$ 19,480
22		$ 1,870	$ 25,410	$ 258,598	$ 19,646
23		$ 1,583	$ 26,321	$ 267,292	$ 19,816
24		$ 1,339	$ 27,233	$ 275,836	$ 19,990
25		$ 1,133	$ 28,144	$ 284,228	$ 20,167

Min	**$18,448**
Year	**11**

Figure 4-18 Life Cycle Cost Analysis - District 6 – Indexed and Overhead

The optimum life cycle cost for District 1 is obtained when vehicles are replaced after 10 years, resulting in an estimated annual cost of $19,476. Vehicles from District 6, on the other hand, should be replaced when they are 11 years old and their annual cost is $18,448.

4.2 Double Regression Analysis

This section contains the results of the analysis when using linear regression of parts and labor costs independently.

4.2.1 Non-Indexed Data and No Overhead

Figure 4-19 and Figure 4-20 show the results of these regression analyses done for District 1 and District 6 class 330 vehicles with data taken from MAPS system. The two lower graphs represent the results of the regression analysis performed over parts and labor costs. The first graph shows the result of combining those two regressions. In this first initial analysis the data were not indexed and it did not contain overhead costs because that was how it was done in last year's research. More analyses were done taking into account indexed values and also overhead.

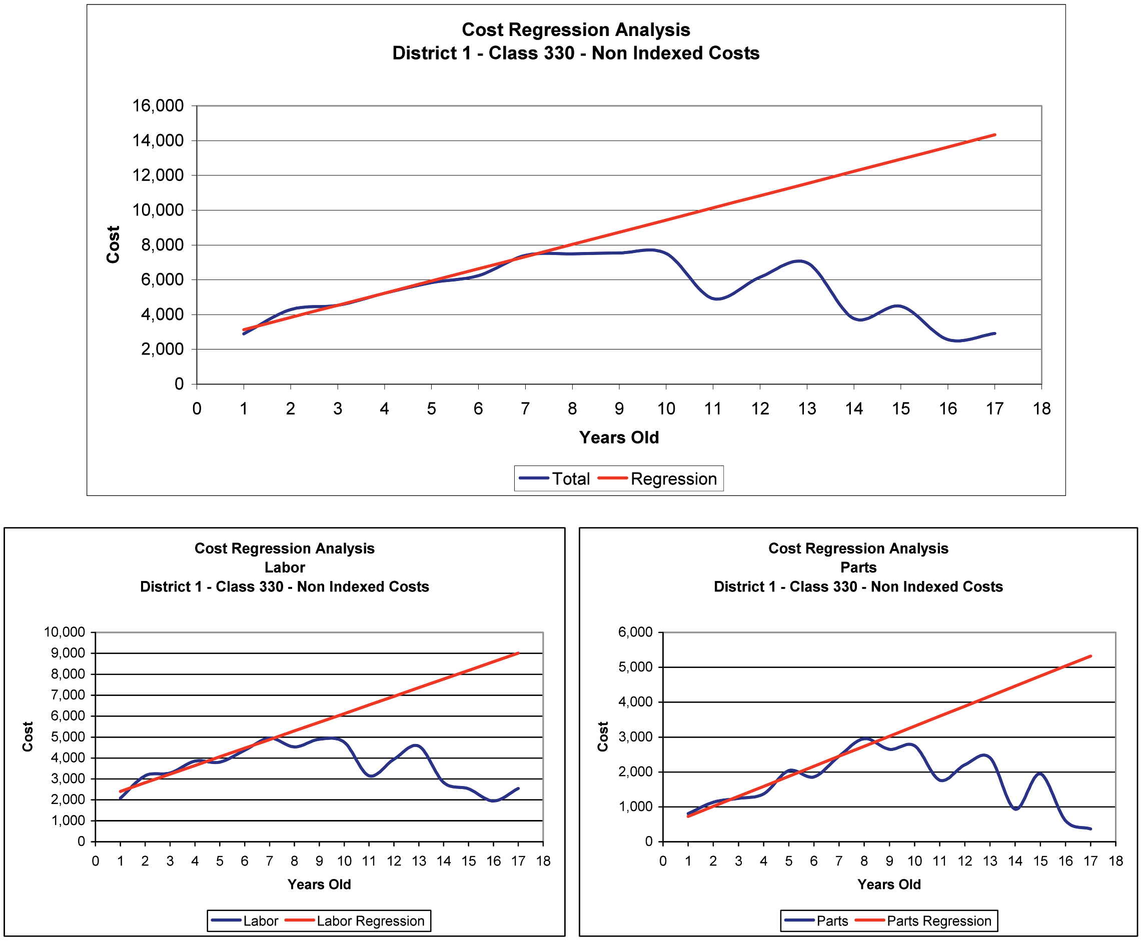


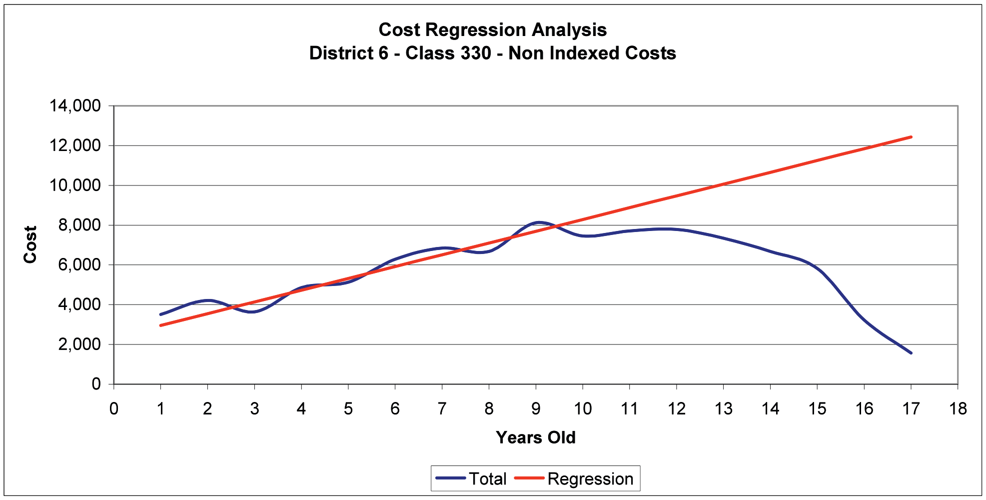
Figure 4-19 Cost Regression Analysis Result - District 1 – Non-Indexed Costs and No Overhead

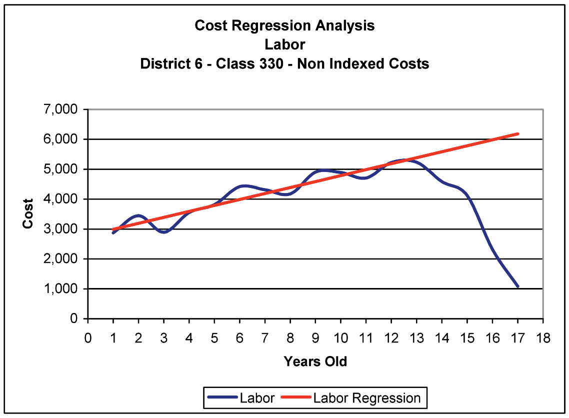
The linear regression analyses for District 1 data generated the following results:

- Labor:
    - Years used for correlation: 1 - 7
    - Intercept: $1,994
    - Yearly maintenance increase: $413
    - Regression correlation: 96.61 %
- Parts:
    - Years used for correlation: 1 - 8
    - Intercept: $439

- Yearly maintenance increase: $287
- Regression correlation: 96.75 %

- Total:
  - Intercept: $2,433
  - Yearly maintenance increase: $700





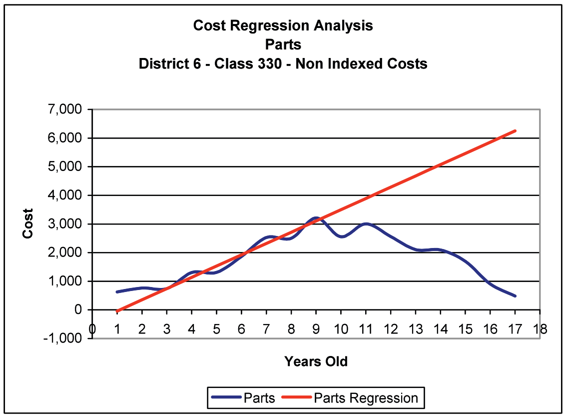


Figure 4-20 Cost Regression Analysis Result - District 6 – Non-Indexed Costs and No Overhead

The linear regression analysis for District 6 data generated the following results:

- Labor:
  - Years used for correlation: 1 - 13
  - Intercept: $2,792

  - Yearly maintenance increase: $199
  - Regression correlation: 94.96 %
- Parts:
  - Years used for correlation: 3 - 9
  - Intercept: - $435
  - Yearly maintenance increase: $393
  - Regression correlation: 98.02 %
- Total:
  - Intercept: $2,357
  - Yearly maintenance increase: $593

Every linear regression analysis has a high correlation factor, as has happened in the other cases.

The calculated purchase cost for District 1 and 6, without using price indexes, were $76,429 and $67,622 respectively. A life cycle cost analysis was done using these costs, double depreciation over 13 years, and 5 percent of interest rate. The results of these analyses are shown in Figure 4-21 and Figure 4-22 for District 1 and District 6, respectively.

District 1 Using cost without overhead and without indexes

Purchase:	$ 76,429	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 700	Depreciation (years):	13
Intercept:	$ 2,433		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 76,429	$ 76,429			
1		$ 64,671	$ 3,133	$ 17,822	$ 18,713
2		$ 54,721	$ 3,833	$ 33,256	$ 17,885
3		$ 46,303	$ 4,533	$ 46,808	$ 17,188
4		$ 39,179	$ 5,233	$ 58,878	$ 16,604
5		$ 33,152	$ 5,934	$ 69,785	$ 16,119
6		$ 28,051	$ 6,634	$ 79,778	$ 15,718
7		$ 23,736	$ 7,334	$ 89,054	$ 15,390
8		$ 20,084	$ 8,034	$ 97,766	$ 15,127
9		$ 16,994	$ 8,734	$ 106,035	$ 14,918
10		$ 14,380	$ 9,434	$ 113,954	$ 14,758
11		$ 12,167	$ 10,134	$ 121,593	$ 14,638
12		$ 10,296	$ 10,834	$ 129,007	$ 14,555
13		$ 8,712	$ 11,534	$ 136,237	$ 14,503
14		$ 7,371	$ 12,235	$ 143,313	$ 14,478
15		$ 6,237	$ 12,935	$ 150,258	$ 14,476
16		$ 5,278	$ 13,635	$ 157,086	$ 14,494
17		$ 4,466	$ 14,335	$ 163,810	$ 14,530
18		$ 3,779	$ 15,035	$ 170,436	$ 14,580
19		$ 3,197	$ 15,735	$ 176,967	$ 14,643
20		$ 2,705	$ 16,435	$ 183,407	$ 14,717
21		$ 2,289	$ 17,135	$ 189,756	$ 14,800
22		$ 1,937	$ 17,835	$ 196,012	$ 14,891
23		$ 1,639	$ 18,536	$ 202,176	$ 14,989
24		$ 1,387	$ 19,236	$ 208,244	$ 15,092
25		$ 1,174	$ 19,936	$ 214,214	$ 15,199

Min	**$14,476**
Year	**15**

Figure 4-21 Life Cycle Cost Analysis - District 1 – Non-Indexed and No Overhead

District 6 Using cost without overhead and without indexes

Purchase	$ 67,622			Interest Rate:	5%
Maintenance Linear Regression					
Slope	$ 593			Depreciation (years):	13
Intercept	$ 2,357				

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 67,622	$ 67,622			
1		$ 57,218	$ 2,950	$ 15,937	$ 16,734
2		$ 48,416	$ 3,543	$ 29,730	$ 15,989
3		$ 40,967	$ 4,135	$ 41,828	$ 15,360
4		$ 34,664	$ 4,728	$ 52,588	$ 14,830
5		$ 29,331	$ 5,321	$ 62,293	$ 14,388
6		$ 24,819	$ 5,914	$ 71,168	$ 14,021
7		$ 21,001	$ 6,506	$ 79,387	$ 13,720
8		$ 17,770	$ 7,099	$ 87,090	$ 13,475
9		$ 15,036	$ 7,692	$ 94,383	$ 13,279
10		$ 12,723	$ 8,285	$ 101,351	$ 13,125
11		$ 10,765	$ 8,877	$ 108,057	$ 13,009
12		$ 9,109	$ 9,470	$ 114,552	$ 12,924
13		$ 7,708	$ 10,063	$ 120,874	$ 12,868
14		$ 6,522	$ 10,656	$ 127,049	$ 12,835
15		$ 5,519	$ 11,248	$ 133,099	$ 12,823
16		$ 4,670	$ 11,841	$ 139,039	$ 12,829
17		$ 3,951	$ 12,434	$ 144,879	$ 12,851
18		$ 3,343	$ 13,026	$ 150,626	$ 12,886
19		$ 2,829	$ 13,619	$ 156,286	$ 12,932
20		$ 2,394	$ 14,212	$ 161,859	$ 12,988
21		$ 2,025	$ 14,805	$ 167,349	$ 13,053
22		$ 1,714	$ 15,397	$ 172,753	$ 13,124
23		$ 1,450	$ 15,990	$ 178,073	$ 13,202
24		$ 1,227	$ 16,583	$ 183,307	$ 13,284
25		$ 1,038	$ 17,176	$ 188,452	$ 13,371

Min	**$12,823**
Year	**15**

Figure 4-22 Life Cycle Cost Analysis District 6 – Non-Indexed and No Overhead

The optimum life cycle cost for District 1 is obtained when vehicles are replaced after 15 years, resulting in an estimated annual cost of $14,476. Vehicles from District 6, on the other hand, should be replaced when they are 15 years old and their annual cost is $12,823.

4.2.2 Indexed Data and No Overhead

Figure 4-23 and Figure 4-24 show the results of these regression analyses done for District 1 and District 6 class 330 vehicles with data taken from MAPS system. In this analysis, the data were indexed but did not contain overhead costs.

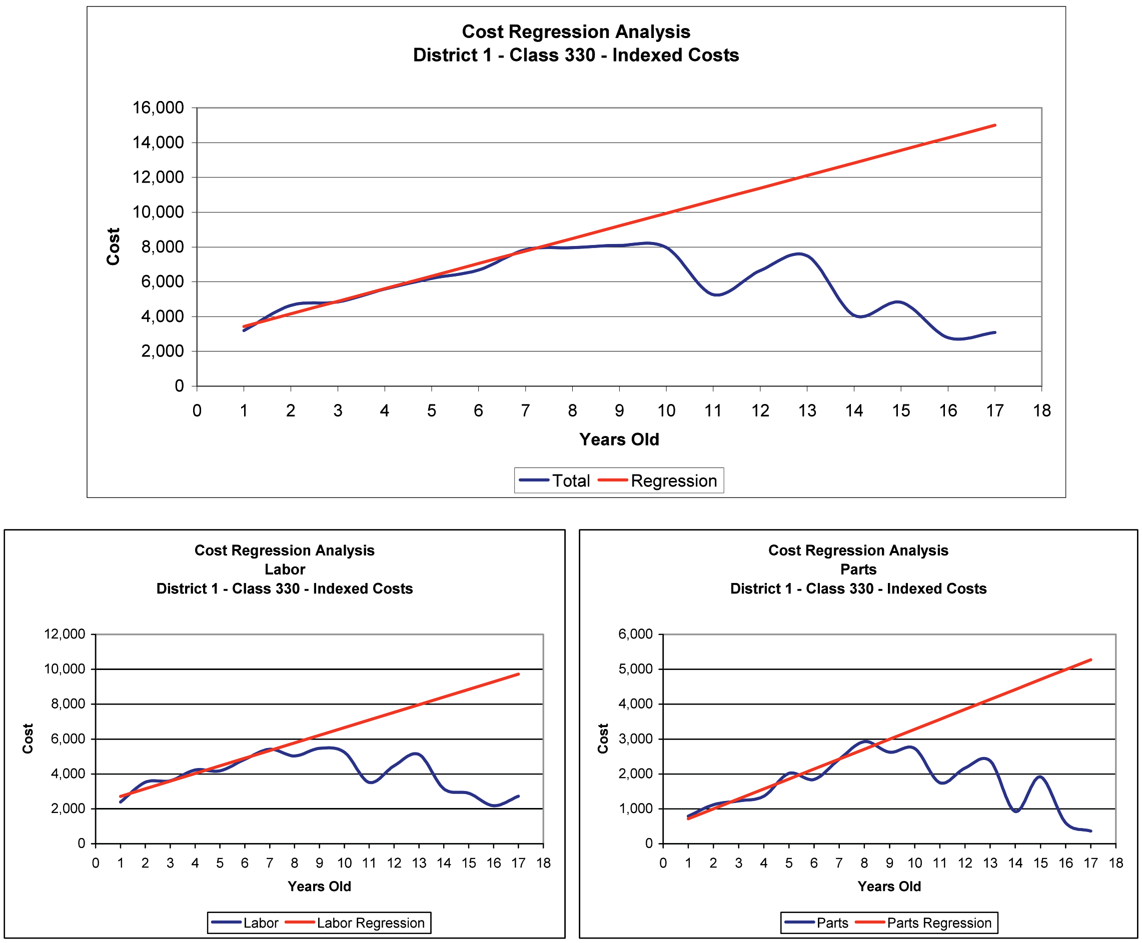


Figure 4-23 Cost Regression Analysis Result - District 1 – Indexed Costs and No Overhead

The linear regression analyses for District 1 data generated the following results:

- Labor:
  - Years used for correlation: 1 - 7
  - Intercept: $2,277

- Yearly maintenance increase: $438
- Regression correlation: 96.71 %

- Parts:
  - Years used for correlation: 1 - 8
  - Intercept: $431
  - Yearly maintenance increase: $285
  - Regression correlation: 96.8 %
- Total:
  - Intercept: $2,708
  - Yearly maintenance increase: $723

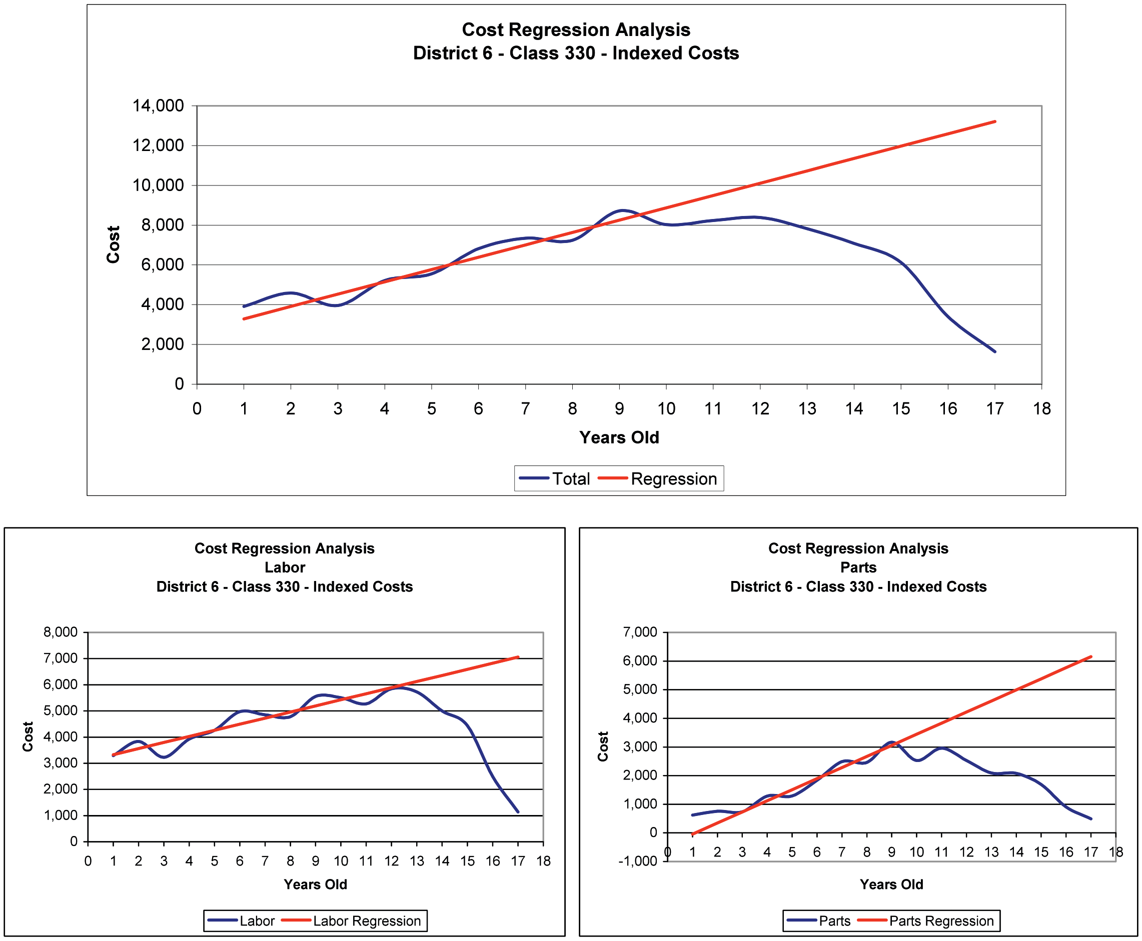


Figure 4-24 Cost Regression Analysis Result - District 6 – Indexed Costs and No Overhead

The linear regression analysis for District 6 data generated the following results:

- Labor:
    - Years used for correlation: 1 - 12
    - Intercept: $3,094
    - Yearly maintenance increase: $233
    - Regression correlation: 94.23 %
- Parts:
    - Years used for correlation: 3 - 9
    - Intercept: - $429

    - Yearly maintenance increase: $387
    - Regression correlation: 97.99 %
- Total:
    - Intercept: $2,665
    - Yearly maintenance increase: $620

Every linear regression analysis has a high correlation factor as before. At the same time, initial cost and yearly increases are very similar in both districts even though District 1 values are higher.

The calculated purchase cost for District 1 and 6, using price indexes, were $77,908 and $73,800 respectively. A LCC analysis was done using these costs, double depreciation over 13 years, and 5 percent of interest rate. The results of these analyses are shown in Figure 4-25 and Figure 4-26 for District 1 and District 6, respectively.

District 1 Using cost without overhead and with indexes

Purchase: $ 77,908 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 723 Depreciation (years): 13

Intercept: $ 2,708

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 77,908	$ 77,908			
1		$ 65,922	$ 3,431	$ 18,393	$ 19,313
2		$ 55,780	$ 4,154	$ 34,350	$ 18,473
3		$ 47,199	$ 4,877	$ 48,385	$ 17,767
4		$ 39,937	$ 5,600	$ 60,908	$ 17,177
5		$ 33,793	$ 6,323	$ 72,241	$ 16,686
6		$ 28,594	$ 7,046	$ 82,640	$ 16,281
7		$ 24,195	$ 7,769	$ 92,304	$ 15,952
8		$ 20,473	$ 8,492	$ 101,390	$ 15,687
9		$ 17,323	$ 9,215	$ 110,021	$ 15,479
10		$ 14,658	$ 9,938	$ 118,290	$ 15,319
11		$ 12,403	$ 10,661	$ 126,270	$ 15,202
12		$ 10,495	$ 11,384	$ 134,017	$ 15,121
13		$ 8,880	$ 12,108	$ 141,573	$ 15,071
14		$ 7,514	$ 12,831	$ 148,967	$ 15,049
15		$ 6,358	$ 13,554	$ 156,224	$ 15,051
16		$ 5,380	$ 14,277	$ 163,358	$ 15,073
17		$ 4,552	$ 15,000	$ 170,380	$ 15,113
18		$ 3,852	$ 15,723	$ 177,299	$ 15,167
19		$ 3,259	$ 16,446	$ 184,118	$ 15,235
20		$ 2,758	$ 17,169	$ 190,839	$ 15,313
21		$ 2,334	$ 17,892	$ 197,463	$ 15,401
22		$ 1,975	$ 18,615	$ 203,989	$ 15,497
23		$ 1,671	$ 19,338	$ 210,416	$ 15,600
24		$ 1,414	$ 20,061	$ 216,741	$ 15,707
25		$ 1,196	$ 20,784	$ 222,964	$ 15,820

Min	**$15,049**
Year	**14**

Figure 4-25 Life Cycle Cost Analysis - District 1 – Indexed and No Overhead

District 6 Using cost without overhead and with indexes

Purchase	$ 73,800	Interest Rate:	5%

Maintenance Linear Regression

Slope	$ 620	Depreciation (years):	13
Intercept	$ 2,665		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 73,800	$ 73,800			
1		$ 62,446	$ 3,286	$ 17,457	$ 18,330
2		$ 52,839	$ 3,906	$ 32,546	$ 17,503
3		$ 44,710	$ 4,527	$ 45,761	$ 16,804
4		$ 37,831	$ 5,147	$ 57,494	$ 16,214
5		$ 32,011	$ 5,768	$ 68,055	$ 15,719
6		$ 27,086	$ 6,388	$ 77,692	$ 15,307
7		$ 22,919	$ 7,009	$ 86,597	$ 14,966
8		$ 19,393	$ 7,629	$ 94,923	$ 14,687
9		$ 16,410	$ 8,250	$ 102,789	$ 14,461
10		$ 13,885	$ 8,870	$ 110,288	$ 14,283
11		$ 11,749	$ 9,491	$ 117,492	$ 14,145
12		$ 9,941	$ 10,111	$ 124,456	$ 14,042
13		$ 8,412	$ 10,732	$ 131,222	$ 13,969
14		$ 7,118	$ 11,352	$ 137,822	$ 13,923
15		$ 6,023	$ 11,973	$ 144,279	$ 13,900
16		$ 5,096	$ 12,593	$ 150,610	$ 13,897
17		$ 4,312	$ 13,214	$ 156,829	$ 13,911
18		$ 3,649	$ 13,834	$ 162,942	$ 13,939
19		$ 3,087	$ 14,455	$ 168,957	$ 13,980
20		$ 2,612	$ 15,075	$ 174,876	$ 14,032
21		$ 2,211	$ 15,696	$ 180,701	$ 14,094
22		$ 1,870	$ 16,316	$ 186,432	$ 14,163
23		$ 1,583	$ 16,937	$ 192,071	$ 14,240
24		$ 1,339	$ 17,557	$ 197,615	$ 14,321
25		$ 1,133	$ 18,178	$ 203,063	$ 14,408

Min	**$13,897**
Year	**16**

Figure 4-26 Life Cycle Cost Analysis - District 6 – Indexed and No Overhead

The optimum life cycle cost for District 1 is obtained when vehicles are replaced after 14 years, resulting in an estimated annual cost of $15,049. Vehicles from District 6, on the other hand, should be replaced when they are 16 years old and their annual cost is $13,897.

4.2.3 Indexed Data and Overhead

Figure 4-27 and Figure 4-28 show the results of these regression analyses done for District 1 and District 6 class 330 vehicles with data taken from MAPS system. In this analysis, the data were indexed and it contained overhead costs.

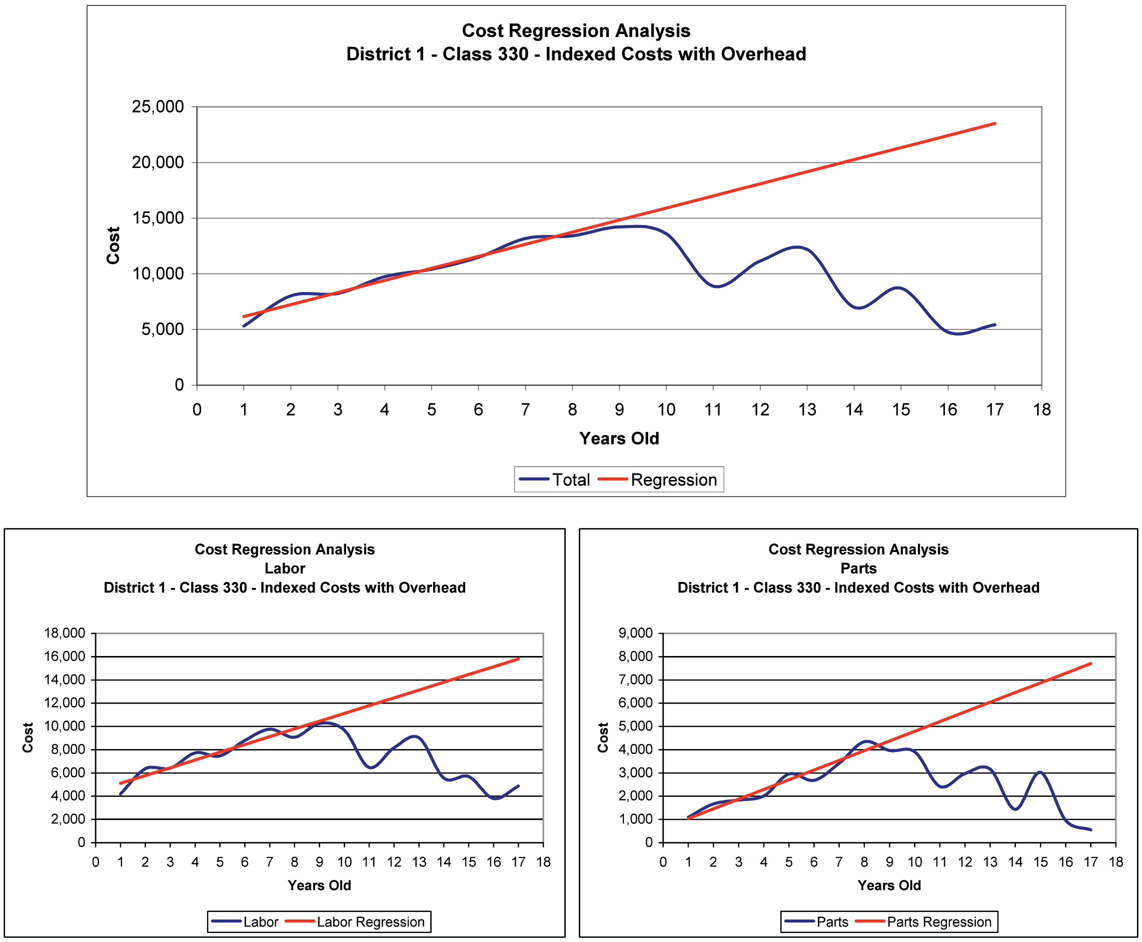


Figure 4-27 Cost Regression Analysis Result - District 1 – Indexed Costs and Overhead

The linear regression analyses for District 1 data generated the following results:

- Labor:
  - Years used for correlation: 1 - 9
  - Intercept: $4,441

    - Yearly maintenance increase: $668
    - Regression correlation: 95.29 %
- Parts:
    - Years used for correlation: 1 - 8
    - Intercept: $629
    - Yearly maintenance increase: $416
    - Regression correlation: 96.44 %
- Total:
    - Intercept: $5,070
    - Yearly maintenance increase: $1,085

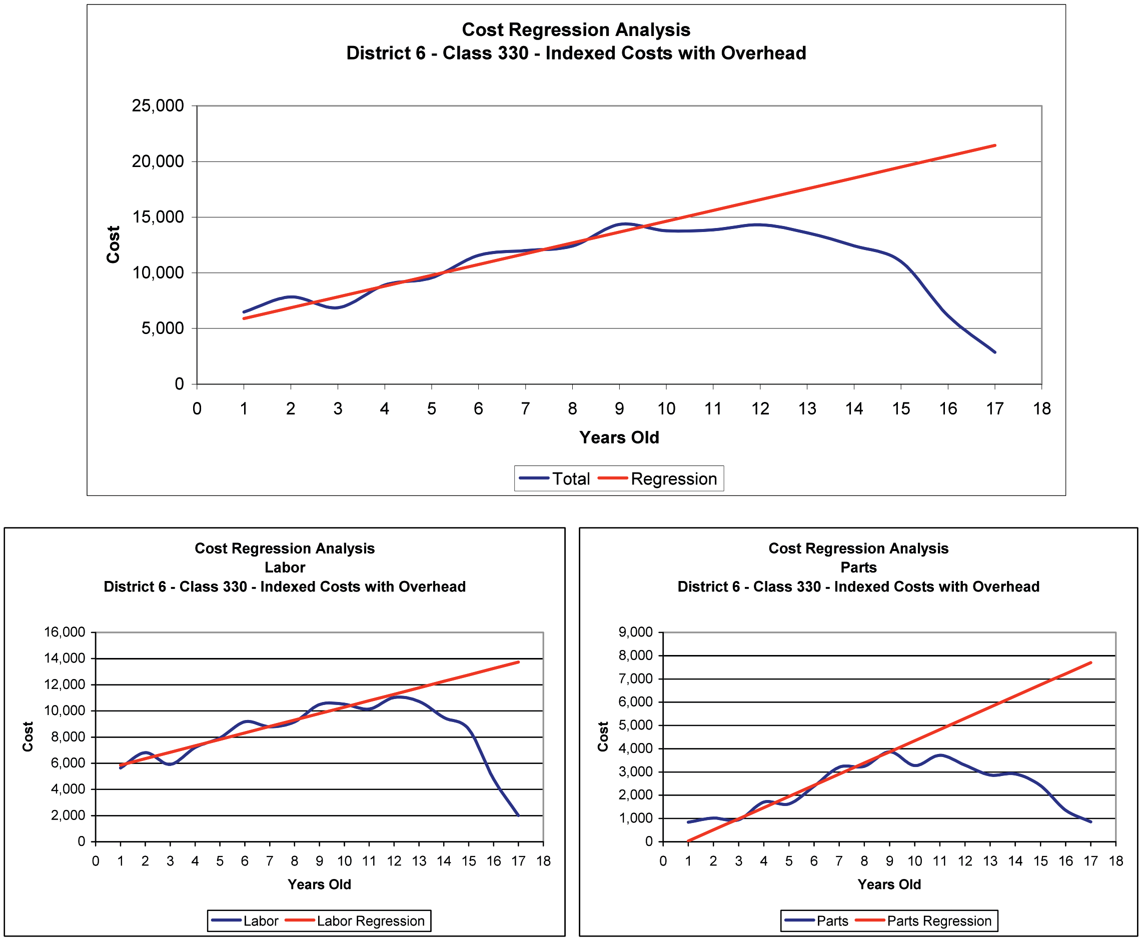


Figure 4-28 Cost Regression Analysis Result - District 6 – Indexed Costs and Overhead

The linear regression analysis for District 6 data generated the following results:

- Labor:
  - Years used for correlation: 1 - 12
  - Intercept: $5,363
  - Yearly maintenance increase: $493
  - Regression correlation: 96.08 %
- Parts:
  - Years used for correlation: 3 - 9
  - Intercept: - $450

  - Yearly maintenance increase: $480
  - Regression correlation: 97.95 %
- Total:
  - Intercept: $4,914
  - Yearly maintenance increase: $972

Every linear regression analysis has a high correlation factor. At the same time, initial cost and yearly increases are very similar in both districts even though District 1 values are higher.

The calculated purchase cost for District 1 and 6, using price indexes, were $77,908 and $73,800 respectively. A LCC analysis was done using these costs, double depreciation over 13 years, and 5 percent of interest rate. The results of these analyses are shown in Figure 4-29 and Figure 4-30 for District 1 and District 6, respectively.

District 1 Using cost with overhead and indexes

Purchase: $ 77,908 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 1,085 Depreciation (years): 13

Intercept: $ 5,070

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 77,908	$ 77,908			
1		$ 65,922	$ 6,155	$ 20,986	$ 22,036
2		$ 55,780	$ 7,239	$ 39,741	$ 21,373
3		$ 47,199	$ 8,324	$ 56,754	$ 20,840
4		$ 39,937	$ 9,408	$ 72,409	$ 20,420
5		$ 33,793	$ 10,493	$ 87,009	$ 20,097
6		$ 28,594	$ 11,577	$ 100,789	$ 19,857
7		$ 24,195	$ 12,662	$ 113,930	$ 19,689
8		$ 20,473	$ 13,746	$ 126,572	$ 19,583
9		$ 17,323	$ 14,831	$ 138,823	$ 19,531
10		$ 14,658	$ 15,916	$ 150,761	$ 19,524
11		$ 12,403	$ 17,000	$ 162,448	$ 19,557
12		$ 10,495	$ 18,085	$ 173,926	$ 19,623
13		$ 8,880	$ 19,169	$ 185,226	$ 19,718
14		$ 7,514	$ 20,254	$ 196,370	$ 19,838
15		$ 6,358	$ 21,338	$ 207,371	$ 19,979
16		$ 5,380	$ 22,423	$ 218,237	$ 20,137
17		$ 4,552	$ 23,507	$ 228,971	$ 20,310
18		$ 3,852	$ 24,592	$ 239,575	$ 20,495
19		$ 3,259	$ 25,677	$ 250,047	$ 20,690
20		$ 2,758	$ 26,761	$ 260,384	$ 20,894
21		$ 2,334	$ 27,846	$ 270,580	$ 21,104
22		$ 1,975	$ 28,930	$ 280,633	$ 21,320
23		$ 1,671	$ 30,015	$ 290,536	$ 21,539
24		$ 1,414	$ 31,099	$ 300,284	$ 21,762
25		$ 1,196	$ 32,184	$ 309,873	$ 21,986

Min	**$19,524**
Year	**10**

Figure 4-29 Life Cycle Cost Analysis - District 1 – Indexed and Overhead

District 6 Using cost with overhead and indexes

Purchase	$ 73,800	Interest Rate:	5%
Maintenance Linear Regression			
Slope	$ 972	Depreciation (years):	13
Intercept	$ 4,914		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 73,800	$ 73,800			
1		$ 62,446	$ 5,886	$ 19,933	$ 20,930
2		$ 52,839	$ 6,858	$ 37,700	$ 20,275
3		$ 44,710	$ 7,831	$ 53,769	$ 19,744
4		$ 37,831	$ 8,803	$ 68,509	$ 19,320
5		$ 32,011	$ 9,776	$ 82,211	$ 18,989
6		$ 27,086	$ 10,748	$ 95,101	$ 18,737
7		$ 22,919	$ 11,720	$ 107,355	$ 18,553
8		$ 19,393	$ 12,693	$ 119,108	$ 18,429
9		$ 16,410	$ 13,665	$ 130,465	$ 18,355
10		$ 13,885	$ 14,638	$ 141,505	$ 18,325
11		$ 11,749	$ 15,610	$ 152,286	$ 18,334
12		$ 9,941	$ 16,582	$ 162,854	$ 18,374
13		$ 8,412	$ 17,555	$ 173,238	$ 18,442
14		$ 7,118	$ 18,527	$ 183,462	$ 18,534
15		$ 6,023	$ 19,500	$ 193,539	$ 18,646
16		$ 5,096	$ 20,472	$ 203,480	$ 18,775
17		$ 4,312	$ 21,444	$ 213,290	$ 18,919
18		$ 3,649	$ 22,417	$ 222,970	$ 19,074
19		$ 3,087	$ 23,389	$ 232,520	$ 19,240
20		$ 2,612	$ 24,362	$ 241,939	$ 19,414
21		$ 2,211	$ 25,334	$ 251,223	$ 19,594
22		$ 1,870	$ 26,306	$ 260,370	$ 19,780
23		$ 1,583	$ 27,279	$ 269,376	$ 19,971
24		$ 1,339	$ 28,251	$ 278,235	$ 20,164
25		$ 1,133	$ 29,224	$ 286,946	$ 20,360

Min	**$18,325**
Year	**10**

Figure 4-30 Life Cycle Cost Analysis - District 6 – Indexed and Overhead

The optimum life cycle cost for District 1 is obtained when vehicles are replaced after 10 years, resulting in an estimated annual cost of $19,524. Vehicles from District 6, on the other hand, should be replaced when they are 10 years old and their annual cost is $18,325.

4.3 Summary

This section contains the results presented before to easy their analysis and comparison. Figure 4-31 shows the results of the different analysis performed on District 1. Figure 4-32, on the other hand, show the results for District 6.

	Type of Regression					
	Single			Double		
Indexes		X	X		X	X
Overhead			X			X
EUAC	$ 13,979	$ 14,587	$ 19,476	$ 14,476	$ 15,049	$ 19,524
Lifecycle	17	17	10	15	14	10

Figure 4-31 Results Summary District 1

	Type of Regression					
	Single			Double		
Indexes		X	X		X	X
Overhead			X			X
EUAC	$ 12,903	$ 13,987	$ 18,448	$ 12,823	$ 13,897	$ 18,325
Lifecycle	16	16	11	15	16	10

Figure 4-32 Results Summary District 6

Before comparing the results obtained now with the ones from the 2003-04 research, another interesting behavior shown with the double regression analysis will be presented.

The number of years considered in each analysis presented in the previous section was very similar for both parts and labor in District 1. Section 4.2.1 used years 1 through 7 and 1 through 8 for labor and parts, respectively; Section 4.2.2 used the same years; and Section 4.2.3 used years 1 through 9 and 1 through 8. This was not the case with District 6. Section 4.2.1 used years 1 through 13 and 3 through 9 for labor and parts, respectively; while Sections 4.2.2 and 4.2.3 used years 1 through 12 and 3 through 9. District 6 shows a linear behavior on the cost of labor during more years than on the parts costs. This extended linear behavior is higher than the one of District 1.

A possible explanation of this behavior is that District 6 keeps doing maintenance at the same level throughout the life cycle according to Mn/DOT's policy with the exception of maintenances that require many parts. District 1 seems to decrease the level of all maintenances as units reach the end of their life cycle.

After identifying this behavior, it is recommended to use independent regression analysis for parts and labor. Otherwise, it is possible to hide deviations caused by human and policy behaviors when aggregating costs, affecting the results of the analysis.

4.3.1 Comparison with Last Year's Research

The results obtained in last year's research on class 330 single-axle snowplows were the following: District 1 had an average optimum life cycle of 9 years and District 6 had an average optimum life cycle of 11 years (Sivanich, 2005). The analysis was done without considering price indexes or overhead. That research did incorporate, as close as possible, the actual costs of ownership associated with each individual unit using the MAPS system.

The results obtained by the different methods are quite different. Using the new method with the same conditions of no price indexing and no overhead, District 1 now has an optimal life cycle of 17 years for the class 330 units as compared to the 9 years obtained in 2004. Similarly, District 6 now has an optimal life cycle of 16 years compared to the 11 years from the 2004 research. There are many reasons for these differences.

One of the main differences between the two methodologies is that last year's the regression analysis of costs was done on the basis of individual units, whereas this method aggregated the cost information for the class 330 units in each district as a group. An individual unit may have greater deviations of cost during any given year, which have a significant impact on that individual unit. It might be possible that something broke in a particular unit, increasing considerably the costs of parts and labor. If that unit is aggregated with the other units of the fleet, the aggregated cost would not shift considerably. As shown in Section 3.4, relatively small differences in the life cycle cost model generate important differences in the result. The model is highly sensitive. Aggregated data handle differences more gracefully providing, in general, better results.

Another problem when doing regression analysis for each unit is that the uncertainty of the result is greater. Usually, individual units have greater variations that generate lower correlation factors. Analyzing the regression results from last year, there are some regressions with correlation factors as low as 10 percent. On the other hand, all the regressions of aggregated costs had correlation factors of at least 95 percent. High regression uncertainty mixed with a sensitive model can generate results that are far from optimum.

Last year's methodology used values from the regression analysis only for those years where data were not available. This allows having in the life cycle cash flow peaks in costs that may determine the optimum life cycle for individual units.

In addition, last year's research used different type of regressions depending on how they fit the data for each unit. The result was that a high percentage of units ended up having exponential cost structures. Exponential costs make the optimal life cycle much lower than linear costs. The cost analysis done during this research indicates that, in general, the cost follows a linear pattern for a class at a district.

Finally, in this research, the number of units used was 57 for District 1 and 70 units for District 6. In comparison, last year's research used only 19 units for District 1 and 26 units for District 6. The reason for this major increase in units to analyze the fleet's life cycle is that the new methodology mixes information from many units, independent of how many years of information are available for each unit. The methodology used last year forced the selection of only those units which had many years of information in order to have relatively enough data for the regression analysis. As shown in Section 3.3, having more data available increases the likelihood of generating a result nearer the true life cycle. At the same time, the new methodology assures that all the new information that is gathered can be used to improve the results even if there is not enough information to analyze that unit alone.

It should be noted, however, that in the case of incorporating both price indexes and overhead to this model, the average optimal life cycle for class 330 vehicles is found to be 10 years in both District 1 and District 6. This is very close to the 9 year and 11 year average optimal life cycles for Districts 1 and 6, respectively, found by Sivanich (2004). It can be argued that by using actual cost data, price indexes were built in. It is not so clear if overhead was included in those costs, however.

5 Analysis of M4 Data

This section includes the analysis of the M4 data. First, it describes the steps done to process the data. Second, it describes the data quality and its differences with MAPS data. Third, the results of the analysis are presented. Finally, a summary of the results is shown and analyzed.

The reason to use data from the M4 system was that the State of Minnesota has elected to move toward using a standard fleet management information system. Therefore, M4 is intended to be the source for fleet management data.

5.1 Data Processing

The cost data provided from the M4 system contained costs of fuel, parts, labor, and outside jobs. In a different file, mileage information was also provided. The major differences between M4 and MAPS were that M4 data did not contain overhead costs and the data were already grouped by month for each unit.

Another difference between the data sets obtained from the M4 and the MAPS systems was that the former did not have as many years of data available as the latter. M4 system contains only 4 or 5 years of data while MAPS may contain up to 10 years for each vehicle. This is a source of problems considering how the results of the new methodology changes with the quantity of data available (as discussed in Section 3.3).

5.1.1 Data Quantity

One of the first decisions to make was to what level of grouping could be analyzed with a certain level of confidence. The two options for the analysis were to look at the whole state of Minnesota or at each district.

Figure 5-1 shows how many units had data grouped by the class of unit and their age at a state level.

	Class						
YearsOld	80	90	180	190	250	330	350
0	94	60	50	423	65	150	201
1	96	60	52	296	70	164	204
2	124	61	112	259	79	184	220
3	138	45	135	199	93	182	198
4	127	46	189	51	96	181	170
5	147	41	222	49	79	153	150
6	122	35	267	40	71	148	139
7	102	37	368	41	63	150	136
8	90	30	294	33	47	132	125
9	84	15	242	27	21	155	125
10	44	12	247	29	26	175	133
11	22	9	222	24	25	183	126
12	8	5	131	15	14	179	111
13	4	2	52	10	11	169	72
14	1	2	23	7	11	135	48
15	1		7	4	5	117	36
16			1	3	3	57	15
17					2	20	8
18					1	6	6
19						2	
20						1	1
21						1	1
22						1	

Figure 5-1 Number of Units with Data per Class and Age

Figures 5-2 through 5-8 show how many units had data for each different District, grouped by the class of unit and age.

		District								
Class	**YearsOld**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
80	0	9	7	9	6	30	4	3	3	23
	1	11	8	8	9	25	4	1	3	27
	2	13	8	6	10	43	4	1	3	36
	3	10	7	13	9	45	5	2	3	44
	4	10	8	14	7	38	6	3	5	36
	5	11	8	19	8	59	8	5	8	21
	6	6	7	24	4	44	7	7	9	14
	7	5	8	21	6	26	10	7	9	10
	8	8	4	13	7	31	8	8	9	2
	9	8		16	5	34	7	6	8	
	10	5	1	12	3	16	2	3	2	
	11		1	10	2	6	2		1	
	12			5		3				
	13			3		1				
	14			1						
	15			1						

Figure 5-2 Number of Units with Data for Class 80

		District								
Class	**YearsOld**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
90	0		7	2	4		4	4	5	34
	1	1	7	2	2		6	4	2	36
	2	1	3	2	3		5	4	3	40
	3	1	4	2	3	8	3	3	3	18
	4	1	3	1	2	12	2	3	1	21
	5	2	3	1	2	13	2	1	1	16
	6	1	1	1	2	13	2	1	3	11
	7	2	2	1	1	16	2	1	4	8
	8	2				15	2	1	4	6
	9	2			1	4		1	4	3
	10			1	3	4		1	3	
	11			1	3	3			1	1
	12		1		1	2				1
	13		1			1				
	14		1			1				

Figure 5-3 Number of Units with Data for Class 90

		District								
Class	YearsOld	1	2	3	4	5	6	7	8	9
180	0	4		19	8	6		9	1	3
	1	4		17	8	9		9	2	3
	2	7		21	13	39	11	9	8	4
	3	9		22	14	57	16	5	10	2
	4	18	2	18	14	91	23	4	17	2
	5	36	4	16	9	108	27	2	18	2
	6	39	4	24	8	139	29	4	18	2
	7	48	7	36	15	175	50	9	26	2
	8	51	10	31	9	129	38	6	18	2
	9	47	10	30	7	93	30	6	17	2
	10	31	14	32	7	103	30	13	16	1
	11	31	14	29	5	92	16	21	14	
	12	24	19	16	2	38	12	12	6	2
	13	4	15	7	2	4	5	9	4	2
	14		6	2	2	2		7	3	1
	15		2	1	1	1		1	1	
	16		1							

Figure 5-4 Number of Units with Data for Class 180

		District								
Class	YearsOld	1	2	3	4	5	6	7	8	9
190	0	11	4	2	5	25	8	11	13	344
	1	11	4	1	6	24	8	11	9	222
	2	10	1	1	4	26	6	10	8	193
	3	10	1	1	7	23	5	11	8	133
	4	6	1	1	7	21	2	10	1	2
	5	6	1	1	7	21	2	9	1	1
	6	5	1	1	6	18	2	4	2	1
	7	8		1	6	16	4	4	2	
	8	7		2	2	13	3	3	2	1
	9	3		2	4	8	5	3	1	1
	10	4		3	3	8	5	3	1	2
	11	4		3	2	8	2	2	1	2
	12	2		3	2	4			1	3
	13	2		3		3			1	1
	14	2		1		3			1	
	15	2						1	1	
	16	1						1	1	

Figure 5-5 Number of Units with Data for Class 190

Class	YearsOld	District								
		1	2	3	4	5	6	7	8	9
250	0	9	4	7	9	15	11	5	3	2
	1	10	5	6	11	17	10	5	4	2
	2	10	7	5	10	25	10	6	4	2
	3	9	10	10	9	33	8	8	4	2
	4	8	11	9	7	39	10	7	3	2
	5	6	11	9	5	30	9	7	2	
	6	6	9	9	4	26	10	6	1	
	7	4	7	11	4	18	8	8	3	
	8	3	6	7	2	11	7	7	4	
	9		5	5	1		2	3	4	1
	10	1	5	6	2		2	3	6	1
	11	1	5	6	1		2	4	6	
	12	1	2	3	1			1	6	
	13	1	1	3				1	5	
	14	1		3			1	1	5	
	15			1			1	1	2	
	16			1			1		1	
	17			1			1			
	18						1			

Figure 5-6 Number of Units with Data for Class 250

Class	YearsOld	District								
		1	2	3	4	5	6	7	8	9
330	0	14	8	17	18	56	12	14	9	2
	1	18	12	17	22	48	16	18	12	1
	2	19	17	21	24	48	20	22	12	1
	3	26	16	16	20	47	24	21	11	1
	4	28	11	14	17	50	22	24	14	1
	5	27	13	10	13	35	21	22	12	
	6	20	10	13	8	47	21	19	10	
	7	20	7	10	6	54	21	20	12	
	8	12	7	12	6	55	14	18	8	
	9	11	11	20	7	62	19	14	11	
	10	13	11	26	7	70	22	14	12	
	11	10	9	30	6	65	25	15	23	
	12	11	11	26	9	61	25	16	19	1
	13	10	10	28	8	54	23	13	22	1
	14	7	5	20	6	48	17	12	19	1
	15	7	5	18	17	28	12	14	15	1
	16	4	3	8	12	10	3	10	6	1
	17	1	4	1	6	1	1	5		1
	18	1	2	1	1		1			
	19				1			1		
	20							1		
	21							1		
	22							1		

Figure 5-7 Number of Units with Data for Class 330

		District								
Class	**YearsOld**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
350	0	25	16	26	19	54	28	20	11	2
	1	27	16	30	16	52	29	20	13	1
	2	25	16	33	15	63	30	21	16	1
	3	17	15	32	12	58	27	21	15	1
	4	9	17	34	10	48	23	14	15	
	5	8	14	28	10	39	24	16	11	
	6	7	15	22	13	41	22	13	6	
	7	15	20	22	15	29	20	13	2	
	8	15	17	16	17	27	19	12	2	
	9	21	15	9	15	35	19	11		
	10	21	17	9	16	40	19	11		
	11	23	13	9	16	39	15	11		
	12	20	8	10	11	41	12	9		
	13	15	5	9	3	30	4	6		
	14	10	4	9	1	20		4		
	15	10	4	10	2	9		1		
	16	5	3	3	1	3				
	17	1	1	4	1	1				
	18	1	1	4						
	20									1
	21									1

Figure 5-8 Number of Units with Data for Class 350

As shown from Figure 5-2 through Figure 5-8, the number of units with data is not high enough to do the analysis per district. There are some cases, such as District 5, that the analysis would be possible but that is not the general case. It is this reason why the analyses of M4's data were only done at a state level.

5.1.2 Overhead

Some of the analyses done with MAPS data in Section 4 included overhead costs. The M4 data provided did not contain overhead data. In order to be able to do the same analysis, overhead costs were calculated based on MAPS data.

Figure 5-9 shows the overhead factors calculated from the MAPS data used in Section 4. The calculation did not take into account jobs done outside Mn/DOT because those do not have any overhead.

Activity	Year	MinFact	MaxFact	AvgFact
Fuel	1996	0.000	0.366	0.228
Fuel	1997	0.000	0.367	0.253
Fuel	1998	0.000	0.644	0.600
Fuel	1999	0.000	0.738	0.664
Fuel	2000	0.316	0.768	0.661
Fuel	2001	0.000	0.657	0.601
Fuel	2002	0.000	0.656	0.516
Fuel	2003	0.320	0.798	0.614
Fuel	2004	0.000	1.003	0.707
Labor	1996	0.000	2.000	0.836
Labor	1997	0.000	1.409	0.777
Labor	1998	0.000	1.358	0.676
Labor	1999	0.000	1.237	0.817
Labor	2000	0.000	1.240	0.676
Labor	2001	0.000	1.500	0.786
Labor	2002	0.000	1.534	0.880
Labor	2003	0.000	1.532	0.903
Labor	2004	0.000	1.364	0.600
Parts	1996	0.000	1.000	0.067
Parts	1997	0.000	0.400	0.192
Parts	1998	0.000	0.667	0.443
Parts	1999	0.000	0.759	0.539
Parts	2000	0.000	0.778	0.541
Parts	2001	0.000	1.295	0.489
Parts	2002	0.000	0.696	0.449
Parts	2003	0.000	1.363	0.580
Parts	2004	0.000	1.019	0.625

Figure 5-9 Overhead Factors from MAPS Data

The factors calculated show that they are not constant during the same year or for the type of cost. Thus, the best possible factor to use was the average within a year.

The usage of these factors was a temporary solution and was considered adequate. The best possible solution would have been to extract cost's overheads from the M4 system. The reality was that, given the data quality (see Section 5.2), it did not make sense to redo all the manual data corrections, verifications, and calculations to get the real overhead costs.

5.2 Data Quality

The validity of a data driven analysis depends on the quality of the data used. This section contains an analysis of M4's data quality.

Correct fuel and mileage information is very important to determine the optimum life cycle of an asset because they provide information about the level of utilization of each asset.

The level of utilization affects the other types of costs. It is impossible to conclude anything about how much a vehicle costs without paying attention to its utilization factor. For example, a low maintenance cost for a given year may indicate that the vehicle did not break too often or that it broke a lot depending if the mileage or fuel costs were high or low, respectively.

5.2.1 Fuel

Fuel data were found to be incorrect in many cases during last year's research. There were cases where a vehicle was used during the year while its fuel cost was zero. The opposite was also true. There were cases where a unit's fuel cost was high in comparison to the average while it was used less than the average. Last year's research found that even if Mn/DOT uses credit cards to purchase fuel and each credit card is only for one vehicle, people would charge fuel for many vehicles on only one card.

Independent of the information system used, MAPS or M4, the fuel information cannot be fully trusted. There is a human behavior problem. It might be close to the real cost if it is considered at a District or State level. Of course, the usage of an information system can make the problem even worse.

5.2.2 Mileage

The mileage information provided by Mn/DOT taken from the M4 system also showed some problems. There were cases where a vehicle reported more than 100,000 miles driven in a month. There were other cases where a vehicle made no miles while it incurred fuel and other types of costs.

A meeting was held at Mn/DOT to see how the M4 system works. It was shown how the mileage information is entered into the system and the logic applied to it. Mileage information is entered every time there is maintenance on a vehicle or when a vehicle is filled up with fuel. The information is entered manually into the system. The quality of the data entered in the system is questionable with such a high number of manual entries.

The logic used in M4 with the mileage information also generates problems. The system checks that new mileage information is greater than previous information. It actually does not prohibit entering a lower number. It just calculates the mileage between those entries as zero. Looking at the mileage data provided, it is clear that this is a major source of problems. There are cases where the mileage entered in the system was high enough to be obviously wrong. Because of the logic in the reporting system, all the following data entries which might be correct were not used because the mileage was lower than the previous incorrect entry.

For example, suppose that a vehicle has 50,000 miles. At one point, somebody enters 500,000 miles because it entered one more zero. From that moment on, the entries are 51,000, 51,500, 53,000 miles, and so on. It is clear that the entry with 500,000 miles is incorrect. The system reports that, if that mileage was entered each month, the mileage per month was: 50,000, 500,000, 0, 0 , and 0 miles. The vehicle would not incur into any miles until the actual mileage is greater than 500,000 miles. All those months without any miles driven, which are wrong, were created by one and only one bad entry.

The previous example might be an exaggeration of the real situation. Still, some of those cases were found. The problem with that logic is that it is really easy to make an error and that error affects many other entries. There were many cases where a relatively high mileage shows up and from that moment on there are many months with no mileage. It is hard to know if either of those mileages is correct.

In summary, neither fuel nor mileage information from M4 can be trusted. The whole analysis suffers due to the importance of those two variables to determine utilization factors.

5.2.3 MAPS and M4 Data Comparison

One of the tests done with the data provided was to compare the cost information provided by MAPS and M4 for each unit. The methodology used was to only consider those units where information was provided by both systems. Thus, the information compared included class 330 vehicles from Districts 1 and 6.

The first set of comparisons was done for each type of cost and also for the total cost based on the age of the vehicles. Figure 5-10 shows the difference between fuel costs reported by MAPS and M4 systems. Figure 5-11 and Figure 5-12 do the same with labor and parts costs. Finally, Figure 5-13 shows the difference of the total cost between the two information systems.

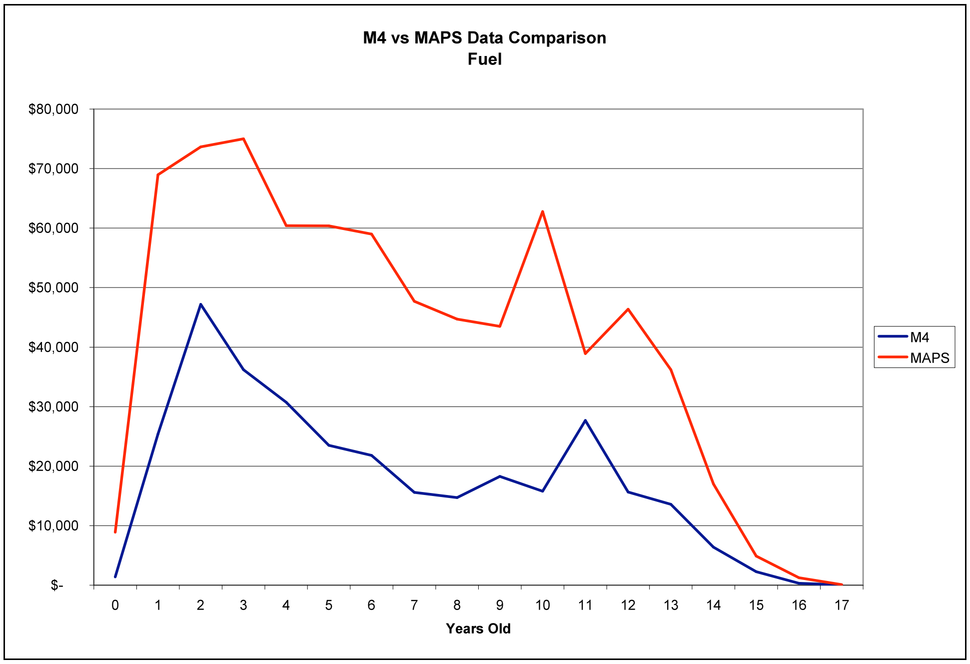


Figure 5-10 M4 vs. MAPS Fuel Costs – Age Based

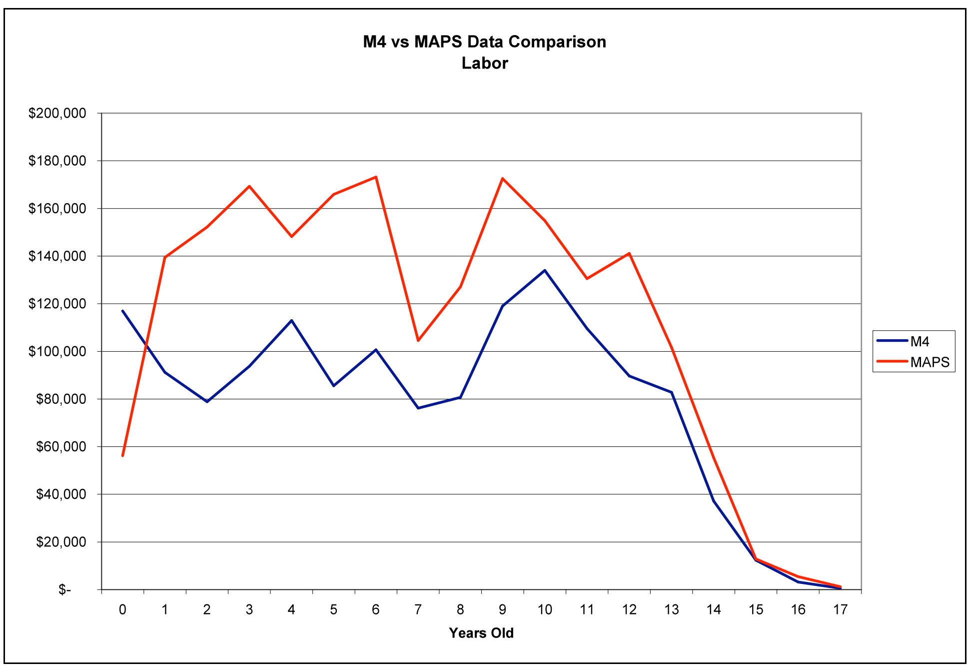


Figure 5-11 M4 vs. MAPS Labor Costs – Age Based

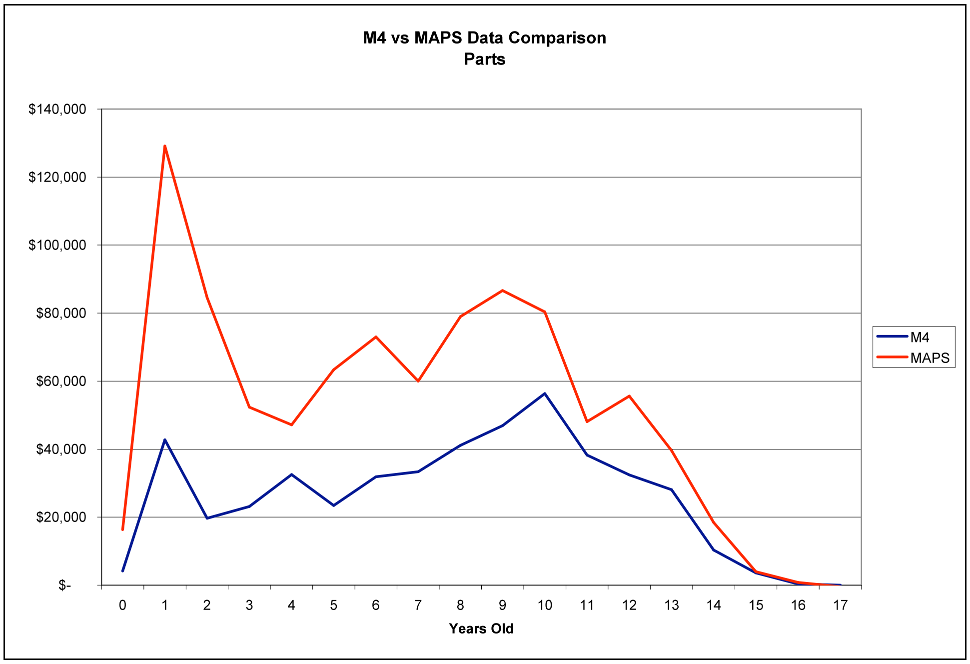


Figure 5-12 M4 vs. MAPS Parts Costs – Age Based

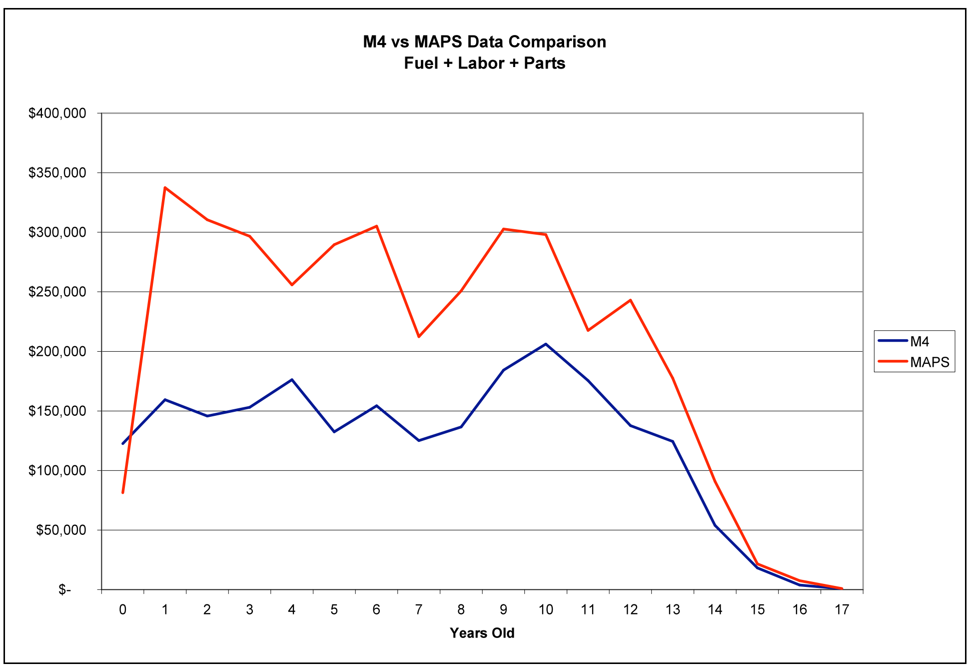


Figure 5-13 M4 vs. MAPS Total Costs – Age Based

The second set of comparisons was done for each type of cost and also for the total cost based on the year the data were entered into the system. Figure 5-14 shows the difference between fuel costs reported by MAPS and M4 systems. Figure 5-15 and Figure 5-16 do the same with labor and parts costs. Finally, Figure 5-17 shows the difference of the total cost between the two information systems.

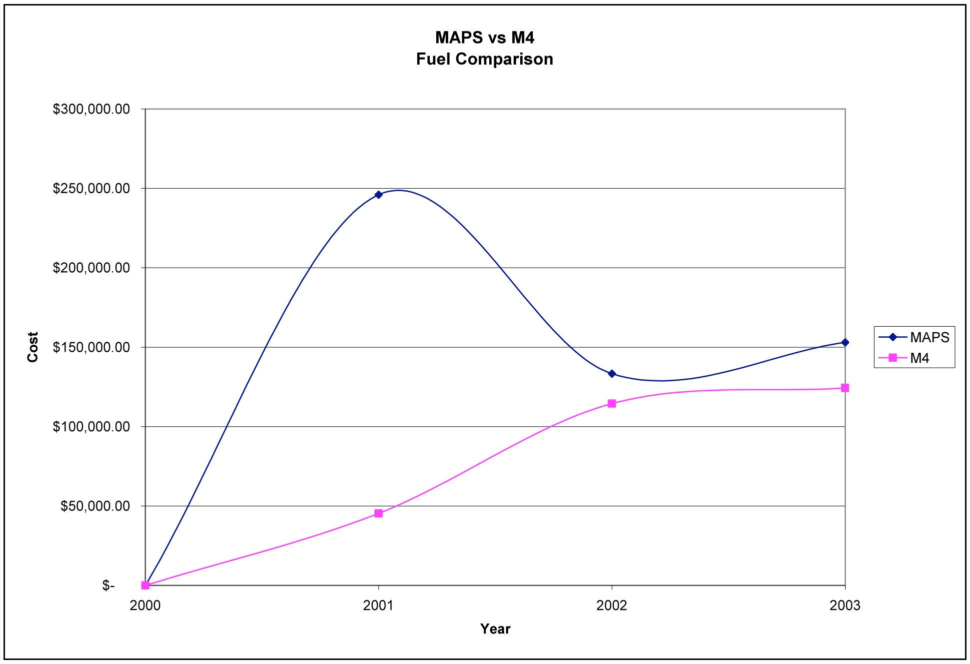


Figure 5-14 M4 vs. MAPS Fuel Costs – Year Based

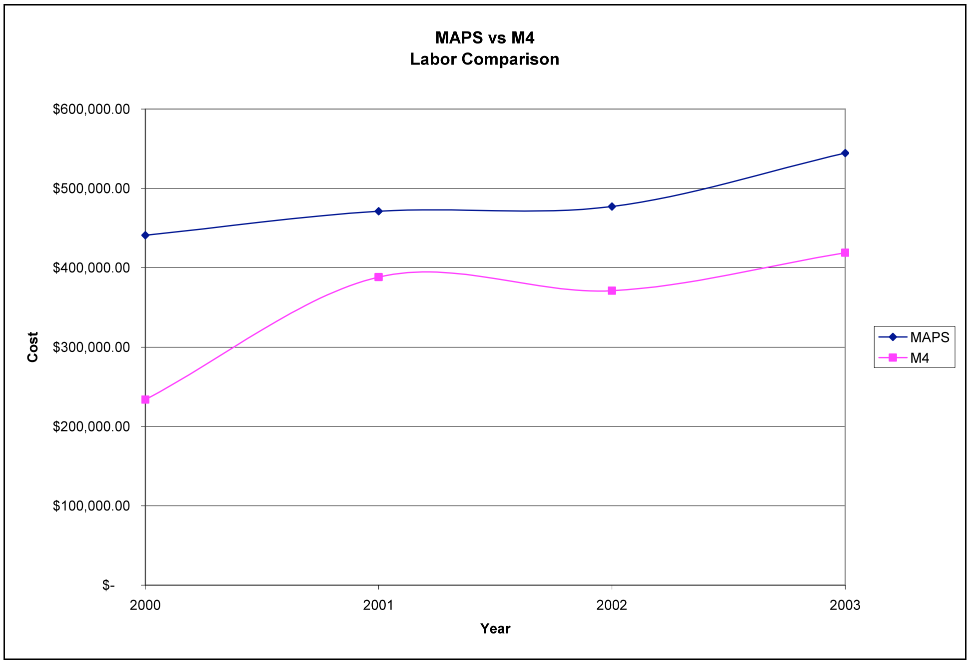


Figure 5-15 M4 vs. MAPS Labor Costs – Year Based

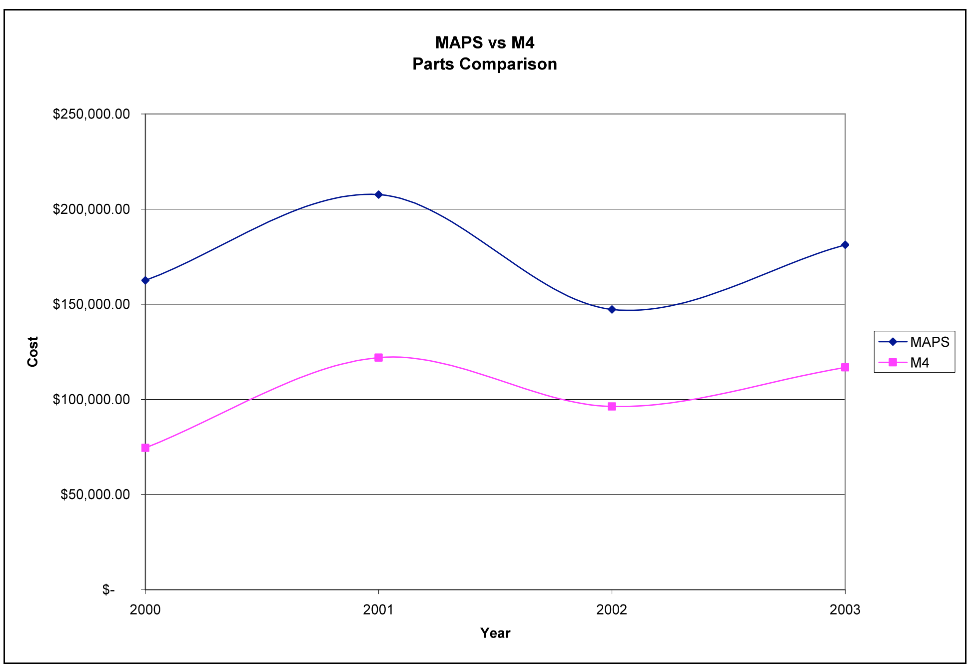


Figure 5-16 M4 vs. MAPS Parts Costs – Year Based

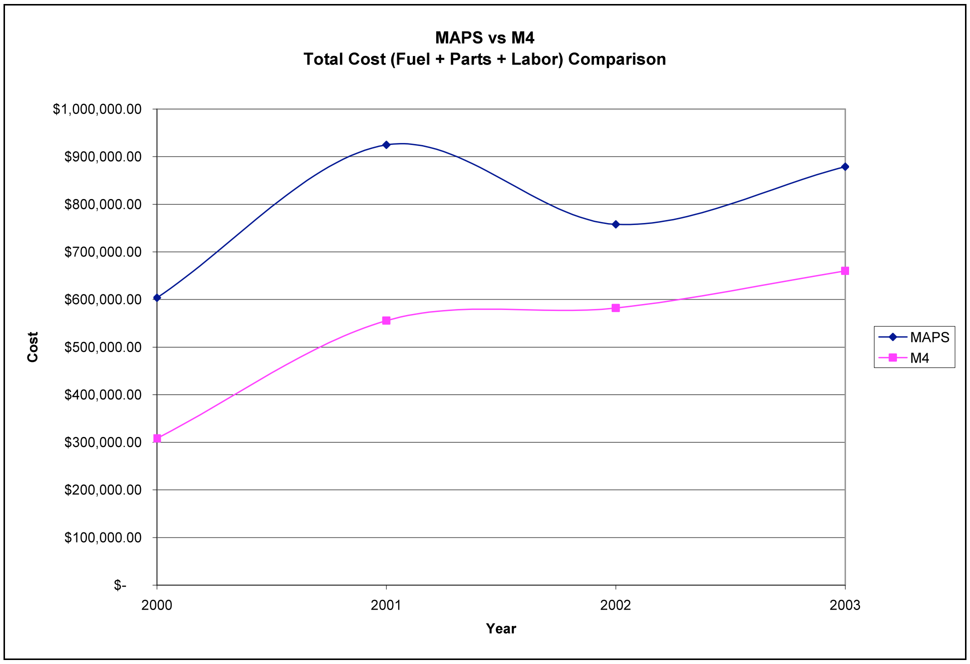


Figure 5-17 M4 vs. MAPS Total Costs – Year Based

It is clear from the previous graphs that M4 costs are always lower than MAPS costs, independent of the type of cost. MAPS costs can be as much as 300 percent of those reported by M4.

One of the downsides is that M4 data do not seem to get better with time. The differences between MAPS and M4 data tend to decrease with new data but not in a considerable way.

Mn/DOT people believe that MAPS data are more accurate than M4 data. Looking at those graphs and considering the general feeling about M4 data, it is clear that M4 data cannot be trusted in its current form.

5.3 General Analysis

Figures 5-18 through 5-24 show the average cost of parts, labor, and fuel for the whole state according to vehicle's age for each class (80, 90, 180, 190, 250, 330, and 350). These costs do not include either overhead or price indexes. The analysis of costs was done for the whole state instead of for each particular district because there was not enough information at a district level to obtain valid results.

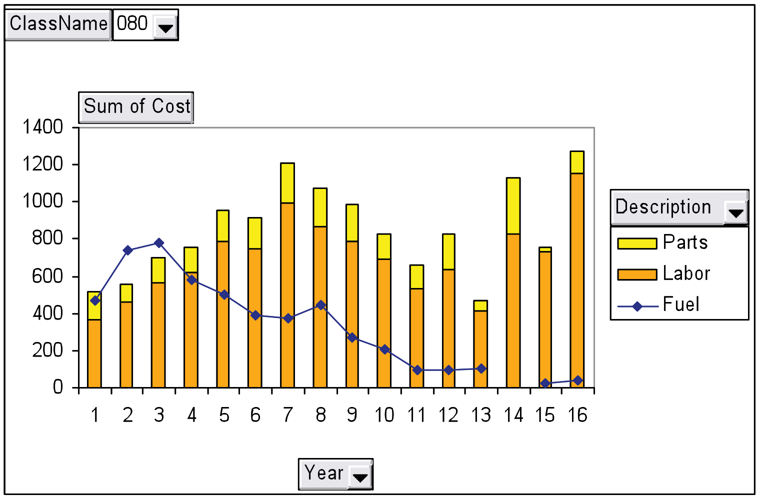


Figure 5-18 Cost Structure of Class 80 (M4 Data)

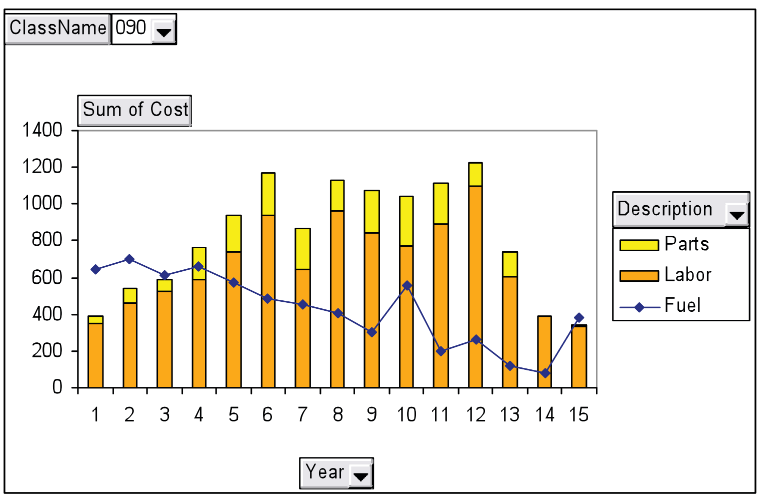


Figure 5-19 Cost Structure of Class 90 (M4 Data)

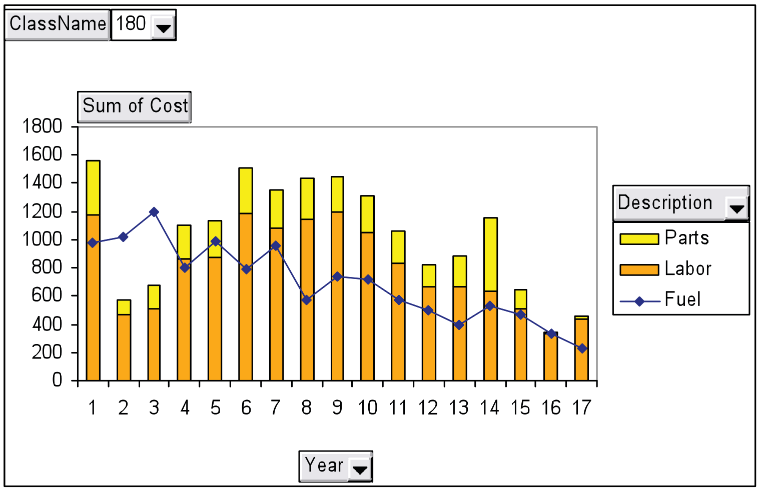


Figure 5-20 Cost Structure of Class 180 (M4 Data)

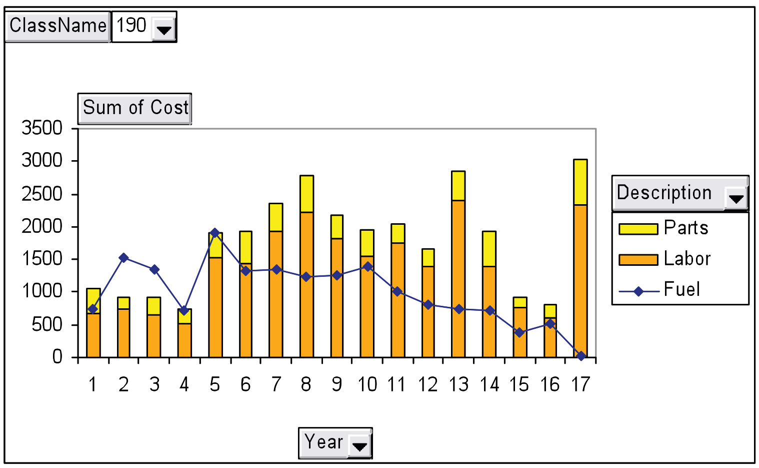


Figure 5-21 Cost Structure of Class 190 (M4 Data)

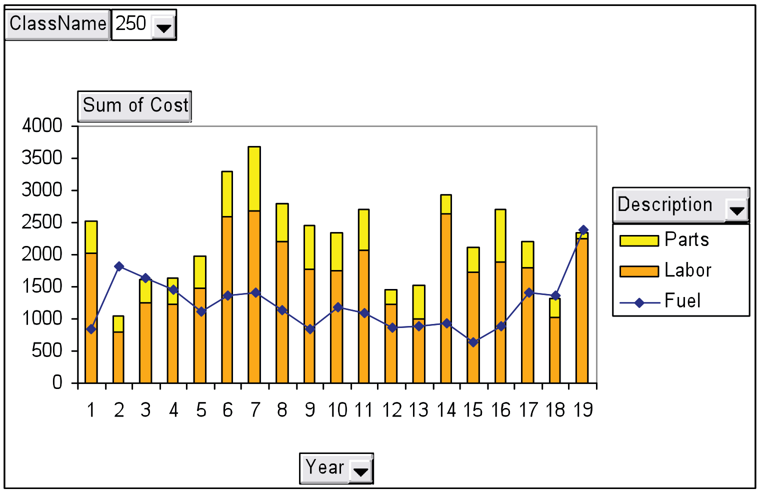


Figure 5-22 Cost Structure of Class 250 (M4 Data)

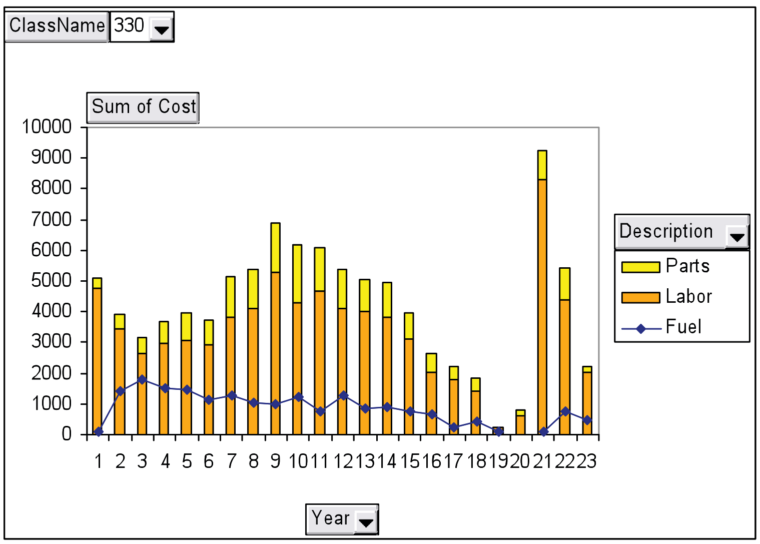


Figure 5-23 Cost Structure of Class 330 (M4 Data)

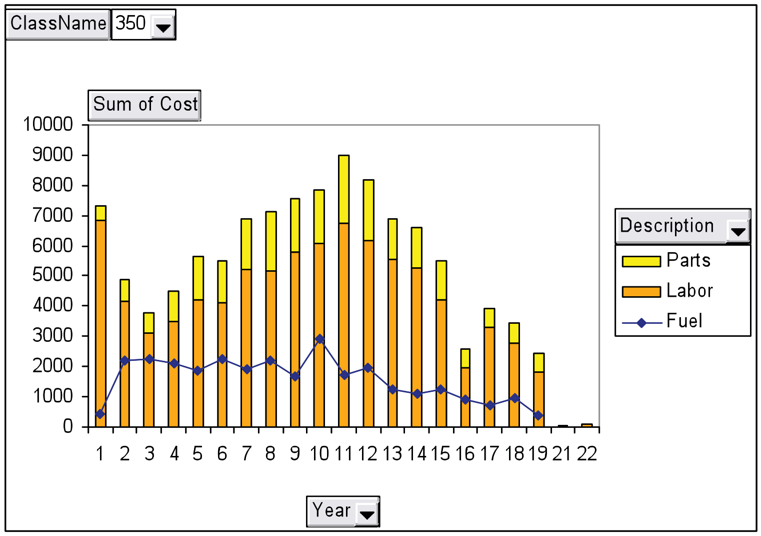


Figure 5-24 Cost Structure of Class 350 (M4 Data)

Looking through the previous figures, it seems that the cost structures follow the same pattern presented in Section 4. Class 330 and 350 vehicles show clearly a linear growth of costs for the first 9 or 12 years while their fuel consumption stays relatively constant. The other classes of vehicles also show a tendency of costs to grow linearly in the first years, but their fuel consumption is not that steady compared to classes 330 and 350.

The following sections contain the results of the analysis done considering only double regression analysis for each different class of vehicle. The different scenarios have a different combination of usage of price indexes and usage of overhead. The methodology used is the same applied to MAPS data (see Section 4.)

5.3.1 Non-Indexed Data and No Overhead

Figure 5-25 through Figure 5-31 show the results of the regression analyses done for the State considering the different classes of vehicles with data taken from M4 system. The two lower graphs represent the results of the regression analysis performed over parts and labor costs. The upper graph shows the result of combining those two regressions. In this first initial analysis, the data were not indexed using CPI or PPI, and it did not contain overhead costs. More analyses were done taking into account those scenarios.

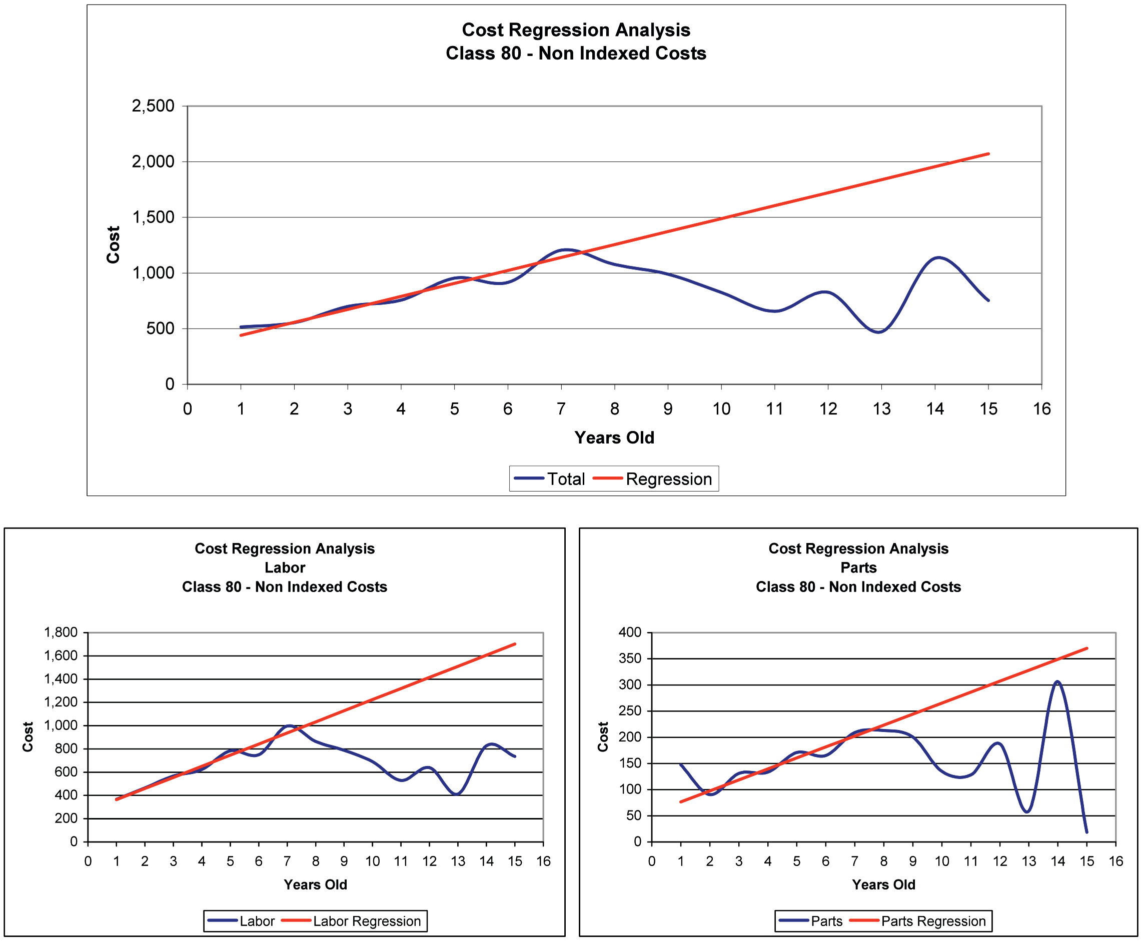


Figure 5-25 Cost Regression Analysis Result – Class 80 – Non-Indexed Costs and No Overhead

The linear regression analyses for class 80 data generated the following results:

- Labor:
  - Years used for correlation: 1 - 7
  - Intercept: $269
  - Yearly maintenance increase: $96
  - Regression correlation: 97.32 %

- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $56
  - Yearly maintenance increase: $21
  - Regression correlation: 95.93 %
- Total:
  - Intercept: $324
  - Yearly maintenance increase: $116

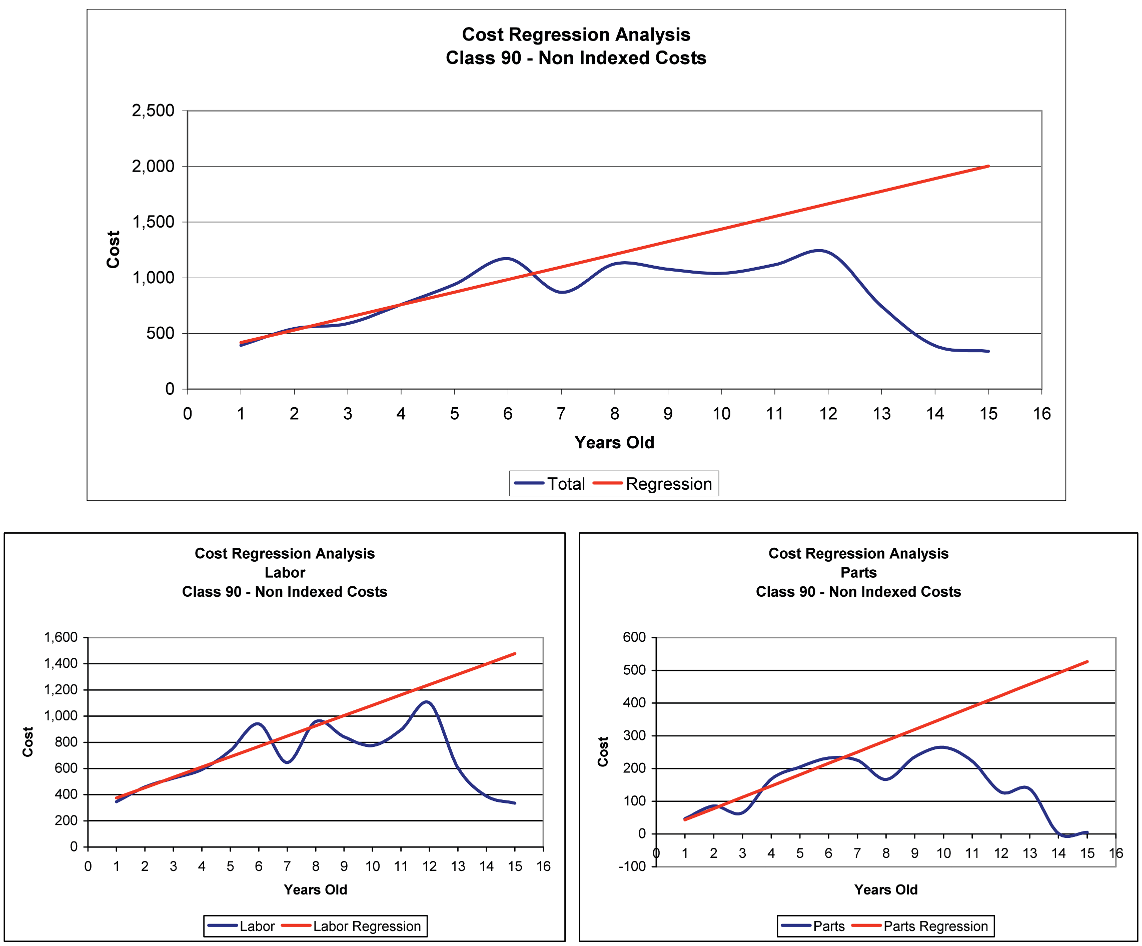
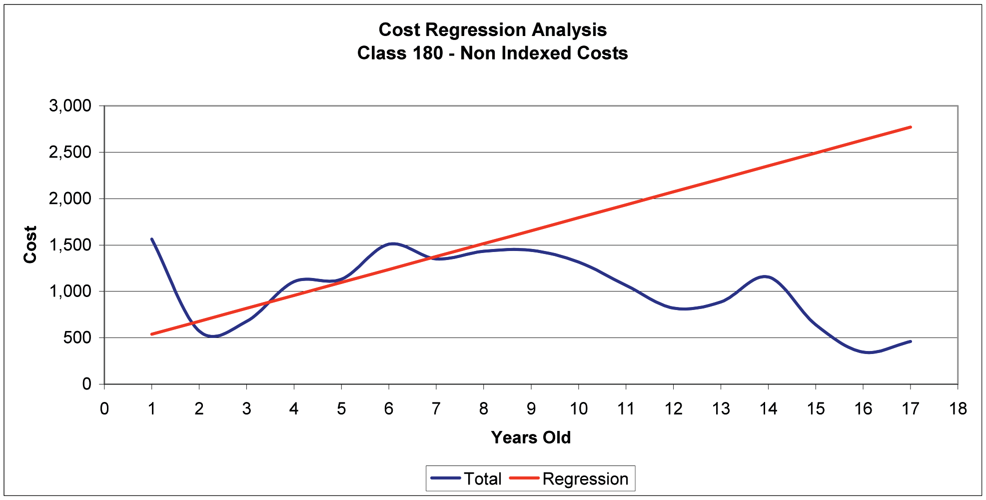
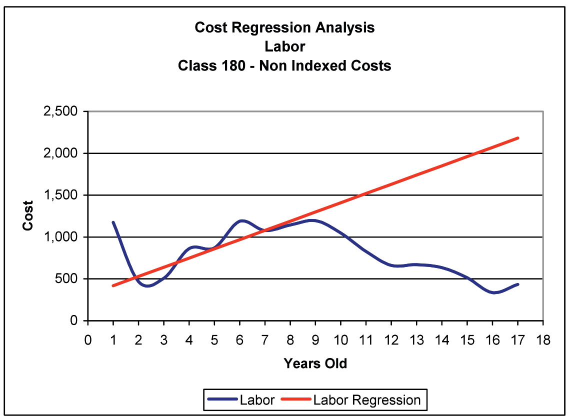


Figure 5-26 Cost Regression Analysis Result – Class 90 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 90 data generated the following results:

- Labor:
    - Years used for correlation: 1 - 8
    - Intercept: $296
    - Yearly maintenance increase: $79
    - Regression correlation: 88.13 %
- Parts:
    - Years used for correlation: 1 - 7
    - Intercept: $9
    - Yearly maintenance increase: $35
    - Regression correlation: 94.18 %
- Total:
    - Intercept: $305
    - Yearly maintenance increase: $113





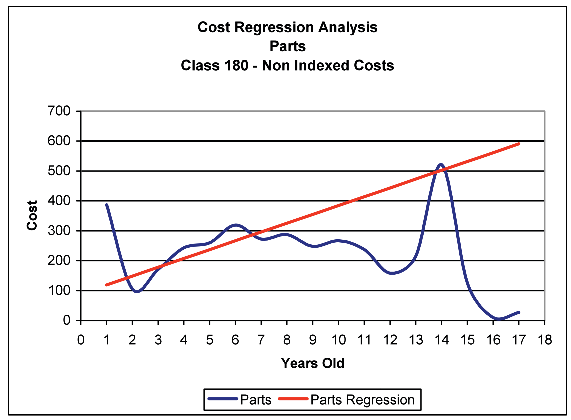


Figure 5-27 Cost Regression Analysis Result – Class 180 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 180 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 9
  - Intercept: $308
  - Yearly maintenance increase: $110
  - Regression correlation: 91.75 %
- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $90

- Yearly maintenance increase: $29
- Regression correlation: 86.12 %

- Total:
    - Intercept: $398
    - Yearly maintenance increase: $140

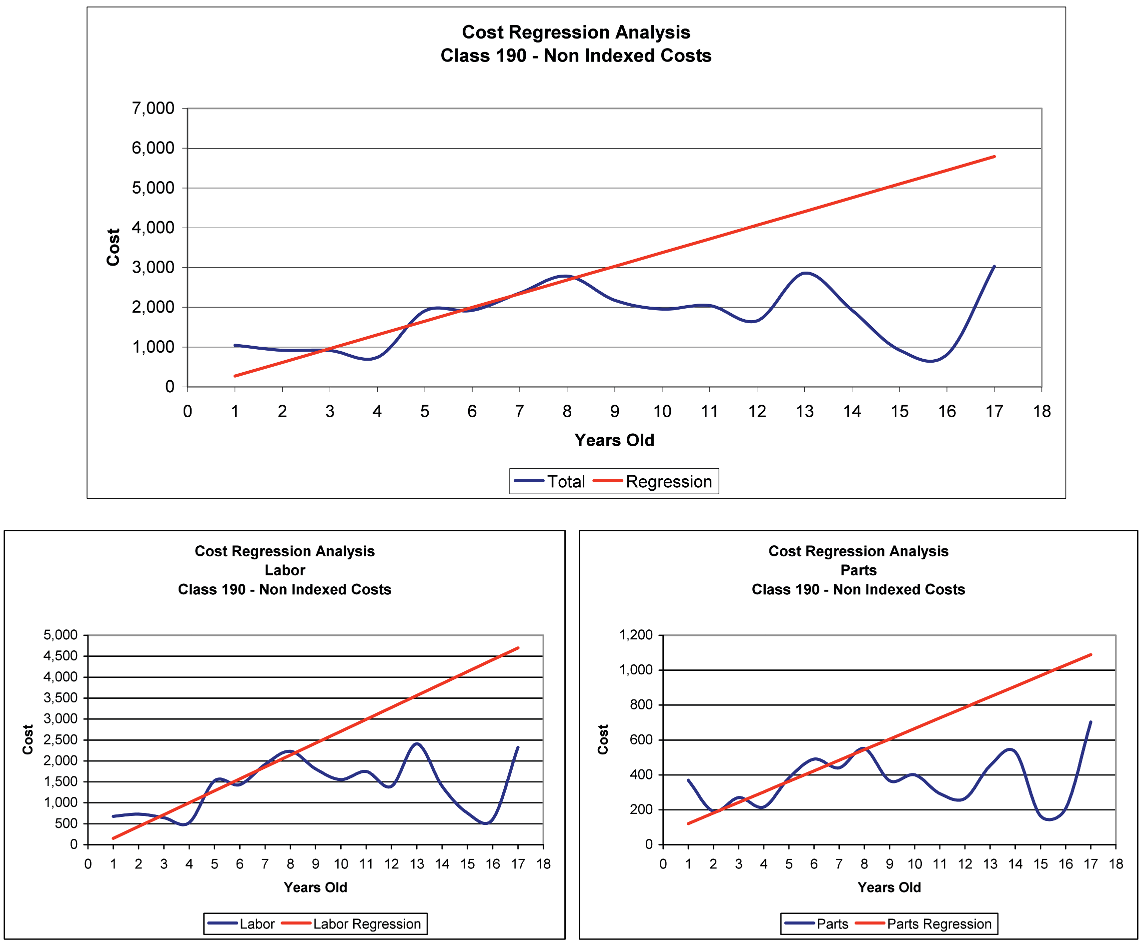


Figure 5-28 Cost Regression Analysis Result – Class 190 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 190 data generated the following results:

- Labor:
    - Years used for correlation: 2 - 8
    - Intercept: - $134

  - Yearly maintenance increase: $284
  - Regression correlation: 92.04 %
- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $61
  - Yearly maintenance increase: $61
  - Regression correlation: 93.29 %
- Total:
  - Intercept: - $74
  - Yearly maintenance increase: $345

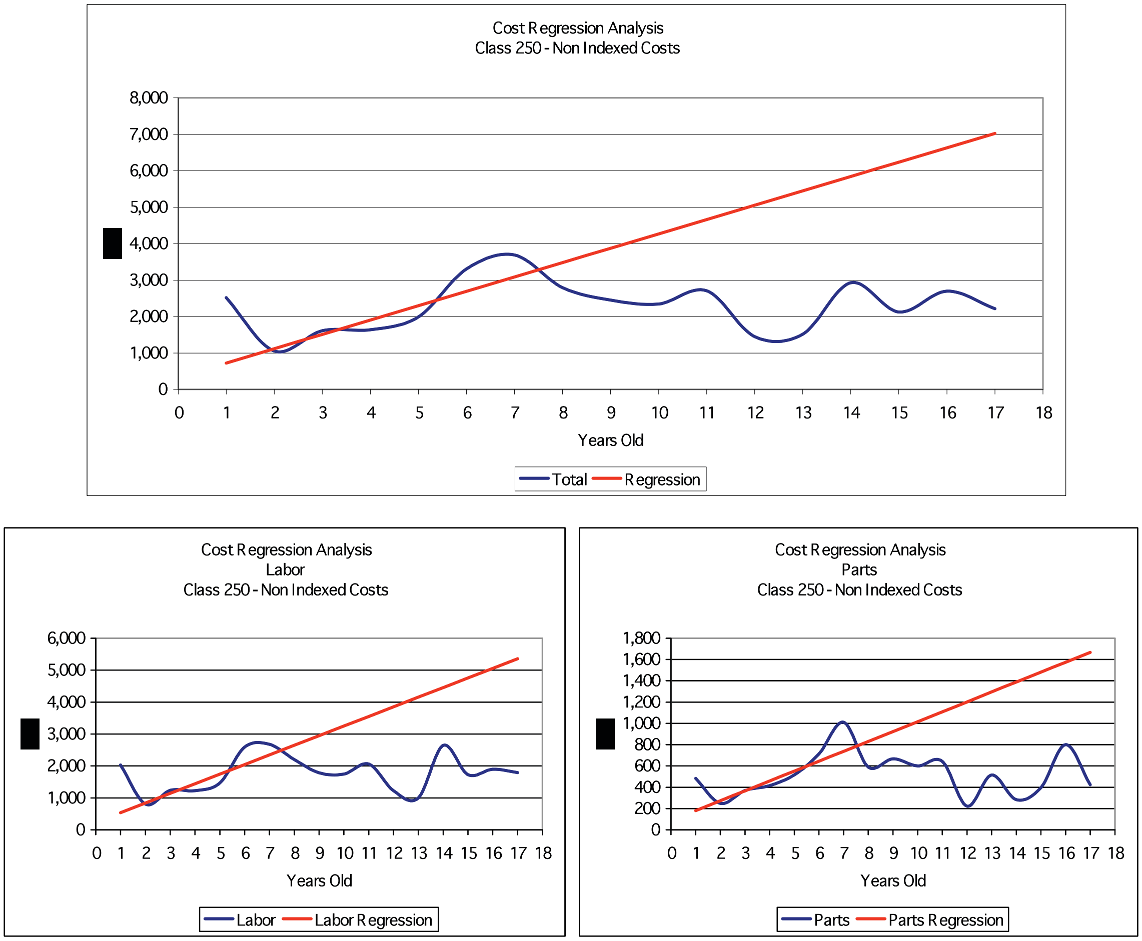


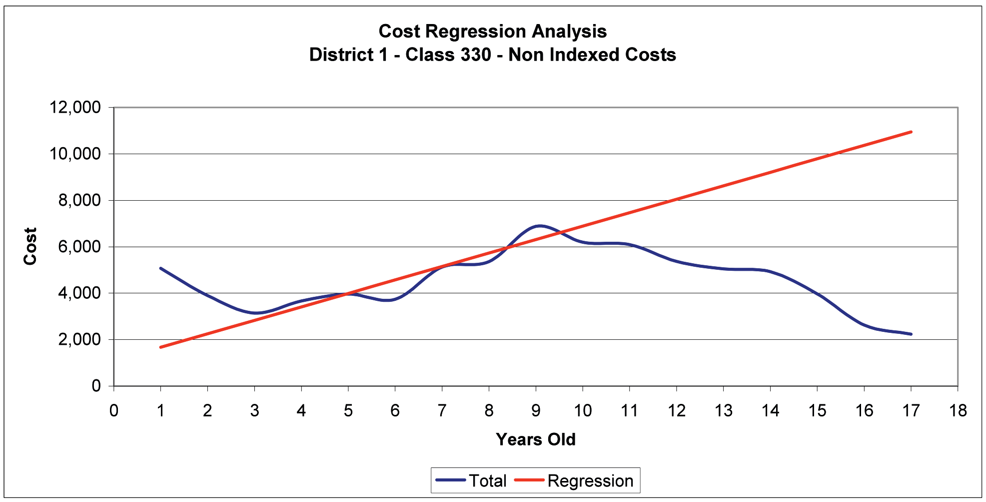
Figure 5-29 Cost Regression Analysis Result – Class 250 – Non-Indexed Costs and No Overhead

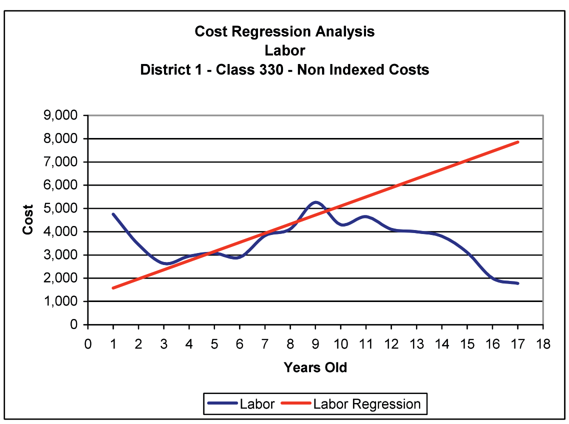
The linear regression analysis for class 250 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 8
  - Intercept: $239
  - Yearly maintenance increase: $301
  - Regression correlation: 87.99 %
- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $87

- Yearly maintenance increase: $93
- Regression correlation: 79.49 %

- Total:
  - Intercept: $326
  - Yearly maintenance increase: $394





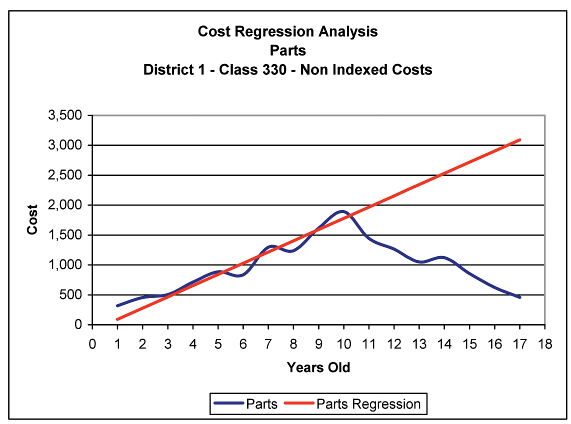


Figure 5-30 Cost Regression Analysis Result – Class 330 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 330 data generated the following results:

- Labor:
  - Years used for correlation: 3 - 9
  - Intercept: $1,189

- Yearly maintenance increase: $392
- Regression correlation: 91.16 %

- Parts:
  - Years used for correlation: 3 - 10
  - Intercept: - $97
  - Yearly maintenance increase: $188
  - Regression correlation: 96.99 %
- Total:
  - Intercept: $1,092
  - Yearly maintenance increase: $580

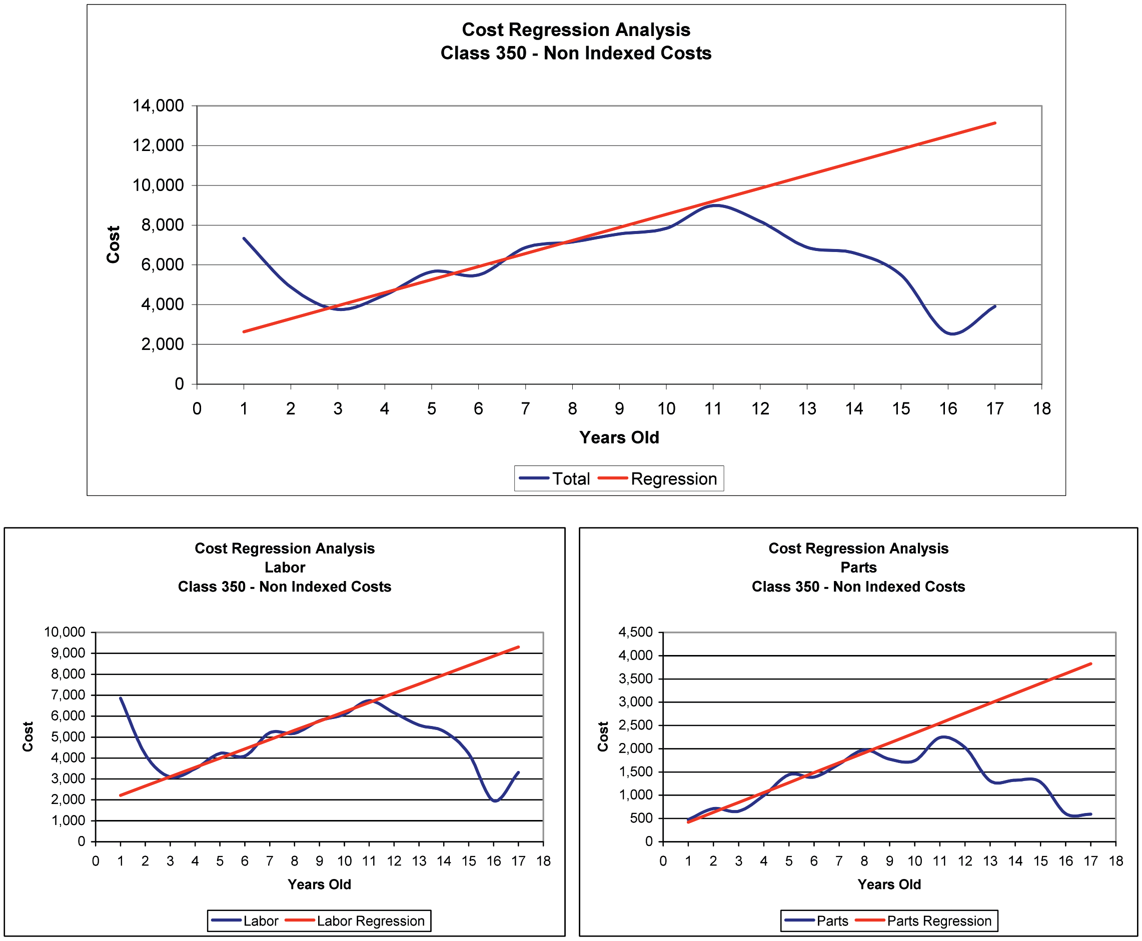


Figure 5-31 Cost Regression Analysis Result – Class 350 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 350 data generated the following results:

- Labor:
  - Years used for correlation: 3 - 11
  - Intercept: $1,777
  - Yearly maintenance increase: $443
  - Regression correlation: 98.68 %
- Parts:
  - Years used for correlation: 1 - 8
  - Intercept: $207

  - Yearly maintenance increase: $213
  - Regression correlation: 97.70 %
- Total:
  - Intercept: $1,983
  - Yearly maintenance increase: $656

Every linear regression has a high correlation factor as happened previously with MAPS data. More than 80 percent of the variation of the maintenance costs can be explained with the vehicle's increased age.

Table 5-1 shows the average purchase price of the different classes of vehicles without considering price indexes. A LCC analysis was done using these prices, the previously calculated maintenance costs, double depreciation, and 5 percent of interest rate. The results of these analyses are shown in Figure 5-32 through Figure 5-38.

Class	**80**	**90**	**180**	**190**	**250**	**330**	**350**
Purchase Cost	$13,240	$15,607	$12,294	$20,406	$30,322	$69,738	$89,645

Table 5-1 Purchase Cost without Indexes

Class 80 Using cost without overhead and without indexes

Purchase: $13,239.53 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 116 Depreciation (years): 10

Intercept: $ 324

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$13,239.53	$ 13,240			
1		$ 10,592	$ 441	$ 3,572	$ 3,751
2		$ 8,473	$ 557	$ 6,479	$ 3,485
3		$ 6,779	$ 674	$ 8,891	$ 3,265
4		$ 5,423	$ 790	$ 10,936	$ 3,084
5		$ 4,338	$ 907	$ 12,709	$ 2,935
6		$ 3,471	$ 1,023	$ 14,282	$ 2,814
7		$ 2,777	$ 1,140	$ 15,708	$ 2,715
8		$ 2,221	$ 1,256	$ 17,028	$ 2,635
9		$ 1,777	$ 1,373	$ 18,271	$ 2,571
10		$ 1,422	$ 1,489	$ 19,458	$ 2,520
11		$ 1,137	$ 1,606	$ 20,605	$ 2,481
12		$ 910	$ 1,722	$ 21,722	$ 2,451
13		$ 728	$ 1,839	$ 22,818	$ 2,429
14		$ 582	$ 1,955	$ 23,897	$ 2,414
15		$ 466	$ 2,072	$ 24,963	$ 2,405
16		$ 373	$ 2,188	$ 26,019	$ 2,401
17		$ 298	$ 2,305	$ 27,065	$ 2,401
18		$ 239	$ 2,421	$ 28,102	$ 2,404
19		$ 191	$ 2,537	$ 29,130	$ 2,410
20		$ 153	$ 2,654	$ 30,148	$ 2,419
21		$ 122	$ 2,770	$ 31,156	$ 2,430
22		$ 98	$ 2,887	$ 32,154	$ 2,443
23		$ 78	$ 3,003	$ 33,139	$ 2,457
24		$ 63	$ 3,120	$ 34,113	$ 2,472
25		$ 50	$ 3,236	$ 35,073	$ 2,489

Min	**$2,401**
Year	**17**

Figure 5-32 Life Cycle Cost Analysis – Class 80 – Non-Indexed and No Overhead

Class 90 Using cost without overhead and without indexes

Purchase: $15,606.86 | Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 113 | Depreciation (years): 10

Intercept: $ 305

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$15,606.86	$ 15,607			
1		$ 12,485	$ 418	$ 4,114	$ 4,320
2		$ 9,988	$ 531	$ 7,427	$ 3,994
3		$ 7,991	$ 645	$ 10,141	$ 3,724
4		$ 6,393	$ 758	$ 12,408	$ 3,499
5		$ 5,114	$ 871	$ 14,343	$ 3,313
6		$ 4,091	$ 984	$ 16,031	$ 3,158
7		$ 3,273	$ 1,098	$ 17,538	$ 3,031
8		$ 2,618	$ 1,211	$ 18,912	$ 2,926
9		$ 2,095	$ 1,324	$ 20,187	$ 2,840
10		$ 1,676	$ 1,437	$ 21,391	$ 2,770
11		$ 1,341	$ 1,550	$ 22,542	$ 2,714
12		$ 1,072	$ 1,664	$ 23,655	$ 2,669
13		$ 858	$ 1,777	$ 24,740	$ 2,634
14		$ 686	$ 1,890	$ 25,803	$ 2,607
15		$ 549	$ 2,003	$ 26,849	$ 2,587
16		$ 439	$ 2,117	$ 27,882	$ 2,573
17		$ 351	$ 2,230	$ 28,902	$ 2,564
18		$ 281	$ 2,343	$ 29,913	$ 2,559
19		$ 225	$ 2,456	$ 30,912	$ 2,558
20		$ 180	$ 2,570	$ 31,902	$ 2,560
21		$ 144	$ 2,683	$ 32,881	$ 2,565
22		$ 115	$ 2,796	$ 33,849	$ 2,572
23		$ 92	$ 2,909	$ 34,806	$ 2,580
24		$ 74	$ 3,023	$ 35,750	$ 2,591
25		$ 59	$ 3,136	$ 36,682	$ 2,603

Min	**$2,558**
Year	**19**

Figure 5-33 Life Cycle Cost Analysis – Class 90 – Non-Indexed and No Overhead

Class 180 Using cost without overhead and without indexes

Purchase: $12,293.72 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 140 Depreciation (years): 10

Intercept: $ 398

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$12,293.72	$ 12,294			
1		$ 9,835	$ 538	$ 3,439	$ 3,611
2		$ 7,868	$ 677	$ 6,284	$ 3,379
3		$ 6,294	$ 817	$ 8,688	$ 3,190
4		$ 5,036	$ 957	$ 10,770	$ 3,037
5		$ 4,028	$ 1,096	$ 12,615	$ 2,914
6		$ 3,223	$ 1,236	$ 14,289	$ 2,815
7		$ 2,578	$ 1,375	$ 15,839	$ 2,737
8		$ 2,063	$ 1,515	$ 17,301	$ 2,677
9		$ 1,650	$ 1,655	$ 18,700	$ 2,631
10		$ 1,320	$ 1,794	$ 20,055	$ 2,597
11		$ 1,056	$ 1,934	$ 21,378	$ 2,574
12		$ 845	$ 2,074	$ 22,680	$ 2,559
13		$ 676	$ 2,213	$ 23,966	$ 2,551
14		$ 541	$ 2,353	$ 25,239	$ 2,550
15		$ 433	$ 2,492	$ 26,503	$ 2,553
16		$ 346	$ 2,632	$ 27,759	$ 2,561
17		$ 277	$ 2,772	$ 29,006	$ 2,573
18		$ 221	$ 2,911	$ 30,244	$ 2,587
19		$ 177	$ 3,051	$ 31,473	$ 2,604
20		$ 142	$ 3,191	$ 32,693	$ 2,623
21		$ 113	$ 3,330	$ 33,901	$ 2,644
22		$ 91	$ 3,470	$ 35,097	$ 2,666
23		$ 73	$ 3,610	$ 36,279	$ 2,690
24		$ 58	$ 3,749	$ 37,447	$ 2,714
25		$ 46	$ 3,889	$ 38,600	$ 2,739

Min	**$2,550**
Year	**14**

Figure 5-34 Life Cycle Cost Analysis – Class 180 – Non-Indexed and No Overhead

Class 190 Using cost without overhead and without indexes

Purchase: $20,405.78 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 345 Depreciation (years): 10

Intercept: $ (74)

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$20,405.78	$ 20,406			
1		$ 16,325	$ 271	$ 5,117	$ 5,373
2		$ 13,060	$ 616	$ 9,377	$ 5,043
3		$ 10,448	$ 961	$ 13,028	$ 4,784
4		$ 8,358	$ 1,306	$ 16,251	$ 4,583
5		$ 6,687	$ 1,651	$ 19,182	$ 4,430
6		$ 5,349	$ 1,995	$ 21,918	$ 4,318
7		$ 4,279	$ 2,340	$ 24,532	$ 4,240
8		$ 3,424	$ 2,685	$ 27,073	$ 4,189
9		$ 2,739	$ 3,030	$ 29,578	$ 4,161
10		$ 2,191	$ 3,375	$ 32,070	$ 4,153
11		$ 1,753	$ 3,720	$ 34,565	$ 4,161
12		$ 1,402	$ 4,064	$ 37,072	$ 4,183
13		$ 1,122	$ 4,409	$ 39,597	$ 4,215
14		$ 897	$ 4,754	$ 42,139	$ 4,257
15		$ 718	$ 5,099	$ 44,700	$ 4,307
16		$ 574	$ 5,444	$ 47,276	$ 4,362
17		$ 459	$ 5,789	$ 49,864	$ 4,423
18		$ 368	$ 6,133	$ 52,461	$ 4,488
19		$ 294	$ 6,478	$ 55,061	$ 4,556
20		$ 235	$ 6,823	$ 57,660	$ 4,627
21		$ 188	$ 7,168	$ 60,254	$ 4,700
22		$ 151	$ 7,513	$ 62,838	$ 4,774
23		$ 120	$ 7,858	$ 65,409	$ 4,849
24		$ 96	$ 8,202	$ 67,961	$ 4,925
25		$ 77	$ 8,547	$ 70,492	$ 5,002

Min	**$4,153**
Year	**10**

Figure 5-35 Life Cycle Cost Analysis – Class 190 – Non-Indexed and No Overhead

Class 250 Using cost without overhead and without indexes

Purchase:	$30,321.88	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 394	Depreciation (years):	10
Intercept:	$ 326		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$30,321.88	$ 30,322			
1		$ 24,258	$ 720	$ 7,905	$ 8,300
2		$ 19,406	$ 1,114	$ 14,416	$ 7,753
3		$ 15,525	$ 1,508	$ 19,909	$ 7,311
4		$ 12,420	$ 1,902	$ 24,667	$ 6,956
5		$ 9,936	$ 2,296	$ 28,899	$ 6,675
6		$ 7,949	$ 2,690	$ 32,760	$ 6,454
7		$ 6,359	$ 3,084	$ 36,364	$ 6,284
8		$ 5,087	$ 3,478	$ 39,794	$ 6,157
9		$ 4,070	$ 3,872	$ 43,110	$ 6,065
10		$ 3,256	$ 4,266	$ 46,353	$ 6,003
11		$ 2,605	$ 4,660	$ 49,554	$ 5,966
12		$ 2,084	$ 5,054	$ 52,731	$ 5,949
13		$ 1,667	$ 5,448	$ 55,897	$ 5,951
14		$ 1,334	$ 5,842	$ 59,058	$ 5,966
15		$ 1,067	$ 6,236	$ 62,218	$ 5,994
16		$ 853	$ 6,631	$ 65,378	$ 6,032
17		$ 683	$ 7,025	$ 68,536	$ 6,079
18		$ 546	$ 7,419	$ 71,689	$ 6,133
19		$ 437	$ 7,813	$ 74,835	$ 6,192
20		$ 350	$ 8,207	$ 77,969	$ 6,256
21		$ 280	$ 8,601	$ 81,088	$ 6,325
22		$ 224	$ 8,995	$ 84,187	$ 6,396
23		$ 179	$ 9,389	$ 87,262	$ 6,469
24		$ 143	$ 9,783	$ 90,309	$ 6,545
25		$ 115	$ 10,177	$ 93,325	$ 6,622

Min	**$5,949**
Year	**12**

Figure 5-36 Life Cycle Cost Analysis – Class 250 – Non-Indexed and No Overhead

Class 330 Using cost without overhead and without indexes

Purchase:	$69,737.90	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 580	Depreciation (years):	13
Intercept:	$ 1,092		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$69,737.90	$ 69,738			
1		$ 59,009	$ 1,672	$ 15,131	$ 15,887
2		$ 49,931	$ 2,251	$ 28,083	$ 15,103
3		$ 42,249	$ 2,831	$ 39,321	$ 14,439
4		$ 35,749	$ 3,410	$ 49,212	$ 13,878
5		$ 30,249	$ 3,990	$ 58,048	$ 13,408
6		$ 25,596	$ 4,570	$ 66,060	$ 13,015
7		$ 21,658	$ 5,149	$ 73,427	$ 12,690
8		$ 18,326	$ 5,729	$ 80,293	$ 12,423
9		$ 15,506	$ 6,309	$ 86,768	$ 12,207
10		$ 13,121	$ 6,888	$ 92,937	$ 12,036
11		$ 11,102	$ 7,468	$ 98,867	$ 11,903
12		$ 9,394	$ 8,048	$ 104,609	$ 11,803
13		$ 7,949	$ 8,627	$ 110,199	$ 11,731
14		$ 6,726	$ 9,207	$ 115,668	$ 11,685
15		$ 5,691	$ 9,787	$ 121,035	$ 11,661
16		$ 4,816	$ 10,366	$ 126,315	$ 11,655
17		$ 4,075	$ 10,946	$ 131,519	$ 11,666
18		$ 3,448	$ 11,525	$ 136,653	$ 11,690
19		$ 2,917	$ 12,105	$ 141,722	$ 11,727
20		$ 2,469	$ 12,685	$ 146,727	$ 11,774
21		$ 2,089	$ 13,264	$ 151,668	$ 11,830
22		$ 1,767	$ 13,844	$ 156,547	$ 11,893
23		$ 1,496	$ 14,424	$ 161,360	$ 11,963
24		$ 1,265	$ 15,003	$ 166,106	$ 12,038
25		$ 1,071	$ 15,583	$ 170,784	$ 12,118

Min	**$11,655**
Year	**16**

Figure 5-37 Life Cycle Cost Analysis – Class 330 – Non-Indexed and No Overhead

Class 350 Using cost without overhead and without indexes

Purchase:	$89,644.90	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 656	Depreciation (years):	13
Intercept:	$ 1,983		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$89,644.90	$ 89,645			
1		$ 75,853	$ 2,639	$ 19,917	$ 20,913
2		$ 64,184	$ 3,296	$ 36,931	$ 19,862
3		$ 54,309	$ 3,952	$ 51,647	$ 18,965
4		$ 45,954	$ 4,608	$ 64,546	$ 18,203
5		$ 38,884	$ 5,264	$ 76,010	$ 17,556
6		$ 32,902	$ 5,920	$ 86,342	$ 17,011
7		$ 27,840	$ 6,576	$ 95,782	$ 16,553
8		$ 23,557	$ 7,232	$ 104,518	$ 16,171
9		$ 19,933	$ 7,888	$ 112,699	$ 15,856
10		$ 16,866	$ 8,544	$ 120,439	$ 15,597
11		$ 14,271	$ 9,200	$ 127,828	$ 15,389
12		$ 12,076	$ 9,857	$ 134,937	$ 15,224
13		$ 10,218	$ 10,513	$ 141,817	$ 15,097
14		$ 8,646	$ 11,169	$ 148,510	$ 15,003
15		$ 7,316	$ 11,825	$ 155,046	$ 14,937
16		$ 6,190	$ 12,481	$ 161,447	$ 14,897
17		$ 5,238	$ 13,137	$ 167,729	$ 14,877
18		$ 4,432	$ 13,793	$ 173,904	$ 14,877
19		$ 3,750	$ 14,449	$ 179,979	$ 14,892
20		$ 3,173	$ 15,105	$ 185,961	$ 14,922
21		$ 2,685	$ 15,761	$ 191,850	$ 14,964
22		$ 2,272	$ 16,418	$ 197,650	$ 15,016
23		$ 1,922	$ 17,074	$ 203,359	$ 15,076
24		$ 1,627	$ 17,730	$ 208,978	$ 15,145
25		$ 1,376	$ 18,386	$ 214,505	$ 15,220

Min	**$14,877**
Year	**18**

Figure 5-38 Life Cycle Cost Analysis – Class 350 – Non-Indexed and No Overhead

Table 5-2 shows a summary of the optimum life cycle calculated for each class of vehicle as well as their annual cost.

Class	80	90	180	190	250	330	350
Life Cycle	17	19	14	10	12	16	18
Annual Cost	$2,401	$2,558	$2,550	$4,153	$5,949	$11,655	$14,877

Table 5-2 Summary M4 Analysis - No Indexes and no Overhead

5.3.2 Indexed Data and No Overhead

Figure 5-39 through Figure 5-45 show the results of the regression analyses done for the State considering the different classes of vehicles with data taken from the M4 system. In this second analysis, the data were indexed but it did not contain overhead costs.

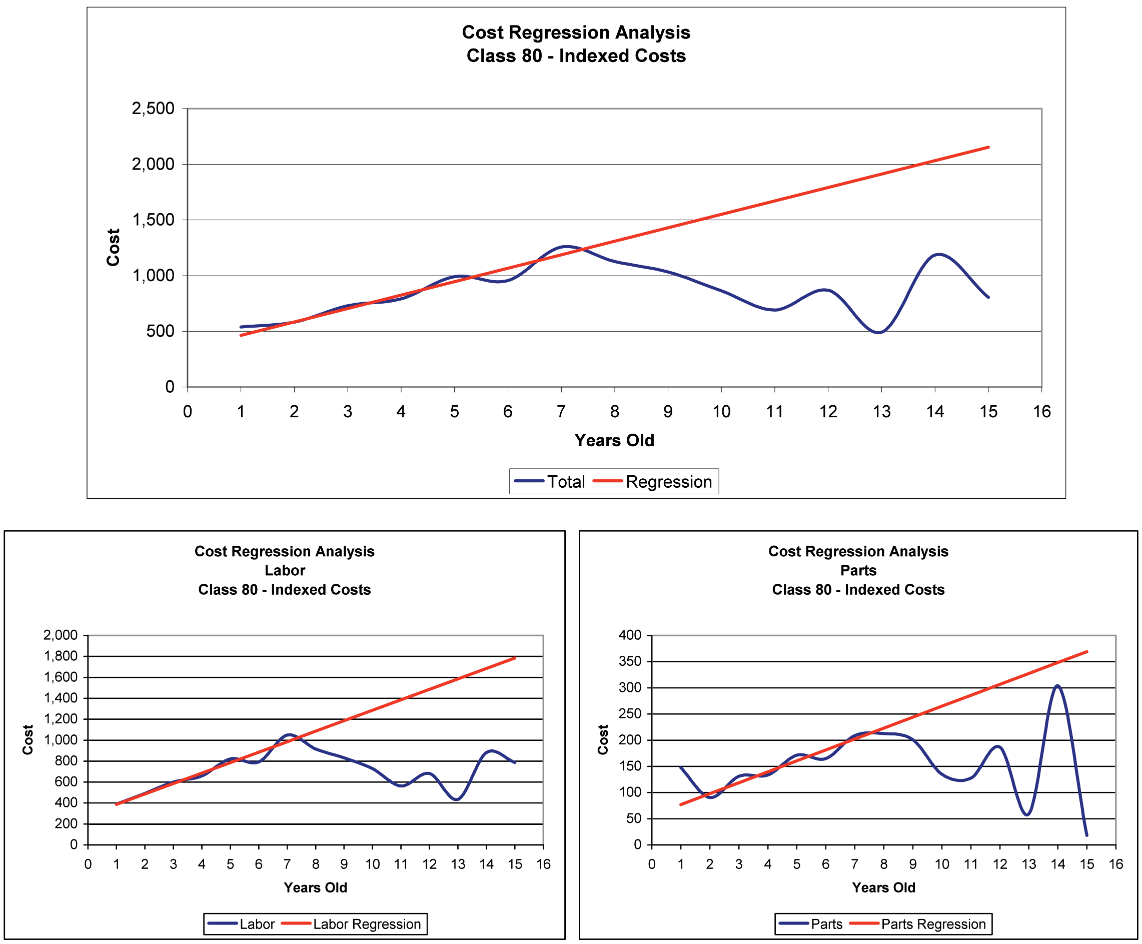


Figure 5-39 Cost Regression Analysis Result – Class 80 – Indexed Costs and No Overhead

The linear regression analyses for class 80 data generated the following results:

- Labor:

    - Years used for correlation: 1 - 7
    - Intercept: $287
    - Yearly maintenance increase: $100
    - Regression correlation: 97.41 %
- Parts:
    - Years used for correlation: 2 - 7
    - Intercept: $56
    - Yearly maintenance increase: $21
    - Regression correlation: 95.82 %
- Total:
    - Intercept: $343
    - Yearly maintenance increase: $121

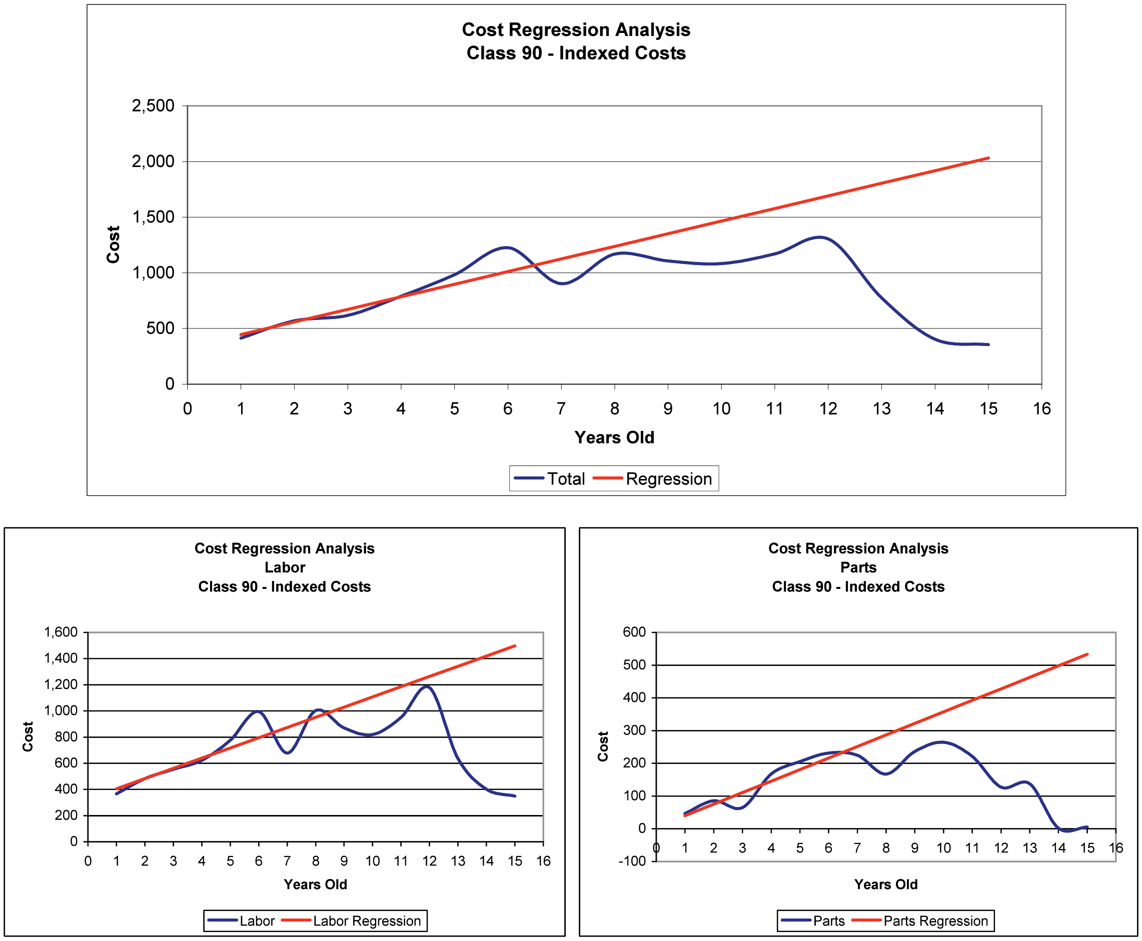


Figure 5-40 Cost Regression Analysis Result – Class 90 – Indexed Costs and No Overhead

The linear regression analysis for class 90 data generated the following results:

- Labor:
    - Years used for correlation: 1 - 7
    - Intercept: $327
    - Yearly maintenance increase: $78
    - Regression correlation: 81.96 %
- Parts:
    - Years used for correlation: 2 - 7
    - Intercept: $5

- Yearly maintenance increase: $35
- Regression correlation: 91.50 %

- Total:
  - Intercept: $332
  - Yearly maintenance increase: $113

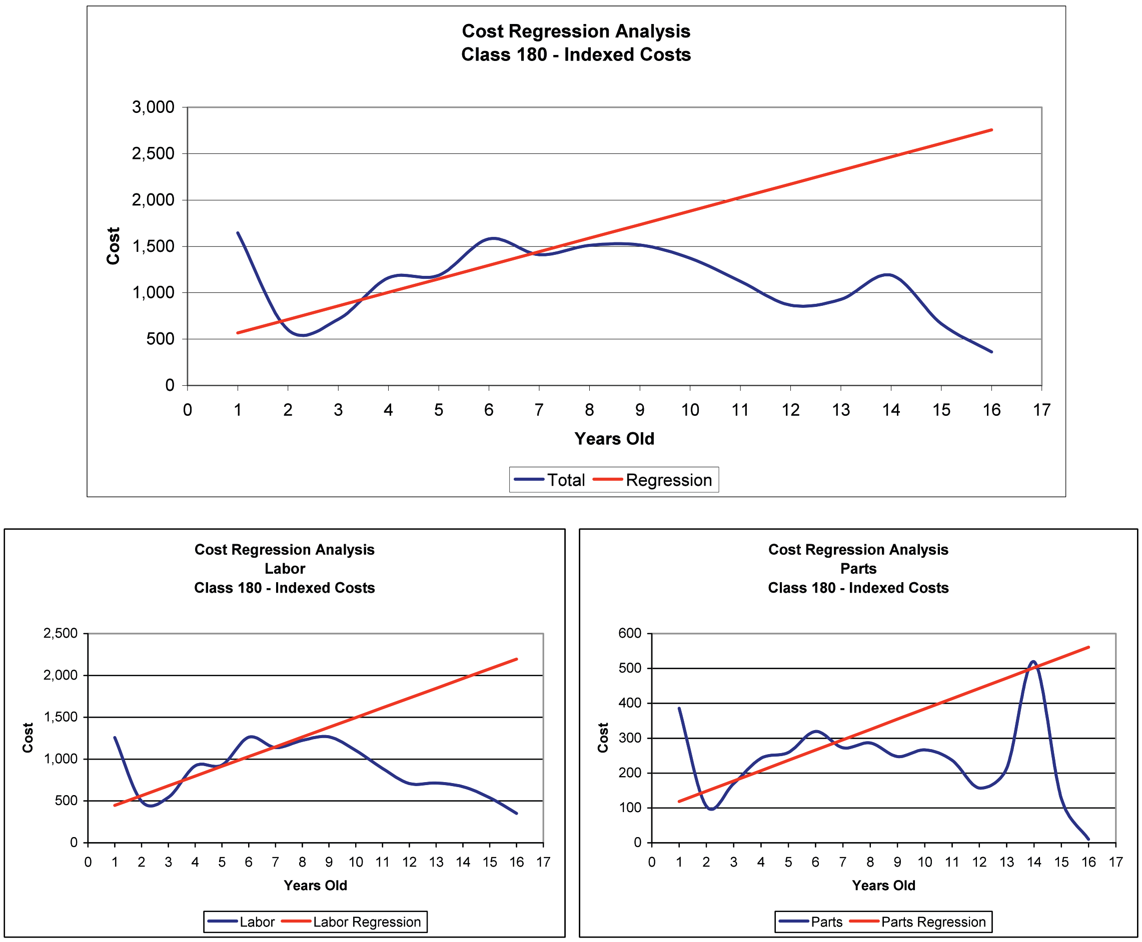


Figure 5-41 Cost Regression Analysis Result – Class 180 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 180 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 9
  - Intercept: $331

    - Yearly maintenance increase: $117
    - Regression correlation: 91.81 %
- Parts:
    - Years used for correlation: 2 - 8
    - Intercept: $89
    - Yearly maintenance increase: $30
    - Regression correlation: 86.16 %
- Total:
    - Intercept: $420
    - Yearly maintenance increase: $146

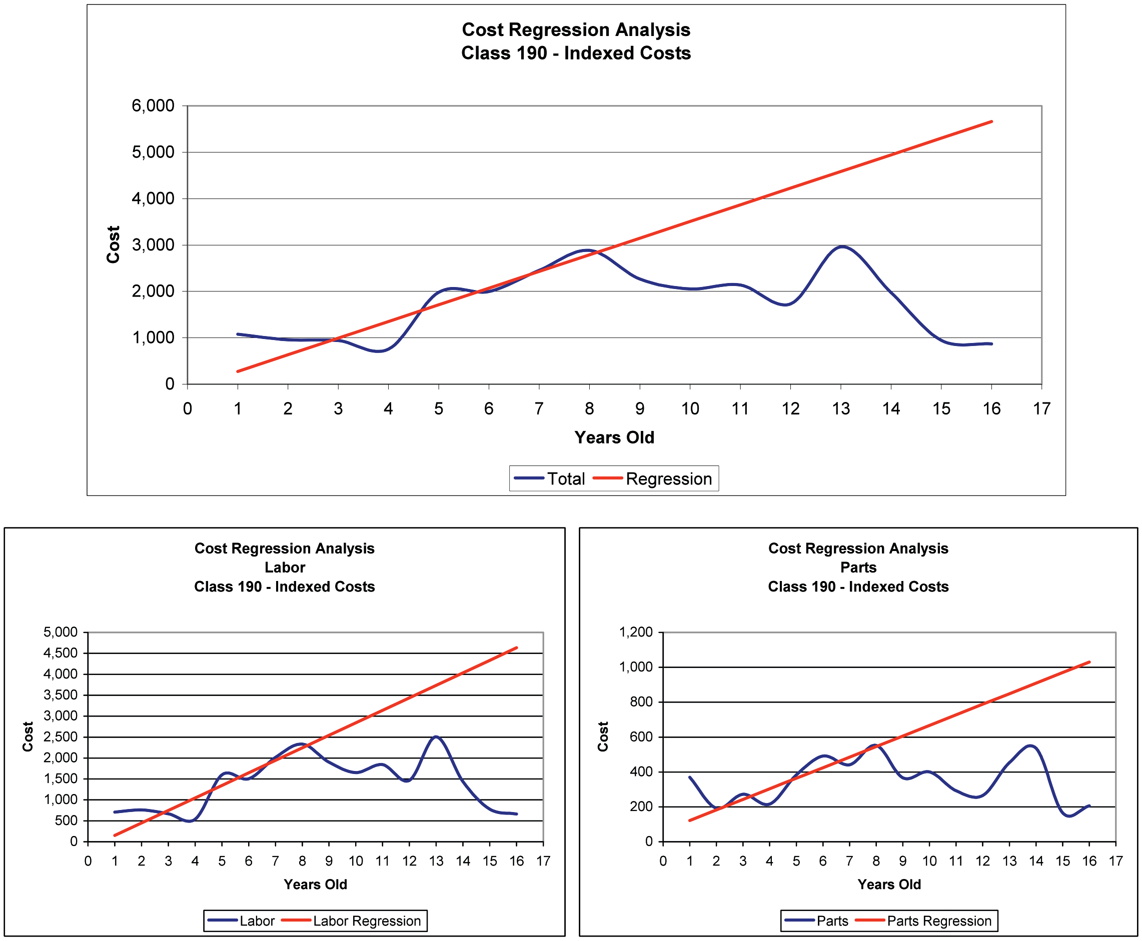


Figure 5-42 Cost Regression Analysis Result – Class 190 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 190 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 8
  - Intercept: - $147
  - Yearly maintenance increase: $299
  - Regression correlation: 91.93 %
- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $61

- Yearly maintenance increase: $61
- Regression correlation: 93.22 %

- Total:
  - Intercept: - $86
  - Yearly maintenance increase: $359

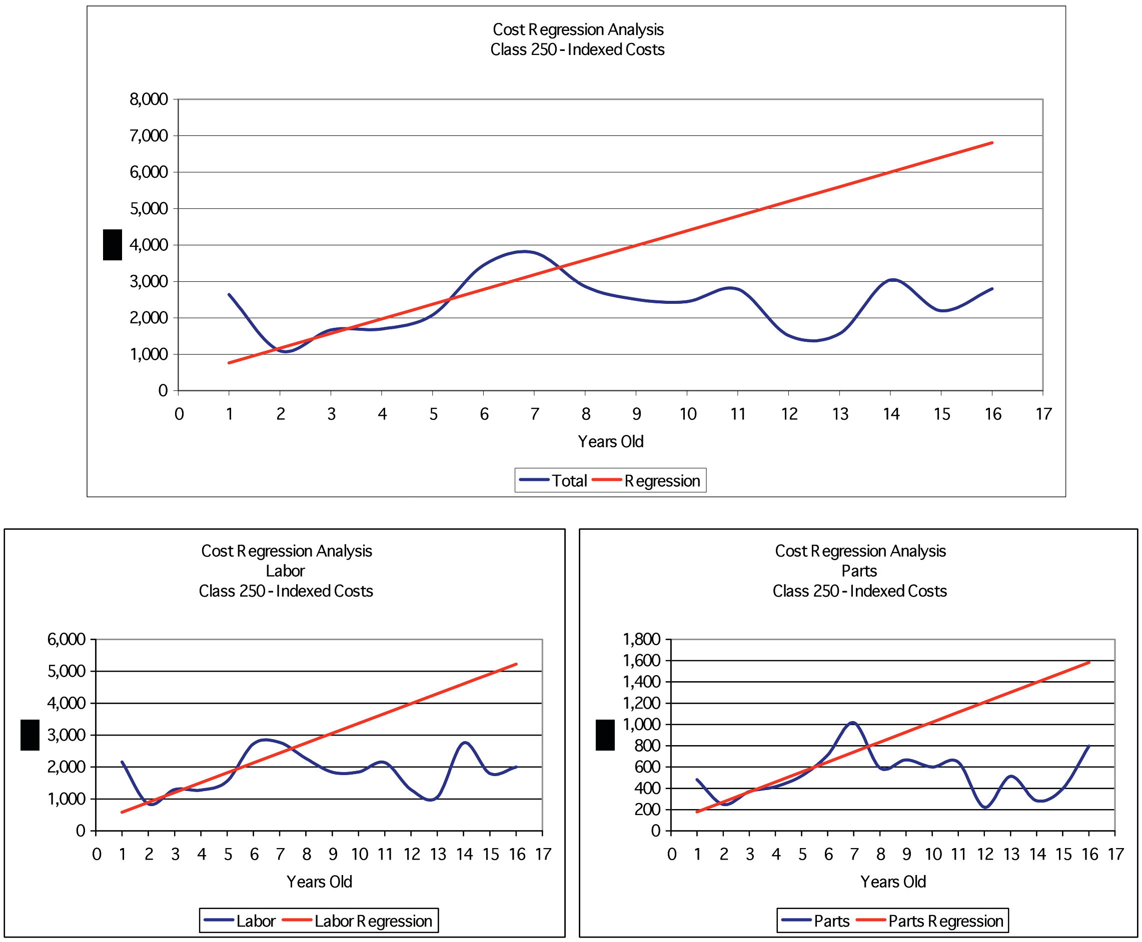


Figure 5-43 Cost Regression Analysis Result – Class 250 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 250 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 8
  - Intercept: $275

- Yearly maintenance increase: $309
- Regression correlation: 87.34 %

- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $85
  - Yearly maintenance increase: $94
  - Regression correlation: 79.49 %
- Total:
  - Intercept: $360
  - Yearly maintenance increase: $403

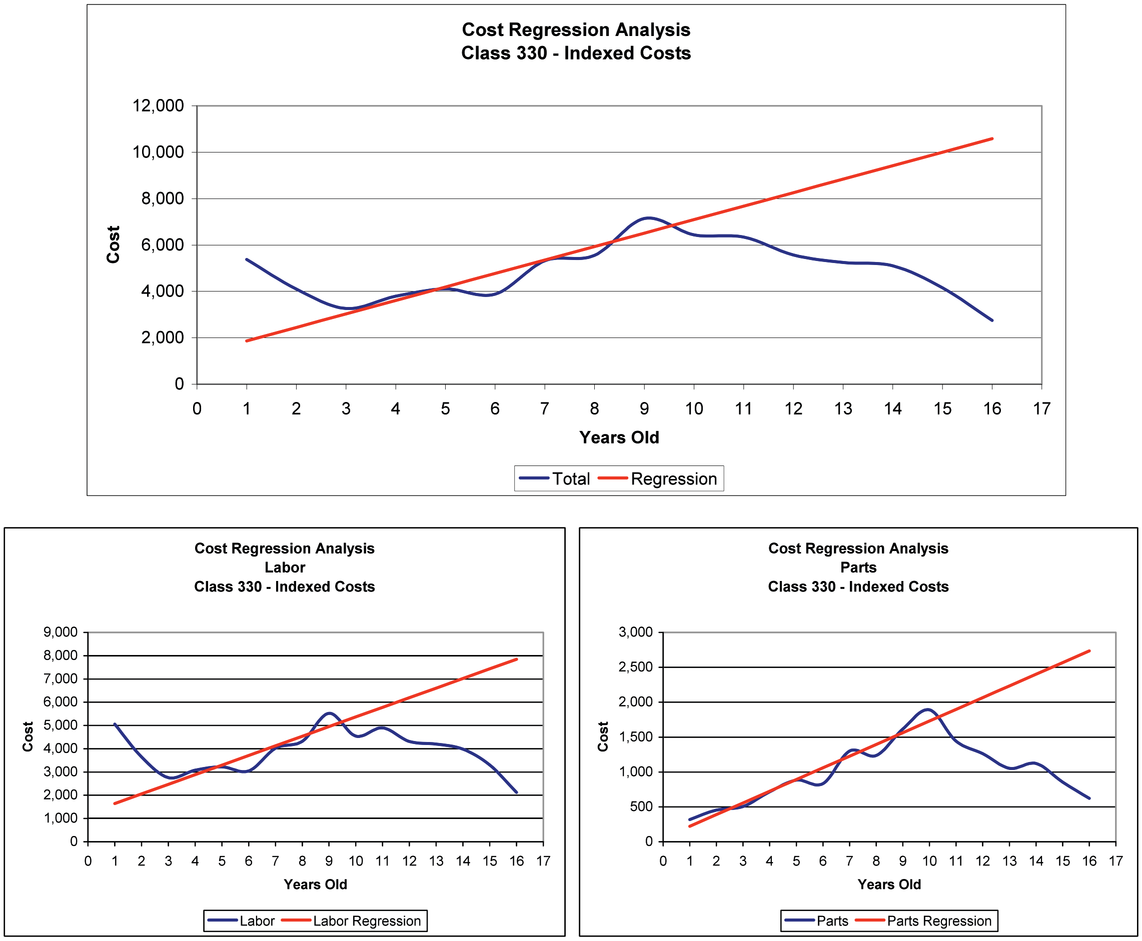


Figure 5-44 Cost Regression Analysis Result – Class 330 – Non-Indexed Costs and No Overhead

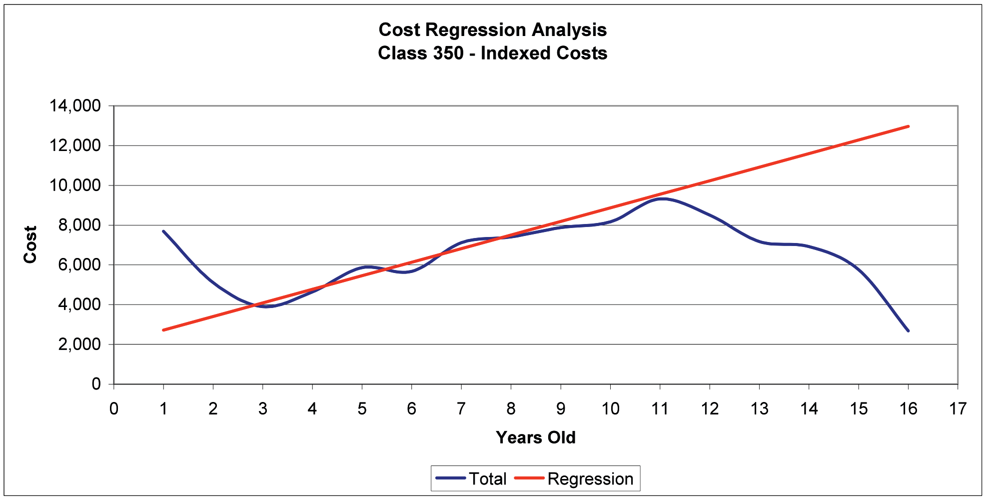
The linear regression analysis for class 330 data generated the following results:

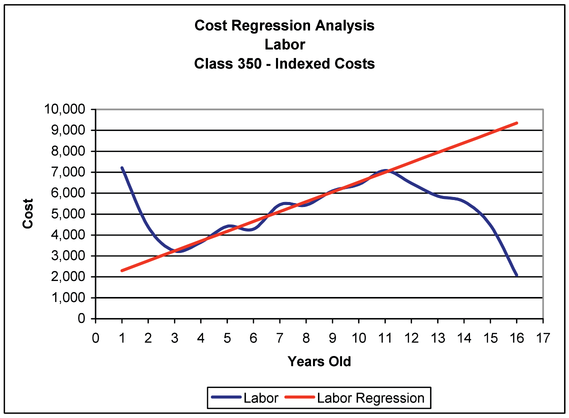
- Labor:
  - Years used for correlation: 3 - 9
  - Intercept: $1,229
  - Yearly maintenance increase: $414
  - Regression correlation: 91.32 %
- Parts:
  - Years used for correlation: 1 - 10
  - Intercept: $54

- Yearly maintenance increase: $168
- Regression correlation: 97.38 %

• Total:

- Intercept: $1,283
- Yearly maintenance increase: $581





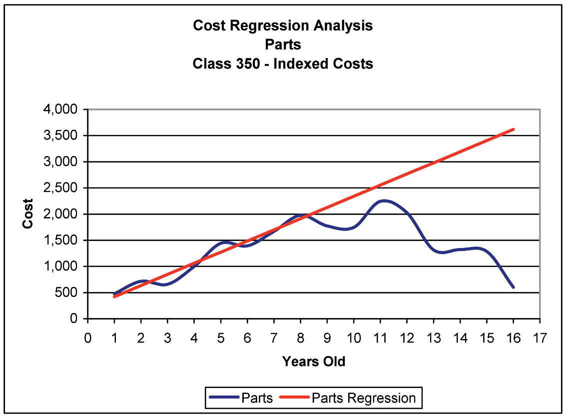


Figure 5-45 Cost Regression Analysis Result – Class 350 – Non-Indexed Costs and No Overhead

The linear regression analysis for class 350 data generated the following results:

• Labor:

- Years used for correlation: 3 - 11
- Intercept: $1,831

- Yearly maintenance increase: $470
- Regression correlation: 98.70 %

- Parts:
  - Years used for correlation: 1 - 8
  - Intercept: $207
  - Yearly maintenance increase: $213
  - Regression correlation: 97.71 %
- Total:
  - Intercept: $2,038
  - Yearly maintenance increase: $683

Again, every linear regression has a high correlation factor. More than 80 percent of the variation of the maintenance costs can be explained with the vehicle's increased age.

Table 5-3 shows the average purchase price of the different classes of vehicles considering price indexes. A life cycle cost analysis was done using these prices, the previously calculated maintenance costs, double depreciation, and 5 percent of interest rate. The results of these analyses are shown from Figure 5-46 through Figure 5-52.

Class	80	90	180	190	250	330	350
Purchase Cost	$13,526	$16,028	$13,187	$20,859	$30,986	$75,803	$94,947

Table 5-3 Purchase Cost without Indexes

Class 80 Using cost without overhead and with indexes

Purchase:	$ 13,526.49	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 121	Depreciation (years):	10
Intercept:	$ 343		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 13,526	$ 13,526			
1		$ 10,821	$ 463	$ 3,662	$ 3,845
2		$ 8,657	$ 584	$ 6,646	$ 3,574
3		$ 6,926	$ 705	$ 9,124	$ 3,350
4		$ 5,540	$ 826	$ 11,228	$ 3,166
5		$ 4,432	$ 946	$ 13,055	$ 3,015
6		$ 3,546	$ 1,067	$ 14,678	$ 2,892
7		$ 2,837	$ 1,188	$ 16,152	$ 2,791
8		$ 2,269	$ 1,309	$ 17,518	$ 2,710
9		$ 1,815	$ 1,429	$ 18,805	$ 2,646
10		$ 1,452	$ 1,550	$ 20,035	$ 2,595
11		$ 1,162	$ 1,671	$ 21,225	$ 2,555
12		$ 930	$ 1,792	$ 22,384	$ 2,525
13		$ 744	$ 1,912	$ 23,521	$ 2,504
14		$ 595	$ 2,033	$ 24,642	$ 2,489
15		$ 476	$ 2,154	$ 25,750	$ 2,481
16		$ 381	$ 2,275	$ 26,846	$ 2,477
17		$ 305	$ 2,395	$ 27,933	$ 2,478
18		$ 244	$ 2,516	$ 29,010	$ 2,482
19		$ 195	$ 2,637	$ 30,078	$ 2,489
20		$ 156	$ 2,758	$ 31,136	$ 2,498
21		$ 125	$ 2,878	$ 32,183	$ 2,510
22		$ 100	$ 2,999	$ 33,219	$ 2,524
23		$ 80	$ 3,120	$ 34,243	$ 2,539
24		$ 64	$ 3,241	$ 35,254	$ 2,555
25		$ 51	$ 3,361	$ 36,251	$ 2,572

Min	**$2,477**
Year	**16**

Figure 5-46 Life Cycle Cost Analysis – Class 80 – Indexed and No Overhead

Class 90 Using cost without overhead and with indexes

Purchase:	$ 16,028		Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 113		Depreciation (years):	10
Intercept:	$ 332			

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 16,028	$ 16,028			
1		$ 12,822	$ 445	$ 4,240	$ 4,452
2		$ 10,258	$ 558	$ 7,654	$ 4,117
3		$ 8,206	$ 672	$ 10,450	$ 3,837
4		$ 6,565	$ 785	$ 12,784	$ 3,605
5		$ 5,252	$ 898	$ 14,773	$ 3,412
6		$ 4,202	$ 1,012	$ 16,508	$ 3,252
7		$ 3,361	$ 1,125	$ 18,054	$ 3,120
8		$ 2,689	$ 1,238	$ 19,461	$ 3,011
9		$ 2,151	$ 1,351	$ 20,765	$ 2,921
10		$ 1,721	$ 1,465	$ 21,994	$ 2,848
11		$ 1,377	$ 1,578	$ 23,168	$ 2,789
12		$ 1,101	$ 1,691	$ 24,302	$ 2,742
13		$ 881	$ 1,804	$ 25,404	$ 2,704
14		$ 705	$ 1,918	$ 26,484	$ 2,676
15		$ 564	$ 2,031	$ 27,546	$ 2,654
16		$ 451	$ 2,144	$ 28,593	$ 2,638
17		$ 361	$ 2,257	$ 29,627	$ 2,628
18		$ 289	$ 2,371	$ 30,649	$ 2,622
19		$ 231	$ 2,484	$ 31,661	$ 2,620
20		$ 185	$ 2,597	$ 32,661	$ 2,621
21		$ 148	$ 2,710	$ 33,651	$ 2,625
22		$ 118	$ 2,824	$ 34,629	$ 2,631
23		$ 95	$ 2,937	$ 35,594	$ 2,639
24		$ 76	$ 3,050	$ 36,548	$ 2,649
25		$ 61	$ 3,163	$ 37,487	$ 2,660

Min	**$2,620**
Year	**19**

Figure 5-47 Life Cycle Cost Analysis – Class 90 – Indexed and No Overhead

Class 180 Using cost without overhead and with indexes

Purchase:	$ 13,187		Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 146		Depreciation (years):	10
Intercept:	$ 420			

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 13,187	$ 13,187			
1		$ 10,549	$ 566	$ 3,679	$ 3,863
2		$ 8,439	$ 712	$ 6,717	$ 3,612
3		$ 6,752	$ 858	$ 9,281	$ 3,408
4		$ 5,401	$ 1,004	$ 11,496	$ 3,242
5		$ 4,321	$ 1,150	$ 13,455	$ 3,108
6		$ 3,457	$ 1,296	$ 15,229	$ 3,000
7		$ 2,765	$ 1,442	$ 16,868	$ 2,915
8		$ 2,212	$ 1,588	$ 18,411	$ 2,849
9		$ 1,770	$ 1,734	$ 19,886	$ 2,798
10		$ 1,416	$ 1,881	$ 21,312	$ 2,760
11		$ 1,133	$ 2,027	$ 22,704	$ 2,733
12		$ 906	$ 2,173	$ 24,071	$ 2,716
13		$ 725	$ 2,319	$ 25,421	$ 2,706
14		$ 580	$ 2,465	$ 26,757	$ 2,703
15		$ 464	$ 2,611	$ 28,083	$ 2,706
16		$ 371	$ 2,757	$ 29,399	$ 2,713
17		$ 297	$ 2,903	$ 30,706	$ 2,724
18		$ 238	$ 3,049	$ 32,004	$ 2,738
19		$ 190	$ 3,195	$ 33,291	$ 2,755
20		$ 152	$ 3,341	$ 34,568	$ 2,774
21		$ 122	$ 3,487	$ 35,834	$ 2,795
22		$ 97	$ 3,633	$ 37,086	$ 2,817
23		$ 78	$ 3,779	$ 38,324	$ 2,841
24		$ 62	$ 3,925	$ 39,547	$ 2,866
25		$ 50	$ 4,071	$ 40,754	$ 2,892

Min	**$2,703**
Year	**14**

Figure 5-48 Life Cycle Cost Analysis – Class 180 – Indexed and No Overhead

Class 190 Using cost without overhead and with indexes

Purchase: $ 20,859 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 359 Depreciation (years): 10

Intercept: $ (86)

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 20,859	$ 20,859			
1		$ 16,687	$ 274	$ 5,227	$ 5,488
2		$ 13,350	$ 633	$ 9,585	$ 5,155
3		$ 10,680	$ 992	$ 13,325	$ 4,893
4		$ 8,544	$ 1,352	$ 16,634	$ 4,691
5		$ 6,835	$ 1,711	$ 19,648	$ 4,538
6		$ 5,468	$ 2,070	$ 22,468	$ 4,427
7		$ 4,374	$ 2,429	$ 25,166	$ 4,349
8		$ 3,500	$ 2,789	$ 27,794	$ 4,300
9		$ 2,800	$ 3,148	$ 30,387	$ 4,275
10		$ 2,240	$ 3,507	$ 32,970	$ 4,270
11		$ 1,792	$ 3,867	$ 35,558	$ 4,281
12		$ 1,433	$ 4,226	$ 38,161	$ 4,306
13		$ 1,147	$ 4,585	$ 40,783	$ 4,342
14		$ 917	$ 4,945	$ 43,425	$ 4,387
15		$ 734	$ 5,304	$ 46,086	$ 4,440
16		$ 587	$ 5,663	$ 48,765	$ 4,500
17		$ 470	$ 6,022	$ 51,456	$ 4,564
18		$ 376	$ 6,382	$ 54,157	$ 4,633
19		$ 301	$ 6,741	$ 56,862	$ 4,705
20		$ 240	$ 7,100	$ 59,566	$ 4,780
21		$ 192	$ 7,460	$ 62,265	$ 4,856
22		$ 154	$ 7,819	$ 64,955	$ 4,935
23		$ 123	$ 8,178	$ 67,630	$ 5,014
24		$ 99	$ 8,538	$ 70,287	$ 5,094
25		$ 79	$ 8,897	$ 72,921	$ 5,174

Min	**$4,270**
Year	**10**

Figure 5-49 Life Cycle Cost Analysis – Class 190 – Indexed and No Overhead

Class 250 Using cost without overhead and with indexes

Purchase:	$ 30,986	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 403	Depreciation (years):	10
Intercept:	$ 360		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 30,986	$ 30,986			
1		$ 24,789	$ 763	$ 8,104	$ 8,510
2		$ 19,831	$ 1,166	$ 14,783	$ 7,950
3		$ 15,865	$ 1,569	$ 20,421	$ 7,499
4		$ 12,692	$ 1,972	$ 25,306	$ 7,137
5		$ 10,154	$ 2,375	$ 29,653	$ 6,849
6		$ 8,123	$ 2,778	$ 33,620	$ 6,624
7		$ 6,498	$ 3,181	$ 37,324	$ 6,450
8		$ 5,199	$ 3,584	$ 40,849	$ 6,320
9		$ 4,159	$ 3,986	$ 44,256	$ 6,226
10		$ 3,327	$ 4,389	$ 47,589	$ 6,163
11		$ 2,662	$ 4,792	$ 50,878	$ 6,125
12		$ 2,129	$ 5,195	$ 54,141	$ 6,108
13		$ 1,703	$ 5,598	$ 57,392	$ 6,110
14		$ 1,363	$ 6,001	$ 60,638	$ 6,126
15		$ 1,090	$ 6,404	$ 63,882	$ 6,155
16		$ 872	$ 6,807	$ 67,126	$ 6,194
17		$ 698	$ 7,210	$ 70,366	$ 6,241
18		$ 558	$ 7,613	$ 73,602	$ 6,296
19		$ 447	$ 8,016	$ 76,829	$ 6,357
20		$ 357	$ 8,419	$ 80,044	$ 6,423
21		$ 286	$ 8,822	$ 83,243	$ 6,493
22		$ 229	$ 9,224	$ 86,421	$ 6,565
23		$ 183	$ 9,627	$ 89,574	$ 6,641
24		$ 146	$ 10,030	$ 92,698	$ 6,718
25		$ 117	$ 10,433	$ 95,790	$ 6,797

Min	**$6,108**
Year	**12**

Figure 5-50 Life Cycle Cost Analysis – Class 250 – Indexed and No Overhead

Class 330 Using cost without overhead and with indexes

Purchase: $ 75,803   Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 581   Depreciation (years): 13

Intercept: $ 1,283

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 75,803	$ 75,803			
1		$ 64,141	$ 1,864	$ 16,492	$ 17,316
2		$ 54,273	$ 2,445	$ 30,569	$ 16,440
3		$ 45,923	$ 3,027	$ 42,740	$ 15,695
4		$ 38,858	$ 3,608	$ 53,410	$ 15,062
5		$ 32,880	$ 4,189	$ 62,899	$ 14,528
6		$ 27,821	$ 4,770	$ 71,460	$ 14,079
7		$ 23,541	$ 5,352	$ 79,294	$ 13,704
8		$ 19,920	$ 5,933	$ 86,558	$ 13,392
9		$ 16,855	$ 6,514	$ 93,374	$ 13,137
10		$ 14,262	$ 7,096	$ 99,840	$ 12,930
11		$ 12,068	$ 7,677	$ 106,028	$ 12,765
12		$ 10,211	$ 8,258	$ 111,996	$ 12,636
13		$ 8,640	$ 8,839	$ 117,788	$ 12,539
14		$ 7,311	$ 9,421	$ 123,435	$ 12,470
15		$ 6,186	$ 10,002	$ 128,963	$ 12,425
16		$ 5,234	$ 10,583	$ 134,389	$ 12,400
17		$ 4,429	$ 11,164	$ 139,726	$ 12,394
18		$ 3,748	$ 11,746	$ 144,982	$ 12,403
19		$ 3,171	$ 12,327	$ 150,162	$ 12,425
20		$ 2,683	$ 12,908	$ 155,271	$ 12,459
21		$ 2,270	$ 13,490	$ 160,309	$ 12,503
22		$ 1,921	$ 14,071	$ 165,278	$ 12,556
23		$ 1,626	$ 14,652	$ 170,175	$ 12,616
24		$ 1,376	$ 15,233	$ 175,002	$ 12,683
25		$ 1,164	$ 15,815	$ 179,754	$ 12,754

Min	**$12,394**
Year	**17**

Figure 5-51 Life Cycle Cost Analysis – Class 330 – Indexed and No Overhead

Class 350 Using cost without overhead and with indexes

Purchase:	$ 94,947			Interest Rate:	5%
Maintenance Linear Regression					
Slope:	$ 683			Depreciation (years):	13
Intercept:	$ 2,038				

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 94,947	$ 94,947			
1		$ 80,340	$ 2,721	$ 21,024	$ 22,075
2		$ 67,980	$ 3,404	$ 38,966	$ 20,956
3		$ 57,521	$ 4,087	$ 54,467	$ 20,001
4		$ 48,672	$ 4,770	$ 68,038	$ 19,188
5		$ 41,184	$ 5,453	$ 80,085	$ 18,498
6		$ 34,848	$ 6,136	$ 90,929	$ 17,915
7		$ 29,487	$ 6,820	$ 100,824	$ 17,424
8		$ 24,950	$ 7,503	$ 109,970	$ 17,015
9		$ 21,112	$ 8,186	$ 118,525	$ 16,675
10		$ 17,864	$ 8,869	$ 126,612	$ 16,397
11		$ 15,116	$ 9,552	$ 134,326	$ 16,171
12		$ 12,790	$ 10,235	$ 141,741	$ 15,992
13		$ 10,822	$ 10,918	$ 148,913	$ 15,853
14		$ 9,157	$ 11,601	$ 155,887	$ 15,748
15		$ 7,749	$ 12,284	$ 162,694	$ 15,674
16		$ 6,556	$ 12,967	$ 169,358	$ 15,627
17		$ 5,548	$ 13,650	$ 175,897	$ 15,602
18		$ 4,694	$ 14,334	$ 182,322	$ 15,597
19		$ 3,972	$ 15,017	$ 188,644	$ 15,609
20		$ 3,361	$ 15,700	$ 194,866	$ 15,637
21		$ 2,844	$ 16,383	$ 200,992	$ 15,677
22		$ 2,406	$ 17,066	$ 207,024	$ 15,728
23		$ 2,036	$ 17,749	$ 212,963	$ 15,788
24		$ 1,723	$ 18,432	$ 218,807	$ 15,857
25		$ 1,458	$ 19,115	$ 224,555	$ 15,933

Min	**$15,597**
Year	**18**

Figure 5-52 Life Cycle Cost Analysis – Class 350 – Indexed and No Overhead

Table 5-4 shows a summary of the optimum life cycle calculated for each class of vehicle as well as their annual cost.

Class	80	90	180	190	250	330	350
Life Cycle	16	19	14	10	12	17	18
Annual Cost	$2,477	$2,620	$2,703	$4,270	$6,108	$12,394	$15,597

Table 5-4 Summary M4 Analysis - Indexes and no Overhead

5.3.3 Indexed Data and Overhead

Figure 5-53 through Figure 5-59 show the results of the regression analyses done for the State considering the different classes of vehicles with data taken from the M4 system. In this third analysis, the data were indexed and it also contains overhead costs.

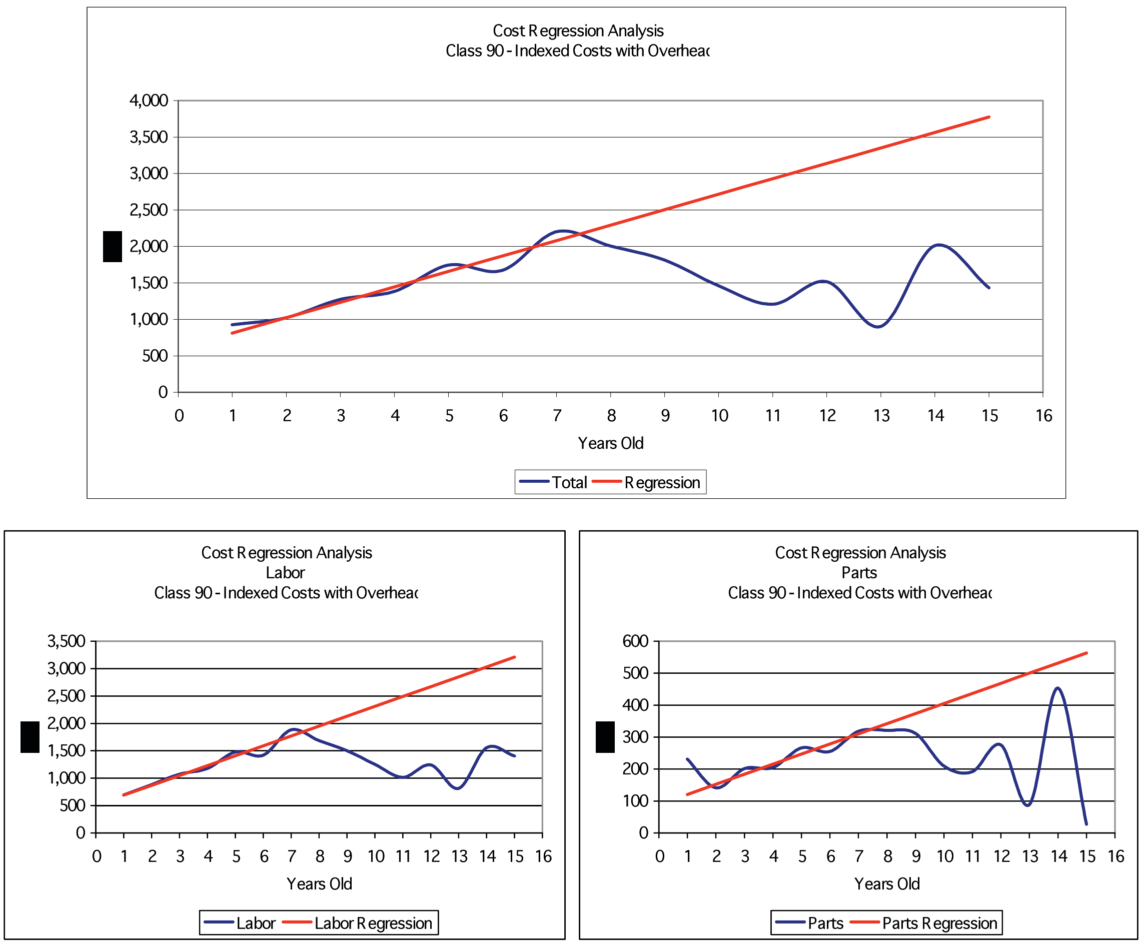


Figure 5-53 Cost Regression Analysis Result – Class 80 – Indexed Costs and Overhead

The linear regression analyses for class 80 data generated the following results:

- Labor:

- Years used for correlation: 1 - 7
- Intercept: $509
- Yearly maintenance increase: $180
- Regression correlation: 97.34 %

- Parts:
  - Years used for correlation: 2 - 7
  - Intercept: $89
  - Yearly maintenance increase: $32
  - Regression correlation: 95.92 %
- Total:
  - Intercept: $598
  - Yearly maintenance increase: $212

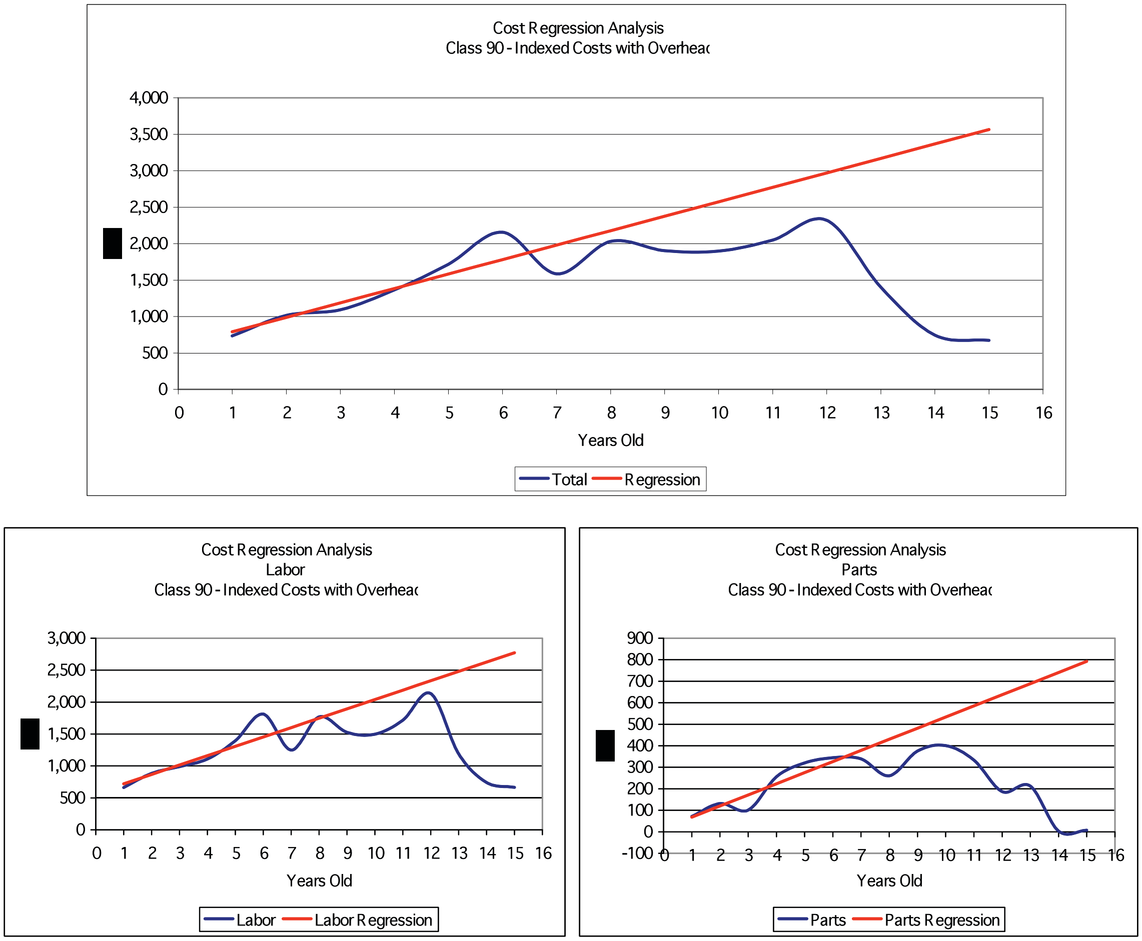


Figure 5-54 Cost Regression Analysis Result – Class 90 – Indexed Costs and Overhead

The linear regression analysis for class 90 data generated the following results:

- Labor:
  - Years used for correlation: 1 - 8
  - Intercept: $574
  - Yearly maintenance increase: $147
  - Regression correlation: 87.81 %
- Parts:
  - Years used for correlation: 1 - 7
  - Intercept: $16

- Yearly maintenance increase: $52
- Regression correlation: 93.87 %

- Total:
  - Intercept: $591
  - Yearly maintenance increase: $198

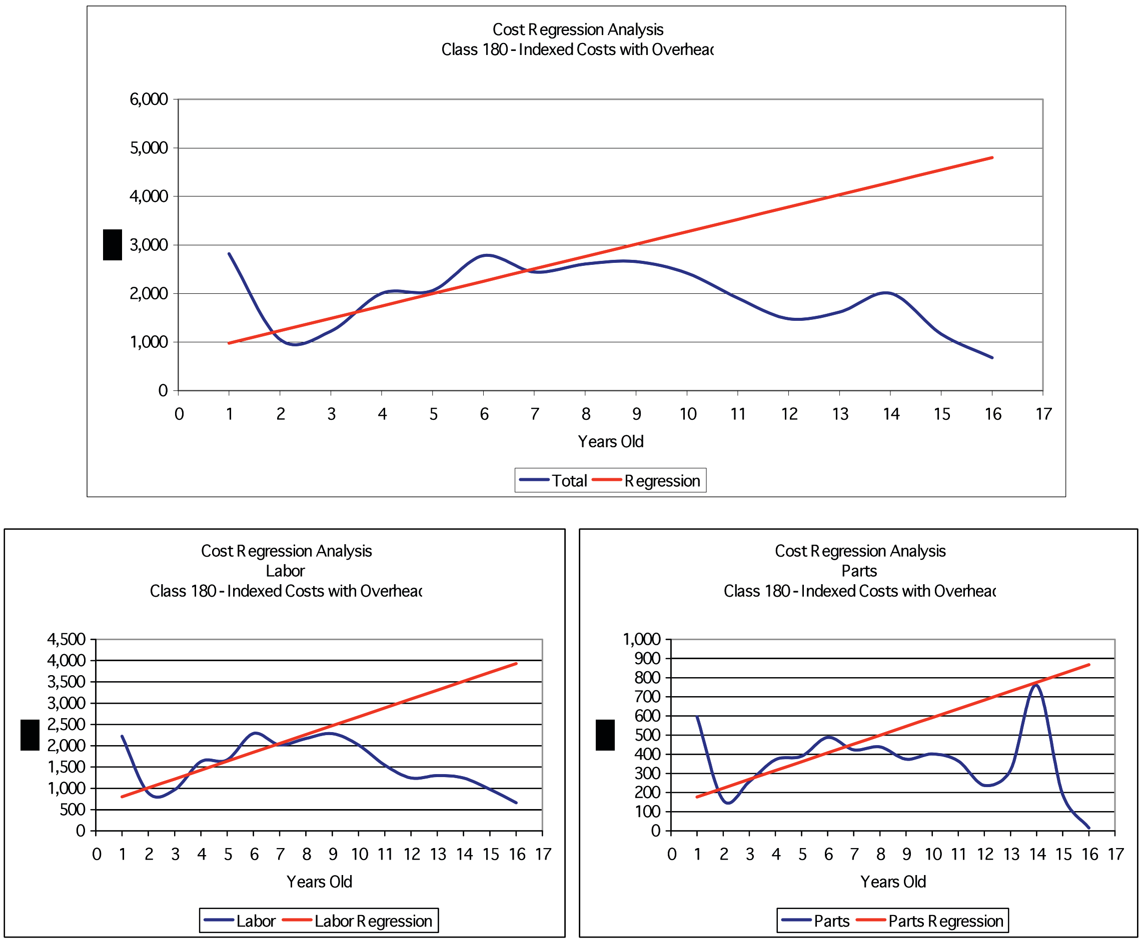


Figure 5-55 Cost Regression Analysis Result – Class 180 – Indexed Costs and Overhead

The linear regression analysis for class 180 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 9
  - Intercept: $593

- Yearly maintenance increase: $209
- Regression correlation: 91.39 %

- Parts:
    - Years used for correlation: 2 - 8
    - Intercept: $131
    - Yearly maintenance increase: $46
    - Regression correlation: 86.77 %
- Total:
    - Intercept: $724
    - Yearly maintenance increase: $255

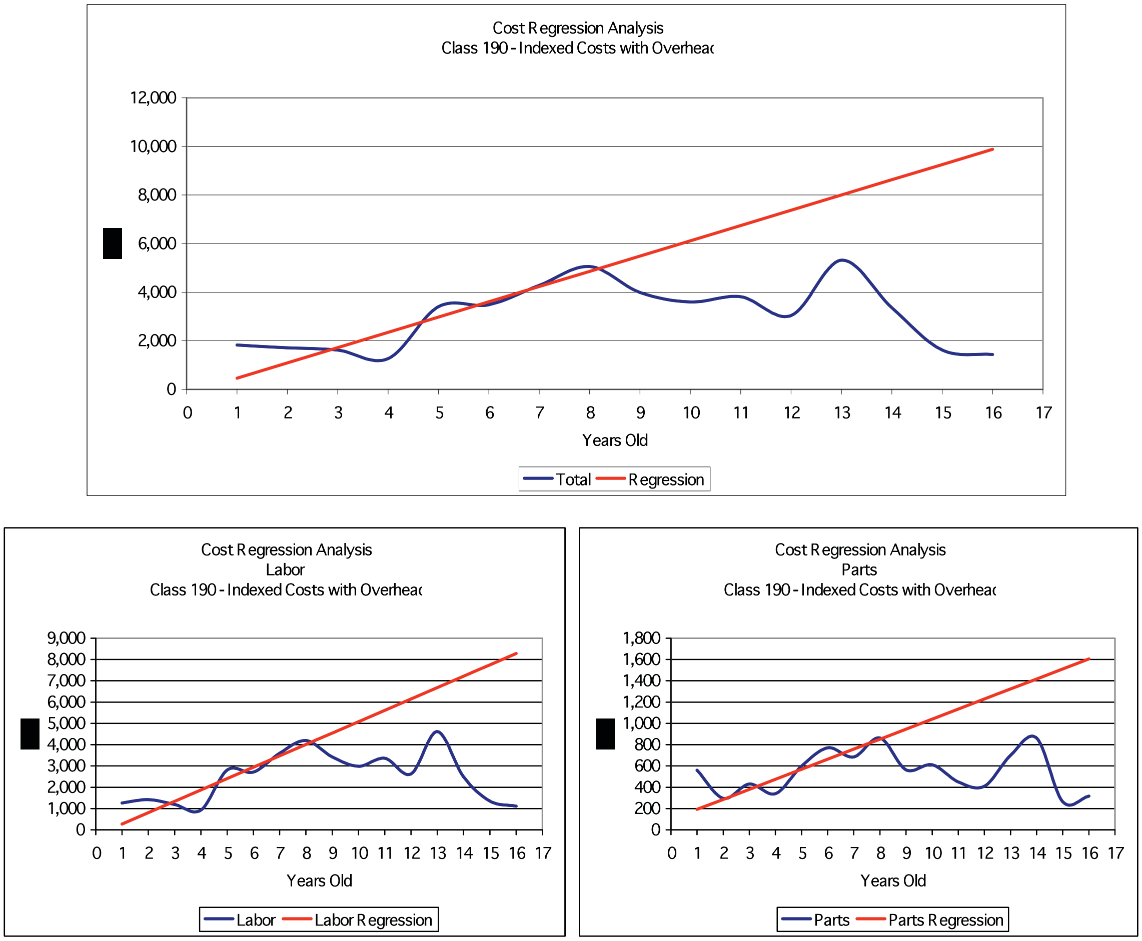


Figure 5-56 Cost Regression Analysis Result – Class 190 – Indexed Costs and No Overhead

The linear regression analysis for class 190 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 8
  - Intercept: - $262
  - Yearly maintenance increase: $534
  - Regression correlation: 91.47 %
- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $97

- Yearly maintenance increase: $94
- Regression correlation: 93.01 %

- Total:
  - Intercept: - $165
  - Yearly maintenance increase: $628

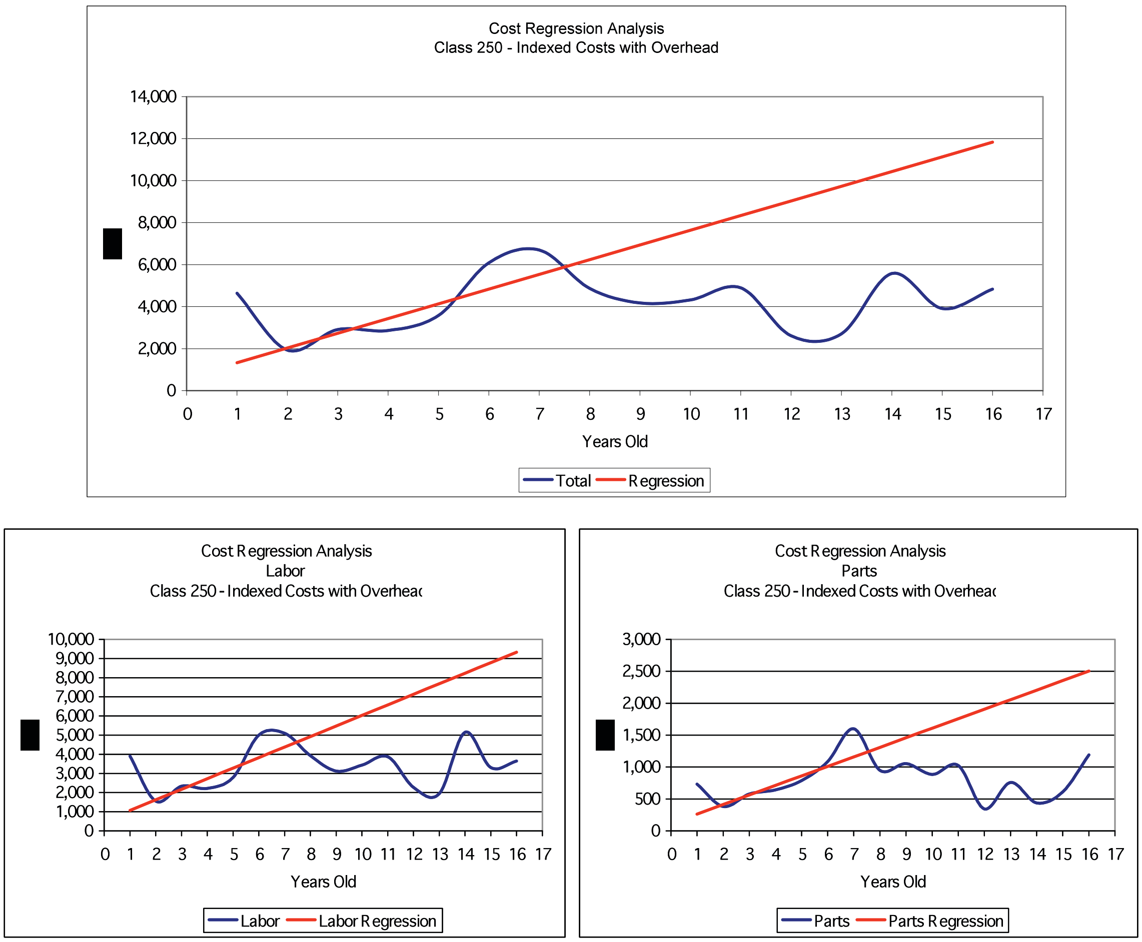


Figure 5-57 Cost Regression Analysis Result – Class 250 – Indexed Costs and No Overhead

The linear regression analysis for class 250 data generated the following results:

- Labor:
  - Years used for correlation: 2 - 8
  - Intercept: $521

- Yearly maintenance increase: $551
- Regression correlation: 84.45 %

- Parts:
  - Years used for correlation: 2 - 8
  - Intercept: $114
  - Yearly maintenance increase: $149
  - Regression correlation: 80.40 %
- Total:
  - Intercept: $635
  - Yearly maintenance increase: $700

Figure 5-58 Cost Regression Analysis Result – Class 330 – Indexed Costs and No Overhead

The linear regression analysis for class 330 data generated the following results:

- Labor:
    - Years used for correlation: 3 - 9
    - Intercept: $2,229
    - Yearly maintenance increase: $731
    - Regression correlation: 92.00 %
- Parts:
    - Years used for correlation: 1 - 10
    - Intercept: $93

- Yearly maintenance increase: $256
- Regression correlation: 97.60 %

- Total:
  - Intercept: $2,322
  - Yearly maintenance increase: $987

Figure 5-59 Cost Regression Analysis Result – Class 350 – Indexed Costs and No Overhead

The linear regression analysis for class 350 data generated the following results:

- Labor:
  - Years used for correlation: 3 - 11
  - Intercept: $3,216

- Yearly maintenance increase: $845
    - Regression correlation: 98.86 %
- Parts:
    - Years used for correlation: 1 - 8
    - Intercept: $323
    - Yearly maintenance increase: $331
    - Regression correlation: 97.70 %
- Total:
    - Intercept: $3,540
    - Yearly maintenance increase: $1,175

Again, every linear regression has a high correlation factor. More than 80 percent of the variation of the maintenance costs can be explained with the vehicle's increased age.

Table 5-5 shows the average purchase price of the different classes of vehicles considering price indexes. A life cycle cost analysis was done using these prices, the previously calculated maintenance costs, double depreciation, and 5 percent of interest rate. The results of these analyses are shown from Figure 5-60 through Figure 5-66.

Class	80	90	180	190	250	330	350
Purchase Cost	$13,526	$16,028	$13,187	$20,859	$30,986	$75,803	$94,947

Table 5-5 Purchase Cost without Indexes

Class 80 Using cost with overhead and with indexes

Purchase: $ 13,526.49 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 212 Depreciation (years): 10

Intercept: $ 598

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 13,526	$ 13,526			
1		$ 10,821	$ 810	$ 3,992	$ 4,192
2		$ 8,657	$ 1,022	$ 7,373	$ 3,965
3		$ 6,926	$ 1,233	$ 10,308	$ 3,785
4		$ 5,540	$ 1,445	$ 12,921	$ 3,644
5		$ 4,432	$ 1,657	$ 15,305	$ 3,535
6		$ 3,546	$ 1,869	$ 17,526	$ 3,453
7		$ 2,837	$ 2,080	$ 19,634	$ 3,393
8		$ 2,269	$ 2,292	$ 21,666	$ 3,352
9		$ 1,815	$ 2,504	$ 23,645	$ 3,327
10		$ 1,452	$ 2,716	$ 25,591	$ 3,314
11		$ 1,162	$ 2,927	$ 27,515	$ 3,313
12		$ 930	$ 3,139	$ 29,425	$ 3,320
13		$ 744	$ 3,351	$ 31,325	$ 3,335
14		$ 595	$ 3,562	$ 33,218	$ 3,356
15		$ 476	$ 3,774	$ 35,105	$ 3,382
16		$ 381	$ 3,986	$ 36,986	$ 3,413
17		$ 305	$ 4,198	$ 38,859	$ 3,447
18		$ 244	$ 4,409	$ 40,722	$ 3,484
19		$ 195	$ 4,621	$ 42,575	$ 3,523
20		$ 156	$ 4,833	$ 44,415	$ 3,564
21		$ 125	$ 5,045	$ 46,240	$ 3,607
22		$ 100	$ 5,256	$ 48,047	$ 3,650
23		$ 80	$ 5,468	$ 49,836	$ 3,695
24		$ 64	$ 5,680	$ 51,603	$ 3,740
25		$ 51	$ 5,891	$ 53,347	$ 3,785

Min	**$3,313**
Year	**11**

Figure 5-60 Life Cycle Cost Analysis – Class 80 – Indexed and Overhead

Class 90 Using cost with overhead and with indexes

Purchase: $ 16,028 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 198 Depreciation (years): 10

Intercept: $ 591

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 16,028	$ 16,028			
1		$ 12,822	$ 789	$ 4,568	$ 4,796
2		$ 10,258	$ 987	$ 8,371	$ 4,502
3		$ 8,206	$ 1,186	$ 11,610	$ 4,263
4		$ 6,565	$ 1,384	$ 14,437	$ 4,071
5		$ 5,252	$ 1,582	$ 16,962	$ 3,918
6		$ 4,202	$ 1,781	$ 19,271	$ 3,797
7		$ 3,361	$ 1,979	$ 21,424	$ 3,702
8		$ 2,689	$ 2,177	$ 23,466	$ 3,631
9		$ 2,151	$ 2,376	$ 25,431	$ 3,578
10		$ 1,721	$ 2,574	$ 27,341	$ 3,541
11		$ 1,377	$ 2,772	$ 29,214	$ 3,517
12		$ 1,101	$ 2,971	$ 31,060	$ 3,504
13		$ 881	$ 3,169	$ 32,886	$ 3,501
14		$ 705	$ 3,367	$ 34,698	$ 3,505
15		$ 564	$ 3,566	$ 36,498	$ 3,516
16		$ 451	$ 3,764	$ 38,287	$ 3,533
17		$ 361	$ 3,962	$ 40,065	$ 3,554
18		$ 289	$ 4,160	$ 41,831	$ 3,578
19		$ 231	$ 4,359	$ 43,584	$ 3,606
20		$ 185	$ 4,557	$ 45,324	$ 3,637
21		$ 148	$ 4,755	$ 47,047	$ 3,669
22		$ 118	$ 4,954	$ 48,753	$ 3,704
23		$ 95	$ 5,152	$ 50,440	$ 3,739
24		$ 76	$ 5,350	$ 52,106	$ 3,776
25		$ 61	$ 5,549	$ 53,751	$ 3,814

Min	**$3,501**
Year	**13**

Figure 5-61 Life Cycle Cost Analysis – Class 90 – Indexed and Overhead

Class 180 Using cost with overhead and with indexes

Purchase:	$ 13,187	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 255	Depreciation (years):	10
Intercept:	$ 724		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 13,187	$ 13,187			
1		$ 10,549	$ 979	$ 4,072	$ 4,275
2		$ 8,439	$ 1,233	$ 7,583	$ 4,078
3		$ 6,752	$ 1,488	$ 10,691	$ 3,926
4		$ 5,401	$ 1,743	$ 13,513	$ 3,811
5		$ 4,321	$ 1,998	$ 16,136	$ 3,727
6		$ 3,457	$ 2,252	$ 18,623	$ 3,669
7		$ 2,765	$ 2,507	$ 21,019	$ 3,633
8		$ 2,212	$ 2,762	$ 23,356	$ 3,614
9		$ 1,770	$ 3,017	$ 25,657	$ 3,610
10		$ 1,416	$ 3,271	$ 27,937	$ 3,618
11		$ 1,133	$ 3,526	$ 30,206	$ 3,636
12		$ 906	$ 3,781	$ 32,469	$ 3,663
13		$ 725	$ 4,036	$ 34,729	$ 3,697
14		$ 580	$ 4,290	$ 36,988	$ 3,737
15		$ 464	$ 4,545	$ 39,244	$ 3,781
16		$ 371	$ 4,800	$ 41,496	$ 3,829
17		$ 297	$ 5,055	$ 43,741	$ 3,880
18		$ 238	$ 5,309	$ 45,978	$ 3,933
19		$ 190	$ 5,564	$ 48,204	$ 3,989
20		$ 152	$ 5,819	$ 50,415	$ 4,045
21		$ 122	$ 6,074	$ 52,608	$ 4,103
22		$ 97	$ 6,328	$ 54,782	$ 4,162
23		$ 78	$ 6,583	$ 56,933	$ 4,221
24		$ 62	$ 6,838	$ 59,059	$ 4,280
25		$ 50	$ 7,092	$ 61,158	$ 4,339

Min	**$3,610**
Year	**9**

Figure 5-62 Life Cycle Cost Analysis – Class 180 – Indexed and Overhead

Class 190 Using cost with overhead and with indexes

Purchase: $ 20,859 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 628 Depreciation (years): 10

Intercept: $ (165)

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 20,859	$ 20,859			
1		$ 16,687	$ 463	$ 5,408	$ 5,678
2		$ 13,350	$ 1,091	$ 10,181	$ 5,476
3		$ 10,680	$ 1,719	$ 14,550	$ 5,343
4		$ 8,544	$ 2,347	$ 18,678	$ 5,267
5		$ 6,835	$ 2,976	$ 22,683	$ 5,239
6		$ 5,468	$ 3,604	$ 26,647	$ 5,250
7		$ 4,374	$ 4,232	$ 30,626	$ 5,293
8		$ 3,500	$ 4,860	$ 34,655	$ 5,362
9		$ 2,800	$ 5,488	$ 38,757	$ 5,453
10		$ 2,240	$ 6,116	$ 42,941	$ 5,561
11		$ 1,792	$ 6,744	$ 47,212	$ 5,684
12		$ 1,433	$ 7,372	$ 51,566	$ 5,818
13		$ 1,147	$ 8,000	$ 55,999	$ 5,961
14		$ 917	$ 8,628	$ 60,502	$ 6,112
15		$ 734	$ 9,256	$ 65,064	$ 6,268
16		$ 587	$ 9,885	$ 69,677	$ 6,429
17		$ 470	$ 10,513	$ 74,327	$ 6,593
18		$ 376	$ 11,141	$ 79,005	$ 6,759
19		$ 301	$ 11,769	$ 83,700	$ 6,926
20		$ 240	$ 12,397	$ 88,400	$ 7,093
21		$ 192	$ 13,025	$ 93,097	$ 7,261
22		$ 154	$ 13,653	$ 97,781	$ 7,428
23		$ 123	$ 14,281	$ 102,443	$ 7,595
24		$ 99	$ 14,909	$ 107,075	$ 7,760
25		$ 79	$ 15,537	$ 111,671	$ 7,923

Min	**$5,239**
Year	**5**

Figure 5-63 Life Cycle Cost Analysis – Class 190 – Indexed and Overhead

Class 250 Using cost with overhead and with indexes

Purchase:	$ 30,986	Interest Rate:	5%

Maintenance Linear Regression

Slope:	$ 700	Depreciation (years):	10
Intercept:	$ 635		

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 30,986	$ 30,986			
1		$ 24,789	$ 1,335	$ 8,649	$ 9,082
2		$ 19,831	$ 2,035	$ 16,116	$ 8,667
3		$ 15,865	$ 2,735	$ 22,762	$ 8,358
4		$ 12,692	$ 3,435	$ 28,851	$ 8,136
5		$ 10,154	$ 4,135	$ 34,577	$ 7,986
6		$ 8,123	$ 4,835	$ 40,079	$ 7,896
7		$ 6,498	$ 5,535	$ 45,456	$ 7,856
8		$ 5,199	$ 6,235	$ 50,776	$ 7,856
9		$ 4,159	$ 6,935	$ 56,084	$ 7,890
10		$ 3,327	$ 7,635	$ 61,410	$ 7,953
11		$ 2,662	$ 8,335	$ 66,770	$ 8,038
12		$ 2,129	$ 9,035	$ 72,171	$ 8,143
13		$ 1,703	$ 9,735	$ 77,616	$ 8,263
14		$ 1,363	$ 10,435	$ 83,102	$ 8,395
15		$ 1,090	$ 11,135	$ 88,622	$ 8,538
16		$ 872	$ 11,835	$ 94,169	$ 8,689
17		$ 698	$ 12,535	$ 99,733	$ 8,846
18		$ 558	$ 13,235	$ 105,305	$ 9,008
19		$ 447	$ 13,935	$ 110,875	$ 9,174
20		$ 357	$ 14,635	$ 116,433	$ 9,343
21		$ 286	$ 15,335	$ 121,970	$ 9,513
22		$ 229	$ 16,035	$ 127,476	$ 9,684
23		$ 183	$ 16,735	$ 132,943	$ 9,856
24		$ 146	$ 17,435	$ 138,364	$ 10,027
25		$ 117	$ 18,135	$ 143,730	$ 10,198

Min	**$7,856**
Year	**7**

Figure 5-64 Life Cycle Cost Analysis – Class 250 – Indexed and Overhead

Class 330 Using cost with overhead and with indexes

Purchase: $ 75,803 Interest Rate: 5%

Maintenance Linear Regression

Slope: $ 987 Depreciation (years): 13

Intercept: $ 2,322

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 75,803	$ 75,803			
1		$ 64,141	$ 3,310	$ 17,869	$ 18,762
2		$ 54,273	$ 4,297	$ 33,626	$ 18,084
3		$ 45,923	$ 5,285	$ 47,748	$ 17,533
4		$ 38,858	$ 6,272	$ 60,609	$ 17,093
5		$ 32,880	$ 7,260	$ 72,504	$ 16,747
6		$ 27,821	$ 8,247	$ 83,660	$ 16,482
7		$ 23,541	$ 9,235	$ 94,253	$ 16,289
8		$ 19,920	$ 10,222	$ 104,420	$ 16,156
9		$ 16,855	$ 11,210	$ 114,263	$ 16,076
10		$ 14,262	$ 12,197	$ 123,861	$ 16,041
11		$ 12,068	$ 13,185	$ 133,269	$ 16,044
12		$ 10,211	$ 14,172	$ 142,530	$ 16,081
13		$ 8,640	$ 15,160	$ 151,674	$ 16,147
14		$ 7,311	$ 16,147	$ 160,719	$ 16,236
15		$ 6,186	$ 17,135	$ 169,677	$ 16,347
16		$ 5,234	$ 18,122	$ 178,557	$ 16,475
17		$ 4,429	$ 19,109	$ 187,360	$ 16,619
18		$ 3,748	$ 20,097	$ 196,086	$ 16,774
19		$ 3,171	$ 21,084	$ 204,732	$ 16,941
20		$ 2,683	$ 22,072	$ 213,294	$ 17,115
21		$ 2,270	$ 23,059	$ 221,768	$ 17,297
22		$ 1,921	$ 24,047	$ 230,146	$ 17,484
23		$ 1,626	$ 25,034	$ 238,424	$ 17,676
24		$ 1,376	$ 26,022	$ 246,595	$ 17,871
25		$ 1,164	$ 27,009	$ 254,654	$ 18,068

Min	**$16,041**
Year	**10**

Figure 5-65 Life Cycle Cost Analysis – Class 330 – Indexed and Overhead

Class 350 Using cost with overhead and with indexes

Purchase:	$ 94,947			Interest Rate:	5%
Maintenance Linear Regression					
Slope:	$ 1,175			Depreciation (years):	13
Intercept:	$ 3,540				

EOY	Purchase	Selling	Maintenance	NPV	UAC
0	$ 94,947	$ 94,947			
1		$ 80,340	$ 4,715	$ 22,923	$ 24,069
2		$ 67,980	$ 5,890	$ 43,120	$ 23,190
3		$ 57,521	$ 7,065	$ 61,193	$ 22,471
4		$ 48,672	$ 8,240	$ 77,619	$ 21,890
5		$ 41,184	$ 9,415	$ 92,770	$ 21,428
6		$ 34,848	$ 10,591	$ 106,938	$ 21,069
7		$ 29,487	$ 11,766	$ 120,348	$ 20,799
8		$ 24,950	$ 12,941	$ 133,175	$ 20,605
9		$ 21,112	$ 14,116	$ 145,553	$ 20,478
10		$ 17,864	$ 15,291	$ 157,583	$ 20,408
11		$ 15,116	$ 16,467	$ 169,340	$ 20,387
12		$ 12,790	$ 17,642	$ 180,879	$ 20,408
13		$ 10,822	$ 18,817	$ 192,241	$ 20,465
14		$ 9,157	$ 19,992	$ 203,452	$ 20,554
15		$ 7,749	$ 21,167	$ 214,532	$ 20,669
16		$ 6,556	$ 22,342	$ 225,491	$ 20,806
17		$ 5,548	$ 23,518	$ 236,335	$ 20,963
18		$ 4,694	$ 24,693	$ 247,065	$ 21,135
19		$ 3,972	$ 25,868	$ 257,681	$ 21,322
20		$ 3,361	$ 27,043	$ 268,178	$ 21,519
21		$ 2,844	$ 28,218	$ 278,553	$ 21,726
22		$ 2,406	$ 29,394	$ 288,799	$ 21,940
23		$ 2,036	$ 30,569	$ 298,911	$ 22,160
24		$ 1,723	$ 31,744	$ 308,883	$ 22,385
25		$ 1,458	$ 32,919	$ 318,707	$ 22,613

Min	**$20,387**
Year	**11**

Figure 5-66 Life Cycle Cost Analysis – Class 350 – Indexed and Overhead

Table 5-6 shows a summary of the optimum life cycle calculated for each class of vehicle as well as their annual cost.

Class	80	90	180	190	250	330	350
Life Cycle	11	13	9	5	7	10	11
Annual Cost	$3,313	$3,501	$3,610	$5,239	$7,856	$16,041	$20,387

Table 5-6 Summary M4 Analysis - Indexes and Overhead

5.4 Summary

A summary of the results presented in the previous sections is shown in Table 5-7 and Table 5-8.

Class	80	90	180	190	250	330	350
No Indexes and No Overhead	17	19	14	10	12	16	18
Indexes and No Overhead	16	19	14	10	12	17	18
Indexes and Overhead	11	13	9	5	7	10	11

Table 5-7 Life Cycle Summary M4 Data

Class	80	90	180	190	250	330	350
No Indexes and No Overhead	$2,401	$2,558	$2,550	$4,153	$5,949	$11,655	$14,877
Indexes and No Overhead	$2,477	$2,620	$2,703	$4,270	$6,108	$12,394	$15,597
Indexes and Overhead	$3,313	$3,501	$3,610	$5,239	$7,856	$16,041	$20,387

Table 5-8 Cost per Year Summary M4 Data

The usage of price indexes generated higher costs per year but still maintained almost the same optimal life cycle. The addition of overhead changed considerably the optimum life cycle and cost per year, as was expected.

The optimal life cycles seem to be too high in the first two scenarios, as also happened using the MAPS data in Section 4. The usage of overhead resulted in some possibly correct life cycles while in other cases it might not. For example, classes 250, 330, and 350 have an optimum life cycle of 7, 10, and 11 years, which might be correct and are similar to the results of the 2004 study for class 330. The result of class 330 is the same one obtained with MAPS data. It does not seem correct that the optimum life cycle of classes 80 and 90 resulted in 11 and 13 years, respectively. Usually, these types of vehicles (automobiles) have a shorter life cycle than bigger vehicles like classes 330 and 350. It is also odd to note that class 180 has an optimum life cycle of 9 years while class 190 has one of only 5 years. These two classes are very similar to each other and it is not obvious that the life cycles should be so different.

A possible source of those results is how much each vehicle is utilized. Looking at Figure 5-18 through Figure 5-24, classes 250, 330, and 350 have the most constant fuel consumption. This means that, in average, the level of utilization of the vehicles does not vary that much depending on their age. As said before, level of utilization is an important factor because it is a big driver of maintenance costs. It is understandable that vehicles are used less when they get older, so there must be a way to deal with this.

One of the first attempts to process the data taking caring of utilization levels was to use only those units that were used within a mileage or fuel range. If, for example, class 330 vehicles were considered in the analysis only if they were used between 7,000 and 13,000 miles, the utilization level would be comparable between different vehicles. It was impossible to do this because of data quality problems with both fuel and mileage information (see Sections 5.2.1 and 5.2.2.)

Finally, the results presented in this section should not be considered for any managerial decision. The bad quality of data mixed with a highly sensitive model generates no confidence at all for those results. Before using this methodology, better data should be gathered.

6 Discussion

6.1 Assumptions

The methodology used for gathering the data and processing it required making some assumptions.

LCC analysis does not consider usage factors. It is obvious that the more a vehicle is used, the higher the probability of having higher maintenance costs. Going to an extreme, a vehicle not used at all should not cost anything to maintain. At the same time, if a vehicle were used at its maximum capacity 24 hours a day, it is highly probable that it will break down more often, requiring maintenance.

One option to minimize usage factors is to only consider those units used within an acceptable or normal usage range. Usage can be measured by fuel consumed, vehicle mileage, or engine-hours. Another option would be to consider that maintenance costs depend directly on mile traveled or gallon of fuel used. It might be difficult to find out what type of relationship exists between those variables. None of those proposed methodologies was used in this research because the data provided by M4 and MAPS systems were not good enough on a per-vehicle basis. It is considered that implementing this change would make the optimum life cycle decrease because "cheap units," since they were not used, are not part of the average costs calculated.

Another assumption made by the methodology is that each unit is going to be used and maintained following the same pattern independently of when it is going to be disposed. Considering the results of the analysis presented in Section 4, this is not necessarily true.

First of all, it seems completely correct to minimize maintenance on those units that are going to be disposed in the near future. In that case, the real cost structure changes depending on the policy adopted. This should be taken into account in future analyses. An easy way to model it is by considering the last 3 years of the cash flow analysis to be 95, 90, and 80 percent of the ideal costs, for example. Those values should be calculated based on historical data. Also, it should be analyzed how many years are affected by the policy depending on the class of vehicle.

It is important to have a manual analysis of the gathered cost data in order to see when these behaviors appear and adapt the model to them. In this research, the behavior was considered when determining the range of years used for the linear regression analysis.

Another assumption on the LCC analysis used in this research is that all the vehicles are used at the same level. The reality is that usage levels depend on the number of vehicles available or fleet size and the demand for those vehicles. It makes perfect economic sense to keep some old units in the fleet for use during peak demand periods. The economic model used in this research would never allow doing this situation because it would consider that an old unit would cost too much to maintain. As stated before, maintenance costs depend on the level of usage. If an old vehicle is kept on service "just in case," it would cost almost nothing if it is not used. At the same time, having a newer vehicle actually costs more if it is not used. They cost more not because of the maintenance requirements but because of depreciation costs. A newer vehicle would still decrease in value even if it is not used, something that is almost negligible with an old vehicle.

Finally, this research assumed that maintenance costs grow linearly depending on the age of the vehicle. It seems to be an accurate assumption based on the analysis of MAPS data. A linear relationship was also used by Navon and Maor (1995) in their analysis of a civil engineering fleet. The poor quality of M4 data did not allow this research to verify this assumption on other classes or vehicles. Even if the graphs have a linear shape during the first several years of an asset's life, the poor quality of data prohibits any meaningful conclusion.

6.2 Problems

A general problem encountered during the research was the quality of the data provided by Mn/DOT's information systems. Data quality was already a problem with last year's research when MAPS data were used. It became much worse with the usage of M4. Some of the problems found in the data were presented in Section 5.2. The huge cost differences (Section 5.2.3) reported by both systems make any result almost useless for any managerial problem. There is a common expression used in this type of situation: "Garbage in, garbage out."

The lack of quality data of fuel and mileage made it impossible to try to normalize the average fleet cost based on a certain utilization level. At the beginning of the research, it was attempted to use a linear relationship between maintenance cost and usage level in order to calculate all costs at the same utilization level. The results were a disaster. The variability of the results was too high, considerably affecting the analysis because of its sensitivity. It is unknown if that methodology can be applied or not because the bad quality of data interfered in the analysis.

Another source of problems was how different behaviors affect the data. Those behaviors were presented in Section 4. It was very interesting from a management perspective to find out how different districts behave. For example, District 6 seems to fully maintain their class 330 snowplows longer into the lifecycle than does District 1. The behaviors found with MAPS data from the previous research allowed this research to improve the methodology by giving some insights on how policies affect the data. It would have been very interesting to be able to see how things change between different districts and classes of vehicles. Unfortunately, it was impossible to reach to any conclusion based on M4 data.

A summary of the problems encountered during the research can be the following: we were fighting against the data instead of using the data to help us understand Mn/DOT's operation.

Finally, the sensitivity analysis performed on the methodology and life cycle cost method showed that any result obtained is highly uncertain unless the original data can be highly trusted. The results can only be trusted if there is enough information in order to reduce errors introduced by local variations and if cost and utilization data are accurate.

6.3 Overhead Usage

One of the considerations during this year research was the usage of overhead costs in the life cycle analysis. Overhead is usually avoided in these analyses. Overhead was not used in last year's research.

The following description of what is considered by Mn/DOT for the calculation of overhead (Malholtra, 2005):

> Labor Additive overhead- is used to collect costs for vacation, holiday, sick leave, jury duty, military leave, workers and unemployment comp and fringe benefits received by employees to develop the labor overhead rate. The labor additive is applied to all that labor costs.
>
> Maintenance Overhead rate: is used to collect costs that cannot be assigned directly to a maintenance operation. Those costs include training, supervision, small tools and supplies and other indirect costs. The maintenance overhead rate is used to distribute these costs to maintenance work on highways throughout state.
>
> Shop Overhead rate- is used to collect costs that cannot be directly charged to maintenance on vehicle. Costs included in this pool are training, supervision, small tools and parts, oil and other indirect costs. Shop overhead is applied to each hour of labor charged to repairing of vehicle.

> Materials handling rate: is used to collect costs for running the inventory centers. The material handling rate is charged the costs of each item issued from the inventory centers.
>
> Equipment Rental Rates: is used to collect costs associate with operating and maintaining vehicles. Each vehicle has job number. Tires, parts, fuel, insurance, depreciation, and labor to repair the vehicle are charged to the job number. Each vehicle belongs to a class of similar pieces of equipment. When rate is developed all of the costs for each vehicle in the class are lumped together to come up with a rate for the class.

According to the previous description, most of overhead costs associated with fleet maintenance are directly related to it. Those costs include maintenance personnel's compensation, benefits, and training; tools; supplies; direct supervision; and inventory. Even if there is not a one-to-one relationship between those costs and a given job, those costs clearly have a direct relationship. Those costs would not happen if there was no maintenance to be done. They are part of the real cost of operating the fleet. It is this reason why we consider that the analysis should include overhead costs.

6.4 Key Findings

One of the key findings during the research was that M4 data are not getting better with time. It was expected that the first years of data from M4 diverge considerably from the data gathered from MAPS. It always happens when implementing a new system that people need some time to get used to the system and how it works. This usually results in erroneous data. On the other hand, it was not expected to see such a difference when comparing both systems data after some years of having M4 in production mode. The difference mentioned here was presented in Section 5.2.3.

One of the possible solutions to the data quality problem is to automate data acquisition. The M4 system requires manual entries of data. Manual entries are error prone, especially when the amount of numbers required and the frequency of input is high. Mileage information, for example, is entered many times independently of the previous entry for a particular unit. The reality is that this type of information is not required to be entered that often in order to provide data good enough for further analysis.

Automatic data acquisition may generate people issues. A senior design team of mechanical and industrial engineering students at the University of Minnesota Duluth identified some of the intangible items to consider in life cycle costing (Cirilli, Marksteiner, and Trainor, 2005). Fleetrio Consulting's survey showed that "65.7% of the people surveyed said they would not want automated data collection, and the ones that thought it would be okay still seemed skeptical about its accuracy and performance." If it is decided to implement this type of system, Mn/DOT would have to have a plan to overcome people's resistance to change.

An important finding that utilization levels of units is usually not fully considered in the LCC analysis literature. As discussed in Section 4, Mn/DOT costs are heavily influenced by its life cycle policies. The behavior considerably affects the costs associated with each vehicle. This is one reason why the whole calculation process cannot easily be fully automated. There has to be human intervention in order to decide which information might or might not be influenced by such factors.

Finally, the calculated cost curves are relatively flat. This makes the calculated optimum life cycle uncertain. The minimum cost is not clearly defined, making any error in the data possible affect the result. At the same time, there is not a big difference in annual cost between the calculated minimum and the surrounding years, making the decision of how often an asset should be replaced less determinant of the total cost. It allows Mn/DOT to focus on other issues independently of the cost associated with a given life cycle. It makes intangible issues more important in setting a life cycle standard.

Some of the intangibles found by Fleetrio Consulting (Cirilli, Marksteiner, and Trainor, 2005) in their survey of District 1 that should be considered to set up a life cycle policy are:

- Control of Vehicle: This was sort of a toss-up. Some people liked the newer electronic controls and some thought the old hydraulic controls were causing them injuries. On the other hand there were also complaints about the lack of feedback and the lack of instant reactions with the electronic controls.
- Control of Data: The fact that only 34% of the people said they would want automated data collection, something that should make their job easier, seems to indicate that the drivers want to feel in control of their data.
- Comfort: Many comments were made about comfort in the snowplows. 85% of the people surveyed said newer vehicles were more comfortable then the older ones. Fleetrio was also given many comments on how comfort could be improved in the snowplows. Several people complained about a lack of right arm rests. Newer snowplows were also said to be quieter and warmer, having fewer air leaks than the older ones.
- Uniformity: When asked if it would be beneficial for all vehicles for performing a particular function to be identical, 78% said yes. There were many reasons given for this, such as ease of maintenance, ease of operation, and less chance of errors. On the other hand many comments were made questioning the practicality of this concept.
- Visibility: When asked if it was easier to see out of new vehicles the responses were pretty much a three way tie between yes, no, and the old and new being the same. There were some visibility issues that were pointed out in response to later questions about what features could be added to the vehicles to improve their ability to do their jobs. One of the most frequent comments was the need for better headlamps. A few other people thought heated windshields or wipers would allow windshields to be kept clear much more easily without having to crank the heat in the cab, which one driver pointed out tends to make him sleepy.
- Safety: Safety is obviously a major intangible for fleet vehicles. If new vehicles can be shown to be safer than it would seem that replacing vehicles sooner would have a positive economic effect by decreasing accidents and the threat of lawsuits. The questionnaire seems to indicate that the drivers don't feel that newer vehicles are safer. They were just about evenly split when asked if new vehicles had better visibility, and only 40% said they felt safer in new vehicles. A study could be done to look at accident reports and investigate if newer snowplows get in accidents less frequently. If they are found to, these data could be used to assign a safety cost to plows depending on their age.
- Reliability: Of the people surveyed, 40% said the age of the vehicle did not matter to them; many of those people also commented that it was the condition and reliability of the vehicle that ultimately mattered to them. It is easy to see how having a snowplow breakdown can be costly; the loss of production is difficult to measure and keep track of, but could impact a life-cycle cost greatly.

7 Recommendations and Conclusions

According to the study developed in this research, it seems that the optimal life cycle for class 330 vehicles should be lower than the actual policy of 12 years. This agrees with last' year's results, even though that study did not include overhead and had made a different assumption on costs. Due to the problems with data quality, it is impossible to arrive at a conclusion with a high enough level of confidence about any of the other classes of vehicles used by Mn/DOT.

The most important recommendation is that Mn/DOT should do something about the quality of the data input into the M4 system (soon to be the M5 system.) It is impossible to determine an optimal life cycle with enough certainty where the result is due to real costs and not just wrong data. The possibility to save money by a better use of assets is there. Even if the current life cycle policies are correct, Mn/DOT should have data to back up those policies.

One of the major drivers of data quality is manual intervention. The higher the level of manual data input into the system, the greater the possibility of having bad quality data entered. There is a clear opportunity here to automate data acquisition of, at least, fuel and mileage. There are ways to collect that information automatically, assuring high quality.

Another problem within Mn/DOT's processing system is how data input is controlled. Even if the data continue to be input into the system manually, the quality of data can be improved by generating a control system to monitor problems. A control system should provide feedback quickly. For example, if mileage information entered into the system means that the vehicle was used 24 hours a day during an entire month traveling at 2,000 miles per hour, there is obviously a problem. That data should not be able to be entered into the system. The system should verify it and block the entry. Even if that example seems outrageous, it happened. There are many other simple verifications that can be implemented easily into the system. There are cases where problems in the data have not been detected for months or even for years. Consistency checks need to be done regularly and frequently in order to avoid these cases. What is not easy to change and requires time and perseverance is involving people to improve the information. If data acquisition is not automatic, automatic checks and people issues are where Mn/DOT can primarily focus.

The methodology developed in this research project allows doing life cycle cost analysis even if the data available do not contain the whole history of an asset. A copy of the life cycle analysis tool is written in Excel and has been provided to Mn/DOT personnel in St. Paul. The certainty and quality of the result improves dramatically as more information is available. Mn/DOT will be able to analyze the cost of its fleets within four years after it starts producing better data.

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9 Appendix

9.1 PPI Commodity Data – Fuel Items

Source of information: ftp://ftp.bls.gov/pub/time.series/wp/wp.item

```
item_code   item_name
05    -           Fuels and related products and power
05    1           Coal
05    11          Anthracite
05    1101        Prepared anthracite shipped
05    110101      Chestnut
05    110103      Buckwheat no. 1
05    110104      Buckwheat no. 2
05    110105      Buckwheat no. 3
05    110106      Buckwheat no. 4
05    110107      Buckwheat no. 5
05    110108      Egg
05    110109      Stove
05    110111      Pea
05    110117      Prepared anthracite shipped
05    1102        Unprepared anthracite shipped
05    110214      Unprepare anthracite shipped
05    12          Bituminous coal and Lignite
05    1201        Domestic sizes
05    120101      Retail dealers                          net ton
05    120104      Large sizes                             net ton
05    120105      Stoker                                  net ton
05    1202        Spot sales of prepared bituminous coal
05    120208      Screenings                              net ton
05    120209      Steam electric utilities
05    120211      Manufacturing                           net ton
05    120212      Metallurgical/coke producers
05    120213      Metallurgical, low volatile
05    120215      All other industrial users
05    1203        Contract sales of prepared bituminous coal
05    120301      Steam electric utilities
05    120302      Manufacturing
05    120303      Metallurgical/coke producers
05    120304      Metallurgical, low volatile
05    120305      Metallurgical, medium volatile
05    120306      All other industrial users
05    120321      Export
05    1204        Unprepared bituminous coal and lignite
05    120402      Unprepared bituminous coal and lignite
05    1205        Prepared bituminous coal, resid./comm. use
05    120501      Prepared bituminous coal, residential/commercial u
05    1206        Prepared bituminous coal for export
05    120601      Prepared bituminous coal for export
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05	1207	Prepared bituminous coal, intracomp. trans.	
05	120701	Prepared bituminuos coal, intracompany transfers	
05	1208	Unprepared bituminous coal and Lignite	
05	120801	Unprepared bituminous coal and Lignite	
05	1209	Prepared bituminous and Lignite	
05	120901	Mechanically cleaned bituminous coal and lignite	
05	120902	Bituminous coal and Lignite, other preparation	
05	2	Coke oven products	
05	21	Coke (foundry by-products)	
05	210102	Birmingham, Alabama	net ton
05	210103	Milwaukee, Wisconsin	net ton
05	210104	Kearney, New Jersey	
05	210106	Detroit, Michigan	net ton
05	210107	Ironton, Ohio	net ton
05	210108	Indianapolis, Indiana	net ton
05	210109	St. Louis, Missouri	net ton
05	210111	Philadelphia, Pennsylvania	net ton
05	22	Coke	
05	2201	Coke	
05	220101	Coke	
05	220105	Coke oven and blast furnace products	
05	220198	Other coke furnace products	
05	220199	Other coke oven products	
05	3	Gas fuels	
05	31	Natural gas	
05	3101	Natural gas	
05	310101	Gas, natural	1000 mcf
05	310102	Interstate	
05	310103	Intrastate	
05	310104	Imported	mcf
05	310105	Natural gas	
05	32	Liquefied petroleum gas	
05	3201	Liquefied petroleum gas	
05	320103	Gas, propane, Okla., group 3	gal.
05	320104	Propane	
05	320105	Butane	
05	320106	Ethane	
05	320107	Gas mixtures and other natural gas liquids	
05	4	Electric power	
05	41	Residential electric power	
05	4121	Residential electric power	
05	412101	Residential electric power	
05	42	Commercial electric power	
05	4211	New England	
05	421101	New England	10,000 kwh
05	4212	Mid-Atlantic	
05	421204	Mid-Atlantic	10,000 kwh
05	421307	East North Central	10,000 kwh
05	4214	West North Central	
05	421411	West North Central	10,000 kwh
05	4215	South Atlantic	
05	421514	South Atlantic	10,000 kwh
05	4216	East South Central	
05	421617	East South Central	10,000 kwh
05	4217	West South Central	
05	421721	West South Central	10,000 kwh
05	4218	Mountain	

05	421824	Mountain	10,000 kwh
05	4219	Pacific	
05	421927	Pacific	10,000 kwh
05	4221	Commercial electric power	
05	422101	Commercial electric power	
05	43	Industrial electric power	
05	431101	New England	200000 kwh
05	4312	Mid-Atlantic	
05	431204	Mid-Atlantic	200000 kwh
05	4313	East North Central	
05	431307	East North Central	200000 kwh
05	4314	West North Central	
05	431411	West North Central	200000 kwh
05	4315	South Atlantic	
05	431514	South Atlantic	200000 kwh
05	4316	East South Central	
05	431617	East South Central	200000 kwh
05	4317	West South Central	
05	431721	West South Central	200000 kwh
05	4318	Mountain	
05	431824	Mountain	200000 kwh
05	4319	Pacific	
05	431927	Pacific	200000 kwh
05	4321	Industrial electric power	
05	432101	Industrial electric power	
05	45	Other electric power	
05	4521	Other electric power	
05	452101	Other electric power	
05	5	Utility natural gas	
05	51	Residential natural gas	
05	5121	Residential natural gas	
05	512101	Residential natural gas	
05	52	Commercial natural gas	
05	5221	Commercial natural gas	
05	522101	Commercial natural gas	
05	53	Industrial natural gas	
05	5321	Industrial natural gas	
05	532101	Industrial natural gas	
05	54	Natural gas to electric utilities	
05	5421	Natural gas to electric utilities	
05	542101	Natural gas to electric utilities	
05	55	Other natural gas	
05	5521	Other natural gas	
05	552101	Other natural gas	
05	6	Crude petroleum (domestic production)	
05	61	Crude petroleum (domestic production)	
05	6101	Crude petroleum (domestic production)	
05	610101	Illinois Basin, sweet	bbl.
05	610102	Crude petroleum (domestic production)	
05	610111	Oklahoma, sweet	bbl.
05	610121	West Texas, sour	bbl.
05	610122	Texas Coast, upper, sweet	bbl.
05	610131	Wyoming, sour	bbl.
05	610141	California, Signal Hill, sour barrel	
05	7	Petroleum products, refined	
05	71	Gasoline	
05	710102	Gulf Coast, 94 octane, regular	gal.

05	710103	Tulsa, 92 octane, regular	gal.
05	710104	Los Angeles, 91 octane, regular	gal.
05	710105	Chicago, 94 octane, regular	gal.
05	7102	Leaded regular motor gasoline	
05	710201	Dealer tank-wagon to retail outlets	gal.
05	710202	Sales to jobbers, retailers and other resellers	
05	710203	Sales to end users	
05	7103	Unleaded premium gasoline	
05	710301	Dealer tank-wagon to retail outlets	gal.
05	710302	Sales to jobbers, retailers and other resellers	
05	710303	Sales to end users	
05	710304	Unleaded premium gasoline	
05	7104	Unleaded regular gasoline	
05	710401	Dealer tank-wagon to retail outlets	gal.
05	710402	Sales to jobbers, retailers and other resellers	
05	710403	Sales to end users	
05	710404	Unleaded regular gasoline	
05	7105	Unleaded mid-premium gasoline	
05	710502	Sales to jobbers, retailers and other resellers	
05	710503	Sales to end users	
05	710504	Unleaded mid-premium gasoline	
05	72	Kerosene and jet fuels	
05	720101	New York, kerosene or no. 1	gal.
05	720102	Gulf Coast, kerosene	gal.
05	720103	Tulsa, kerosene	gal.
05	720105	Chicago, range or no. 1	gal.
05	720106	Los Angeles, ps100, stove	gal.
05	7202	Kerosene	
05	720201	Kerosene	
05	7203	Jet fuel	
05	720301	Jet fuel	
05	720303	Naphtha-type	
05	73	Light fuel oils	
05	730101	New York,no. 2.	
05	730102	Gulf Coast,no. 2.	
05	730103	Tulsa,no. 2 or diesel fuel.	
05	730104	Los Angeles,ps200,diesel fuel	
05	730105	Chicago,no. 2	
05	7302	Home heating oil and other distillates	
05	730201	Home heating oil and distillates	
05	7303	#2 diesel fuel	
05	730301	Sales to end users	
05	730302	No. 2 diesel fuel	
05	7304	Other light fuel oils	
05	730401	Other light fuel oils	
05	74	Residual fuels	
05	740101	New York, bunker C, domestic	bbl.
05	740102	Gulf Coast, bunker C, ordinary	bbl.
05	740103	Tulsa no.6, ordinary	bbl.
05	740104	San Pedro, bunker C	bbl.
05	740105	Chicago, no. 6, 1 pct. max. sulfur	bbl.
05	7402	Cargo shipments to resellers	
05	740201	Cargo shipments to resellers	gal.
05	740301	Steam electric utilities	gal.
05	7404	Residual fuels	
05	740401	Containing 0.3% or less sulfur	
05	7405	Containing 0.31 to 1.0% sulfur	

05	740501	Containing 0.31 to 1.0% sulfur	
05	7406	Containing more than 1% sulfur	
05	740601	Containing more than 1% sulfur	
05	7407	Residual fuels	
05	740701	Containing < 1% sulfur	
05	740702	Containing > 1% sulfur	
05	740703	Heavy fuel oils, incl. #5, #6, & other residual fu	
05	7408	Sales to end users	
05	740801	Sales to end users	
05	75	Lubricating oil materials	
05	7501	Lubricating oil base stocks	
05	750101	Neutral, West Pennsylvania	gal.
05	750102	Bright stock, West Pennsylvania	gal.
05	750103	Cylinder stock, West Pennsylvania	gal.
05	750104	Neutral, Tulsa	gal.
05	750105	Bright stock, Tulsa	gal.
05	750106	Industrial oil	gal.
05	750107	Pale, South Texas	gal.
05	750111	Bright stock	gal.
05	750112	Neutral stock	gal.
05	750113	Pale oil	gal.
05	76	Finished lubricants	
05	7601	Automotive oil	
05	760101	Automotive motor oil, retail	
05	760102	Other automotive oil, retail	
05	760103	Automotive motor oil, commercial	
05	760104	Other automotive oil, commercial	
05	760106	Industrial oils	gal.
05	760111	Petroleum grease	lb.
05	7602	Industrial oil	
05	760201	Industrial oils	
05	760202	Process oil	
05	760203	Metalworking oil	
05	7603	Lubricating grease	
05	760301	Petroleum grease	
05	760303	Lubricating grease	
05	7604	Lubricating and similar oils	
05	760401	Lubricating and similar oils	
05	77	Petroleum wax	
05	7701	Petroleum wax	
05	770101	E. of Rockies, refined, 122-149 ASTM	lb.
05	8	Petroleum and coal products, n.e.c.	
05	81	Petroleum and coal products, n.e.c.	
05	8101	Petroleum and coal products, n.e.c.	
05	810111	Petroleum coke	
05	810112	Asphalt	
05	810119	Other petroleum and coal products	

9.2 PPI Commodity Data – Transportation Equipment

Source of information: ftp://ftp.bls.gov/pub/time.series/wp/wp.item

item_code item_name

14	-	Transportation equipment
14	1	Motor vehicles and equipment
14	11	Motor vehicles
14	1101	Passenger cars
14	110131	Passenger cars
14	1102	Motor trucks and truck tractors
14	110271	Trucks 10,000 lbs gvw and under
14	110281	Trucks 10,001 lbs gvw and over
14	1103	Buses and military vehicles
14	110305	Buses and military vehicles
14	110307	Buses and military vehicles
14	1104	Motorcycles
14	110401	Motorcycles
14	1105	Trucks, 14,000 lbs. and under
14	110571	Trucks, truck tractors & bus chassis 14000 lb & le
14	1106	Trucks, over 14,000 lbs. GVW
14	110681	Trucks, over 10,000 lbs. gvw
14	110682	Trucks, truck tractors & bus chassis 14001 to 3300
14	110683	Trucks, truck tractors & bus chassis 33001 lb & mo
14	1107	Truck tractors
14	110791	Truck tractors
14	1108	Fire department vehicles
14	110801	Fire department vehicles
14	12	Motor vehicle parts
14	1203	Motor vehicle parts, new
14	120331	Motor vehicle parts, new, excl. motorcycle parts
14	120335	Motorcycle parts, new
14	1204	Motor vehicle parts, rebuilt
14	120431	Motor vehicle parts, rebuilt
14	1205	Motor vehicles parts
14	120501	Gasoline engine and engine parts
14	120502	Motor vehicle steering and suspension parts
14	120503	Motor vehicle transmission and power train
14	120504	Motor vehicle brake systems
14	120505	Filters
14	120506	Exhaust systems
14	120507	Wheels
14	120508	Other motor vehicle parts
14	120509	Motorcycle parts
14	120511	Vehicle seating and interior trim
14	13	Truck and bus bodies
14	1301	Truck and bus bodies sold separately
14	130102	Truck bodies sold separately
14	130104	Bus bodies sold separately
14	130106	Other vehicle bodies, incl truck cabs, beds and ki
14	130191	Truck and bus bodies sold separately
14	1302	Completed vehicles on purchased chassis
14	130202	Trucks & other h'way vehicles sold on purc. chassi
14	130204	Bus bodies sold on purchased chassis
14	130206	Emergency vehicles sold on purchased chassis
14	130278	Complete vehicles produced on purchased chassis
14	14	Truck trailers
14	1401	Vans, over 10,000 lbs.
14	140101	Closed top vans, insul. & semi-ins.
14	140102	Aluminum closed top vans
14	140103	Drop frame vans, except livestock
14	140104	Other closed top vans

14	140105	Open top vans
14	140106	Closed top vans
14	1402	Tanks, over 10,000 lbs.
14	140201	Tanks for flammable liquids
14	140202	Aluminum tanks
14	140203	All other tanks
14	140204	Tanks for chemicals and acids
14	140206	Other tanks
14	1403	Other trailers and chassis, over 10,000 lbs.
14	140301	Bulk commodity trailers
14	140302	Pole and logging trailers
14	140303	Platform trailers
14	140304	Low-bed heavy haulers
14	140305	Dump trailers and chassis
14	140306	Dollies and converter gear
14	140307	Other trailers and chassis
14	140308	Automobile transport trailers
14	140309	Other trailer and chassis
14	1404	Detach. trailers & converter gear
14	140401	Detachable trailer chassis, over 10,000 lbs.
14	140403	Dollies and converter gear
14	140404	Detach. trailers, dollies & converter gear
14	140501	Truck trailers under 10,000 lbs.
14	1406	Truck trailers & chassis, under 10,000 lbs.
14	140601	Truck trailers & chassis, axle rating > 10,000 lbs
14	15	Motor homes built on purchased chassis
14	1501	Motor homes, built on purchased chassis
14	150101	Motor homes built on purchased chassis
14	16	Travel trailers and campers
14	1601	Travel trailers
14	160101	Travel trailers (with rigid structures)
14	1602	Campers, pickup covers and parts
14	160201	Camping trailers, truck campers, pickup covers & p
14	2	Aircraft and aircraft equipment
14	21	Aircraft
14	2101	Military aircraft
14	210101	Complete military aircraft
14	2102	Civilian aircraft
14	210201	Single engine, fixed wing
14	210202	Multiengine, fixed wing
14	210203	Rotary wing
14	210205	Fixed wing
14	210206	Complete civilian aircraft
14	2111	Fixed wing, utility aircraft
14	22	Rotary wing
14	2211	Rotary wing, utility
14	23	Aircraft engines and engine parts
14	2301	Aircraft engines and engine parts
14	230101	Aircraft engines and engine parts
14	25	Aircraft parts and auxiliary equipment, nec
14	2501	Aircraft parts and auxiliary equipment, nec
14	250101	Aircraft parts and auxiliary equipment, n.e.c.
14	3	Ships and boats
14	31	Ships
14	3101	Nonmilitary ships
14	310102	Self-propelled ships, nonmilitary
14	310104	Nonpropelled ships, nonmilitary

14	3102	Self propelled ships, new, U.S. military
14	310201	Self-propelled ships, new, U.S. military
14	3103	Self propelled ships, new, nonmilitary
14	310301	Self-propelled ships, nonmilitary
14	3104	Nonpropelled ships, U.S. military & nonmil.
14	310401	Nonpropelled ships, new, U.S. military and nonmili
14	32	Boats
14	3201	Outboard motorboats
14	320101	Runabouts
14	320103	Other outboard boats
14	320106	Outboard motorboats, incl. commercial and military
14	3202	Inboard motorboats, incl. i.-o. houseboats
14	320201	Runabouts
14	320202	Cabin cruisers, non-military
14	320203	Houseboats
14	320204	Other inboard motor boats
14	320205	Inboard motorboats, incl. commercial and military
14	3203	Inboard-outdrive boats, except houseboats
14	320301	Under 20 ft., L.O.A.
14	320302	Over 20 ft., L.O.A.
14	320303	Less than 26 ft. LOA
14	320304	26 ft. or more LOA
14	320305	Runabouts
14	320306	Cabin cruisers
14	320307	Other inboard-outdrive motorboats
14	320308	Inboard-outdrive boats, inc. commercial and milita
14	3204	All other boats
14	320401	Sailboats, with auxiliary power
14	320402	Sailboats, without auxiliary power
14	320403	Other boats: rowboats, canoes, skiffs, etc.
14	320404	Sail boats, with or without auxiliary power
14	320405	Other boats: rowboats, canoes, skiffs, etc.
14	320406	All other boats, nec
14	4	Railroad equipment
14	41	Locomotives and parts
14	4101	Locomotives
14	4102	Locomotive parts
14	410202	Locomotive parts
14	4104	Locomotives and Locomotive parts
14	410402	Locomotives and Locomotive parts
14	42	Railroad cars and car parts
14	4201	Freight cars
14	420102	Freight cars, new
14	4202	All other railroad cars
14	420202	All other railroad cars
14	4203	Railroad car parts and accessories
14	420302	Car parts and accessories
14	420303	Air brake and other brake equipment
14	420304	All other railroad and streetcar parts and accesso
14	4204	Railroad cars
14	420402	Railroad cars
14	81	Full-tracked armored vehicles
14	9	Transportation equipment, n.e.c.
14	91	Transportation equipment, n.e.c.
14	9111	Transportation equipment, n.e.c.
14	911101	Self-propell. golf carts & in-plant carriers & par
14	911103	Other transportation equipment, n.e.c.

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14    911104      Automobile and light truck trailers
14    911105      Other transportation equipment, n.e.c.
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9.3 CPI – Used Information

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Series Id,Year,Period,Value,
CUUR0000SA0,1980,Jan,77.8
CUUR0000SA0,1980,Feb,78.9
CUUR0000SA0,1980,Mar,80.1
CUUR0000SA0,1980,Apr,81.0
CUUR0000SA0,1980,May,81.8
CUUR0000SA0,1980,Jun,82.7
CUUR0000SA0,1980,Jul,82.7
CUUR0000SA0,1980,Aug,83.3
CUUR0000SA0,1980,Sep,84.0
CUUR0000SA0,1980,Oct,84.8
CUUR0000SA0,1980,Nov,85.5
CUUR0000SA0,1980,Dec,86.3
CUUR0000SA0,1980,Annual,82.4
CUUR0000SA0,1981,Jan,87.0
CUUR0000SA0,1981,Feb,87.9
CUUR0000SA0,1981,Mar,88.5
CUUR0000SA0,1981,Apr,89.1
CUUR0000SA0,1981,May,89.8
CUUR0000SA0,1981,Jun,90.6
CUUR0000SA0,1981,Jul,91.6
CUUR0000SA0,1981,Aug,92.3
CUUR0000SA0,1981,Sep,93.2
CUUR0000SA0,1981,Oct,93.4
CUUR0000SA0,1981,Nov,93.7
CUUR0000SA0,1981,Dec,94.0
CUUR0000SA0,1981,Annual,90.9
CUUR0000SA0,1982,Jan,94.3
CUUR0000SA0,1982,Feb,94.6
CUUR0000SA0,1982,Mar,94.5
CUUR0000SA0,1982,Apr,94.9
CUUR0000SA0,1982,May,95.8
CUUR0000SA0,1982,Jun,97.0
CUUR0000SA0,1982,Jul,97.5
CUUR0000SA0,1982,Aug,97.7
CUUR0000SA0,1982,Sep,97.9
CUUR0000SA0,1982,Oct,98.2
CUUR0000SA0,1982,Nov,98.0
CUUR0000SA0,1982,Dec,97.6
CUUR0000SA0,1982,Annual,96.5
CUUR0000SA0,1983,Jan,97.8
CUUR0000SA0,1983,Feb,97.9
CUUR0000SA0,1983,Mar,97.9
CUUR0000SA0,1983,Apr,98.6
CUUR0000SA0,1983,May,99.2
CUUR0000SA0,1983,Jun,99.5
CUUR0000SA0,1983,Jul,99.9
CUUR0000SA0,1983,Aug,100.2
CUUR0000SA0,1983,Sep,100.7
CUUR0000SA0,1983,Oct,101.0
CUUR0000SA0,1983,Nov,101.2
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CUUR0000SA0,1983,Dec,101.3
CUUR0000SA0,1983,Annual,99.6
CUUR0000SA0,1984,Jan,101.9
CUUR0000SA0,1984,Feb,102.4
CUUR0000SA0,1984,Mar,102.6
CUUR0000SA0,1984,Apr,103.1
CUUR0000SA0,1984,May,103.4
CUUR0000SA0,1984,Jun,103.7
CUUR0000SA0,1984,Jul,104.1
CUUR0000SA0,1984,Aug,104.5
CUUR0000SA0,1984,Sep,105.0
CUUR0000SA0,1984,Oct,105.3
CUUR0000SA0,1984,Nov,105.3
CUUR0000SA0,1984,Dec,105.3
CUUR0000SA0,1984,Annual,103.9
CUUR0000SA0,1984,HALF1,102.9
CUUR0000SA0,1984,HALF2,104.9
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9.4 PPI - WPU057104

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9.5 PPI – WPU057303

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9.6 PPI – WPU1411

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9.7 PPI – WPU1412

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