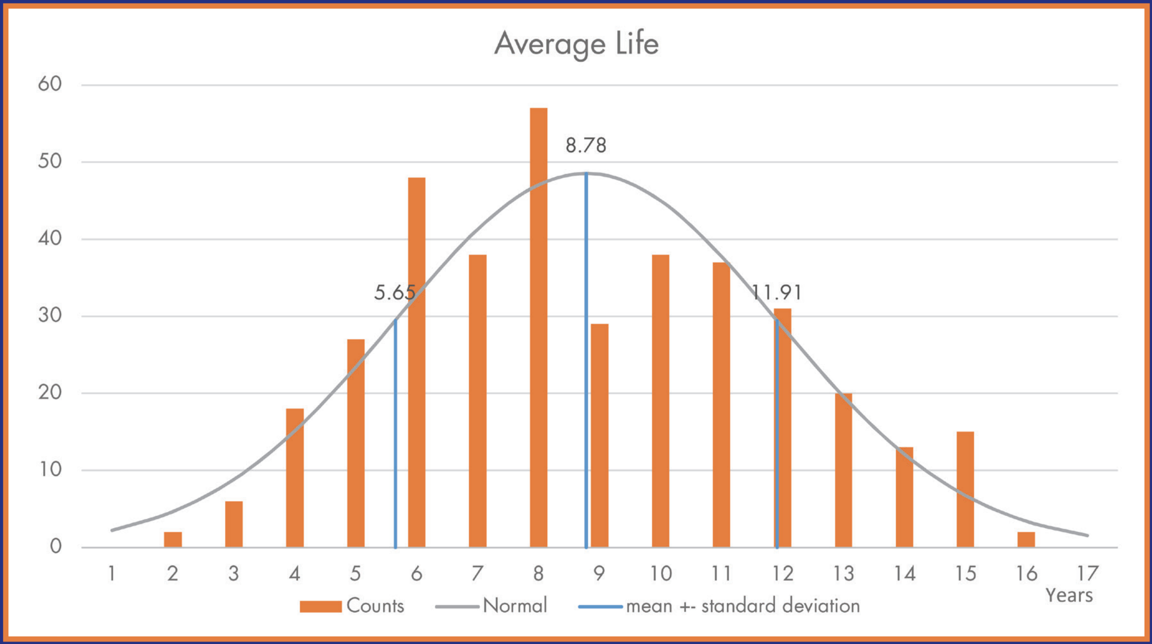
JOINT TRANSPORTATION
RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Development of Standardized Component-Based Equipment Specifications and Transition Plan into a Predictive Maintenance Strategy



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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

This project investigated INDOT equipment records and equipment industry standards to produce standard equipment specifications and a predictive maintenance schedule for the more than 1100 single and tandem axle trucks in use at INDOT. The research utilized equipment records from the M5 software program that INDOT currently uses. The predictive maintenance schedule includes the major components, those items whose cost is more than $200. There were other outcomes and related equipment recommendations produced.

Based on the data analysis, expected component life was calculated and the results reported in the predictive maintenance schedule. The research team consulted with other equipment industry sources to include other components and maintenance activities that should be included in a predictive schedule. Other reported results are a daily driver checklist, other recommended maintenance programs, recommendations to truck specifications, shop based software tools, and oil sampling program.

Also an Excel analysis tool was developed for use at INDOT to categorize parts and perform average life analyses.

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EXECUTIVE SUMMARY

DEVELOPMENT OF STANDARDIZED COMPONENT-BASED EQUIPMENT SPECIFICATIONS AND TRANSITION PLAN INTO A PREDICTIVE MAINTENANCE STRATEGY

Introduction

This project investigated Indiana Department of Transportation equipment records and equipment industry standards in order to produce standard equipment specifications and a predictive maintenance schedule for the more than 1100 single and tandem axle trucks in use at INDOT. The research utilized equipment records from the M5 software program for the years 2008–2014. The predictive maintenance schedule includes the major components, those items whose cost is more than $200. Other deliverables were produced and are described next.

Findings

Based on the data analysis, expected component life was calculated and the results reported in the predictive maintenance schedule. The research team consulted with other equipment industry sources to include other components and maintenance activities that should be included in a predictive schedule. Other reported results are a daily driver checklist, other recommended maintenance programs, recommendations to truck specifications, shop-based software tools, component warranty information, and an oil sampling program.

A software tool, consisting of two macro-enabled Excel files, was developed to perform the component life analyses. This software tool is described herein and is a product of this project.

Implementation

Implementation of the findings will be accommodated through a closeout implementation meeting and a manual. The manual will detail the procedure and data analysis process used to calculate the predictive maintenance schedule and the specification-based information that can be used by the M5 program. One result of this implementation is to prepare INDOT to perform future analysis of its equipment fleet to include the standard trucks as well as other equipment types used at INDOT. The software tool will be issued to INDOT and demonstrated at the implementation meeting.

One outcome of this project is that INDOT has a tool to produce future analyses from M5 data that provides the ability to make more exact decisions on component replacements. Instead of using rule-of-thumb numbers, more accurate life numbers are calculated. This allows for data-based decisions on when to replace components, improved purchasing procedures on when and how many components to have in inventory, and improved maintenance operations through a predictive maintenance schedule.

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1. BACKGROUND AND PROBLEM STATEMENT

1.1 Background

Fleet managers of government agencies equipment fleets must develop equipment specifications that meet quality standards established by the fleet manager and still meet state purchasing requirements. Historically, this has meant selecting a chassis manufacturer and equipment installer, and then modifying the resulting equipment specifications so multiple manufacturer can meet the specifications and satisfy purchasing requirements. Aside from the engine block, trim work, hood and cab accessories, the remainder of the truck is assembled with individual components that are available and common to many different makes and models of equipment. Whether it is on- or off-road equipment, many of today's equipment manufacturers utilize the same components in their models.

Since different truck manufacturers use similar components in building their products, the system lends itself to component performance-based equipment specifications. The methodology behind this strategy can be identified by combining the military system for logistics with today's streamlined manufacturing processes used by the automobile and medium and heavy duty truck manufacturers around the globe. Post-Vietnam era military strategies for logistics required every conceivable item necessary for a successful deployment to have a military specification (mil-spec) number or National Stock Number (NSN). These items carried a unique serial number that not only identified the item but also assured the item met military standards or specifications for performance and reliability.

Prior to 1994, the U.S. military was making every effort to standardize all components so that like equipment can use the same components for repair or replacement. Many of the U.S. military standards were phased out in 1994 and replaced by the use of industry standards (*Perry, 1994*). The standardization effort had many advantages and disadvantages but there is no question that the mil-spec system was successful in tracking and identifying individual components used by the entire Department of Defense (DOD). The National Item Identification Number (NIIN) or NSN is still in use today by the Defense Logistics Agency (DLA) to administer the Federal Catalog System in identifying, classifying and numbering components within the DOD.

Medium- and heavy-duty truck manufacturers provide options in their manufacturing processes that allow buyers to choose from various components that are installed during assembly. For example, a buyer may choose from several different models of Delco-Remy alternators or choose models from additional alternator manufactures. These "optional components" are available throughout the chassis, and with the exception of the cab and body parts, are the exact same "optional components" available from other chassis manufacturers. This system allows a buyer to specify components on a given piece of equipment.

The Indiana Department of Transportation is divided into six districts across the state with 38 maintenance units within the six districts. Each district and each maintenance unit have the responsibility for repairs and regularly scheduled maintenance of their equipment. By analyzing the department's M5 fleet management database it is possible to identify the failure rate of certain major components on the single axle and tandem axle truck fleet. This data can be used to evaluate individual components and track the replacement frequency of components. The process of monitoring component performance can benefit the department in a variety of ways. The data will allow tracking of component replacement trends on units purchased in the same year, of the same make and model, or by geographical location. Decisions by fleet management personnel on specification writing and preventative maintenance activities can be based on performance data.

For years many in the fleet management industry have debated scheduled component replacement or run to failure strategies. It can be said that replacing components before their useful life is like leaving money on the table. The run to failure strategy may work for non-critical equipment in a fleet but for critical equipment like the INDOT winter snow plow fleet; equipment availability has an impact that far outweighs any loss by replacing a component too soon. The goal of a comprehensive predictive maintenance program should be to replace parts on critical equipment before they fail but maximizing the useful life of the part. A comprehensive predictive maintenance program also should factor in other performance measures like oil sampling, equipment inspection and investigation into the cause of the failure.

1.2 Problem Statement and Objectives

The Indiana Department of Transportation (INDOT), as well as many local agencies, creates specifications for medium- and heavy-duty truck chassis and mounted equipment based on past performance of the equipment manufacturer, dealership, equipment installer, while following the State of Indiana purchasing requirements. By identifying all components in the current INDOT fleet and using available equipment history records to track component performance, a set of specifications can be developed that represent the best performing components.

Development of performance-based specifications gives fleet managers flexibility in selecting parts. Implementing such a specification allows department maintenance practices to transition into replacing components close to end of their useful life, before a costly breakdown. This process is known as predictive maintenance and implemented throughout the department it can provide benefits in purchasing parts, scheduling repairs, and minimizing equipment downtime.

There are two objectives in this study. One is to deliver revised component specifications for single/tandem axle, medium-duty truck chassis with mounted winter maintenance equipment. This objective will analyze component replacement data to determine failure rates among the major components and recommend replacement life. This analysis will look at component failures by unit, year, make, model and geographical location. These specifications will serve as boilerplate for future specification development for additional on- and off-road equipment and will help INDOT in transitioning to predictive maintenance practices which is the second objective. Preventive maintenance practices are known to reduce premature component failures.

The second objective is to transfer to INDOT the analysis process developed so that future or other equipment analyses can be performed internally. This will be described in a manual for implementation purposes.

TABLE 2.1
Component group codes.

	Group Codes
01	Frame
02	Brakes
03	Steering
04	Driveline
05	Electrical
06	Engine
07	Cab and Mounted Equipment
08	Hydraulic
09	PM Service
10	Tires/Wheels/Rims

2. WORK ACTIVITIES

To accomplish these objectives the research team is basing their work on equipment data to be supplied by INDOT. This data was acquired through INDOT's M5 program fleet repair and replacement part data for the department's fleet of 1125 single and tandem axle trucks for the years 2008–2014. The data was categorized by group code referenced in both the APWA (2010) Equipment code, and the group codes used by Navistar Corporation. Table 2.1 shows these group codes.

After data was received, researchers reviewed and cleaned the data for inconsistent and erroneous values. Components that fell below the $200 price threshold were removed since the project focused only on major components.

Researchers requested hour or mileage data from the M5 database for the purpose of demonstrating life-cycle costs per unit using major components in the data set and usage hours recorded at the time of replacement. Figure 2.1 is an illustrative example of how hours data is used to determine the cost of components over the life of a single unit. Actual hours and cost data are used in this example.

The request for truck hours and mileage went unfilled as INDOT currently does not have consistent data for these two.

From the data set expected life values for various components were calculated. Figures were developed showing the frequency of component replacement for the truck fleet (for additional details see Chapter 4). Data analysis revealed the performance for each major component and recommend changes to the specifications based on component performance.

Another activity developed a predicative maintenance schedule. This started with collecting truck manufacturers recommended maintenance schedules and component replacement intervals. Once these intervals were identified, researchers used the component database to place components with into the preventive maintenance schedule.

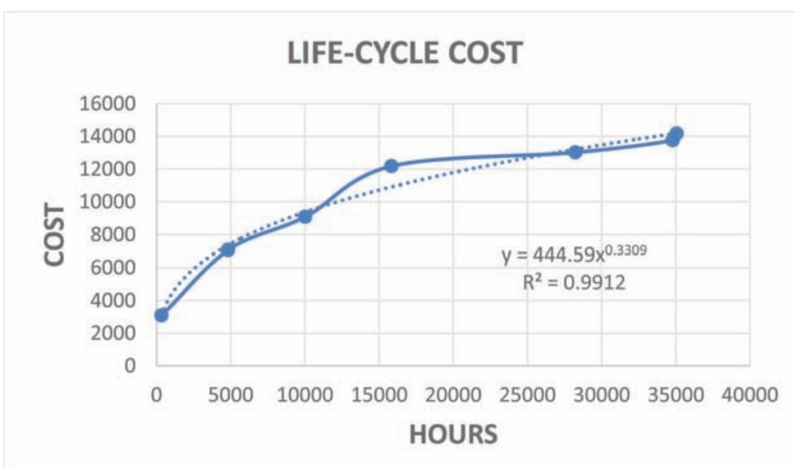


Figure 2.1 Relationship between hours and life-cycle costs.

3. DATA ANALYSIS

INDOT provided seven years of data, 2008–2014. The cleaned data set contained over 18,000 records representing 1125 trucks. Table 3.1 shows the composition of INDOT's fleet by manufacturer. The component data was categorized by part number and description. Even though this was a large data set many common component items were under reported or missing; brake shoe kits, brake linings, brake pads, brake shoe hardware, bake drums, brake rotors, rear springs, walking beam end bushings, walking beam center bushings, torque arm, torque arm bushings and several other suspension components did not have significant enough numbers to draw any conclusions. Some of these repairs are being performed by outside contractors, and are therefore not being captured by the M5 fleet management software.

3.1 Group Codes

Data was grouped into functional codes to associate minor components with similar major components. The Equipment code guidebook developed by the American Public Works Association (APWA, 2010) and the parts identification codes used by the Navistar Corp were used. Equipment specifications and parts inventory can utilize functional codes to track and identify components as well. An example would be a power steering hose is classified in the steering group and a fuel pressure hose in the engine group as opposed to all hoses being classified as hydraulic components.

3.2 Fleet Evaluation

Researchers analyzed component replacement frequency by equipment year, make and model. Data analysis indicates that the Sterling model trucks performance was below that of the other models and had the highest hourly operating cost of all the Department's truck models. Sterling model years 2000–2005 incurred over 62% of the repairs while representing 45% of the truck fleet. Table 3.2 shows the total number of units in each model year and the percent of component replacement for each model year.

3.3 Truck Evaluation

With the large dataset, various types of analyses can be performed and one that was performed looked at trucks that have a high component replacement cost with relatively low mileage. Figure 3.1 shows component replacement cost and mileages for 2003 make and model trucks which represent 9.24% of the fleet. The mileage scale is 100,000 miles, so .1m is 10,000 miles. Each unit is represented by a colored bubble and the color has no meaning. The plot shows the units performed differently over their life and identifies units with significantly higher major component cost. This cost is compared to units that entered service in the same year with similar mileage but may be assigned to a different area of the state. Climate and geography along with maintenance practices are just a few of the factors that can influence the correlation between the component cost and mileage for these units.

Another analysis identified truck life to major component cost and major component cost per hour within the fleet. Trucks of each model year and make were analyzed respectively. This analysis does not account for additional cost related to labor or downtime; it does indicate the frequency of major repairs over the life of the truck. Factoring in labor cost or downtime can sometimes misrepresent how a unit is performing. A busy shop or an inexperienced technician can drive up the per hour cost for a unit. Accounting for the just component cost provides a cleaner look at the performance of the truck. If available, a shop manager can plug in labor time guides and for each component replacement and factor in to the cost of the component, a standard labor and downtime charge. Analysis like this can aid in determining life-cycle cost for each machine and different types of equipment.

All the recommendations are based on the data analysis performed.

TABLE 3.1
Fleet composition by manufacturer.

Make	Total Units	Percent of Fleet
Ford	132	12%
Freightliner	99	9%
International	272	24%
Kenworth	47	4%
Oshkosh	6	1%
Sterling	569	51%
Grand total	**1125**	**100%**

TABLE 3.2
Fleet evaluation.

Year	Component Replace	Total Units	Percent of Fleet
1990	0.03%	2	0.18%
1994	0.07%	1	0.09%
1995	0.17%	3	0.27%
1996	0.50%	14	1.24%
1997	3.71%	44	3.91%
1998	7.89%	72	6.40%
1999	4.92%	43	3.82%
2000	8.21%	67	5.96%
2001	12.59%	103	9.16%
2002	10.92%	75	6.67%
2003	12.63%	104	9.24%
2004	9.44%	86	7.64%
2005	8.46%	80	7.11%
2006	1.85%	14	1.24%
2007	10.47%	160	14.22%
2008	4.46%	72	6.40%
2009	1.31%	30	2.67%
2011	1.62%	75	6.67%
2012	0.25%	29	2.58%
2013	0.43%	42	3.73%
2014	0.08%	9	0.80%
(blank)	0.00%	0	0.00%
Grand total	**100.00%**	**1125**	**100.00%**

4. RECOMMENDATIONS

4.1 Individual Components

Data provided to the research team contained component replacements during the years 2007–2014.

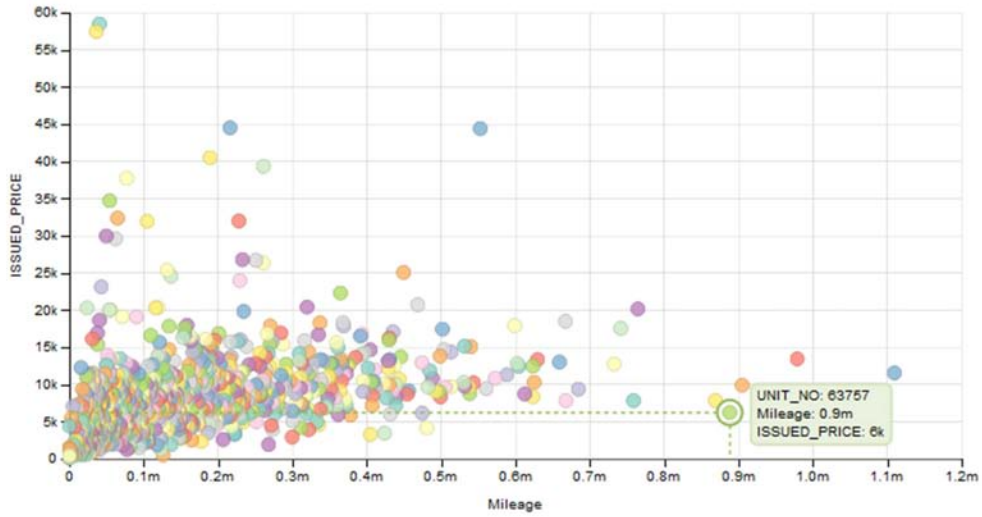


Figure 3.1 2003 trucks: cost vs. mileage.

This data was absent mileage and vehicle hour data. INDOT also provided truck or unit data starting in 1990, however most of the current truck fleet, 1125, was put into service between the years 2000–2007. To calculate component life the research team used the following procedure.

From the component replacement data (2007–2014) unit numbers were identified for each replaced component. Table 4.1 shows the number of units or trucks placed into service during a specific year. Data provided had no trucks in 2010.

4.2 Data Analysis Approach

This section describes the rationale behind the data analysis approach used by the researchers. INDOT provided truck data for the years 2008 to March 2014. This data set included: year truck put into service, component replaced, year component replaced, and material cost. Labor cost was not included. Data went through a checking phase for consistency, and errors; and converted to a format for statistical analyses.

TABLE 4.1
Trucks placed into service.

Truck Model Year	Number of Trucks
2007	160
2008	72
2009	30
2010	0
2011	75
2012	29
2013	42
2014	9
Total	**417**

Components that fell below the $200 price threshold were not included; the analyses focused only on major components.

Once the data were converted to the final tabular format, the next step was data analysis. The analysis objective was to calculate average component life. Since hourly and mileage data was not included in the data set, component life was calculated in years. One assumption was component life started when a truck was put into service. For example, if a truck is placed into service in 2008 and the alternator is replaced in 2012, the component life is 4 years.

To calculate average component life, an Excel pivot table was used. The pivot table allows for the selection of multiple attributes of a component. The component life calculation was performed by first taking the difference between the year the truck was placed into service and the year when the component was replaced. Second, the average is calculated by adding the years of replacement divided by the number of units as showing in Table 4.2. The calculation is performed for all the 7 years (2008–2014). The average component life is calculated by summing up all the average for the 7 years and divided by 7 as shown in the below table. Statistical R software was used to create the box plots showing the number of trucks or units per average component life years.

Table 4.2 is an example of this calculation procedure. In each column year, a cell contains the component life when it was replaced and at the bottom of each column the average life for that year. For example, in 2010 there were 14 replacements for this particular component, and the average life of this component was 8.2 years. The average component life in 2011 was 8 years. The overall component life is the average of all the year's average life which is the average of the bottom row of numbers. In this example the average expected

TABLE 4.2
Example analysis table.

2008	2009	2010	2011	2012	2013	2014
5	7	7	9	12	11	10
5	7	9	8	7	17	9
8	6	9	9	12	12	14
7	10	10	7	10	6	12
7	9	6	10	10	9	14
7	4	10	7	8	12	12
5	11	9	7	10	10	13
8	7	7	9	11	10	13
7	7	7	8	5	10	11
7	7	10	8	10	8	11
6	8	5	7	9	9	10
6	6	9	9	8	9	9
5	6	8	6	8	9	12
5	5	9	6	8	12	
5	7		10	8	10	
12	7			8	14	
10	6			14	10	
	8			14	15	
	6			11		
6.76	**7.05**	**8.21**	**8**	**9.63**	**10.72**	**11.53**
Average life = 8.84						

life is 8.84 years. This procedure was used to calculate average component life for the following components.

4.2.1 Alternators

Analyzing alternators, the same Delco Remy alternator (part number 19020310) was replaced 74 times between 2008 and 2014 and can be found on Sterling's, Ford's and Kenworth model trucks. Researchers also noted that several other common components in the alternator group. Table 4.3 shows the top 10 alternators replaced between 2008 and 2014. These alternators represent 39% of the total alternators replaced during the same period and which trucks were common to each alternator.

During the period 2008–2014, 1191 alternators were replaced. From the data average component life was calculated and a distribution of the average life and years in service is shown in Figure 4.1. The figure shows the number of alternators replaced for life years from 2 to 16 years, which was the range of life years for this component. The average life is 9 years with a standard deviation of 3 years.

TABLE 4.3
Top 10 alternators replaced 2008–2014.

Year	2008	2009	2010	2011	2012	2013	2014	Grand Total
Quantity	**78**	**87**	**84**	**113**	**53**	**79**	**21**	**515**
Alternator Number, Truck Model, Number of Replacements								
110555JHO			**3**	**6**	**2**	**10**	**4**	**25**
FORD			1			5	1	7
STERLING			2	6	2	5	3	18
19020310	**1**	**1**	**8**	**17**	**12**	**29**	**6**	**74**
FORD			3	3	2	18	1	27
KENWORTH					1			1
STERLING	1	1	5	14	9	11	5	46
22SI			**4**	**33**	**16**	**11**	**3**	**67**
FORD			1	7	2		1	11
STERLING			3	26	14	11	2	56
31001005	**14**	**9**	**9**					**32**
FORD			1					1
STERLING	14	9	8					31
31001068	**11**	**11**	**9**	**1**	**3**			**35**
FORD	1							1
INTERNATL		1						1
STERLING	10	10	9	1	3			33
31001082	**19**	**21**	**17**					**57**
FORD	4	4	5					13
STERLING	15	17	12					44
31001394	**13**	**25**	**13**	**1**				**52**
FORD	3	5	2					10
STERLING	10	20	11	1				42
31001999	**20**	**20**	**10**	**10**	**2**			**62**
FORD	4	9	4	5	1			23
STERLING	16	11	6	5	1			39
4940PA			**5**	**6**	**6**	**9**	**2**	**28**
FORD					1			1
FREIGHTLIN						1		1
INTERNATL			1	3	1	3		8
STERLING			4	3	4	5	2	18
AL9960LH			**6**	**39**	**12**	**20**	**6**	**83**
FORD			4	10	3	2	1	20
STERLING			2	29	9	18	5	63

Figure 4.1 Distribution of alternator life years.

4.2.2 Starters

Starter replacement data shows that 1348 starters were replaced between 2008 and 2014, an average of 193 per year. Data shows that 37% of trucks 4 years old had a starter replaced. By the time a truck is 5 years old over 65% have had at least one starter replacement and over 88% of trucks six year old had at least one replacement. Forensic investigation of failed starters may yield clues to early failures and preventive measures may extend the life of starters.

Financial considerations to take into account are the total cost for 2008–2014 and the current cost per year for starters. INDOT spent $395,000 in 2008–2014 and averages $56,544 per year.

From the data average component life was calculated and a distribution of the average life and years in service is shown in Figure 4.2. The figure shows the number of starters replaced for life years from 2 to 16 years, which was the range of life years for this component. The average life was 7.5 years with a standard deviation of 3.5 years.

4.2.3 Batteries

Data shows that 1201 batteries were replaced in 2008–2014. The data shows that in most cases only one battery was replaced at a time, this is assuming that a majority of the INDOT truck fleet is equipped with dual batteries. By the time a truck reaches 4 years old 22% have had at least one battery replaced, 43% by the time a truck is 5 years old and 69% by the time a truck is six years old.

It is recommended that INDOT place batteries on a 5 year predictive maintenance schedule, replacing both batteries or verifying by load testing that both batteries are in good condition and are balanced under load.

4.2.4 Engine

4.2.4.1 Turbochargers. A total of 364 turbocharger replacements were identified on 313 trucks in the INDOT fleet. Researchers analyzed the data by both the trucks they went on and the part numbers of the replacement turbochargers. Data shown in Table 4.4 show the following part numbers, OR6478, OR6942, OR7279, OR7569, OR9865 TUR179030 178089 and 178468 were used on 1994–2006 Caterpillar 3126 and 3126E, 240 HP engines. The data shows that over 126 of these turbochargers were changed between 2008 and 2013. That makes up about 45% of the total number of turbochargers replaced. Although the Caterpillar 3126 engine package is no longer available in truck configurations, the department can identify those trucks with this engine package and identify higher quality remanufactured parts. The data also shows several of the replacement turbochargers lasted only 12 to 24 months; this indicates a possible quality issue with the replacement or remanufactured parts.

After eliminating duplicate entries there is an average of 50 turbochargers replaced each year across the entire INDOT truck fleet. What is most obvious about turbocharger frequency with the INDOT fleet is the number of Sterling trucks that account for the replacements. Table 4.5 shows that 231 or 66% of the turbochargers replaced were on Sterling model trucks.

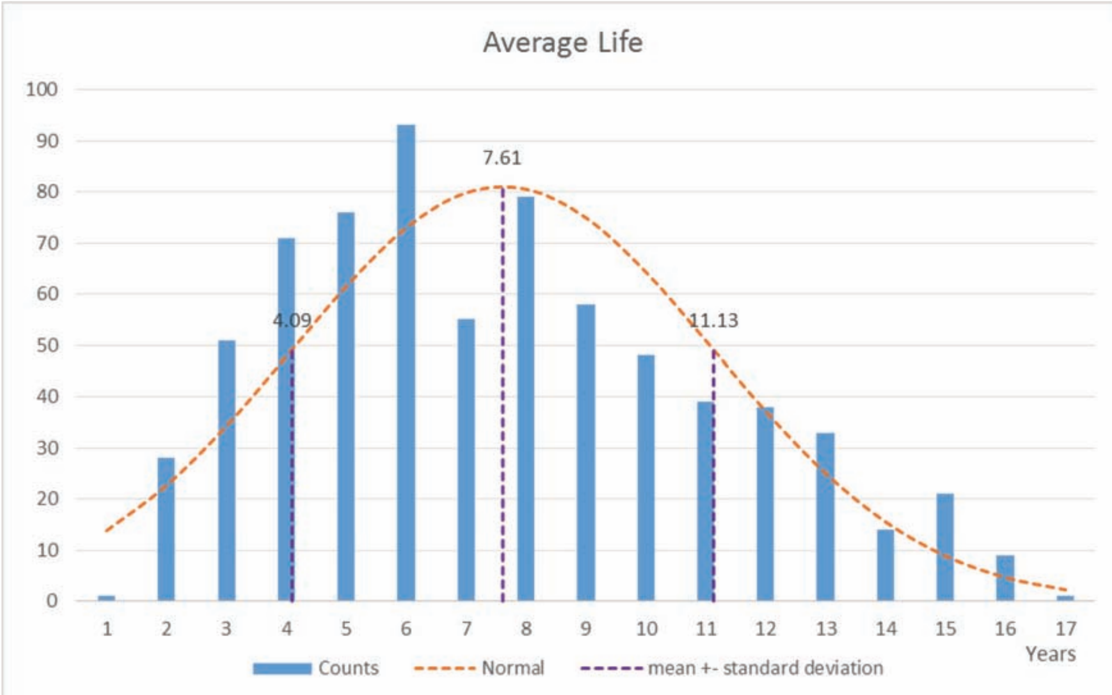


Figure 4.2 Distribution of starter life years.

Another trend is the growing number of International truck turbochargers used on the 2007–2009 trucks. The 42 turbochargers used on International trucks represent 100% increase from the previous year. The data suggests that trends in turbocharger replacement are not found fleet wide but are identified within the different manufacturer of engine and chassis. The Sterling truck has a 6–7 year frequency for turbocharger replacement while International trucks averaged every 5 years.

There are several recommendations for the INDOT fleet management staff to address the growing number of turbocharger failures on international trucks.

1. Identify the remaining international trucks that have not had a turbocharger failure, see Appendix A.
2. Begin oil sampling of all international trucks, specifically the units that have not had a turbocharger replacement. Turbocharger shaft bearings are the fastest moving and highest heat part on a diesel engine. They will be the first indicator of bad engine oil.
3. Leaking or bad fuel injectors can wash oil off cylinder walls and contaminate engine oil. Notice the similarity between injector failures on international trucks in Table 4.6 and the turbocharger failures in the same years for the same international trucks in Table 4.5. Bad fuel injectors may be to blame for the international turbocharger failures as well as the sterling model trucks.
4. Perform an inspection of failed turbochargers to determine if the failure is related to bearing wear, shaft seal failure, turbo fin wear or foreign matter.

Additionally department staff can track fuel mileage on individual units to determine the optimal time to replace fuel injectors maximizing the fuel efficiency and performance while scheduling repairs at during non-critical times. Fuel mileage data can, if available, be plotted with the component data related to fuel injectors, fuel filters and air filters. Fleet managers would see the significance of any improvements to fuel mileage and can adjust the service schedules to compensate.

From the data, average component life was calculated and a distribution of the average life and years in service is shown in Figure 4.3. The figure shows the number of turbochargers replaced for life years from 2 to 16 years, which was the range of life years for this component. The average life was 8.5 years with a standard deviation of 3 years. The average injector life was calculated at 8 years with a standard deviation of 3 years and the distribution is shown in Figure 4.4.

4.2.5 Radiators

Radiator replacement data shows that 905 radiators were replaced between 2008 and 2014. By the time a truck reaches 4 years old 11% have had at least one radiator replaced, 29% by the time a truck is 5 years old and on average 49% by the time a truck is six years old. Developing and implementing weekly or monthly radiator cleaning and chloride neutralizing procedures can help in minimizing the effects of corrosion on radiators. If it determined that snowplowing attributes to damage to the radiator, fleet managers may want to look at a snow foil or air foil on the plow to reduce objects coming into contact with the truck components.

From the data, average component life was calculated and a distribution of the average life and years

TABLE 4.4
Turbocharger replacement by part number, 2008–2014.

Unit/Replacement	2008	2009	2010	2011	2012	2013	2014	Grand Total
TURBOCHARGER	**23**	**20**	**54**	**68**	**71**	**75**	**21**	**332**
006OR7569				1				1
0R6296						1		1
0R6942				1				1
0R7569			1	4	5	1	2	13
0R9865					6	1	1	8
10R3280			1	7	7	6	2	23
178089					1	2		3
178468						3	1	4
179030						1	1	2
1876118C95					1			1
1877634C95					2			2
1877634C96						1		1
201693					1			1
2283228					1			1
2CAOR7569							1	1
2IH1877634C96						1		1
2IH479030						1		1
2IH5010581R91						4		4
2IH5010724R91						1		1
3533008						1		1
3802618RX					1			1
43004025	2							2
43004028					1			1
43004031		2	3					5
43004070		1	5	1				7
43004071	7	5			1			13
43004084	1	1						2
43004105	1	1						2
43004115	1							1
43004123		3						3
43004124		1						1
43004128		1	2			1		4
43004129		1	4			1		6
43004132			1					1
43004300		2						2
43004981	11	2	5					18

TABLE 4.4
(Continued)

Unit/Replacement	2008	2009	2010	2011	2012	2013	2014	Grand Total
43004997						1		1
45001853					1			1
478077						1		1
478089			1	3	7	2	2	15
478468							1	1
479030					4	5	1	10
4956120NX						1		1
5010581R91				3	5	3	3	14
5010581R91A					1			1
5010581R91B					1			1
5010724R91						1	3	4
7569				1	1			2
9865					1			1
OR6478			2	3	1	1		7
OR6942			4	10	5			19
OR7279							1	1
OR7569			15	16	5	9	1	46
OR9865			9	16	7	6		38
Q2A107130053						1		1
R9865			1					1
S300SV						2	1	3
S300V110				1	1			2
SW 179032						4		4
SW178468						1		1
TR479030						1		1
TROR6478				1				1
TUR10R3280						1		1
TUR179030					3	2		5
TUR479030						6		6
TUROR9865					1	1		2

in service is shown in Figure 4.5. The figure shows the number of radiators replaced for life years from 2 to 16 years, which was the range of life years for this component. The average life was 9 years with a standard deviation of 3 years.

4.2.6 Water Pump

Water pump replacement data shows that 417 water pumps were replaced between 2008 and 2014. By the time a truck reaches 4 years old only 9% have had a water pump replaced, 17% by the time a truck is 5 years old and on average 33% by the time a truck is six years old.

From the data, average component life was calculated and a distribution of the average life and years in service is shown in Figure 4.6. The figure shows the number of water pumps replaced for life years from 2 to 16 years, which was the range of life years for this component. The average life was 8.77 years with a standard deviation of 2.86 years.

TABLE 4.5
Turbocharger replacement by manufacturer.

	2008	2009	2010	2011	2012	2013	2014	Grand Total
FORD	3	3	7	11	8	4		36
FREIGHTLIN						2		2
INTERNATL				5	21	42	11	79
STERLING	24	17	46	49	46	37	12	231
Grand Total	**27**	**20**	**53**	**65**	**75**	**85**	**23**	**348**

TABLE 4.6
Injector replacement by manufacturer.

	2008	2009	2010	2011	2012	2013	2014	Grand Total
FORD	10	4	8	30	2	8	7	69
FREIGHTLIN						2		2
INTERNATL			1	7	37	57	21	123
KENWORTH							1	1
STERLING	43	32	103	88	92	115	78	551
Grand Total	53	36	112	125	131	182	107	746

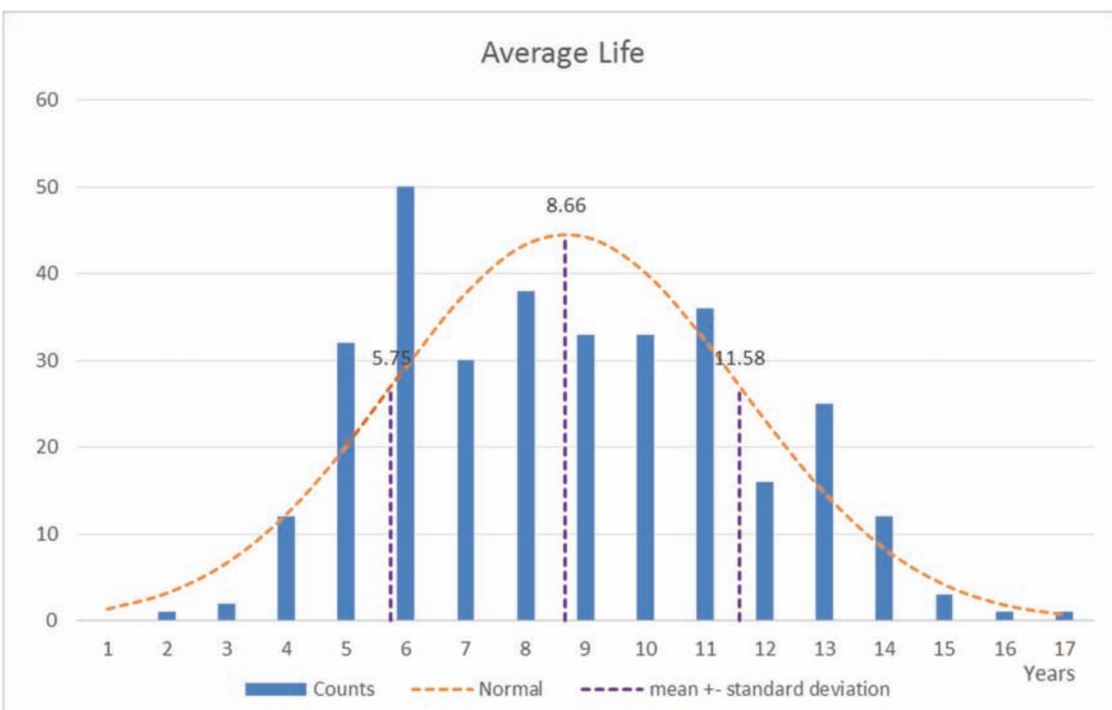


Figure 4.3 Distribution of turbocharger life years.

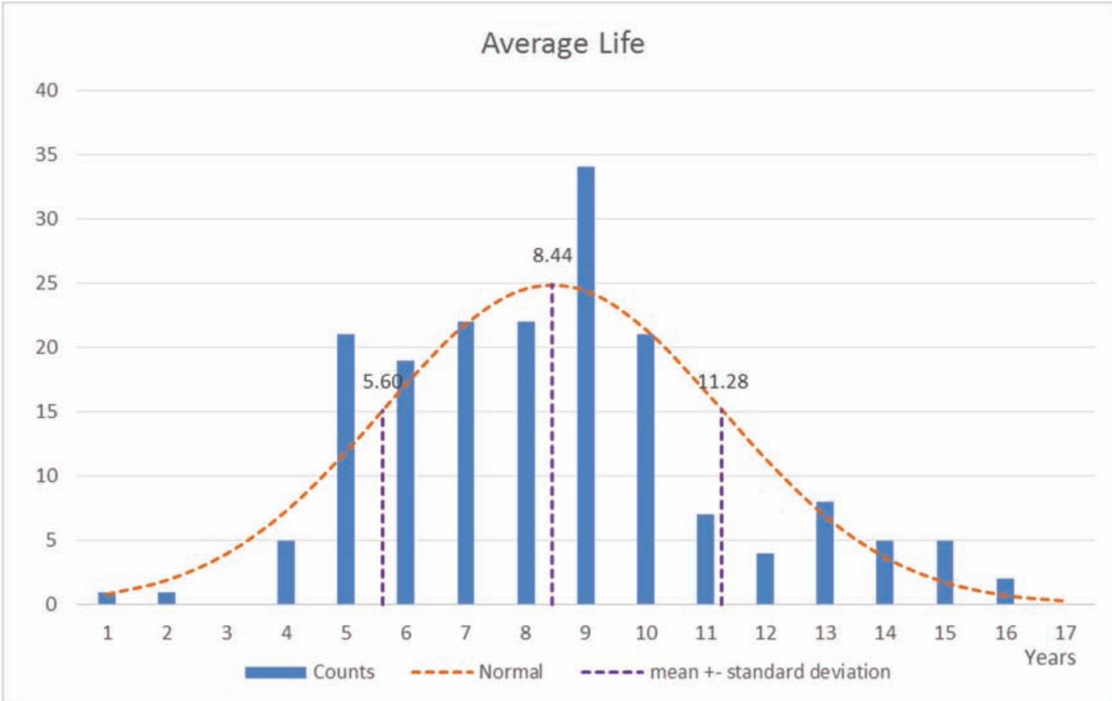


Figure 4.4 Distribution of injector life years.

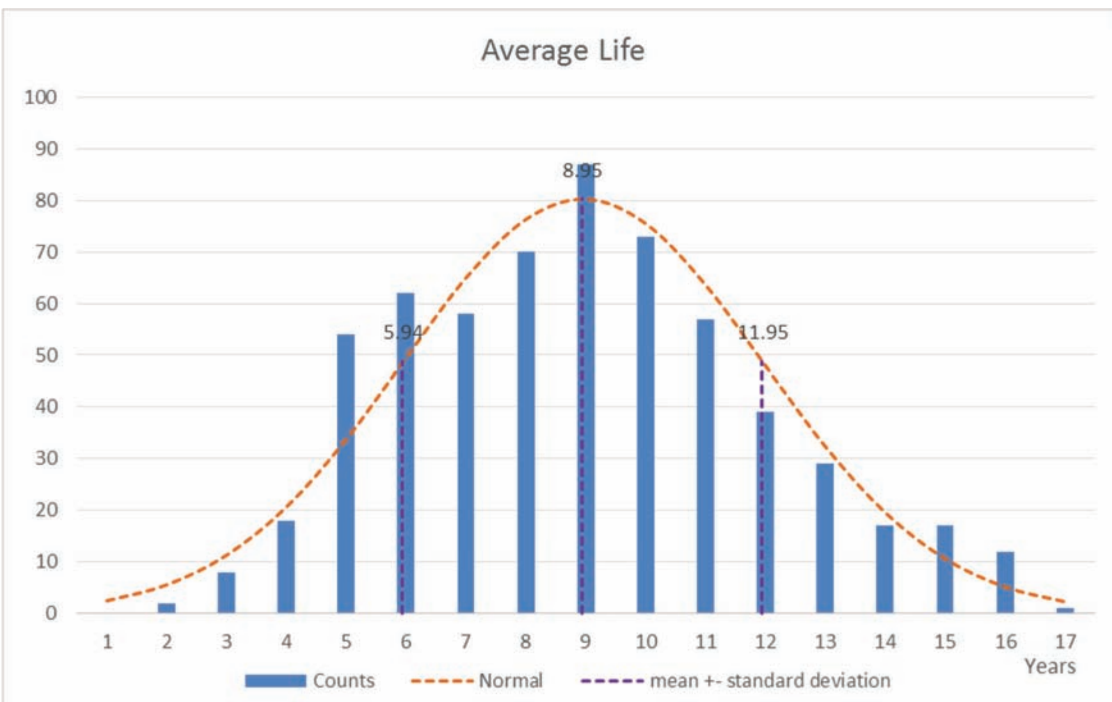


Figure 4.5 Distribution of radiator life years.

4.2.7 Tires

Tire replacement demonstrates wear and damage from a variety of contributing factors. Tire design, miles driven, overloading, or improper inflation can all have an effect on tire wear and damage. Looking at data reveals that aggressive terrain affects a higher replacement frequency. The influence of is shown in Figure 4.7.

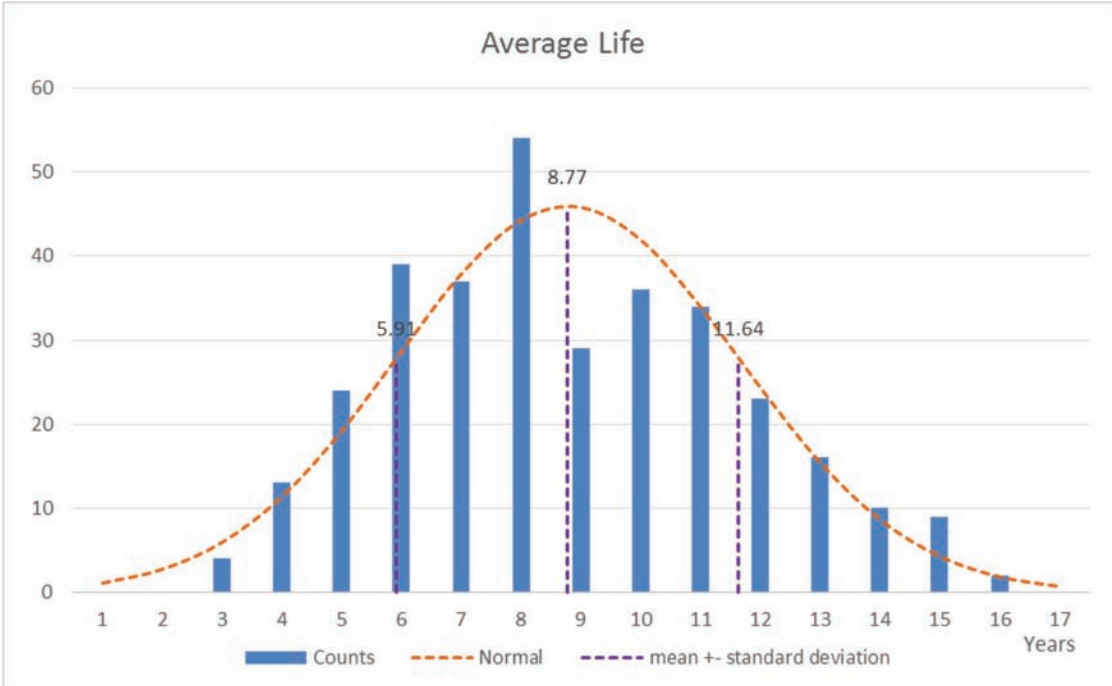


Figure 4.6 Distribution of water pump life years.

The data shows an increase in tire usage for the period 2008–2014. Table 4.7 shows tire replacement values.

Table 4.8 shows the eleven components with the highest replacement frequency. Further investigations show the Seymour district accounted for 24% of the total tire replacement from 2008 through 2014. In the Seymour District, Columbus and Madison sub districts have the highest frequency of tire replacement. Collectively Columbus and Madison sub district make up 6% of the total fleet but accounted for 11% of the total tire replacements from 2008 through 2014. The Indianapolis sub district makes up 6.76% of the fleet but only accounts for 5% of the tire replacements.

From the data, average component life was calculated and a distribution of the average life and years in service is shown in Figure 4.8. The figure shows the number of tires replaced for life years from 1 to 17 years, which was the range of life years for this component. The average life was 7.75 years and the standard deviation is 3.5 years.

4.3 Other Major Components

There was sufficient data on two other major components to perform similar analyses: oil pans and air dryers.

During the analysis time period there were 378 oil pans replaced, some caused by accidents which will affect the life calculations. The average life is 6.5 years with a standard deviation of 2.5 years and Figure 4.9 shows the average life distribution.

During the analysis time period there were 203 air dryer units replaced. The average life is 10 years with a standard deviation of 2.75 years and Figure 4.10 shows the average life distribution.

Table 4.9 is a summary table of the major components average life values.

4.4 Minor Components

Major components were items where part cost is above $200. Items below that amount are considered as minor components. Replacement data is available for these components and therefore is reported. These components are: battery, air compressor, rear brake shoes, front brake shoes, clutch, fan clutch, brake chamber, front leaf springs, rear leaf springs, oil cooler, slack adjusters, conveyor motor, spinner motor, hydraulic pump, power steering gearbox, and transmission cooler. These component average life and replacement life distribution are shown in Appendix B.

Table 4.10 is a summary table of minor components average life values.

4.5 Oil Sampling Program

An oil sampling program for engine oil, transmission oil, hydraulic oil and engine coolant across the fleet is an additional measure for determining the useful life and cause of failure of a component. An example of oil sampling for the department would be to determine early turbocharger failure. Known causes for early turbocharger failure are dirty engine oil and dirty air filters. Oil sampling would show fleet maintenance personnel the conditions the equipment are working in and when to adjust the scheduled intervals. Many times oil sampling will allow fleet maintenance personnel are confident in extending those intervals after oil sampling results are studied.

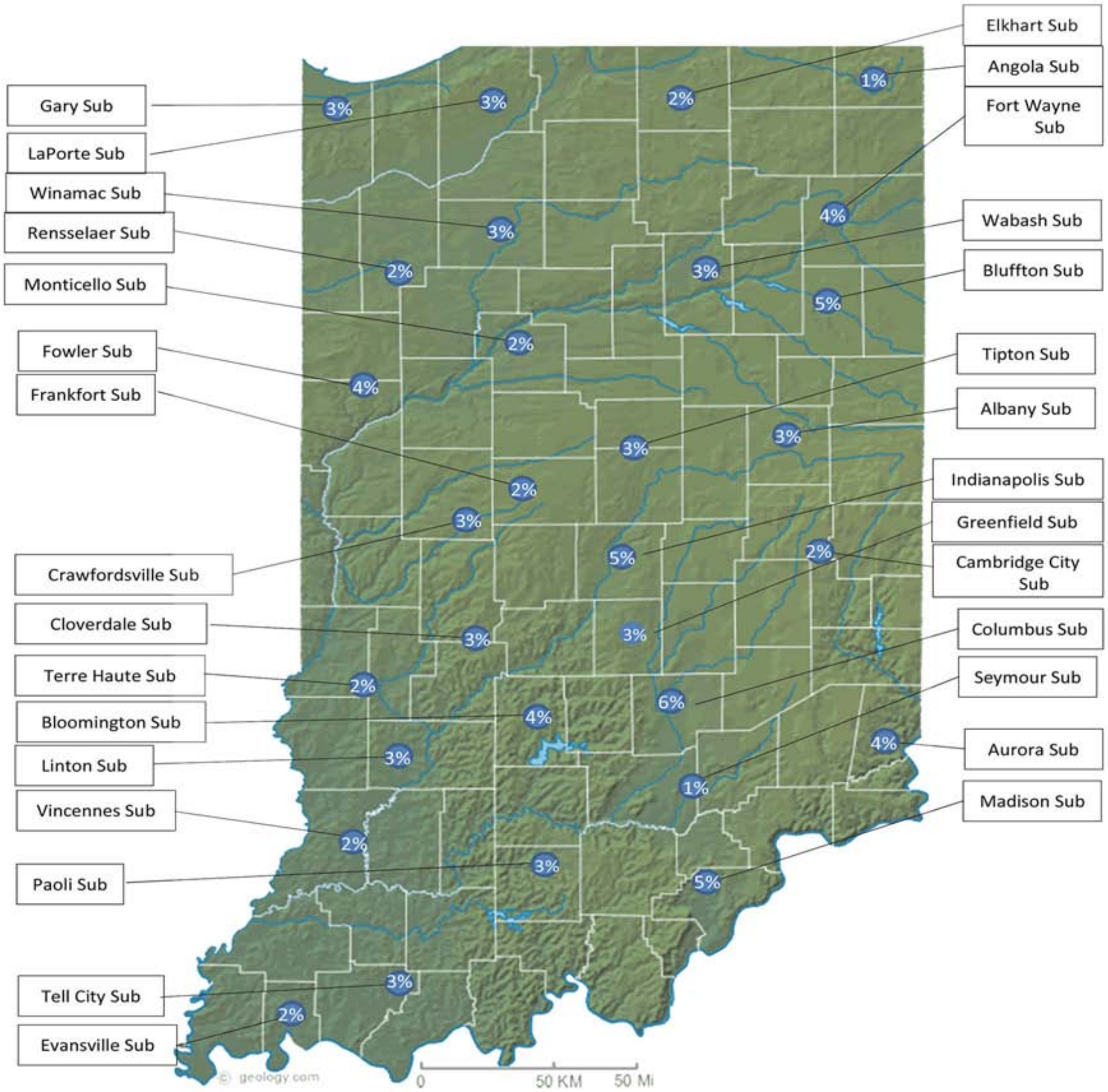


Figure 4.7 State map of tire replacement percentages.

4.6 Maintenance Programs

There are different maintenance programs that equipment fleet managers use. The following are the most common.

Reactive maintenance is the process that most fleet managers live with and make up more than half of the effort of any maintenance facility. When applied to the entire fleet, this can lead to unscheduled repairs to critical equipment during critical times. This approach may be appropriate for non-critical equipment in the fleet, such as pumps, arrow boards, and other equipment that is utilized less often or not vital to the equipment fleet.

Preventive maintenance is an activity performed on a time or equipment run-based schedule that is expected to prolong the life of equipment components by controlling wear and reducing damaging environmental effects that may cause premature failure. Preventive maintenance was pioneered by the U.S. Navy to increase reliability of their vessels and other assets. Preventive maintenance activities can be much more cost effective than traditional reactive maintenance, but can become labor intensive if not designed correctly or during initial implementation.

Predictive maintenance is the measure or detection of wear or failure based on visual inspection, in depth testing or determining the design life. Predictive maintenance is similar to preventive maintenance in that you identify components to be replaced based on a schedule meant to reduce downtime for critical equipment. Predictive maintenance goes a step further by identifying

TABLE 4.7
Tire usage statewide 2008–2014.

Unit Make and Year	2008	2009	2010	2011	2012	2013	2014	Grand Total
TIRES	500	512	636	746	759	923	348	4424
Grand Total	**500**	**512**	**636**	**746**	**759**	**923**	**348**	**4424**

TABLE 4.8
Component replacements by district; eleven most frequent repairs. Percentage of total fleet 2008–2014.

District	Tires	Alternator	Springs	Starter	Radiator	Valve	Exhaust Pipe	Oil Pan	Fuel Injector	Led Top Light	Turbo Charger
LaPorte	14%	20%	21%	24%	15%	19%	20%	16%	21%	10%	18%
Fort Wayne	15%	15%	22%	22%	16%	15%	15%	16%	29%	31%	19%
Crawfordsville	16%	15%	9%	15%	15%	18%	16%	17%	10%	28%	23%
Greenfield	16%	22%	16%	17%	23%	15%	18%	20%	14%	8%	20%
Vincennes	14%	12%	6%	13%	10%	9%	16%	18%	5%	10%	11%
Seymour	24%	16%	25%	8%	20%	22%	12%	11%	21%	13%	9%
INDOT Central Office	1%	1%	1%	1%	1%	1%	2%	1%	0%	1%	0%

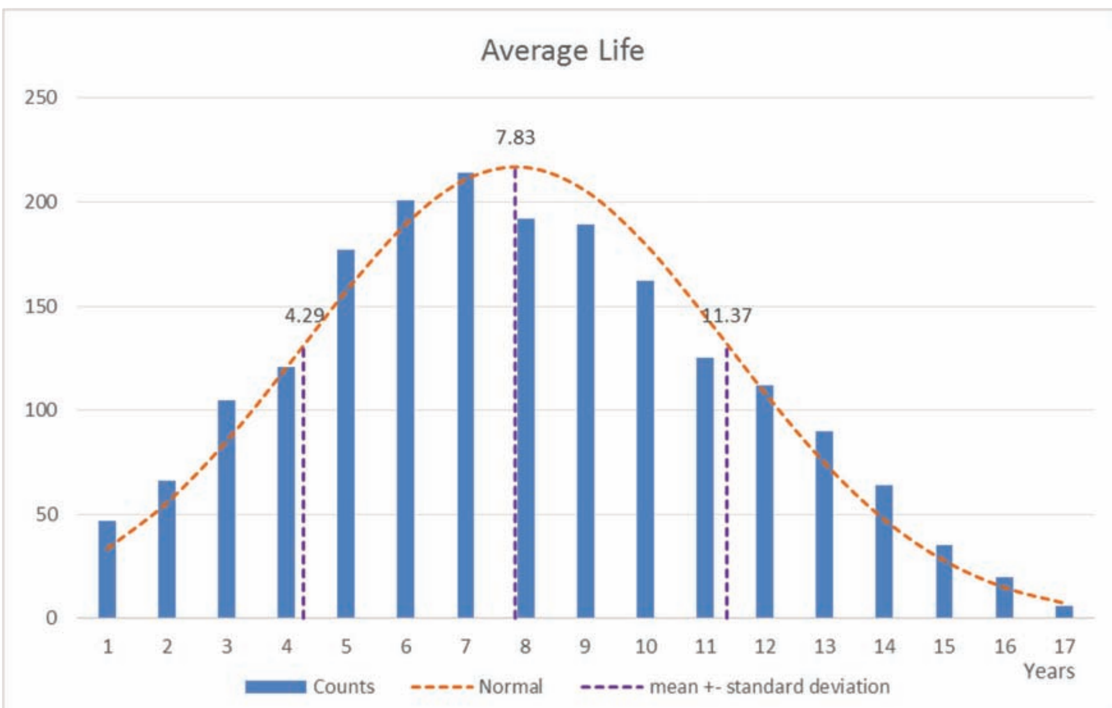


Figure 4.8 Distribution of tire life years.

the life of a component or lubricant and adjusting the preventive maintenance schedule to maximize the life of a component without unscheduled repairs.

Prevention maintenance is referred to as Reliability Centered Maintenance (*Sullivan, Pugh, Melendez, & Hunt, 2010*). Prevention maintenance is a hybrid of the first three maintenance types. Prevention maintenance takes into account several factors that are not recognized in the other maintenance types. In the practical application of fleet management principles, not all equipment has the

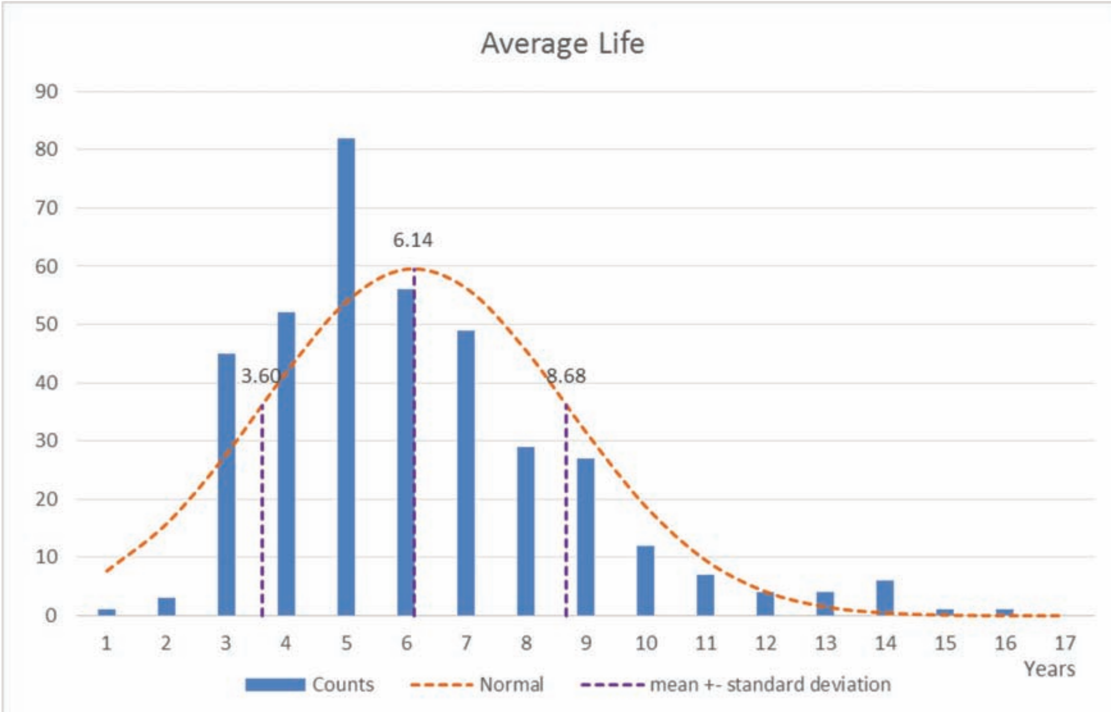


Figure 4.9 Distribution of oil pan life years.

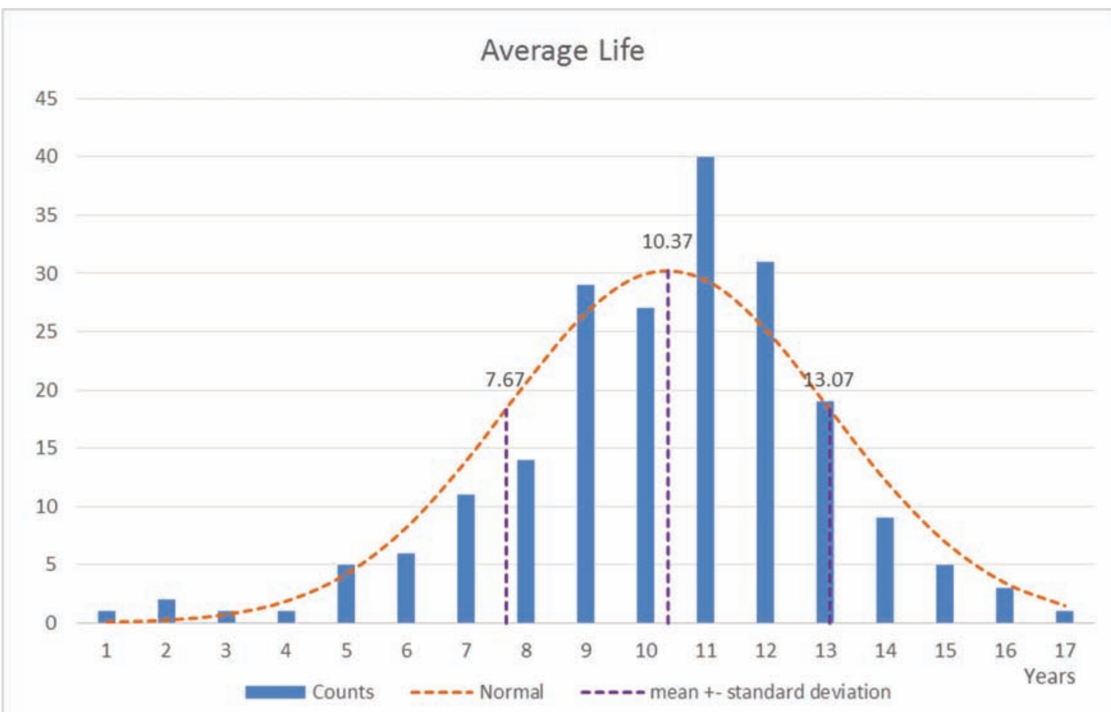


Figure 4.10 Distribution of air dryer life years.

same level of importance or may require the same level of preventive maintenance. Each of the first three types can be applied to different equipment in our fleet at different levels. Arrow boards, pumps, patching equipment, trailers and salt spreaders may not be cost effective candidates for a predictive maintenance program or may only need to apply a reactive maintenance strategy prior to seasonal activities. Equipment that has a critical role in the department's activities can demonstrate a savings from application of a predictive maintenance approach.

TABLE 4.9
Major components average life.

Component Type	Average Life
Alternators	9
Starters	7.5
Turbochargers	8.5
Injectors	8
Radiators	9
Water pumps	8.67
Tires	7.75
Oil Pans	6.5
Air Dryer	10

TABLE 4.10
Minor components average life.

Minor Component Type	Average Life
Battery	8.6
Air Compressor	9.7
Rear Brake Shoes	9.5
Front Brake Shoes	9.5
Clutch	9.5
Fan Clutch	8
Brake Chamber	8
Front Leaf Springs	9
Rear Leaf Springs	10
Oil Cooler	8.5
Slack Adjustors	9
Conveyor Motor	8.5
Spinner Motor	6.5
Hydraulic Pump	9
Power Steering Gear box	8
Power Steering pump	8
Transmission Cooler	10

Operators are the first line of defense against equipment wear, failure, and damage. Equipment must be inspected by the operator on a daily basis before, during, and after operation so defects or malfunctions can be detected before they result in serious damage, failure, or accident. Defects detected during these inspections, or during operation of the equipment, should be reported as soon as possible. The operator must stop operation immediately when a deficiency develops that renders the equipment unsafe, or could damage the equipment. See Appendix C for an example of an operator's daily checklist developed for use by the Lake County Highway Department and regularly provided as an example checklist by Indiana LTAP.

INDOT maintenance units across the state have an average of 28.84 trucks per maintenance unit. The larger maintenance units like Indianapolis sub-district has 76 trucks in their inventory and Angola sub-district is shown with 18. It is important that any scheduling be flexible enough to accommodate every sub-district and still be committed to a standard program that demonstrates saving and performance department wide.

One of the primary deliverables is a schedule for replacing major components. This approach can have many benefits for the fleet maintenance department. Reducing equipment downtime, improving scheduling of equipment for operational activities and improving part and supply inventories are all financial benefits to the departments overall operations.

Equipment classified as critical service level 1, should utilize a 60 day PM schedule. A 60 day PM schedule accounts for an average of 250 working days in a year and 20 working days in a month. This would put a truck in the shop for scheduled maintenance once every three months. For equipment classified as critical service level 2 the frequency can extend to every 4 months and 80 day PM schedule. Each sub-district can adjust up or down from this point based on total trucks in their inventory and staffing available for preventive maintenance activities. Hours and miles listed in the maintenance intervals can also be adjusted to reflect each maintenance district averages. Each sub-district can incorporate other equipment into the grouping based on the critical service levels listed below.

Critical Service Level 1

Equipment deemed to be critical to the operation of the department or emergency response activities. Classified as severe service.

Critical Service Level 2

Equipment necessary for efficient operations but not deemed critical. Equipment not vital to emergency response activities. Classified as normal service.

Critical Service Level 3

Equipment is necessary for critical operations but used only during seasonal activities. Classified as seasonal, service-critical.

Critical Service Level 4

Equipment is not necessary for critical operations. Used during seasonal activities only. Classified as seasonal service-non critical.

Each of these service levels has preventive maintenance intervals that reflect the components to be inspected or serviced. The higher cost of increased maintenance can be justified when fleet managers take into account the cost of equipment not being available at critical moments. Seasonal service, non-critical equipment can continue with the reactive maintenance approach. Fleet managers are able to schedule this equipment for service when it's needed, applying both preventive maintenance methods only when equipment is in service. Equipment can follow regular scheduled intervals during its operating season and may have a procedure for storage depending on the type of equipment.

One of the primary deliverables is a schedule for replacing major components. Planned maintenance can benefit the Department in many ways by reducing equipment downtime, improving scheduling of equipment for operational activities and improving part and supply inventories. Additionally, department staff can track fuel mileage on individual units to determine the optimal time to replace fuel injectors maximizing fuel efficiency and performance while scheduling repairs during non-critical times. Fuel mileage data can be plotted with the component data related to fuel injectors, fuel filters and air filters. Fleet managers would see any improvements to fuel mileage and can adjust their service schedules to compensate.

Appendix D shows fleet managers a proposed schedule of preventive and predictive maintenance for the INDOT fleet.

4.7 Truck Specifications

Component replacement data was used to determine component life and from that identify components that had a higher than normal replacement frequency. Researchers analyzed individual failures looking for high failure rate by part number, application, manufacturer, or if the component was new or remanufactured. Components with a significantly high failure rate were identified within the latest INDOT truck specifications and possible replacement components were recommended. Researchers attempted to identify components that are common to trucks within the INDOT fleet but did not show up as significant numbers in the repair data.

Researchers did not have a list of all the components for each unit, only the failed components were analyzed. For that reason it was challenging to identify the best performing components. Components for fuel injectors, internal engine components, transmissions and tandem axle rear suspension did not appear in the truck record base in sufficient numbers to form judgements on their performance. These components may have been serviced by outside contractors and did not get entered into the fleet database.

Many of these components on the newer model year trucks will appear in the repair data base in the future. If INDOT wants to track this in the future it is recommended that the specifications call for an electronic "build list" or line ticket of all of the major components that are on a truck, to be provided to the department when a new truck is delivered.

Appendix E contains recommended specifications for components.

4.8 Garage Software Tools

The equipment data received had missing data, two inconsistent pieces were hours and mileage which hindered the analysis. Data collection and quality can be improved through the utilization of software tools. It is recommended that INDOT investigate the use of cloud-based data collection software and other emerging technologies. These tools allow any shop location to post data for manager review. This opportunity for real time analysis improves manager's ability to make better decisions on predictive maintenance decisions. The most important aspect of electronic data collection at the technician level is that the inputs are preselected; coded and human errors are eliminated. When a part is purchased and entered into the system it is given a unique ID number and can be tracked and analyzed for performance, logistics and cost. There are many off the shelf systems that can perform this task and some that are customizable for an account as unique as INDOT. These types of systems generally fall into one of three categories. For more specific information contact the listed vendors.

4.8.1 Fleet Operations Software

This software concentrates on GIS or GPS tracking of the fleet, logistics and dispatching operation. Tools have been developed by:

1. Verizon Network Fleet
2. FleetMatics GPS Tracking https://info.fleetmatics.com
3. Telogis www.telogis.com
4. Horizon www.meltontechnologies.com
5. FleetCommander http://www.agilefleet.com/
6. Fleetmatics www.fleetmatics.com

4.8.2 Fleet Management Software

This software is used to manage day to day fleet functions, such as:

- Work order tracking
- Data input
- Tire management systems
- PM scheduling

Many of these are able to work with existing fuel or fleet tracking software. Some of the newer program updates are cloud based and allow for mobile input with tablets or other devices. Recommended tools are:

1. Assetworks Fleetfocus www.assetworks.com
2. AgileAssets Fleet and Equipment Manager http://www.agileassets.com/products/fleet-equipment-manager/
3. Faster Asset Solutions http://www.ccgsystems.com/softwareandservices.php
4. ManagerPlus http://www.managerplus.com/maintenance-software/cloud
5. FleetCommander http://www.agilefleet.com/government-fleet-technology-solutions
6. Cartegraph http://www.cartegraph.com/meet-cartegraph/feature-tour

4.8.3 Fleet Cost Analysis Software

These software systems are designed for the life-cycle cost analysis and financial forecasting that is common with private sector fleet-based businesses. These are common in the freight sector in determining when to own, lease or sell existing equipment and when a piece of equipment is maximizing its earning potential. Recommended tools are:

1. cfc Solutions http://cfcsolutions.squarespace.com/
2. Fleetistics http://www.fleetistics.com//login.php
3. NTEA Vehicle Lifecycle Cost Analysis Tool
4. Orbligic http://www.orblogic.com/

TABLE 4.11
OEM warranties.

Component Name	OEM/Manufacturer Limited Warranty *(Information from available Manufacturer Warranty information—contact manufacturer for detailed information) (Extended warranties may be available)*	
	Months	Miles/Hours
Water Pump	12	Unlimited
Radiator	12	Unlimited
Starter	12	Unlimited
Injector	12	Unlimited
Oil Pan	12	Unlimited
Air Dryer	12	Unlimited
Alternator	36	Unlimited
Turbocharger	12	Unlimited
Tires	12	First 2/32nd wear
Battery	12	Unlimited
Air Compressor	12	Unlimited
Rear Brake shoes	12	Unlimited
Front Brake Shoes	12	Unlimited
Clutch	12	Unlimited
Fan Clutch	12	Unlimited
Brake Chamber	12	Unlimited
Front Leaf Springs	12	Unlimited
Rear Leaf Springs	12	Unlimited
Oil Cooler	12	Unlimited
Slack Adjusters	12	Unlimited
Conveyor Motor	12 mo.—From equipment manufacturer	Unlimited
Spinner Motor	12 mo.—From equipment manufacturer	Unlimited
Hydraulic Pump	12 mo.—From equipment manufacturer	Unlimited
Power Steering Gearbox	12	Unlimited
Power Steering Pump	12	Unlimited
Transmission Cooler	12	Unlimited

4.9 Warranty Information

Using part replacement data the researchers were able to calculate average life and corresponding standard deviation for major and minor parts. This data can be used by INDOT equipment managers to establish part replacement timelines and policy. Another factor to consider is part warranties. Warranties can be used as an indicator of replacement periods.

The research team collected warranty information from truck manufacturers and major part suppliers and produced Tables 4.11 and 4.12. Table 4.11 contains recommended warranties from the Original Equipment Manufacturer (OEM). These warranty values are used as reference values for the values calculated from the truck data and shown in Appendix B.

Table 4.12 contains warranty information published by replacement part suppliers. In this table the information source is provided for obtaining this and additional information.

4.10 Data Analysis Tool

The research team developed a data analysis tool in Excel that was used to calculate a component's life and standard deviation. This tool is described in Appendix F.

TABLE 4.12
New replacement warranties.

Component Name	Months	Miles/Hours	Warranty Source
Water Pump	18	150,000	http://www.internationaltrucks.com
Radiator	12	Unlimited	http://www.internationaltrucks.com
Starter	12	100,000	Delco Remy Product Warranty data sheet Revised June 2014
Injector	12	Unlimited	http://www.internationaltrucks.com
Oil Pan	12	Unlimited	http://www.internationaltrucks.com
Air Dryer	12	100,000/3,600 hours	http://www.bendixvrc.com/itemDisplay.asp?documentID=6333
Alternator	12	Unlimited	Delco Remy Product Warranty data sheet Revised June 2014
Turbocharger	12	100,000	http://www.turbos.bwauto.com/en/aftermarket/downloads.aspx
Tires	12	First 2/32nd wear	http://www.goodyeartrucktires.com
Battery	30	Unlimited	http://www.exide.com
Air Compressor	12	100,000/3,600 hours	http://www.bendixvrc.com
Rear Brake Shoes	12	Limited	http://www.internationaltrucks.com
Front Brake Shoes	12	Limited	http://www.internationaltrucks.com
Clutch	12	Limited	http://www.internationaltrucks.com
Fan Clutch	12	Limited	http://www.hortonww.com/Products/TechnicalResources.aspx
Brake Chamber	36	Limited	http://mgmbrakes.com
Front Leaf Springs	12	Limited	http://www.internationaltrucks.com
Rear Leaf Springs	12	Limited	http://www.internationaltrucks.com
Oil Cooler	12	Limited	http://www.internationaltrucks.com
Slack Adjusters	36	Limited	http://mgmbrakes.com
Conveyor Motor	12	Unlimited	http://www.monroetruck.com
Spinner Motor	12	Unlimited	http://www.monroetruck.com
Hydraulic Pump	12	Unlimited	http://www.monroetruck.com
Power Steering Gearbox	12	Limited	http://www.internationaltrucks.com
Power Steering Pump	12	Limited	http://www.internationaltrucks.com
Transmission Cooler	12	Limited	http://www.internationaltrucks.com

5. CONCLUSIONS

Fleet management personnel encouraged to use these recommendations as a platform to improve the best practices of the fleet department as well as investigate the use of emerging technologies. Many opportunities for fleet managers exist today that include the use of synthetic oils, on board truck ECM diagnostic programs and real time equipment performance data. It is also recommended that the department study the use of electronic shop repair reporting statewide.

Any fleet operation that relies on good data to identify performance or improvements should consider in investing in tools and training that improve the process of recording repair data. Software tools are available to track units, repairs, and parts. Collected data should be used to evaluate equipment and component performance, establish maintenance programs, and create a comprehensive approach to fleet operations.

REFERENCES

APWA. (2000). *APWA Equipment Code*. Kansas City, MO: American Public Works Association.

Delco Remy. (2013). *Heavy duty alternator charging system troubleshooting manual*. Pendleton, IN: Remy International, Inc.

NAVFAC. (1997). *Management of civil engineering support equipment* (Report No. NAVFAC P-300). Alexandria, VA: Naval Facilities Engineering Command. Retrieved from http://64.78.11.86/uxofiles/enclosures/NAVFAC_P-300.pdf

Perry, W. (1994). "Specifications and standards: A new way of doing business." Memorandum from the Secretary of Defense to the Secretaries of the Military Departments, June 29, 1994. The Pentagon, Office of the Secretary of Defense, Washington, DC. Retrieved from http://www.sae.org/standardsdev/military/milperry.htm

Sullivan, G. P., Pugh, R., Melendez, A. P., & Hunt, W. D. (2010). *Operations & Maintenance Best Practices: A Guide to Achieving Operational Efficiency*. Washington, DC: Federal Energy Management Program, U.S. Department of Energy. Retrieved from https://www1.eere.energy.gov/femp/pdfs/OandM.pdf

APPENDIX A: INTERNATIONAL TRUCK TURBOCHARGER REPLACEMENT 2008–2014

Year	2008	2009	2010	2011	2012	2013	2014	Total
FORD	3	3	7	11	8	4		36
FREIGHTLINER						2		2
INTERNATIONAL				5	21	42	11	79
61327					1		1	2
479030					1			1
5010581R91							1	1
61571					1			1
5010581R91					1			1
61572						1		1
SW 179032						1		1
61579						1		1
479030						1		1
61593					1	1		2
479030					1	1		2
61702						1		1
1877634C96						1		1
61745						1		1
479030						1		1
61746						1		1
SW 179032						1		1
61747					1	1		2
43004129						1		1
S300V110					1			1
61752					1			1
201693					1			1
61753						1		1
SW 179032						1		1
61808						1		1
SW 179032						1		1
62324					1			1
5010581R91A					1			1
62338						1		1
1878103C93						1		1
62346					1			1
479030					1			1
62348						1		1
1878103C93						1		1
62398							1	1
5010588R91							1	1
62401					2			2
1876118C95					1			1
1878103C93					1			1
62411						1		1
479030						1		1
62416						1		1
TUR479030						1		1
62422					1			1
5010581R91					1			1
62613						1	1	2
179030						1		1
5010724R91							1	1
63252							2	2

5010581R91							1	1
5010588R91							1	1
63364							1	1
5010581R91							1	1
63554					1			1
5010546R91					1			1
63623					1			1
5010581R91					1			1
63690						1		1
479030						1		1
63700						1		1
TUR479030						1		1
63703						1		1
TUR479030						1		1
63748					1			1
479030					1			1
63754						1		1
5010546R91						1		1
63755						1		1
5010546R91						1		1
63778				1				1
5010581R91				1				1
64082						1		1
5010724R91						1		1
64398						1		1
TR479030						1		1
64399							1	1
179030							1	1
64406						1		1
TUR479030						1		1
64414						2		2
5010546R91						1		1
5010588R91						1		1
64469						1		1
TUR179030						1		1
64474							1	1
479030							1	1
64632					1			1
5010546R91					1			1
64657						1		1
5010546R91						1		1
64660				1				1
5010581R91				1				1
64663				1		1		2
5010581R91				1		1		2
64665						1		1
5010546R91						1		1
64675						1		1
TUR479030						1		1
64680						1		1
TUR479030						1		1
64695					1			1
TUR179030					1			1

64752						**1**		**1**
TUR179030						1		1
64767						**1**		**1**
5010581R91						1		1
64776							**1**	**1**
5010724R91							1	1
64839					**1**			**1**
TUR179030					1			1
64996							**1**	**1**
5010724R91							1	1
65311						**1**		**1**
S300SV						1		1
65314					**1**	**1**		**2**
2IH5010581R91						1		1
5010581R91					1			1
65381						**1**		**1**
2IH5010581R91						1		1
65386						**1**		**1**
2IH5010581R91						1		1
65388						**1**		**1**
2IH5010581R91						1		1
65392					**1**			**1**
5010581R91					1			1
65397						**1**		**1**
2IH479030						1		1
65400						**1**		**1**
9HD3553803						1		1
65408				**1**				**1**
170116				1				1
65593						**1**		**1**
2IH1877634C96						1		1
66384						**1**		**1**
S300SV						1		1
66385					**1**			**1**
TUR179030					1			1
66460				**1**				**1**
S300V110				1				1
66630					**1**			**1**
1877634C95					1			1
66634					**1**			**1**
1877634C95					1			1
66842							**1**	**1**
S300SV							1	1
66843						**1**		**1**
5010581R91						1		1
STERLING	**24**	**17**	**46**	**49**	**46**	**37**	**12**	**231**
Grand Total	**27**	**20**	**53**	**65**	**75**	**85**	**23**	**348**

OEM warranty is the warranty that comes with a new vehicle. New replacement warranty is for a new part.

Battery

Number replaced = 751
Average life = 8.5 years
Standard deviation = 3.5 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 2.5 Year

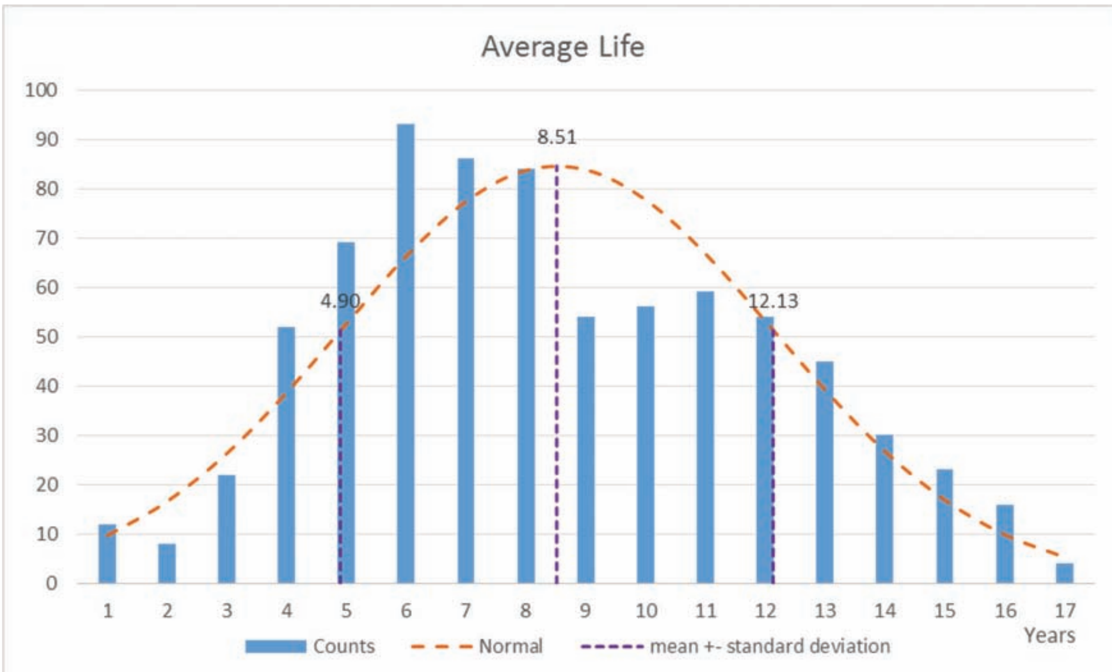


Figure B.1 Battery average life distribution.

Air Compressor

Number replaced = 111
Average life = 9.7 Years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

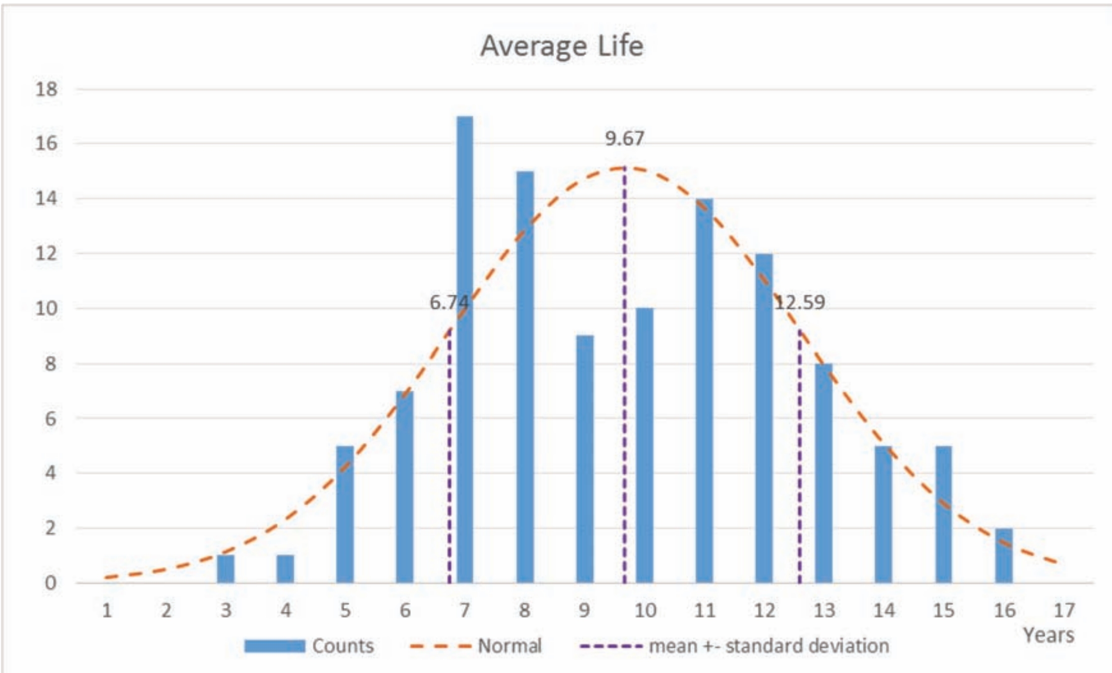


Figure B.2 Air compressor average life distribution.

Rear Brake Shoes

Number replaced = 340
Average life = 9.5 years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

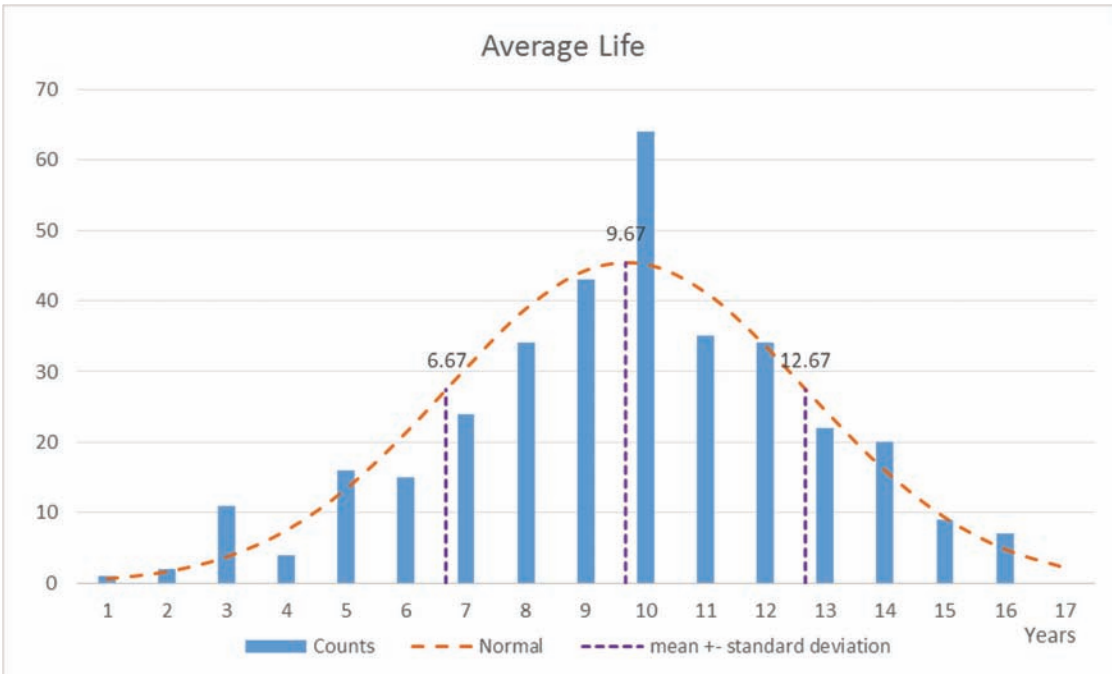


Figure B.3 Rear brake shoes average life distribution.

Front Brake Shoes

Number replaced = 50
Average life = 9.5 years
Standard deviation = 2.4 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

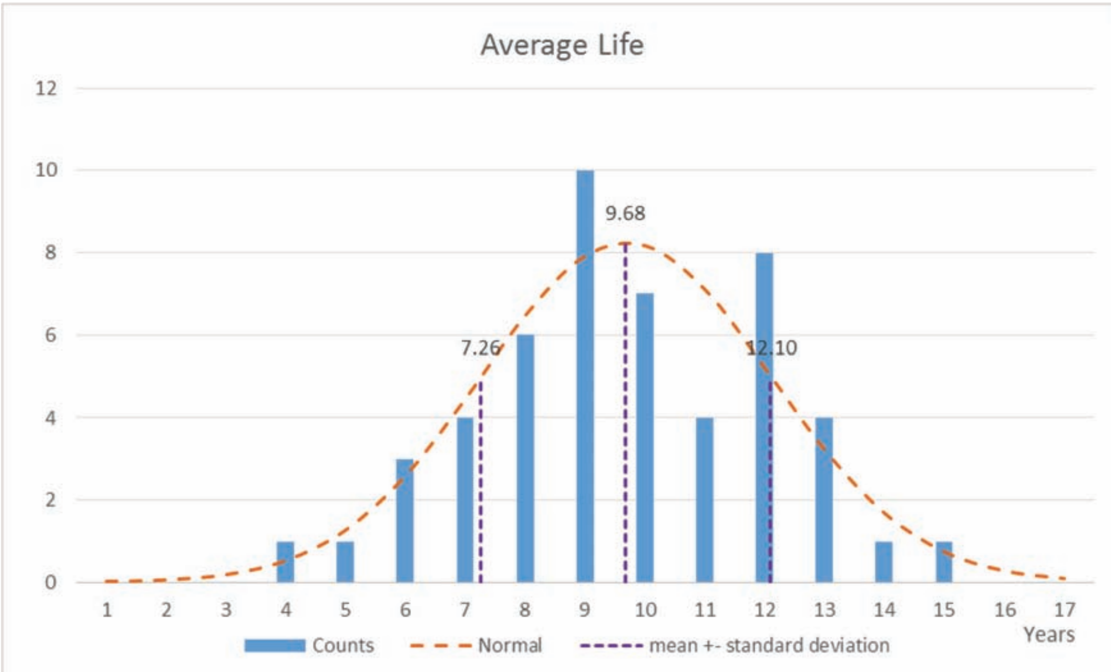


Figure B.4 Front brake shoes average life distribution.

Clutch

Number replaced = 45
Average life = 9.5 years
Standard deviation = 2.5 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

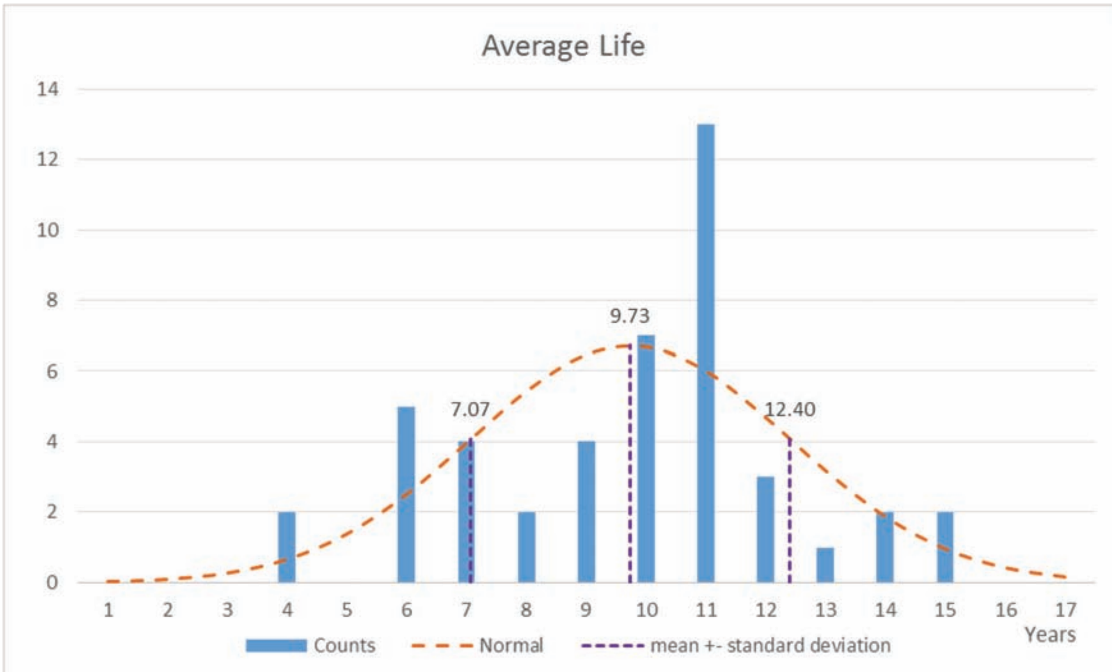


Figure B.5 Clutch average life distribution.

Fan Clutch

Number replaced = 200
Average life = 8 years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

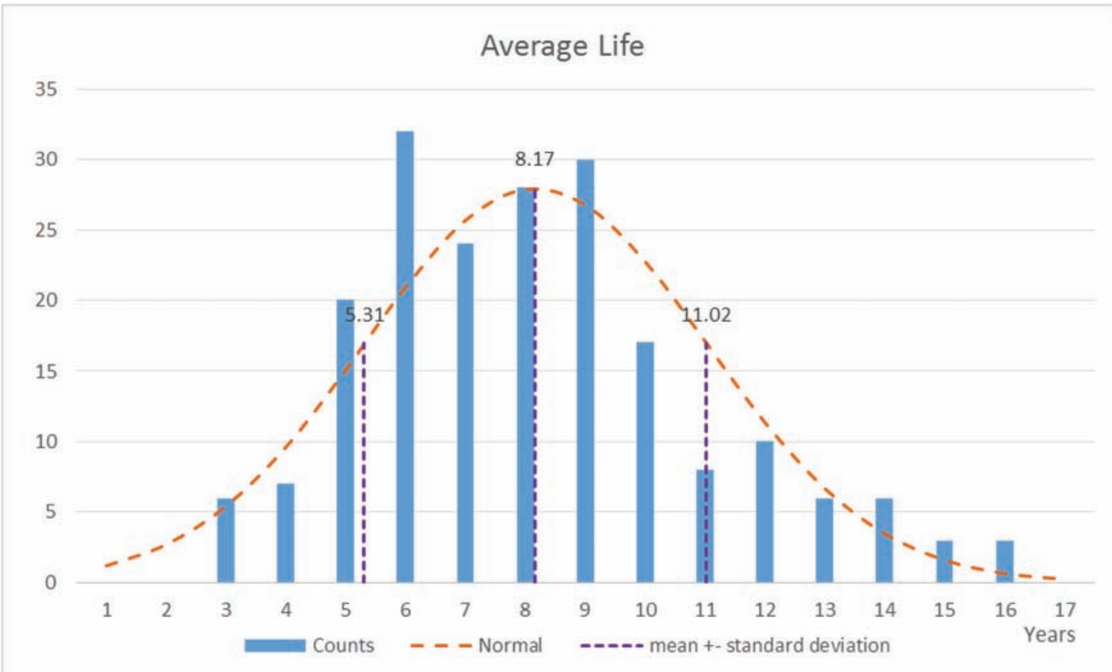


Figure B.6 Fan clutch average life distribution.

Brake Chamber

Number replaced = 1007
Average life = 8 Years
Standard deviation = 3.25 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 3 Year

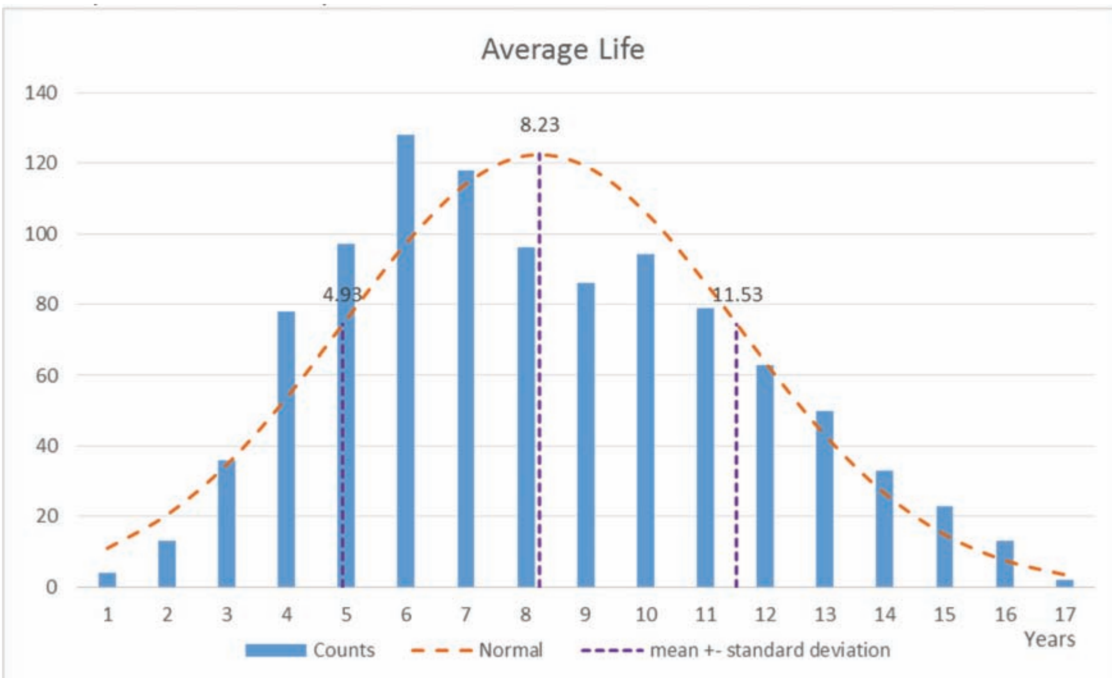


Figure B.7 Brake chamber average life distribution.

Front Leaf Springs

Number replaced = 115
Average life = 9 years
Standard deviation = 2.5 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

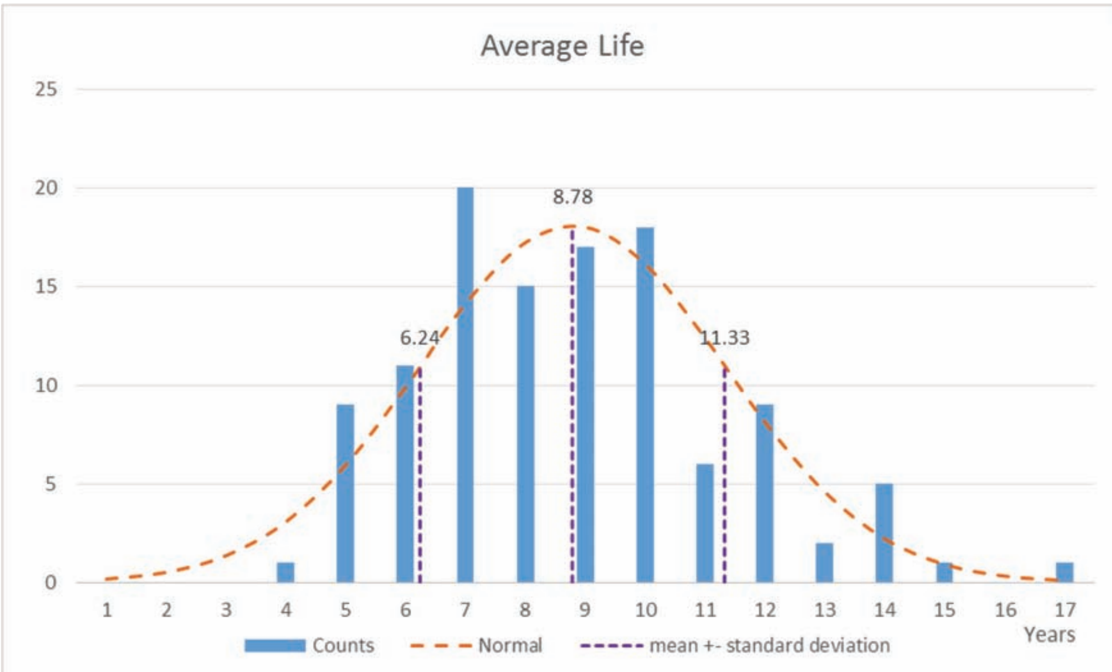


Figure B.8 Front leaf springs average life distributions.

Rear Leaf Springs

Number replaced = 151
Average life = 9.5 years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

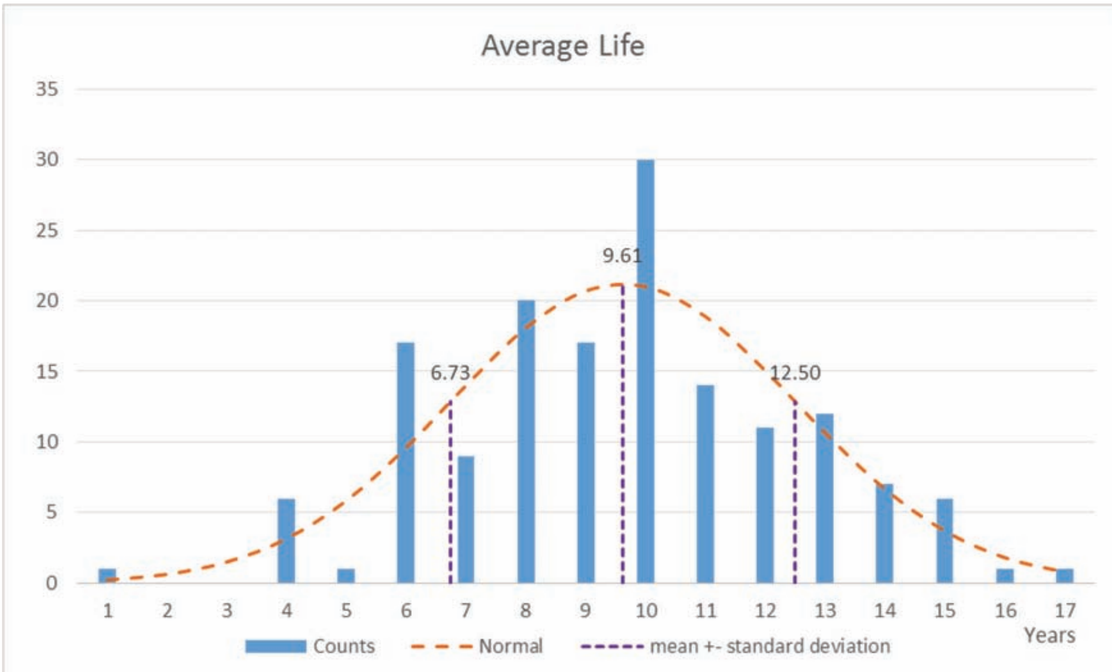


Figure B.9 Rear leaf springs average life distributions.

Oil Cooler

Number replaced = 33
Average life = 8.5 years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

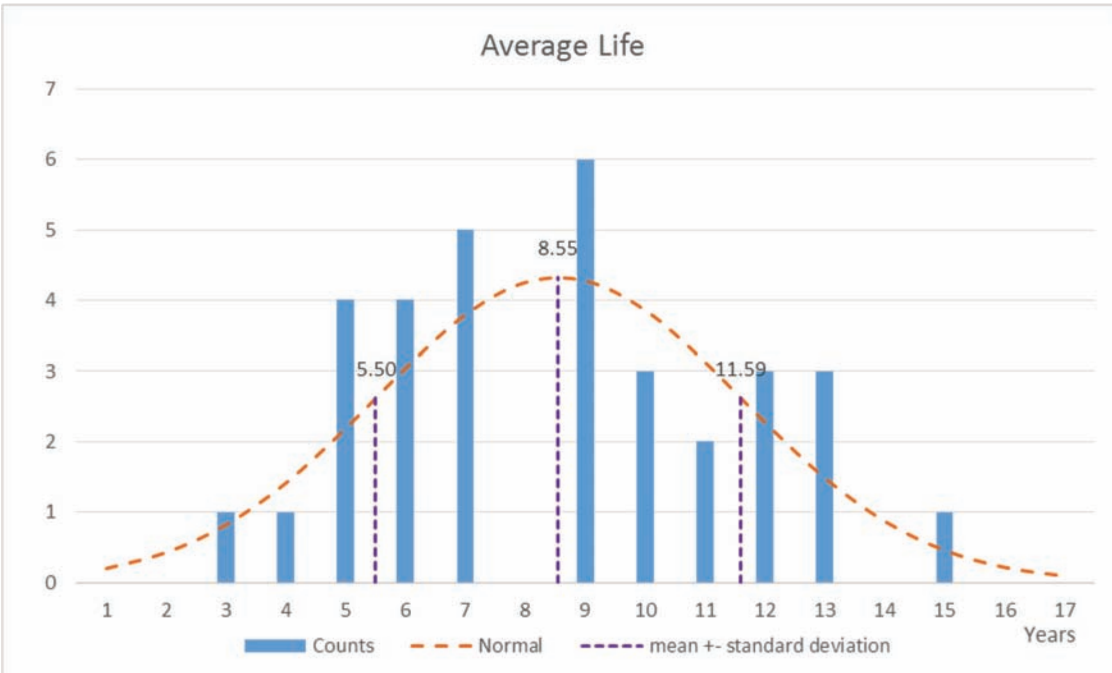


Figure B.10 Oil cooler average life distributions.

Slack Adjusters

Number replaced = 564
Average life = 9 Years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 3 Year

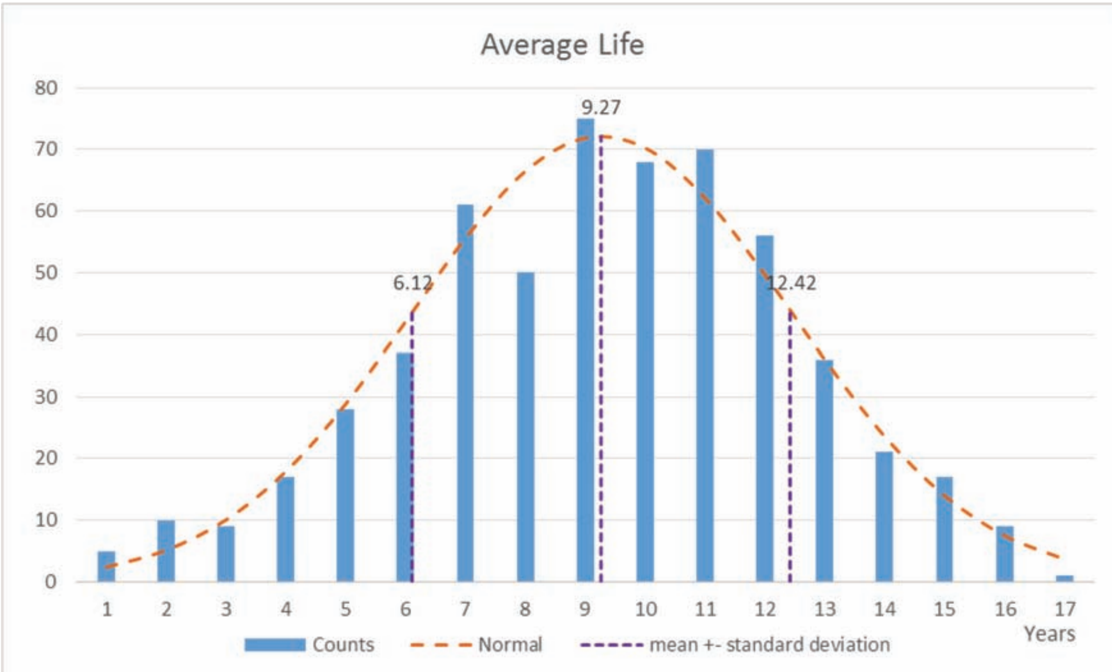


Figure B.11 Slack adjusters average life distributions.

Conveyor Motor

Number replaced = 56
Average life = 8.5 years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

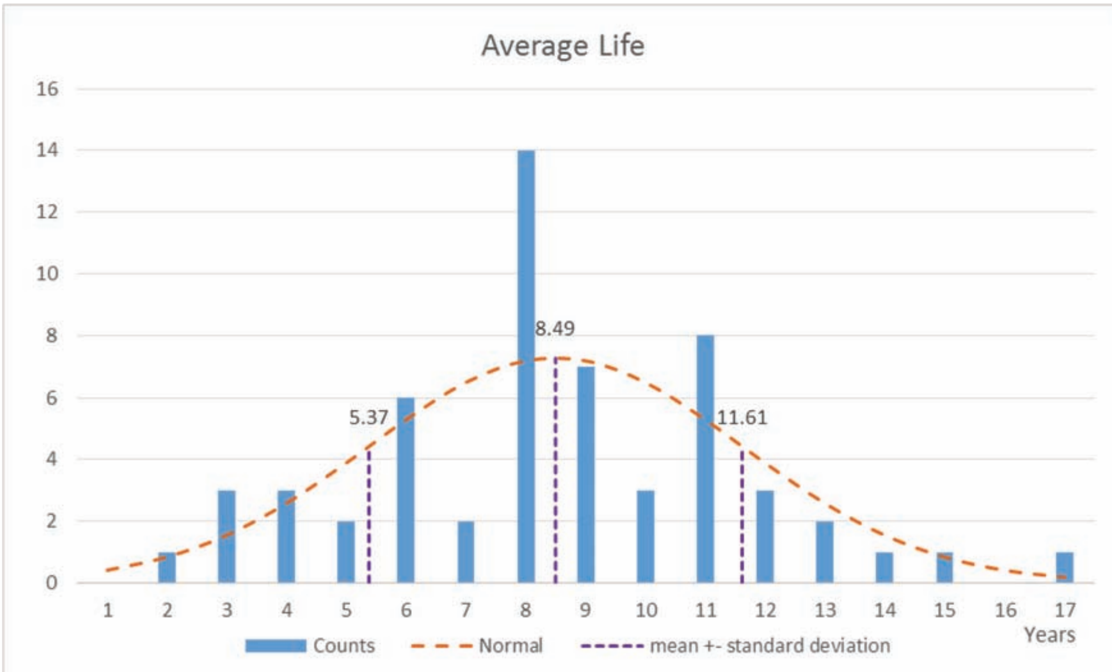


Figure B.12 Conveyor motor average life distributions.

Spinner Motor

Number replaced = 135
Average life =6.5 years
Standard deviation = 3.5 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

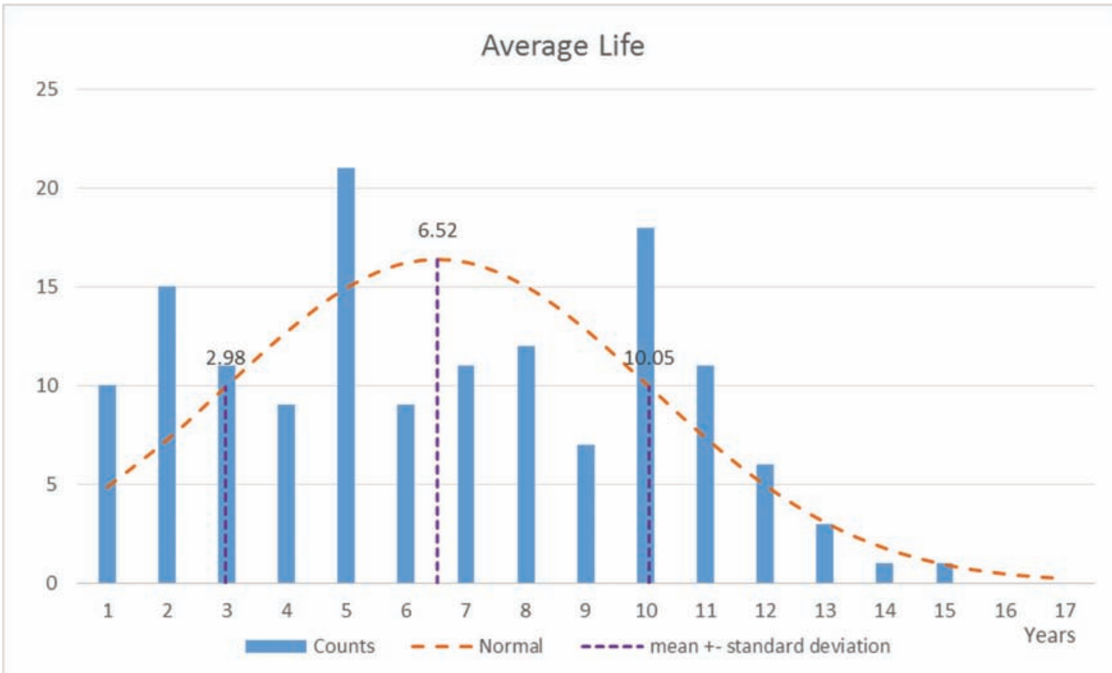


Figure B.13 Spinner motor average life distributions.

Hydraulic Pump

Number replaced = 140
Average life = 8.5 Years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

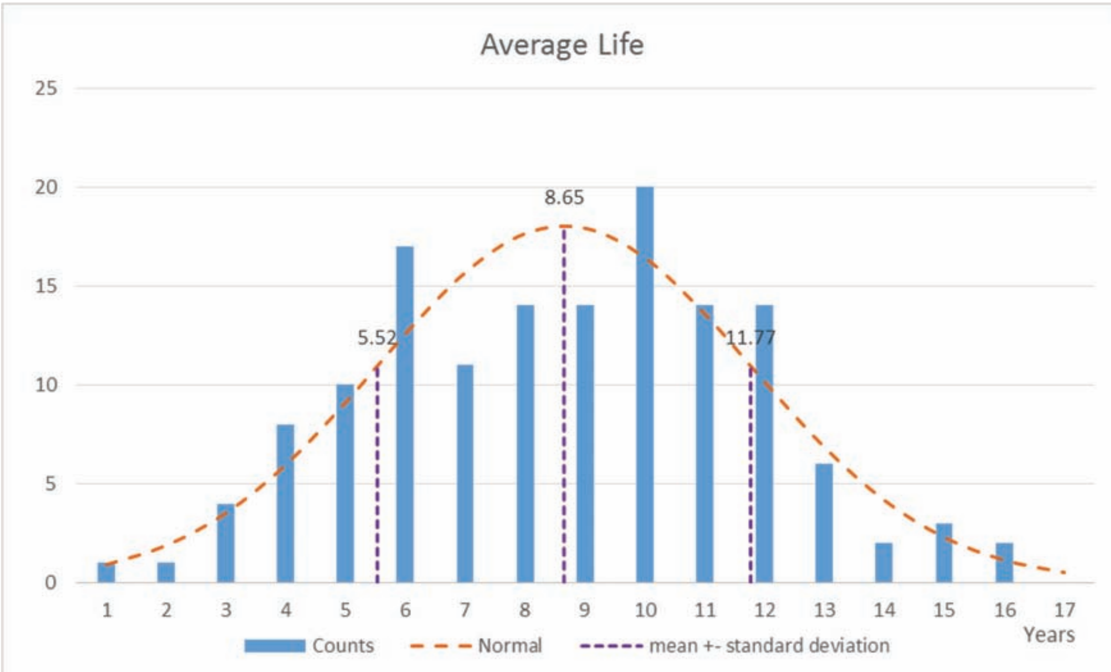


Figure B.14 Hydraulic pump average life distribution.

Power Steering Gearbox

Number replaced = 182
Average life = 8 Years
Standard deviation = 3 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

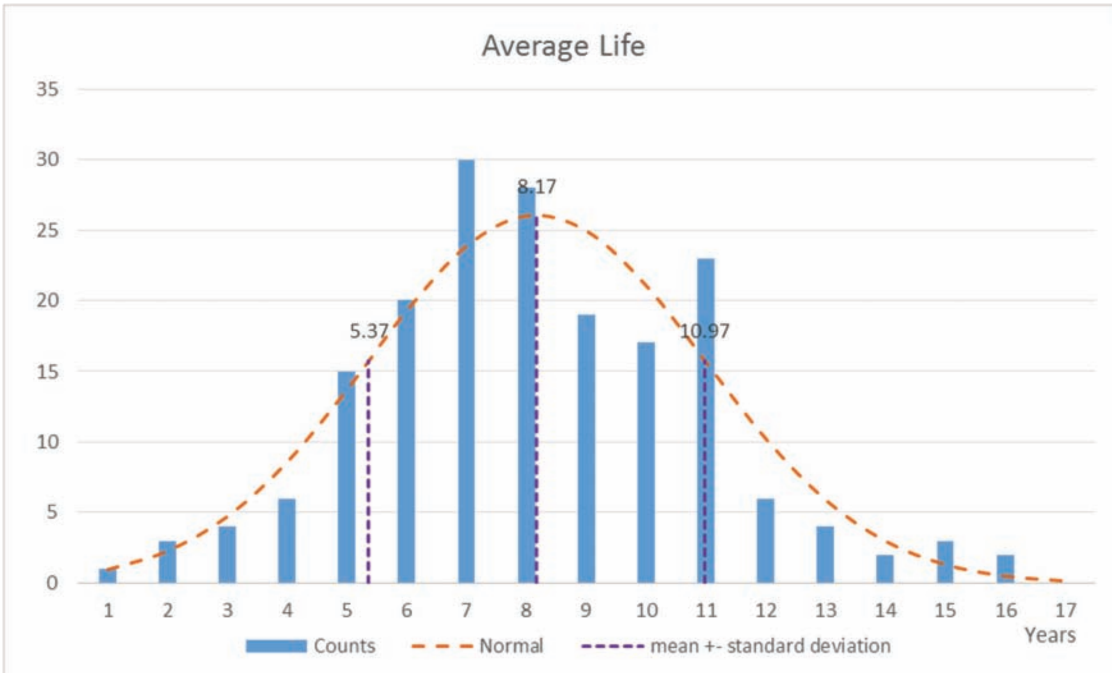


Figure B.15 Power steering gearbox average life distribution.

Power Steering Pump

Number replaced = 66
Average life = 8 Years
Standard deviation = 2.25 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

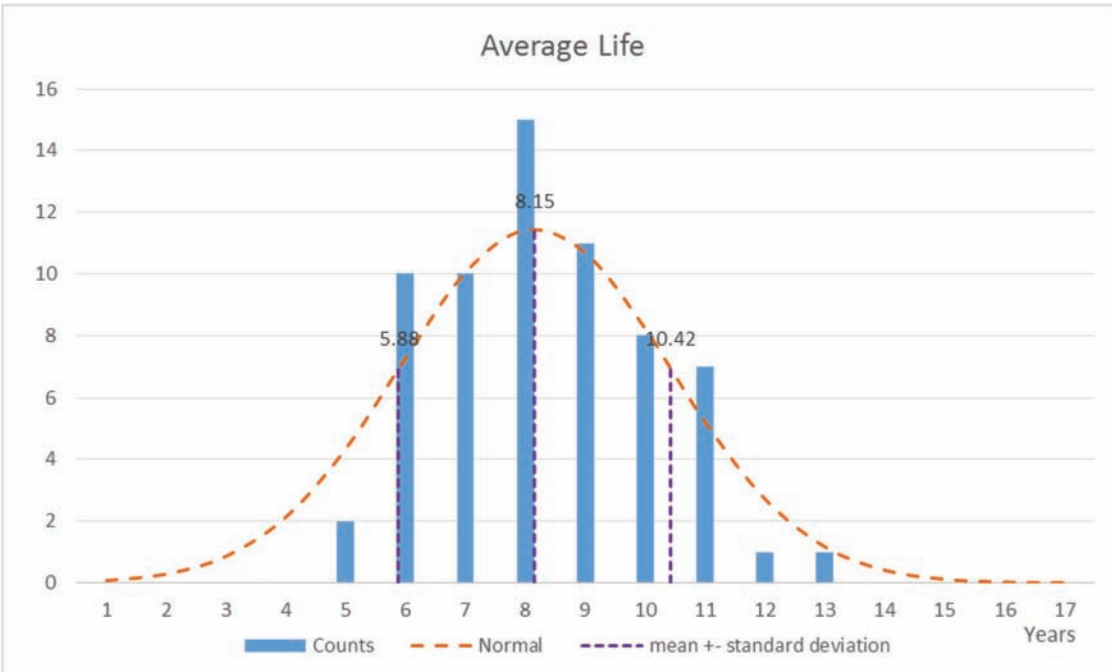


Figure B.16 Power steering pump average life distribution.

Transmission Cooler

Number replaced = 36
Average life = 9.5 Years
Standard deviation = 2.5 years
OEM Manufacturer Warranty = 1 Year
New Replacement Warranty = 1 Year

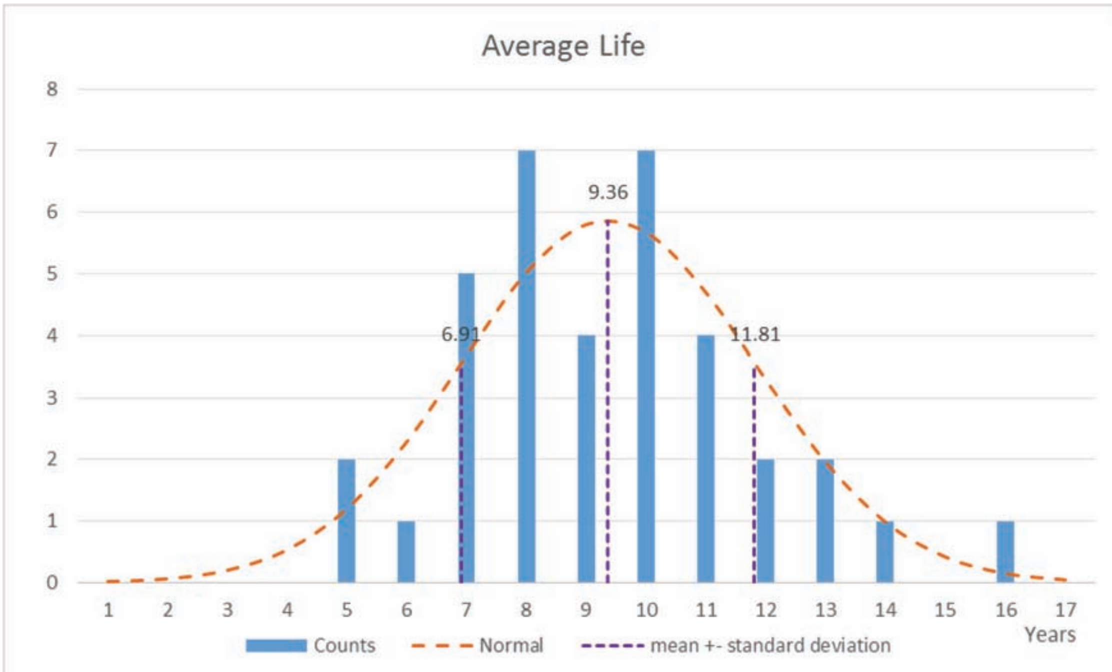


Figure B.17 Transmission cooler average life distribution.

APPENDIX C: DRIVER DAILY CHECKLIST

TRUCK NO:	____________	DATE:	____________
OPERATOR:	____________	DISTRICT:	____________
START TIME:	____________ AM/PM	FINISH TIME:	____________ AM/PM AM/PM

DRIVERS DAILY CHECK LIST

PRE-START: VISUAL WALK AROUND	OK	REPAIR
FRONT OF EQUIPMENT		
LIGHTS	[ ]	[ ]
SPRINGS & SPRING PINS	[ ]	[ ]
HOSES AND LINES	[ ]	[ ]
TIRES	[ ]	[ ]
RIMS	[ ]	[ ]
LUG NUTS	[ ]	[ ]
HUB OIL SEAL	[ ]	[ ]
CAB AREA		
DOORS, MIRRORS & BRACKETS	[ ]	[ ]
FUEL TANK	[ ]	[ ]
BATTERY BOX	[ ]	[ ]
UNDER EQUIPMENT		
(WALK AROUND LOOK UNDER EQUIPMENT)		
EXHAUST SYSTEM	[ ]	[ ]
FRAME (CRACKS, MISSING BOLTS)	[ ]	[ ]
SPRING & SPRING PINS	[ ]	[ ]
TIRES RUBBING	[ ]	[ ]
HOSES AND LINES	[ ]	[ ]
TIRES	[ ]	[ ]
RIMS	[ ]	[ ]
LUG NUTS	[ ]	[ ]
AXLE SEALS	[ ]	[ ]
REAR OF EQUIPMENT		
LIGHTS & REFLECTORS	[ ]	[ ]
SIGNALS / 4-WAYS	[ ]	[ ]
MUD FLAPS	[ ]	[ ]
LICENSE PLATE	[ ]	[ ]
(CLEAN & VISIBLE)	[ ]	[ ]
ENGINE COMPARTMENT		
OIL LEVEL	[ ]	[ ]
COOLANT LEVEL	[ ]	[ ]
POWER STEERING	[ ]	[ ]
HOSES & LEAKS	[ ]	[ ]
BELTS/LOOSE	[ ]	[ ]

HOURS: ____________

MILES: ____________

*WHILE DRIVING THE OPERATOR SHALL BE RESPONSIBLE FOR THE SAFE OPERATION OF EQUIPMENT. REPORT ANY MECHANICAL PROBLEMS TO THE MECHANICAL SUPERVISOR OR FOREMAN AS SOON AS POSSIBLE

	OK	REPAIR
IN CAB CHECKS		
ENGINE START		
AIR BUZZER SOUNDS	[ ]	[ ]
OIL PRESSURE BUILDS	[ ]	[ ]
VOLT METER	[ ]	[ ]
AIR BRAKE CHECK	[ ]	[ ]
(4-POINT, SEE DECAL IN TRUCK FOR PROCEDURE		
STEERING PLAY	[ ]	[ ]
PARKING BRAKE	[ ]	[ ]
MIRRORS/WINDSHIELD	[ ]	[ ]
WIPERS WASHERS	[ ]	[ ]
LIGHTING INDICATORS IN CAB	[ ]	[ ]
AIR HORN	[ ]	[ ]
ELECTRIC HORN	[ ]	[ ]
BACK-UP BEEPER	[ ]	[ ]
HEATER/DEFROSTER	[ ]	[ ]
SEAT BELTS	[ ]	[ ]
SAFETY EQUIPMENT		
FIRE EXTINGUISHER	[ ]	[ ]
REFLECTIVE TRIANGLES	[ ]	[ ]
REGISTRATION	[ ]	[ ]
MOUNTED EQUIPMENT		
(DUMP BOX, PLOWS, SPREADERS, SCRAPERS,)		
MOUNTING (SECURE)	[ ]	[ ]
OPERATION	[ ]	[ ]
LEAKS	[ ]	[ ]
VISUAL INSPECTION	[ ]	[ ]
WEAR POINTS		
PLOW BLADE	[ ]	[ ]
SPINNER BLADE	[ ]	[ ]
SCRAPER	[ ]	[ ]
AUGER	[ ]	[ ]
*****KEEP HANDS AWAY FROM MOVING PARTS*****		
DUMP BOX & TAILGATE	[ ]	[ ]
END OF DAY		
WASHED/CLEANED UNIT	[ ]	[ ]
GREASED UNIT	[ ]	[ ]
FUELED UNIT	[ ]	[ ]

**AT END OF SHIFT, EQUIPMENT SHOULD BE CHECKED FOR LEAKS, DAMAGE, OR FLAT TIRES AND SHOULD BE REPORTED AS SOON AS POSSIBLE

EQUIPMENT INFORMATION (MECHANICAL DEPARTMENT USE ONLY)				
WAS EQUIPMENT DEFECT REPORTED	YES [ ]	NO [ ]	______ INITIALS	SUPERVISOR/FOREMAN
EQUIPMENT OUT OF SERVICE	YES [ ]	NO [ ]	______ INITIALS	SUPERVISOR/FOREMAN
DEFECTS HAVE BEEN REPORTED (SERVICED)	YES [ ]	NO [ ]	______ INITIALS	SUPERVISOR/FOREMAN
DEFECT NEED NOT BE REPORTED FOR SAFE OPERATION OF THIS EQUIPMENT	YES [ ]	NO [ ]	______ INITIALS	SUPERVISOR/FOREMAN

OPERATOR INFORMATION
PRINTED NAME:
SIGNATURE:

APPENDIX D: PREDICTIVE MAINTENANCE SCHEDULE

Preventive Maintenance Schedule is based wholly or in part on manufacturer's recommendations, management of civil engineering support equipment manual (*NAVFAC, 1997*) and the Heavy Duty Alternator Charging System Troubleshooting Manual (*Delco Remy, 2013*).

Predictive maintenance schedule is based wholly on the average life listed in Appendix B, Figures B.1 through B.17.

Critical Service Level 1

CSL 1. Preventive Maintenance Type – 1A, Every 3 Months

1-A-1. An operator's daily checklist completed by qualified maintenance personnel
1-A-2. Lubricate all grease zerk fittings and lubrication points per manufacturer recommendations (Use only approved lubricants)
1-A-3. Air Filter check, Replace as Necessary
1-A-4. Engine Oil Level check (Refer to Engine Manufacturers check/fill procedure and proper lubricants)
1-A-5. Check ECM Engine Service Codes
1-A-6. Fluid Level Check, Hydraulic System (Refer to Hydraulic System manufacturer for check/fill procedure and proper lubricants)
1-A-7. Fluid Level Check, Hydraulic Clutch Control
1-A-8. Clutch Adjustment, Manually Adjusted Clutches
1-A-9. Fluid Level Check Allison Automatic Transmission (Refer to transmission manufacturer for check/fill procedure and proper lubricants)
1-A-10. Trailer Electrical Connector Protection
1-A-11. Fifth Wheel Lubrication *(If Applicable)*
1-A-12. Suspension Inspection
1-A-13. Tie Rod Inspection
1-A-14. Axle Lubricant Level Check
1-A-15. Axle Breather Check
1-A-16. Driveline Inspection
1-A-17. Parking Brake Inspection
1-A-18. Service Air Brake Component Inspection and leak check
1-A-19. Slack Adjuster Lubrication
1-A-20. Brake Camshaft lubrication
1-A-21. Power Steering Fluid Level Inspection
1-A-22. LNG Fuel System Inspection
1-A-23. CNG Fuel System Inspection (Follow manufacturer recommendations for inspection and high pressure fuel filter replacement intervals)
1-A-24. Air Conditioner Components Inspection
1-A-25. Radiator Cap Pressure Test
1-A-26. Exhaust System Inspection
1-A-27. Diesel Exhaust Fluid (DEF) Check and Inspection of System
1-A-28. Power Steering Components Inspection
1-A-29. Engine Drive Belt Inspection
1-A-30. Wheel Nut check
1-A-31. Wheel Rim Inspection
1-A-32. Check Tires for Wear and Damage
1-A-33. Fuel Tank Mounting and Leak Inspection
1-A-34. Warning and Driving Lights Test
1-A-35. Battery Inspection. Check Terminals and clean
1-A-36. Check All Instruments and Controls
1-A-37. Cooling System, Check Mounting and Leaks, Clean and Service Corrosion
1-A-38. Hydraulic System, Inspection, Operation and Leaks
1-A-39. Rear Axle Differentials, Check Leaks and Fluid levels
1-A-40. Check and Inspect Entire Unit for Fluid or Air Leaks
1-A-41. Check for Accident Damage
1-A-42. Check Glass for Cracks and Washer/Wiper Operations
1-A-43. Inspection of all mounted equipment

CSL 1. Preventive Maintenance Type – 1B, Every 6 Months

1-B-1. An operator's daily checklist completed by qualified maintenance personnel
1-B-2. Preventive Maintenance Type – A
1-B-3. Engine Oil and Filter Replacement (Based on Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Engine Oil Testing to determine degradation of oil, contaminants from Internal Engine Components)
1-B-4. Fuel Filter Replacement (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
1-B-5. Starter, Check Mounting Bolts and Electrical Connections
1-B-6. Engine Fan Assembly for damage and lose mounting
1-B-7. Allison and Eaton Fuller Transmission Breather Check
1-B-8. Drive Axle, Differentials, Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
1-B-9. Front Axles, Check for Leaks, Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
1-B-10. Front Springs, Inspect for damage, Check for Loose Bolts
1-B-11. Rear Springs Inspect for Damage, Check for Loose Bolts
1-B-12. Frame, Inspect for Damage, Check for Loose Bolts (For Snow Plow Operations Check for damage to front frame and Plow Frame)
1-B-13. Shocks Absorbers, Inspect, Check For Operation
1-B-14. Service and Inspect Air Compressor and Governor

CSL 1. Preventive Maintenance Type – 1C, Every 12 Months

1-C-1. An operator's daily checklist completed by qualified maintenance personnel
1-C-2. Preventive Maintenance Type – A
1-C-3. Service Hydraulic System Complete-Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage), (Recommend Hydraulic Oil Testing to determine degradation of oil, contaminants from hydraulic components)
1-C-4. Automatic Transmission Fluid and Filter Replace (Based on Transmission Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Transmission Oil Testing to determine degradation of oil, contaminants from Internal Transmission Components)
1-C-5. Battery Load Test, Each Battery Individually
1-C-6. Charging System Test (Refer to Appendix D, Delco Remy Troubleshooting Guide
1-C-7. Turbocharger Inspection, Leaks and Impeller Shaft Wear
1-C-8. Radiator Pressure Flush and Coolant and Coolant Filter Change
1-C-9. Power Steering Fluid and Filter change
1-C-10. Service Air Drier (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
1-C-11. Cabin Air Filter Check
1-C-12. Torque Wheel Nuts
1-C-13. Mounted Equipment Inspection, Check Leaks, Mounting and Loose Bolts

CSL 1. Predictive Maintenance Type – 1D, Every 12 Months

1-D-1. No Items Identified

CSL 1. Predictive Maintenance Type – 1E, Every 24 Months

1-E-1. No Items Identified

CSL 1. Predictive Maintenance Type – 1F, Every 36 Months

1-F-1. No Items Identified

CSL 1. Predictive Maintenance Type – 1G, Every 48 Months

1-G-1. No Items Identified

CSL 1. Predictive Maintenance Type – 1H, Every 60 Months

1-H-1. No Items Identified

CSL 1. Predictive Maintenance Type – 1I, Every 72 Months

1-I-1. Spreader Spinner Motor
1-I-2. Oil Pan

CSL 1. Predictive Maintenance Type – 1J, Every 84 Months

1-J-1. Oil Cooler
1-J-2. Starter
1-J-3. Tires

CSL 1. Predictive Maintenance Type – 1K, Every 96 Months

1-K-1. Battery Replacement
1-K-2. Alternator
1-K-3. Turbocharger
1-K-4. Fan Clutch
1-K-5. Brake Chamber
1-K-6. Front Leaf Springs
1-K-7. Water Pump
1-K-8. Fuel Injectors
1-K-9. Spreader Conveyor Motor
1-K-10. Hydraulic Pump
1-K-11. Power Steering Gearbox
1-K-12. Power Steering Pump

CSL 1. Predictive Maintenance Type –1L, Every 108 Months

1-L-1. Air Compressor
1-L-2. Water Pump
1-L-3. Radiator
1-L-4. Brake Shoes, Rear
1-L-5. Brake Shoes, Front
1-L-6. Slack Adjusters
1-L-7. Clutch
1-L-8. Rear Leaf Springs
1-L-9. Transmission Cooler

CSL 1. Predictive Maintenance Type–1M, Every 120 Months

1-M-1. Air Dryer

Critical Service Level 2

CSL 2. Preventive Maintenance Type – 2A, Every 4 Months

2-A-1. An operator's daily checklist completed by qualified maintenance personnel
2-A-2. Lubricate all grease zerk fittings and lubrication points per manufacturer recommendations (Use only approved lubricants)
2-A-3. Air Filter check, Replace as Necessary
2-A-4. Engine Oil and Filter Replacement (Based on Manufacturers Recommended Interval for Mileage/Hour Usage), (Recommend Engine Oil Testing to determine degradation of oil, contaminants from Internal Engine Components)
2-A-5. Check ECM Engine Service Codes
2-A-6. Fluid Level Check, Hydraulic System (Refer to Hydraulic System manufacturer for check/fill procedure and proper lubricants)

2-A-7. Fluid Level Check, Hydraulic Clutch Control
2-A-8. Clutch Adjustment, Manually Adjusted Clutches
2-A-9. Fluid Level Check Allison Automatic Transmission (Refer to transmission manufacturer for check/fill procedure and proper lubricants)
2-A-10. Trailer Electrical Connector Protection
2-A-11. Trailer Connection Inspection *(If Applicable)*
2-A-12. Suspension Inspection
2-A-13. Tie Rod Inspection
2-A-14. Axle Lubricant Level Check
2-A-15. Axle Breather Check
2-A-16. Driveline Inspection
2-A-17. Parking Brake Inspection
2-A-18. Service Hydraulic Brake Component Inspection and Leak Check
2-A-19. Service Air Brake Component Inspection and leak check
2-A-20. Power Steering Fluid Level Inspection and Leak Check
2-A-21. Air Conditioner Components Inspection
2-A-22. Radiator Cap Pressure Test
2-A-23. Exhaust System Inspection
2-A-24. Diesel Exhaust Fluid (DEF) Check and Inspection of System
2-A-25. Power Steering Components Inspection
2-A-26. Engine Drive Belt Inspection
2-A-27. Wheel Nut check
2-A-28. Wheel Rim Inspection
2-A-29. Check Tires for Wear and Damage
2-A-30. Fuel Tank Mounting and Leak Inspection
2-A-31. Warning and Driving Lights Test
2-A-32. Battery Inspection. Check Terminals and clean
2-A-33. Check All Instruments and Controls
2-A-34. Cooling System, Check Mounting and Leaks, Clean and Service Corrosion
2-A-35. Hydraulic System, Inspection, Operation and Leaks
2-A-36. Rear Axle Differentials, Check Leaks and Fluid levels
2-A-37. Check and Inspect Entire Unit for Fluid or Air Leaks
2-A-38. Check for Accident Damage
2-A-39. Check Glass for Cracks and Washer/Wiper Operations
2-A-40. Inspection of all mounted equipment

CSL 2. Preventive Maintenance Type – 2B, Every 6 Months

2-B-1. An operator's daily checklist completed by qualified maintenance personnel
2-B-2. Preventive Maintenance Type – A
2-B-3. Fuel Filter Replacement (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
2-B-4. Starter, Check Mounting Bolts and Electrical Connections
2-B-5. Engine Fan Assembly for damage and lose mounting
2-B-6. Allison and Eaton Fuller Transmission Breather Check
2-B-7. Drive Axle, Differentials, Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
2-B-8. Front Axles, Check for Leaks, Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
2-B-9. Front Springs, Inspect for damage, Check for Loose Bolts
2-B-10. Rear Springs Inspect for Damage, Check for Loose Bolts
2-B-11. Shocks Absorbers, Inspect, Check For Operation
2-B-12. Frame, Inspect for Damage, Check for Loose Bolts (For Snow Plow Operations Check for damage to front frame and Plow Frame)
2-B-13. Service Air Drier (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
2-B-14. Service and Inspect Air Compressor and Governor

CSL 2. Preventive Maintenance Type – 2C, Every 12 Months

2-C-1. An operator's daily checklist completed by qualified maintenance personnel
2-C-2. Preventive Maintenance Type – A
2-C-3. Engine Ignition components Performance Check (Refer to Manufacturer Recommended Interval for Ignition Components service and replacement Intervals).
2-C-4. Service Hydraulic System Complete. Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Hydraulic Oil Testing to determine degradation of oil, contaminants from hydraulic components)
2-C-5. Automatic Transmission Fluid and Filter Replace (Based on Transmission Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Transmission Oil Testing to determine degradation of oil, contaminants from Internal Transmission Components)
2-C-6. Battery Load Test, Each Battery Individually
2-C-7. Charging System Test (Refer to Appendix D, Delco Remy Troubleshooting Guide
2-C-8. Turbocharger Inspection, Leaks and Impeller Shaft Wear
2-C-9. Radiator Pressure Flush and Coolant and Coolant Filter Change
2-C-10. Power Steering Fluid and Filter change
2-C-11. Cabin Air Filter Check
2-C-12. Torque Wheel Nuts
2-C-13. Mounted Equipment Inspection, Check Leaks, Mounting and Loose Bolts

Critical Service Level 3

CSL 3. Preventive Maintenance Type – 3A, Initial Startup Each Year, Every 4 months or Following Manufacturer Recommended Intervals

3-A-1. An operator's daily checklist completed by qualified maintenance personnel
3-A-2. Lubricate all grease zerk fittings and lubrication points per manufacturer recommendations (Use only approved lubricants)
3-A-3. Air Filter check, Replace as Necessary
3-A-4. Engine Oil and Filter Replacement (Based on Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Engine Oil Testing to determine degradation of oil, contaminants from Internal Engine Components)
3-A-5. Engine Ignition components Performance Check (Refer to Manufacturer Recommended Interval for Ignition Components service and replacement Intervals)
3-A-6. Service Hydraulic System Complete. Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage), (Recommend Hydraulic Oil Testing to determine degradation of oil, contaminants from hydraulic components)
3-A-7. Automatic Transmission Fluid and Filter Replace (Based on Transmission Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Transmission Oil Testing to determine degradation of oil, contaminants from Internal Transmission Components)
3-A-8. Allison and Eaton Fuller Transmission Breather Check
3-A-9. Fuel Filter Replacement (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
3-A-10. Engine Ignition components Performance Check (Refer to Manufacturer Recommended Interval for Ignition Components service and replacement Intervals)
3-A-11. Service Hydraulic System Complete. Inspection, Operation and Leaks (Drain and Refill based on Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Hydraulic Oil Testing to determine degradation of oil, contaminants from hydraulic components)
3-A-12. Automatic Transmission Fluid and Filter Replace (Based on Transmission Manufacturers Recommended Interval for Mileage/Hour Usage) (Recommend Transmission Oil Testing to determine degradation of oil, contaminants from Internal Transmission Components)
3-A-13. Battery Inspection - Check Terminals and clean
3-A-14. Battery Load Test, Each Battery Individually
3-A-15. Charging System Test (Refer to Appendix D, Delco Remy Troubleshooting Guide

3-A-16. Check ECM Engine Service Codes
3-A-17. Engine Fan Assembly for damage and lose mounting
3-A-18. Fluid Level Check, Hydraulic System (Refer to Hydraulic System manufacturer for check/fill procedure and proper lubricants)
3-A-19. Fluid Level Check, Hydraulic Clutch Control
3-A-20. Clutch Adjustment, Manually Adjusted Clutches
3-A-21. Fluid Level Check Allison Automatic Transmission (Refer to transmission manufacturer for check/fill procedure and proper lubricants)
3-A-22. Trailer Electrical Connector Protection
3-A-23. Trailer Connection Inspection *(If Applicable)*
3-A-24. Drive Axle, Differentials, Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
3-A-25. Front Axles, Check for Leaks, Drain and Refill (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
3-A-26. Front Springs, Inspect for damage, Check for Loose Bolts
3-A-27. Rear Springs Inspect for Damage, Check for Loose Bolts
3-A-28. Axle Breather Check
3-A-29. Shocks Absorbers, Inspect, Check For Operation
3-A-30. Frame, Inspect for Damage, Check for Loose Bolts (For Snow Plow Operations Check for damage to front frame and Plow Frame)
3-A-31. Service Air Drier (Based on Manufacturers Recommended Interval for Mileage/Hour Usage)
3-A-32. Service and Inspect Air Compressor and Governor
3-A-33. Tie Rod Inspection
3-A-34. Driveline Inspection
3-A-35. Parking Brake Inspection
3-A-36. Service Hydraulic Brake Component Inspection and Leak Check
3-A-37. Service Air Brake Component Inspection and leak check
3-A-38. Power Steering Fluid Level Inspection and Leak Check
3-A-39. Air Conditioner Components Inspection
3-A-40. Radiator Cap Pressure Test
3-A-41. Radiator Pressure Flush and Coolant and Coolant Filter Change
3-A-42. Cooling System, Check Mounting and Leaks, Clean and Service Corrosion
3-A-43. Engine Drive Belt Inspection
3-A-44. Exhaust System Inspection
3-A-45. Diesel Exhaust Fluid (DEF) Check and Inspection of System
3-A-46. Power Steering Components Inspection
3-A-47. Power Steering Fluid and Filter change
3-A-48. Torque Wheel Nuts
3-A-49. Wheel Rim Inspection
3-A-50. Check Tires for Wear and Damage
3-A-51. Fuel Tank Mounting and Leak Inspection
3-A-52. Warning and Driving Lights Test
3-A-53. Cabin Air Filter Check
3-A-54. Mounted Equipment Inspection, Check Leaks, Mounting and Loose Bolts
3-A-55. Check All Instruments and Controls
3-A-56. Check Glass for Cracks and Washer/Wiper Operations
3-A-57. Check for Accident Damage

CSL 3. Predictive Maintenance Type – 3B, 12 Months or Initial Startup Each Year

3-B-1. Salt Spreader, Replace Hydraulic hoses as necessary
3-B-2. Snowplow, Replace Hydraulic hoses as necessary

APPENDIX E: RECOMMENDATIONS TO THE TRUCK SPECIFICATIONS BASED ON COMPONENT DATA

Item Number	Recommendation/Comments
PARTS/ SERVICE MANUALS AND PARTS LIST, F.	Add a requirement for major component part number list or build list to be provided with equipment upon delivery.
3. CHASSIS SUSPENSION, E, G	INDOT should consider the rubber bolster type suspension, and add bolster replacement as part of the regular PM maintenance schedule. Available data does not include outside suspension repairs to be analyzed.
4. CHASSIS FRAME, E. 18. PLOW HITCH, A-I	Newer available models of plow frame and plow hitch allow for mounting under frame and no requirement for integral front frame extensions.
13. WHEELS/TIRES, E.	Many local agencies have switched to a 12R22.5 Rear tire for the additions rim thickness. Many local agencies have incurred rim bending issues from contact with curbs and raised mediums.
23. SAFETY LIGHTING, G. 24. BACK UP ALARM, A.	Minimum 5 1/2" x 10" Rear light housing shall be recessed into rear pillar and light housing shall be fully enclosed. LED stop, tail and turn lights with rubber grommets recessed in rear corner post light housing. Spreader lights, two (2) each, mounted each side on side of rear corner post with guard. Back up alarm to be mounted to rear corner post. Two top reverse lights mounted to top of corner post, wired to reverse circuit to activate when truck is placed in reverse only. All wiring to terminate in to housing mounted in cab.

Additional Recommendations based on general observations during the research project.

With issues related to premature radiator failure as well as damage caused by high speed tandem plowing, INDOT should look into adding an airfoil to the top of their snowplow to redirect material to the beneath the truck. This will also keep the engine cool at any plow position.

Specifications:

Alaska style full poly airfoil, airfoil shall be full length of plow and constructed of 1/8" angle and 1/8" flat stock with 10 gauge end plates and 1/4" polypropylene.

APPENDIX F: DATA ANALYSIS TOOL

Introduction

The researchers developed a data tool to produce the component analyses found in this report. The tool was developed in Microsoft Excel, version 2013, and consists of two macro-enabled files. The file *Component Name* uses macros to categorize and assign a common component name. This is necessary because of the various names used to describe a part. The other file, *Component Analysis*, calculates the average life, standard deviation, and creates the distribution graph for a component. These Excel files are included as part of the final report for use by INDOT and are explained in this section. They are available for download at http://dx.doi.org/10.5703/1288284316013.

Analysis Procedure

Component Name

Equipment component data is obtained from the M5 program, and the Excel file *Component Name* assigns a common name to each component obtained from M5. One issue discovered in the M5 data was different names are used to describe a part. Figure F.1 is an example. Column R is for part descriptions; in that column you can see different names used. So to analyze similar components a macro was developed to properly categorize common parts. Figure F.2 is an example of multiple names used to describe an alternator in column R and their common component name in column AA. By grouping parts, data analysis is performed on all common parts.

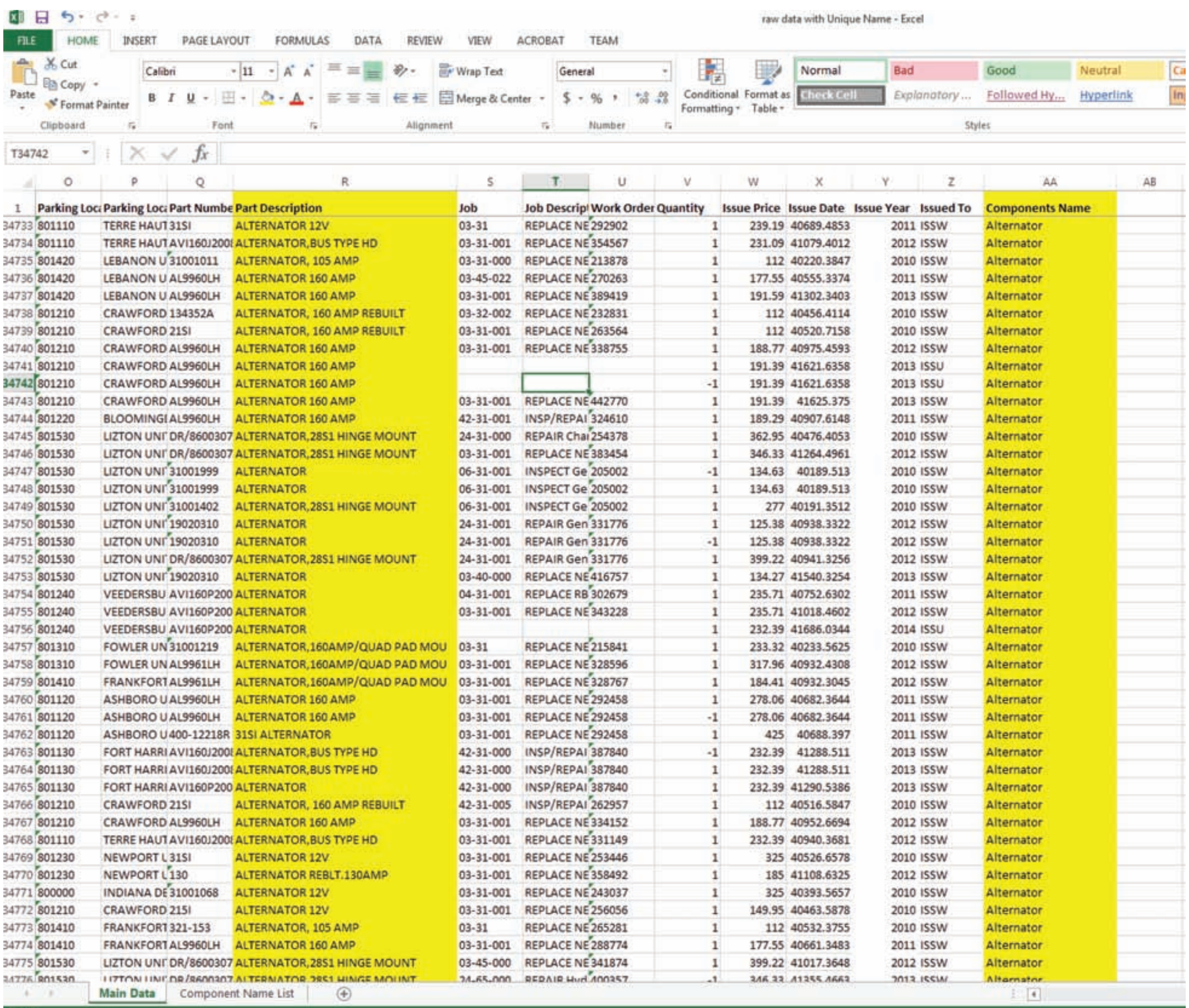


Figure F.1 *Component Name* macro-enabled file.

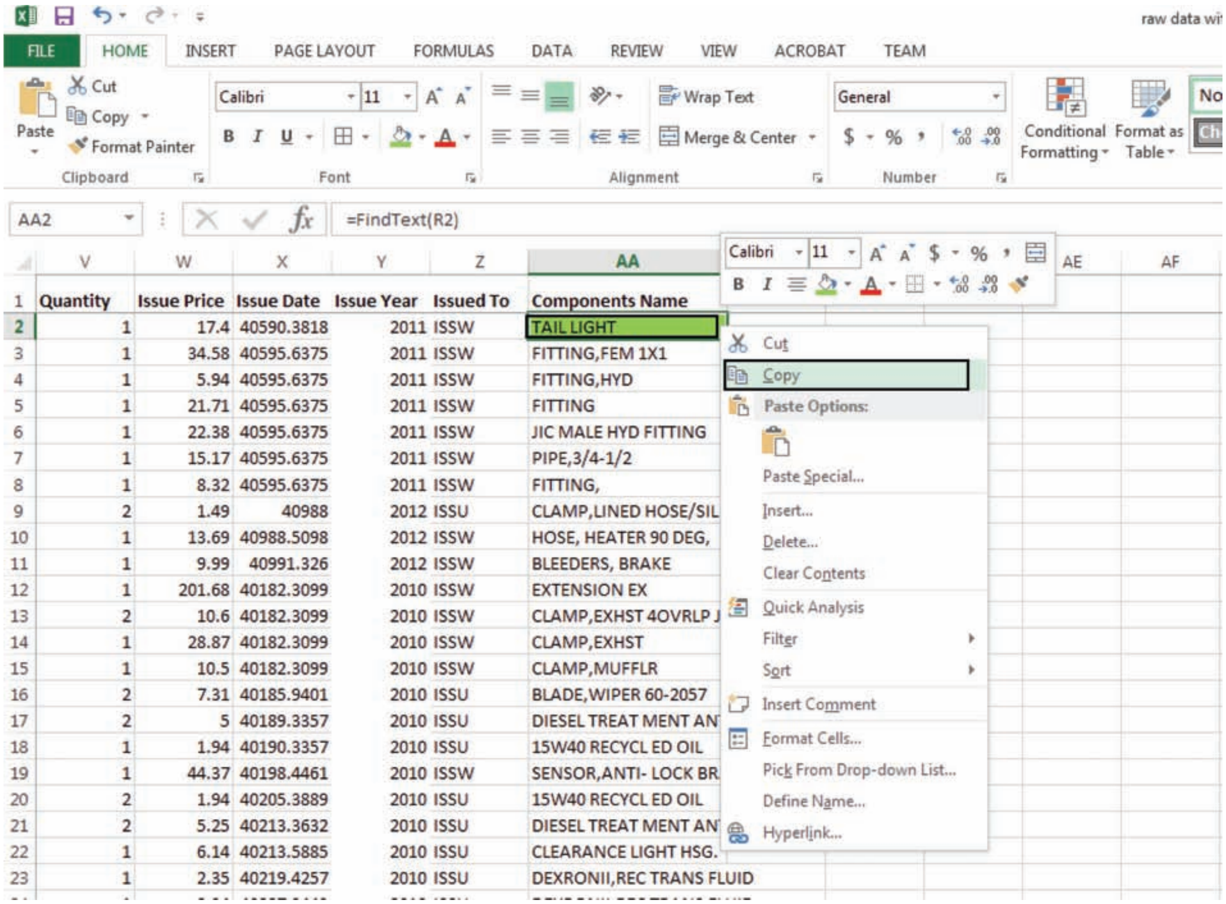


Figure F.2 Formula copy.

Figure F.2 shows an enlarged view of the formula copy process.

For a new analysis copy the data to the bottom of the worksheet; and from the top of column AA copy the cell AA2 which contains a formula then highlight the cells AA corresponding to the new data entries and paste AA. An example of batteries is shown in Figure F.3.

Figure F.4 shows this screen and the popup used to sort. After copying in new data records and getting a common name assigned to each, the next step is to sort the data by component name. Figure F.4 illustrates this step. Select a component (battery, water pump, starter, etc.) you want to analyze and highlight all the rows with the same name in column AA for that component, then copy.

Figure F.5 shows the sorted list for the Starter component.

U303029

	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1	Part Numbe	Part Description	Job	Job Descrip	Work Order	Quantity	Issue Price	Issue Date	Issue Year	Issued To	Components Name	
302997	34001011	HEADLIGHT SEALBEAM 4415A	35-34-007	DIAGNOSE S	205072	1	12.1	40177.9788	2009	ISSW	HEADLIGHT SEALBEAM 4415A	
302998	34001035	LIGHT BULB	35-34-007	DIAGNOSE S	205072	1	5.66	40177.9788	2009	ISSW	LIGHT BULB	
302999	53992025	SOLVENT,WIND SHIELD				1	1.34	40178	2009	ISSU	SOLVENT,WIND SHIELD	
303000	53992158	DEXRONII,REC TRANS FLUID				2	1.56	40178	2009	ISSU	DEXRONII,REC TRANS FLUID	
303001	27012061	FILTER,OIL HYD 9.0 LONG				1	33.52	40178	2009	ISSU	FILTER,OIL HYD 9.0 LONG	
303002	53992025	SOLVENT,WIND SHIELD				1	1.33	40178	2009	ISSU	SOLVENT,WIND SHIELD	
303003	53992025	SOLVENT,WIND SHIELD				1	1.33	40178	2009	ISSU	SOLVENT,WIND SHIELD	
303004	53992025	SOLVENT,WIND SHIELD				1	1.34	40178	2009	ISSU	SOLVENT,WIND SHIELD	
303005	53992025	SOLVENT,WIND SHIELD				1	1.34	40178	2009	ISSU	SOLVENT,WIND SHIELD	
303006	53992170	DIESEL FUEL ANTI GEL 16				1	4.96	40178	2009	ISSU	DIESEL FUEL ANTI GEL 16	
303007	43006110	CLAMP,MUFFLR	02-43-011	CLEAN Exha	203083	1	10.28	40178	2009	ISSW	CLAMP,MUFFLR	
303008	15W40	BATTERY - HEAVY DUTY	07-PM-PMA	PERFORM P	452192	24	1.92	2/10/2015	2015	ISSW	Battery	
303009	1748	BATTERY 12V	07-PM-PMA	PERFORM P	452192	1	21.21	2/11/2015	2015	ISSW	Battery	
303010	WWS-6	BATTERY 12V H/D COMM.	07-PM-PMA	PERFORM P	452192	1	3.47	2/12/2015	2015	ISSW	Battery	
303011	31T36377	BATTERY 12V, WET	42-70-007	INSP/REPAI	452192	1	23.5	2/13/2015	2015	ISSW	Battery	
303012	RCJ2	BATTERY 6 VOLT LANT				2	75.44	2/14/2015	2015	ISSU	Battery	
303013	1409	BATTERY 9V	42-65-010	INSP/REPAI	453433	1	5.38	2/15/2015	2015	ISSW	Battery	
303014	65005165	BATTERY GROUP 31	42-65-010	INSP/REPAI	453433	1	193	2/16/2015	2015	ISSW	Battery	
303015	60-019-1	BATTERY, 75 MONTH BCI#58				2	7.09	2/17/2015	2015	ISSU	Battery	
303016	6601-08-10	BATTERY, 925CCA	42-15-000	INSP/REPAI	453905	1	34.92	2/18/2015	2015	ISSW	Battery	
303017	7191	BATTERY, BCI#31P 36MONTH	42-15-000	INSP/REPAI	453905	1	8.17	2/19/2015	2015	ISSW	Battery	
303018	60-020-1	BATTERY, DEEP CYCLE				2	6.08	4/3/2015	2015	ISSU	Battery	
303019	4M3033-1	BATTERY, HVY COMM., DRY				1	11.34	4/4/2015	2015	ISSU	Battery	
303020	4M3033-2	BATTERY, HVY COMM., SERV.				2	13.72	4/5/2015	2015	ISSU	Battery	
303021	4M3033-2	BATTERY, HVY DUTY DIESEL				3	13.72	4/6/2015	2015	ISSU	Battery	
303022	4M3033-2	BATTERY, INDUSTRIAL 12V 18/30				2	13.72	4/7/2015	2015	ISSU	Battery	
303023	4M3033-2	BATTERY, MACS				1	13.72	4/8/2015	2015	ISSU	Battery	
303024	4M3033-2	BATTERY, WET				2	12.59	7/22/2015	2015	ISSU	Battery	
303025	904322704	BATTERY,12 V COMMERCIAL				3	178.33	7/23/2015	2015	ISSU	Battery	
303026	2894943	BATTERY,12V,31S	42-39-008	INSP/REPAI	452774	1	419.25	7/24/2015	2015	ISSW	Battery	
303027												
303028												

Figure F.3 Adding components for renaming.

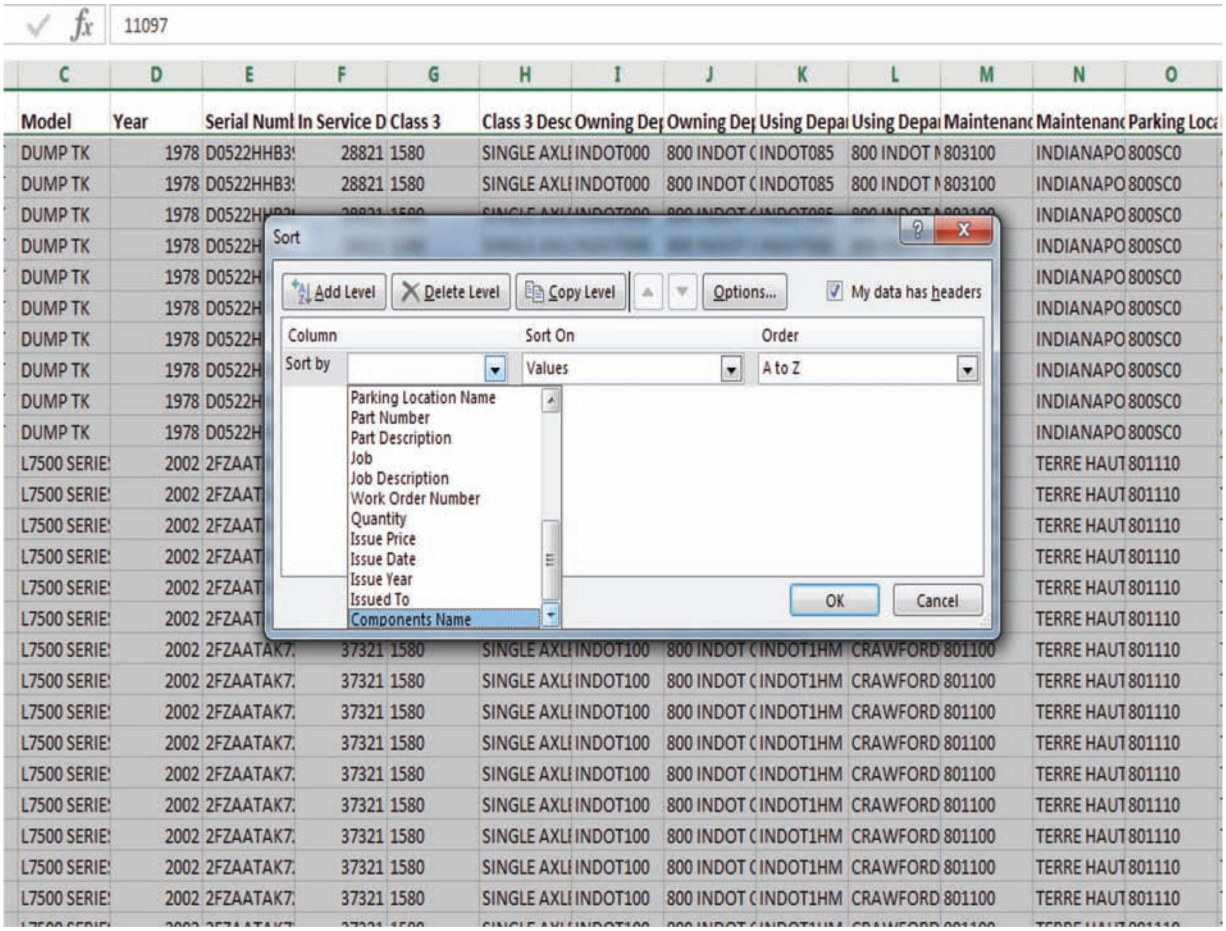


Figure F.4 Sorting records by component name.

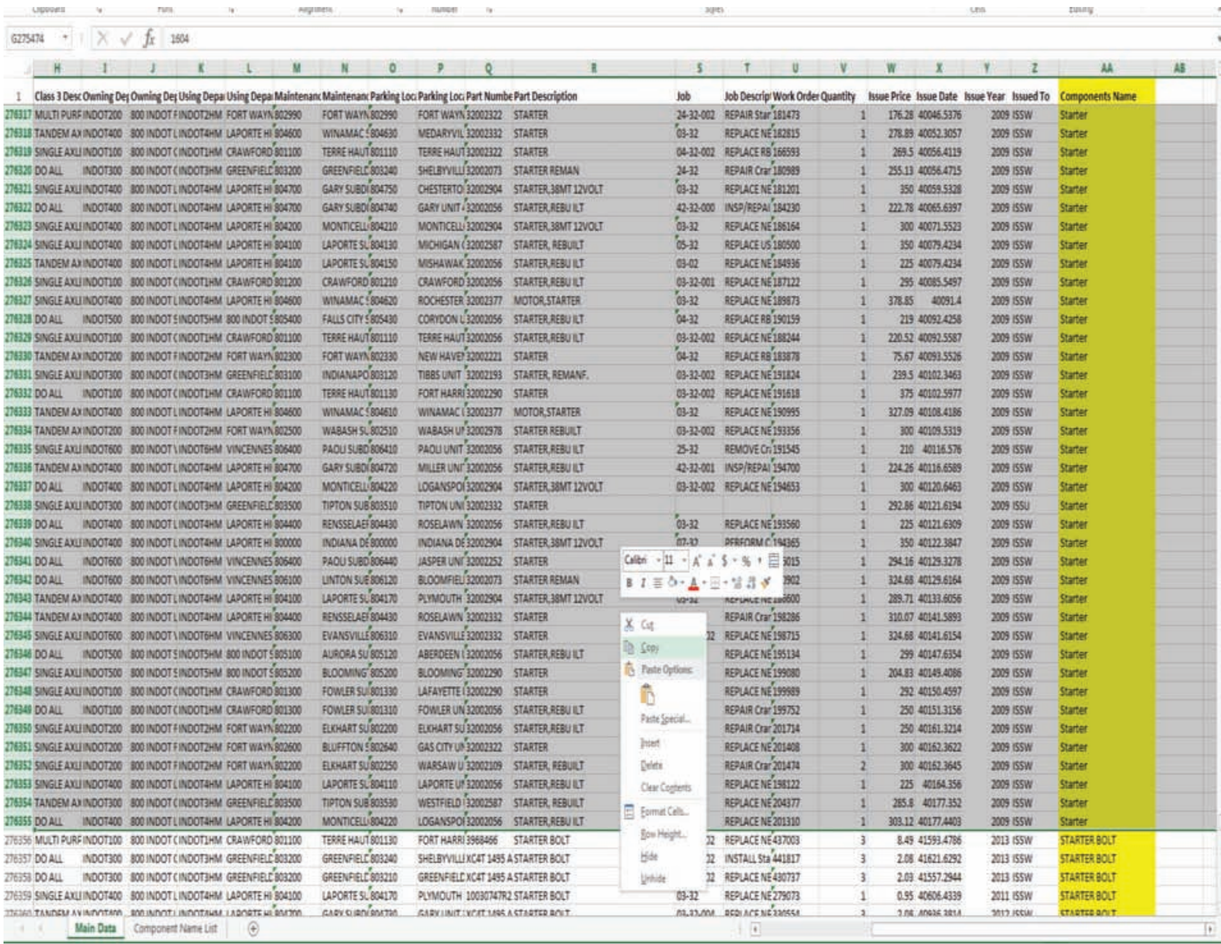
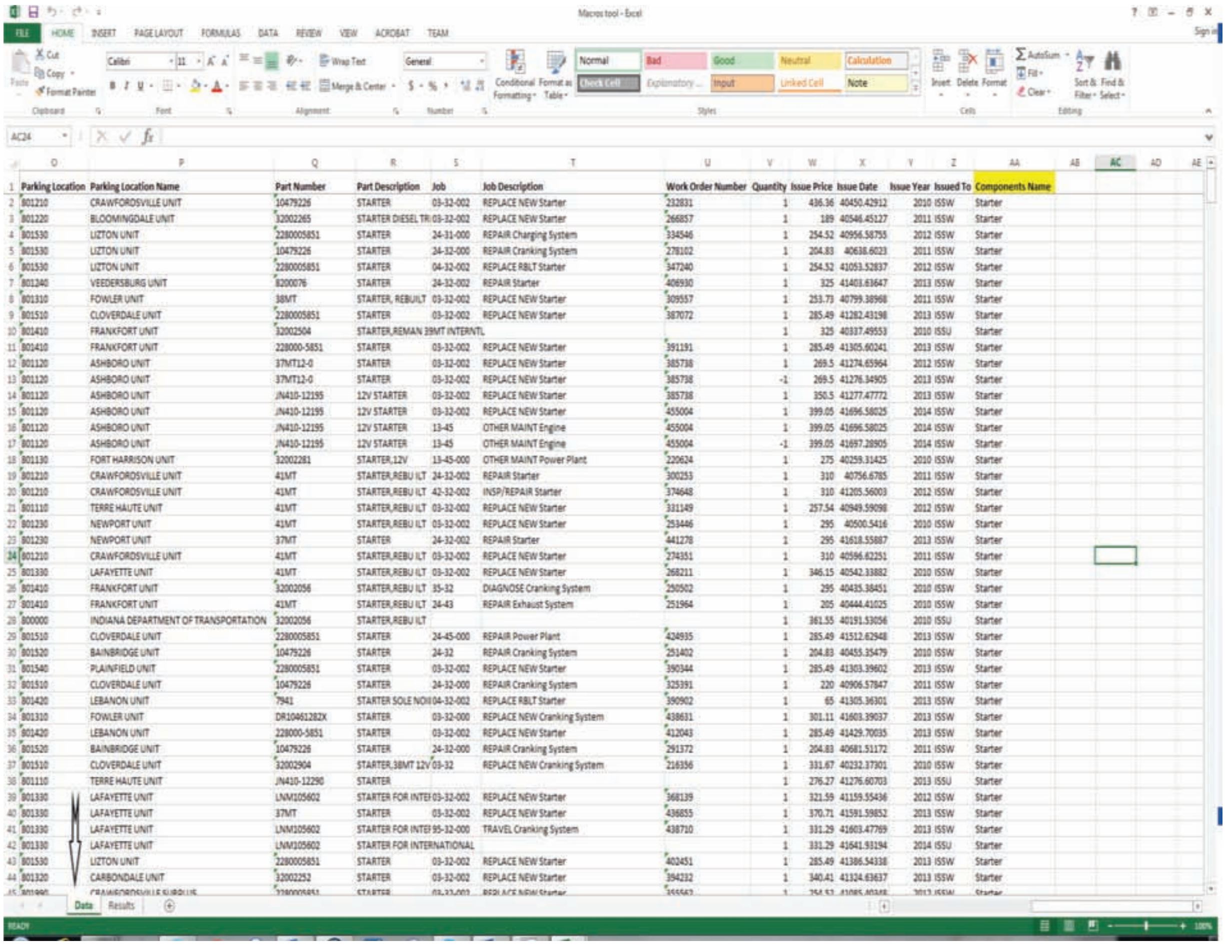


Figure F.5 Sorted starter component list.

Component Analysis

After sorting records by component name, select the component by name and copy all the records with the same name into the Excel file *Component Analysis* Data worksheet (Input). This is shown in Figure F.6.

Next, click on your Results worksheet located next to the Data worksheet, then click 'Run' located in cell O1. The macros will run for few second and your results will be displayed, including standard deviation, average life, average life interval, count, and an average life distribution chart created. Figure F.7 shows an example.



	Parking Location	Parking Location Name	Part Number	Part Description	Job	Job Description	Work Order Number	Quantity	Issue Price	Issue Date	Issue Year	Issued To	Components Name
2	801210	CRAWFORDSVILLE UNIT	10479226	STARTER	03-32-002	REPLACE NEW Starter	232831	1	436.36	40450.42912	2010	ISSW	Starter
3	801220	BLOOMINGDALE UNIT	32002265	STARTER DIESEL TR	03-32-002	REPLACE NEW Starter	266857	1	189	40546.45127	2011	ISSW	Starter
4	801530	LIZTON UNIT	2280005851	STARTER	24-31-000	REPAIR Charging System	334546	1	254.52	40956.58755	2012	ISSW	Starter
5	801530	LIZTON UNIT	10479226	STARTER	24-32-000	REPAIR Cranking System	278102	1	204.83	40638.6023	2011	ISSW	Starter
6	801530	LIZTON UNIT	2280005851	STARTER	04-32-002	REPLACE RBLT Starter	347240	1	254.52	41053.52837	2012	ISSW	Starter
7	801240	VEEDERSBURG UNIT	8200076	STARTER	24-32-002	REPAIR Starter	406930	1	325	41403.63647	2013	ISSW	Starter
8	801310	FOWLER UNIT	38MT	STARTER, REBUILT	03-32-002	REPLACE NEW Starter	309557	1	253.73	40799.38968	2011	ISSW	Starter
9	801510	CLOVERDALE UNIT	2280005851	STARTER	03-32-002	REPLACE NEW Starter	387072	1	285.49	41282.43198	2013	ISSW	Starter
10	801410	FRANKFORT UNIT	32002504	STARTER,REMAN 39MT INTERNTL				1	325	40337.49553	2010	ISSU	Starter
11	801410	FRANKFORT UNIT	228000-5851	STARTER	03-32-002	REPLACE NEW Starter	391191	1	285.49	41305.60241	2013	ISSW	Starter
12	801120	ASHBORO UNIT	37MT12-0	STARTER	03-32-002	REPLACE NEW Starter	385738	1	269.5	41274.65964	2012	ISSW	Starter
13	801120	ASHBORO UNIT	37MT12-0	STARTER	03-32-002	REPLACE NEW Starter	385738	-1	269.5	41276.34905	2013	ISSW	Starter
14	801120	ASHBORO UNIT	JN410-12195	12V STARTER	03-32-002	REPLACE NEW Starter	385738	1	350.5	41277.47772	2013	ISSW	Starter
15	801120	ASHBORO UNIT	JN410-12195	12V STARTER	03-32-002	REPLACE NEW Starter	455004	1	399.05	41696.58025	2014	ISSW	Starter
16	801120	ASHBORO UNIT	JN410-12195	12V STARTER	13-45	OTHER MAINT Engine	455004	1	399.05	41696.58025	2014	ISSW	Starter
17	801120	ASHBORO UNIT	JN410-12195	12V STARTER	13-45	OTHER MAINT Engine	455004	-1	399.05	41697.28905	2014	ISSW	Starter
18	801130	FORT HARRISON UNIT	32002281	STARTER,12V	13-45-000	OTHER MAINT Power Plant	220624	1	275	40259.31425	2010	ISSW	Starter
19	801210	CRAWFORDSVILLE UNIT	41MT	STARTER,REBU ILT	24-32-002	REPAIR Starter	300253	1	310	40756.6785	2011	ISSW	Starter
20	801210	CRAWFORDSVILLE UNIT	41MT	STARTER,REBU ILT	42-32-002	INSP/REPAIR Starter	374648	1	310	41205.56003	2012	ISSW	Starter
21	801110	TERRE HAUTE UNIT	41MT	STARTER,REBU ILT	03-32-002	REPLACE NEW Starter	331149	1	257.54	40949.59098	2012	ISSW	Starter
22	801230	NEWPORT UNIT	41MT	STARTER,REBU ILT	03-32-002	REPLACE NEW Starter	253446	1	295	40500.5416	2010	ISSW	Starter
23	801230	NEWPORT UNIT	37MT	STARTER	24-32-002	REPAIR Starter	441278	1	295	41618.55887	2013	ISSW	Starter
24	801210	CRAWFORDSVILLE UNIT	41MT	STARTER,REBU ILT	03-32-002	REPLACE NEW Starter	274351	1	310	40596.62251	2011	ISSW	Starter
25	801330	LAFAYETTE UNIT	41MT	STARTER,REBU ILT	03-32-002	REPLACE NEW Starter	268211	1	346.15	40542.33882	2010	ISSW	Starter
26	801410	FRANKFORT UNIT	32002056	STARTER,REBU ILT	35-32	DIAGNOSE Cranking System	250502	1	295	40435.38451	2010	ISSW	Starter
27	801410	FRANKFORT UNIT	41MT	STARTER,REBU ILT	24-43	REPAIR Exhaust System	251964	1	205	40444.41025	2010	ISSW	Starter
28	800000	INDIANA DEPARTMENT OF TRANSPORTATION	32002056	STARTER,REBU ILT				1	361.55	40191.53056	2010	ISSU	Starter
29	801510	CLOVERDALE UNIT	2280005851	STARTER	24-45-000	REPAIR Power Plant	424935	1	285.49	41512.62948	2013	ISSW	Starter
30	801520	BAINBRIDGE UNIT	10479226	STARTER	24-32	REPAIR Cranking System	251402	1	204.83	40455.35479	2010	ISSW	Starter
31	801540	PLAINFIELD UNIT	2280005851	STARTER	03-32-002	REPLACE NEW Starter	390344	1	285.49	41303.39602	2013	ISSW	Starter
32	801510	CLOVERDALE UNIT	10479226	STARTER	24-32-000	REPAIR Cranking System	325391	1	220	40906.57847	2011	ISSW	Starter
33	801420	LEBANON UNIT	7941	STARTER SOLE NOI	04-32-002	REPLACE RBLT Starter	390902	1	65	41305.36301	2013	ISSW	Starter
34	801310	FOWLER UNIT	DR10461282X	STARTER	03-32-000	REPLACE NEW Cranking System	438631	1	301.11	41603.39037	2013	ISSW	Starter
35	801420	LEBANON UNIT	228000-5851	STARTER	03-32-002	REPLACE NEW Starter	412043	1	285.49	41429.70035	2013	ISSW	Starter
36	801520	BAINBRIDGE UNIT	10479226	STARTER	24-32-000	REPAIR Cranking System	291372	1	204.83	40681.51172	2011	ISSW	Starter
37	801510	CLOVERDALE UNIT	32002904	STARTER,38MT 12V	03-32	REPLACE NEW Cranking System	216356	1	331.67	40232.37301	2010	ISSW	Starter
38	801110	TERRE HAUTE UNIT	JN410-12290	STARTER				1	276.27	41276.60703	2013	ISSU	Starter
39	801330	LAFAYETTE UNIT	LNM105602	STARTER FOR INTEI	03-32-002	REPLACE NEW Starter	368139	1	321.59	41159.55436	2012	ISSW	Starter
40	801330	LAFAYETTE UNIT	37MT	STARTER	03-32-002	REPLACE NEW Starter	436855	1	370.71	41591.59852	2013	ISSW	Starter
41	801330	LAFAYETTE UNIT	LNM105602	STARTER FOR INTEI	95-32-000	TRAVEL Cranking System	438710	1	331.29	41603.47769	2013	ISSW	Starter
42	801330	LAFAYETTE UNIT	LNM105602	STARTER FOR INTERNATIONAL				1	331.29	41641.93194	2014	ISSU	Starter
43	801530	LIZTON UNIT	2280005851	STARTER	03-32-002	REPLACE NEW Starter	402451	1	285.49	41386.54338	2013	ISSW	Starter
44	801320	CARBONDALE UNIT	32002252	STARTER	03-32-002	REPLACE NEW Starter	394232	1	340.41	41324.63637	2013	ISSW	Starter

Figure F.6 Copying components into the *Component Analysis* Data worksheet.

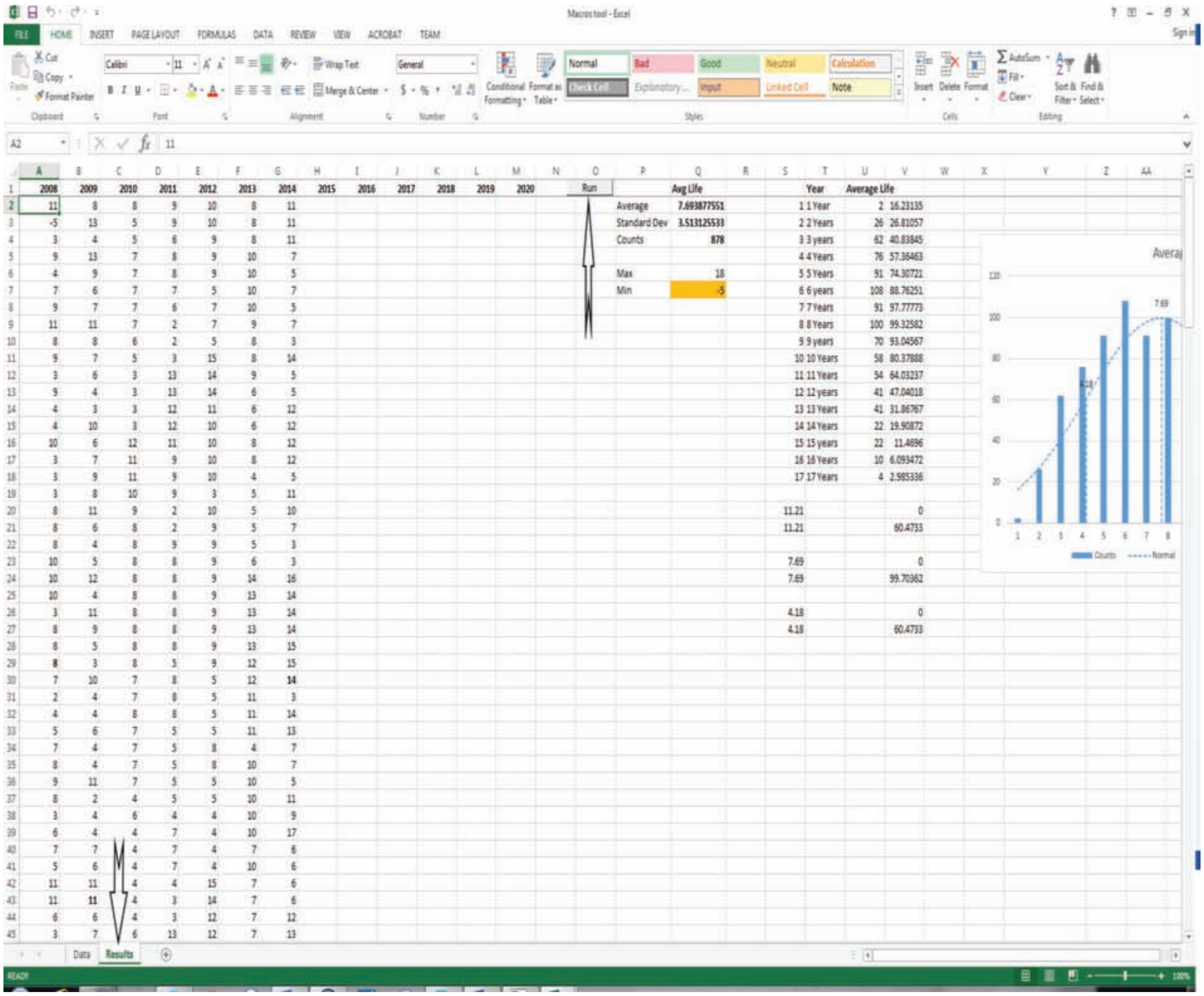


Figure F.7 *Component Analysis* Results worksheet.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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