Optimizing Maintenance Equipment Life-Cycle for Local Agencies

Final Report
October 2019

CONSTRUCTION MANAGEMENT AND TECHNOLOGY

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

Determining the optimal time of equipment replacement is challenging, since the cost of maintaining road equipment increases with equipment operation, while the economic value of the equipment decreases. Accurately estimating the optimal replacement time and predicting future costs of road equipment contribute to the effective use of equipment, while avoiding expensive maintenance activities.

This research project developed a data-driven equipment life-cycle cost analysis (LCCA) model that estimates economic life, replacement time, and future costs of motor graders and trucks for Iowa counties. The current practice of equipment management in Iowa counties was studied by conducting a survey and a follow-up interview. Historical equipment management data for motor graders and trucks were explored to perform regression analysis and derive equipment cost estimation models.

A spreadsheet-based tool was also developed to capture equipment data and provide cost estimation and optimal replacement time. The tool has two modules: (1) deterministic analysis that captures single values as inputs and provides one-point estimation and (2) stochastic analysis, in which a range of values is captured and Monte Carlo simulation is used to provide a range of values as results. The stochastic analysis provides insights about the effect of uncertainties associated with variables to more realistically reflect actual practice. The tool considers both purchasing and leasing options to be applicable for counties that use each method of equipment acquisition.

The research also proposed a template for equipment data record keeping that meets LCCA requirements and allows counties to improve their data collection practices, which can enhance equipment planning over time. The output of this project not only allows Iowa county engineers to support their equipment decisions but also can be used as an example of equipment LCCA for other public agencies.

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EXECUTIVE SUMMARY

Accurately estimating future costs of road equipment and determining the optimal replacement time may have significant contributions to local transportation agencies in their efforts to allocate agency's funds more efficiently. This research conducted an extensive literature review on equipment management, and a comprehensive survey to understand the current practice of equipment management in Iowa counties. Historical cost performance data of motor graders and trucks were collected from Iowa counties and analyzed to develop cost estimation models that predict future costs and determine the optimal replacement time of the same types of equipment currently used in Iowa counties. The research used regression analysis and adopted a life-cycle cost analysis (LCCA) technique to perform the estimations. A user-friendly spreadsheet-based tool was developed to capture current ownership and operating costs to estimate future costs and determine the economic life and the optimal replacement year. The research project also proposed an equipment record-keeping template to improve current practice.

The survey conducted in Iowa counties, in which 54 counties (out of 99 counties) responded, aimed to assess current practices of equipment management. The results indicated that motor graders and trucks are the most common pieces of equipment. Just 30% of respondents collect equipment data and have a replacement process. The current replacement processes included periodic equipment replacement, in which after a certain amount of equipment usage, the equipment is replaced with a new one. The follow-up interviews showed that county engineers replace their motor graders after 10,000 to 15,000 working hours or 7 to 25 years and replace their trucks after 5 to 25 years depending on the condition of the equipment.

To develop cost estimation models, historical equipment data of 64 types of graders and 26 types of trucks including 295 records of graders and 168 records of trucks were collected from 9 counties. Regression analysis was performed to identify the relationship between equipment usage and operating cost. The final derived equations were used in the tool to estimate future operating cost based on equipment usage. To predict ownership costs, trade-in values (or salvage values) for graders and trucks were extracted using Lucko's study (2003), in which trade-in values using the data from 1,499 graders and 3,105 trucks were identified. The data analysis was concluded by obtaining cost estimation models.

As a result of the literature review, a life-cycle approach in equipment management is identified as a better alternative to the current practice of periodic replacement, in that a long-term planning considers a trade-off between increasing maintenance costs and decreasing ownership costs. Therefore, the proposed spreadsheet tool adopted an advanced LCCA technique and uses the regression models derived from cost data analysis to estimate future costs and replacement time. The tool provided two modules (1) deterministic analysis, in which the tool captures single values as inputs and provides one-point estimation and (2) stochastic analysis, in which a range of values are captured from the user and Monte Carlo simulation is used to provide a range of values as results. Stochastic analysis provides insights about the effect of uncertainties associated with variables and better reflects actual practice.

The research also proposed a template for equipment data record keeping that meets LCCA requirements and allows counties to improve their data collection practices, which can enhance equipment planning over time. Iowa counties can use the tool and the proposed record-keeping template for their current graders and trucks to better estimate future costs and replacement time to enhance equipment management within their agencies.

CHAPTER 1. INTRODUCTION

1.1 Overview

Local road agencies are responsible for construction and maintenance of county roads and bridges. To accomplish that mission, local agencies heavily use road equipment for construction and maintenance activities. In Iowa counties, about half of the total budget is spent on road maintenance (Iowa DOT 2015), and equipment expenditures constitute 27% of the total expenditures, including tasks such as obtaining new equipment and equipment operations (ICEA 2018). Challenges faced by Iowa counties include determining the best time for replacing old equipment with new equipment, the economics of leasing versus purchasing, and estimating future equipment budget. An efficient equipment management program that uses advanced techniques and addresses such decision-making challenges can support equipment management decision making and contribute to noticeable savings.

Advanced equipment management programs apply the life-cycle cost analysis (LCCA) approach (FHWA 2003, Hall and Dimitrov 2009, Gransberg and O'Connor 2015). While the operating cost of the equipment increases over time, as maintenance activities tend to increase with age, the financial value of the equipment decreases due to the depreciation of the equipment with time. The LCCA approach takes the two conflicting trends into account and estimates the optimum replacement time of equipment.

Several departments of transportation (DOTs) across the US use advanced technologies that apply the LCCA approach to support their equipment management decisions (Fan et al. 2011, Vance et al. 2014, Gransberg and O'Connor 2015). However, there are some transportation agencies that still use traditional methods resulting in suboptimal decisions. In this research, a robust decision support system for Iowa counties has been developed to provide an efficient plan for equipment management and that optimizes decision making for county engineers. To accomplish this goal, the research team reviewed state-of-the-art LCCA techniques and assessed current equipment management methods and processes used by Iowa counties. The new knowledge created by this project was applied to the development of a framework and a spreadsheet-based tool employing advanced methods designed to be easily adaptable by relevant agencies. This report provides a literature review, data collection and analysis, a description of the framework and the tool, and a brief guideline to use the tool. The full manual is available as a separate document as part of this research.

1.2 Project Objectives

To address Iowa counties' requirements in terms of equipment management, this project developed a model that considers the equipment life-cycle costs (LCC), depreciation, and other influential parameters to optimize equipment maintenance and replacement plans considering both purchasing and leasing options. The final deliverable is a robust spreadsheet-based decision support tool with the two modules of deterministic and stochastic analysis. Also, a sound record-keeping guideline is provided. The following objectives were accomplished in this project:

- Investigate state-of-the-art LCCA methods to identify methodologies that can be adapted by this research project
- Identify current practices of Iowa counties and analyze their equipment management processes and their data collection practices, including purchase price, trade-in value, leasing monthly payment, leasing period, actual equipment usage hours, annual maintenance costs, fuel consumption, etc.
- Develop a framework and a spreadsheet-based decision aid tool for assessing the values of repairing, replacing, or retaining a given piece of equipment and generating options available to the equipment manager, helping them minimize the total LCC of the equipment fleet
- Develop guidelines for data-driven equipment record-keeping practices

1.3 Deliverables

This research project provides the following deliverable products:

- A framework for equipment fleet management decision making based on the LCCA methodology to estimate the economic life of equipment.
- A spreadsheet-based decision aid tool. The tool helps decision-makers make a data-driven and optimized decision on equipment management.
- A guide and a template for equipment record-keeping practices.
- A user's guide that contains a step-by-step illustration on how to use the spreadsheet tool.
- The final report at the completion of the project.

1.4 Benefits

The major benefit to Iowa counties is an enhanced ability to make defensible equipment management decisions. The tool's output can be used for planning, budgeting, and capital equipment purchasing decisions. The tool is also designed to permit users to play "what if" games to not only better understand the sensitivity of assumptions but also to be able to more completely explain decisions to upper management decision-makers. The benefit can be measured by the end users (fleet managers) through comparing actual equipment life-cycle costs to those found in the program's output.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive literature review of equipment LCCA. The chapter begins by introducing equipment costs and describing cost components, followed by presenting the equipment LCCA and calculation methods. A common approach for replacement analysis is presented afterward, followed by cost forecasting methods. Next, the two approaches of deterministic and stochastic analysis in equipment LCCA are described. Finally, current practices within DOT agencies are reviewed to determine the gap between those practices and the state-of-the-art approaches. Those gaps are addressed in the proposed equipment life-cycle cost analysis tool (E-L-T).

2.2 Equipment Costs: Ownership and Operating (O & O) Costs

Accurately estimating the total cost of equipment is important in equipment management. The total cost of equipment typically is divided into two types, ownership and operating costs, which are referred to O & O costs. Equipment ownership costs are incurred regardless of whether the equipment is employed in a job. Operating costs include the expenditures from operating the equipment (Peurifoy et al. 2005, Gransberg et al. 2006, Schaufelberger and Migliaccio 2019). Typical ownership and operating cost components are listed in Table 2.1.

Table 2.1. Types of ownership and operating costs

Total cost of equipment	
Ownership costs	**Operating costs**
Equipment acquisition and initial costs	Maintenance and repair
Depreciation	Consumables
Insurance, overhead, and miscellaneous	Tire (repair or replace)

Sources: Gransberg et al. 2006, Schaufelberger and Migliaccio 2019

A detailed explanation of each item is provided in the next sections.

2.2.1 Ownership Cost Components

2.2.1.1 Equipment Acquisition and Initial Costs

Initial costs incur when the owner acquires the equipment. There are two common options for equipment acquisition: purchasing and leasing. In purchasing, the owner pays upfront; however, in leasing, the owner pays a percentage of the equipment value as a down payment and sets up recurring payments for a specific period of time called the “leasing period.”

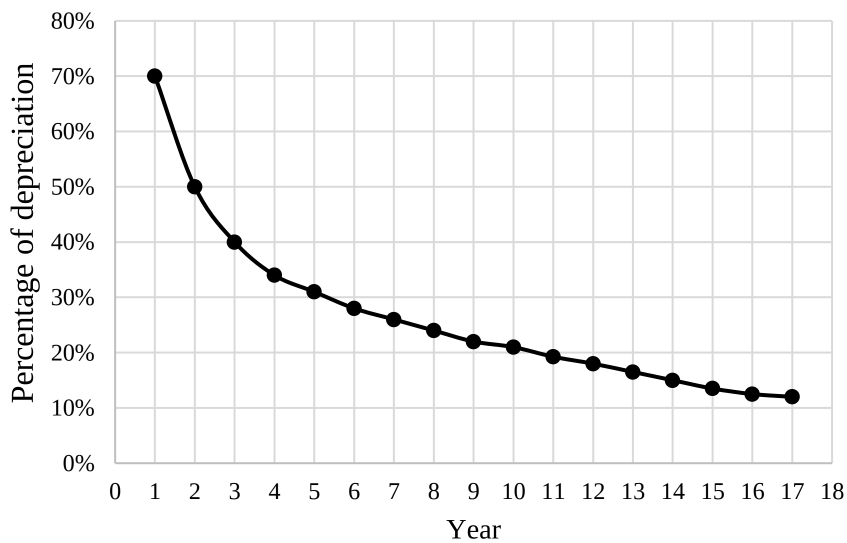
At the end of the equipment’s life, in the case of purchasing, the owner can decide what to do with the obsolete equipment, which can include retaining the equipment or trading it in.

However, in the leasing option, at the end of the leasing period, the piece of equipment is generally returned to the leasing company, or it also can be purchased by paying the residual value of the equipment.

When cash flow does not allow for purchasing new equipment, leasing can be a more appropriate option as initial cash outlay is minimized, and the cost of the piece of equipment is known in advance for the term of the lease. Since leasing companies usually provide leasing options for their brand-new equipment, the user is able to use industry-leading technologies. Also, leasing companies provide a period of time as a warranty during which they handle maintenance and repairs. However, the purchasing option is suitable when the user intends to keep the equipment for the long term and has expertise in maintenance activities. Therefore, agencies decide whether to purchase or lease based on the agency's requirements and policies.

2.2.1.2 Depreciation

The market value of a piece of equipment decreases over time due to operation, deterioration, age, and obsolescence. The economic decline is called depreciation, and the residual value of the vehicle, which is the purchase value minus depreciation, is called the salvage value or trade-in value of the equipment (Gransberg and O'Connor 2015). Salvage value is usually considered as a declining curve throughout the equipment life (Figure 2.1).



Scheibe et al. 2017, InTrans

Figure 2.1. Estimated depreciation values for two classes of snowplow trucks

Scheibe et al. (2017) assessed the current practice of the Iowa DOT. They identified the depreciation curve for two classes of snowplow trucks by conducting interviews with DOT staff. The study found that the Iowa DOT typically keeps the snowplows in use for 15 years before replacing them. Figure 2.1 illustrates the percent of depreciation over the equipment's age obtained through the interviews. The vehicles' decay is exponential in the initial years and then follows a steady downward trend until the 17th year.

2.2.1.3 Insurance, Overhead, and Miscellaneous Costs

Insurance costs represent the payment to an insurance company to cover the incurred costs of fire, theft, and accident, and also includes liability insurance. Some local agencies do not pay an insurance company but rather use a self-insurance policy. In self-insurance, the organization takes on the financial risk directly instead of paying an insurance company to cover risks (Insurance Information Institute 2019). Overhead and miscellaneous costs include some uncategorized expenses of the equipment that are necessary to keep the equipment operating. For example, Iowa county engineers record these as "sundry costs" in their accounting reports and includes the expenses of cleaning, regular inspections, shop utilities, fire extinguishers, light bulbs, first aid supplies, labor for upkeep on equipment, and work for minor tasks such as painting, mowing, and minor repairs (Iowa DOT Secondary Road Budget Accounting Code Series 2005).

In addition, equipment taxes are the property taxes paid to the government and are usually considered ownership costs. Since local road agencies are a type of governmental agency, the equipment taxes are not paid by them (Schaufelberger and Migliaccio 2019).

2.2.2 Operating Cost Components

2.2.2.1 Maintenance and Repair Costs

The cost of maintenance activities typically accounts for the largest portion of operating expenses. The amount of maintenance costs depends on the obsolescence of the equipment, the type of the equipment activity, and the working environment. Regular servicing of the equipment would decrease maintenance costs by avoiding potential machine's failures (Gransberg and O'Connor 2015).

2.2.2.2 Consumable Costs and Tire Costs

Consumable costs are items that are required for equipment operation such as fuel, lubricants, filters, and other small parts and items (Gransberg and O'Connor 2015). They are normally constant for a piece of equipment unless it is worn, in which case it is likely to consume more fuel and the other elements. The cost of replacing or repairing tires is also considered in operating costs.

2.3 Inflation Rate

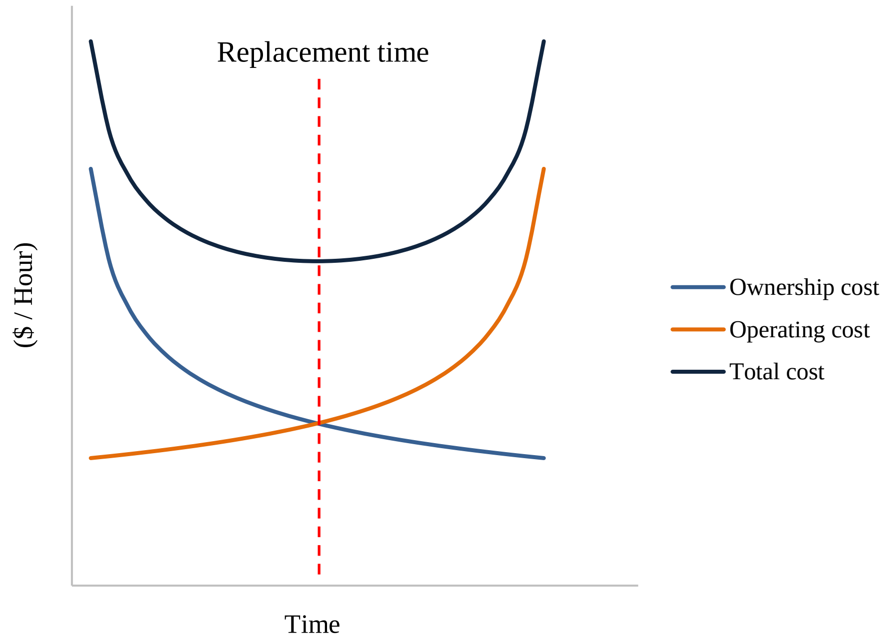
The equipment LCC is affected by the economy. The inflation rate determines the amount of decrease in the purchasing power of a national currency. In this research, the inflation rate is used to adjust future costs to more accurately determine the budget plan. Although the inflation rate should be considered in the equipment LCCA, it can be ignored when there are comparative options because it has the same effect on the options. In practice, estimating the inflation rate is not a straightforward matter. Determining the inflation rate is a challenging job for DOTs and other public agencies (FHWA 2003). However, it can be estimated using the DOT's historical data. For example, Scheibe et al. (2017) estimated the inflation rate of 4.23% based on analyzing historical economic data of the two types of snowplow trucks and discussing with experts in the Iowa DOT to adjust the LCC of trucks.

2.4 Life-Cycle Cost Analysis

LCCA is a systematic process used to evaluate the total cost of an asset throughout its entire life. According to the Federal Highway Administration (FHWA), this process is performed by summing up the monetary equivalent of all costs at their respective time of occurrence throughout the analysis period. The costs in different times are then adjusted to a base year using price indexes (Ozbay et al. 2003). Price indexes are used to normalize costs in different years and remove the impact of inflation on prices. Equipment LCCA includes calculating life-cycle costs, adjusting the costs, and replacement analysis (Gransberg and O'Connor 2015). By estimating future costs, the economic life of the equipment can be identified to be used in replacement decisions.

2.5 Equipment Life and Replacement Analysis

Once a piece of equipment is put to use, it gradually faces mechanical problems and requires maintenance activities. While the operating cost per equipment usage hour increases over time, the ownership cost per hour declines because the depreciation makes the monetary value of the equipment decrease with time (Schaufelberger and Migliaccio 2019). As Figure 2.2 shows, the ownership cost per hour decreases exponentially during the initial ownership period.



After Kauffman et al. 2012, Campbell et al. 2016

Figure 2.2. Change in ownership, operating, and total costs with time

This decrease occurs because the rate of depreciation tends to be greatest at the initial period. Total hourly costs tend to decrease during the initial years, mainly due to the ownership cost decline, to reach its minimum level before beginning to increase again as the operating cost grows toward the end of the equipment's life (Campbell et al. 2016). The economic useful life ends when the total hourly cost reaches its minimum amount. Retaining the equipment after this time indicates high operating costs and a low trade-in value, which is not an efficient situation. The equipment finally finishes its physical life when the equipment is worn out, no longer works properly, and it isn't worth the cost to repair. Although the equipment can still work until the end of its physical life, the end of its economic life can be a more efficient time to replace the equipment (Gransberg and O'Connor 2015, Zong 2017). In this research, the model minimizes the total cost per equipment usage to estimate economic life and replacement time of equipment.

2.6 Equipment Cost Forecasting Models

In order to estimate the economic life of current pieces of equipment during their life cycle, predicting future equipment costs is essential. Previous equipment records can be the best source to estimate future ownership and operating costs since new equipment typically experiences similar working conditions. Researchers used historical data to predict equipment operating costs (Manatakis and Drakatos 1993, Mitchell 1998, Lucko 2003, Fan et al. 2012, Bayzid et al. 2016, Scheibe et al. 2017). Given the data from the equipment's annual cumulative usage hours, age, and purchase price as the predictors and the actual operating cost as the response, researchers applied regression analysis on the historical data to identify a dominant pattern and develop a regression model to predict equipment operating costs. The equation of the model typically follows a second-polynomial expression (Vance et al. 2014, Mitchell et al. 2011). For example, Bayzid et al. (2016) utilized an equipment database to develop a cost prediction model for road equipment units, such as graders and wheel loaders. As another example, Vance et al. (2014) developed equations for predicting the operating costs of different types of equipment using historical records. Equation 2.1 shows a mathematical model for predicting the cumulative operating cost for a tandem-axle truck using equipment working hours, age, and purchase price (Vance et al. 2014).

$$\text{Cumulative operating cost}=52819+0.56\times(\text{Purch})+277.25\times(\text{Age})+13.06\times(\text{Age2})-0.09\times(\text{Age3})+0.07\times(\text{Hours})+0.000090\times(\text{Hours2}) \quad (2.1)$$

where,
Purch = purchase price
Age = age in months
Hours = cumulative equipment working hours

Figure 2.3 shows the average cumulative operating costs versus cumulative usage hours of 576 tandem-axle trucks and the regression model (Vance et al. 2014).

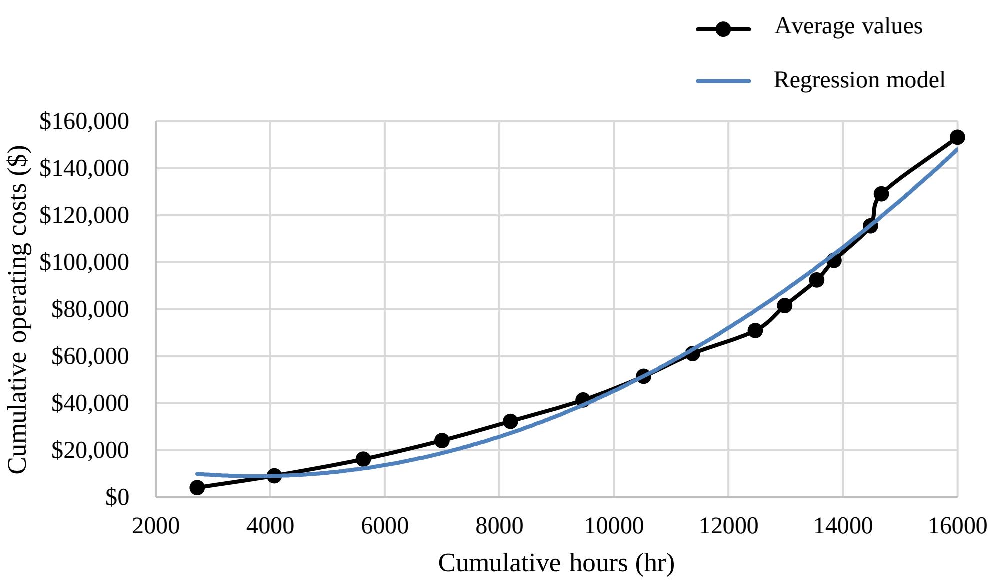


Figure 2.3. Relationship between hours and operating costs for tandem-axle trucks

The cumulative operating cost increases as a polynomial order as a piece of equipment is used and getting older (Vance et al. 2014).

2.7 Deterministic and Stochastic Analysis Approaches

Equipment cost models capture ownership and operating cost components for a piece of equipment, and based on previous costs experiences, the models can predict future costs for the piece of equipment. Equipment cost models can be (1) deterministic or (2) stochastic, or probabilistic. A deterministic analysis model captures determined and single values for inputs and provides one-point estimation for results. However, the single value cannot accurately reflect randomness in real equipment practice due to inherent uncertainties associated with variables. A stochastic, or probabilistic, analysis model can address this issue by considering a range of values for inputs and providing a range of values for results. For example, in the research study of Vance et al. (2014), a deterministic analysis used equation 2.1 and captured equipment purchase price, working hours, and age to estimate the cumulative operating cost. The database of this research (Vance et al. 2014) includes multiple data points of operating costs per working hours for 576 trucks. As shown in Figure 2.4, equation 2.1 assumed an average value of multiple operating costs for each working hour, and each working hour can yield one value as cumulative costs.

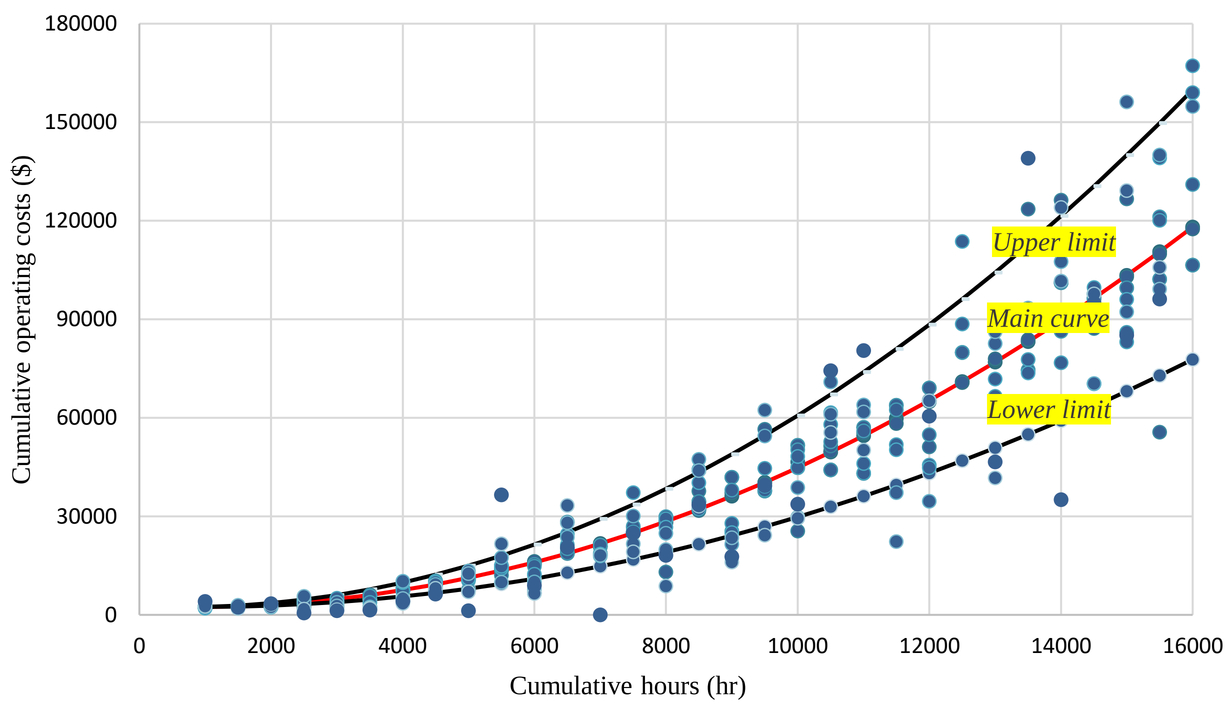


Figure 2.4. Main curve and upper and lower limits for scattered data points by a stochastic analysis model

However, in stochastic analysis, a stochastic regression model can provide a confidence interval to define a lower and an upper limit computed from the data set. It then defines a probabilistic function to provide a range for results. Assuming random data points around the regression curve of Figure 2.3, Figure 2.4 illustrates this concept by providing an upper limit and a lower limit.

In addition, there are other cost components that a stochastic model considers and takes a range of values for them including (1) inflation rate, (2) estimated working hours or mileage, (3) insurance and miscellaneous costs, and (4) trade-in values. In the stochastic method, simulation is a preferred technique to account for uncertainties in LCCA. The Monte Carlo simulation method is usually adopted in the probabilistic approach (Ozbay et al. 2003). The Monte Carlo simulation considers the probability distribution of defined variables and calculates results over and over, each time using different randomly selected values from the probability functions of input variables. It records the result each time and fits a probability distribution to provide a range for results with a certain confidence level and contributes to a better understanding of results.

Scheibe et al. (2017) used a stochastic model to predict the LCC of snowplow trucks. They used a combination of objective and subjective methods to define a probabilistic distribution of equipment salvage values in which they analyzed equipment historical data and also discussed with experts to modify the distribution. They used a triangular distribution for the salvage value, in which for each year, minimum, most likely, and maximum probable salvage values were considered. Although a deterministic model is straightforward and easier to understand, the stochastic model can better reflect the actual practice by addressing inherent uncertainties associated with the variables.

2.8 Current Practices Review

Some DOTs across the U.S have adopted equipment LCCA to enhance equipment management decision making. There are few research studies available in the literature on the application of LCCA in local road agencies. Since DOTs are responsible for maintaining state roads, they perform similar tasks as local road agencies. Therefore, notable applications of equipment LCCA from different DOTs across the US have been collected and reviewed to assess the benefits and identify their gaps. Table 2.2 presents a summary of the practices and their features.

Table 2.2. Notable practices and their features in some DOTs across the US

	State	IA	MN	PA	TX	VA
	Year of publication	2017	2015	2014	2011	2004
	Resource	Scheibe et al.	Gransberg and O'Connor	Vance et al.	Fan et al.	Gillespie and Hyde
Inputs	Initial price	*		*	*	
	Maintenance cost	*	*	*	*	*
	Usage hours	*		*	*	*
	Fuel consumption			*		*
	Labor cost					*
	Inflation	*	*		*	
Process	Maintenance cost forecasting	*	*	*	*	*
	Purchase price forecasting				*	
	Deterioration forecasting	*	*		*	
Outputs	Important factors (efficient year, equipment features)	*	*			
	Ratios (indicating the severity of equipment)			*		*
	Binary decisions (whether or not replacing each unit)				*	
Det./ Stoch.	Deterministic	*		*	*	*
	Stochastic	*	*		*	

For each DOT, the input values, processes, the outputs, and other features are presented. The table includes different models that process the input data in different ways to yield output data for users. For example, maintenance cost forecasting models, as described earlier in this section, receive the current equipment maintenance cost and yield the future maintenance cost of the equipment. Three different types of output were used as follows:

1. Type 1: Condition rating of each equipment unit. These ratings indicate the degree of equipment wear for each unit that can be used to create a prioritization list for equipment replacement (Virginia and Pennsylvania DOT, see Table 2.2).
2. Type 2: Binary decision. It suggests the replacement decision for each unit based on inputs and acceptable condition (Texas DOT, see Table 2.2).
3. Type 3: General recommendations. It determines essential factors contributing to replacement decisions in general such as the optimum life for each type of equipment (Iowa and Minnesota DOT, see Table 2.2)

The different output types are shown in Figure 2.5.

Type 1

	Condition
Eq. #5	13
Eq. #8	12.4
Eq. #3	10.2
Eq. #9	8.4
Eq. #10	7.1
Eq. #6	6.7
Eq. #7	4.8
Eq. #2	3.3
Eq. #4	4.9
Eq. #1	2.5

Type 2

	Decision
Eq. #1	Don't replace
Eq. #2	Don't replace
Eq. #3	Replace
Eq. #4	Don't replace
Eq. #5	Replace
Eq. #6	Don't replace
Eq. #7	Don't replace
Eq. #8	Replace
Eq. #9	Replace
Eq. #10	Replace

Type 3

The efficient time for replacement	
Motor graders	7 years
Trucks	10 years

Figure 2.5. Three types of output of DOT equipment management practices

All the collected DOT practices in Table 2.2 developed cost forecasting models based on historical data analysis. The condition ratings (Type 1, Figure 2.5) present more flexible indicators for equipment replacement rather than binary decisions (Type 2, Figure 2.5), because it permits the equipment manager to perform a trade-off analysis between available budget and overall equipment conditions. In the condition rating type, based on the replacement prioritization list, equipment conditions can be increased by replacing with new units at the expense of increasing required budget. The important factors (Type 3, Figure 2.5) suggest some parameters, such as the efficient replacement year for each type of equipment, be considered by users as a general recommendation. In this form, general recommendations for equipment decisions (such as the estimated optimum replacement year) are provided. However, a general recommendation may not be applicable for specific cases. For example, a recommendation of replacing trucks every seven years may not be suitable for a truck in its seventh year that has not been used for a while. Therefore, a model that identifies the current condition for each piece of equipment individually is expected to be more accurate. However, the model also should be able to predict future costs and determine the best replacement time for each piece of equipment. The model proposed in this research includes useful aspects from the current best practices and addresses their weaknesses.

CHAPTER 3. RESEARCH METHODOLOGY

This chapter describes the research methodology used in this project. A flowchart of the research methodology is shown in Figure 3.1.

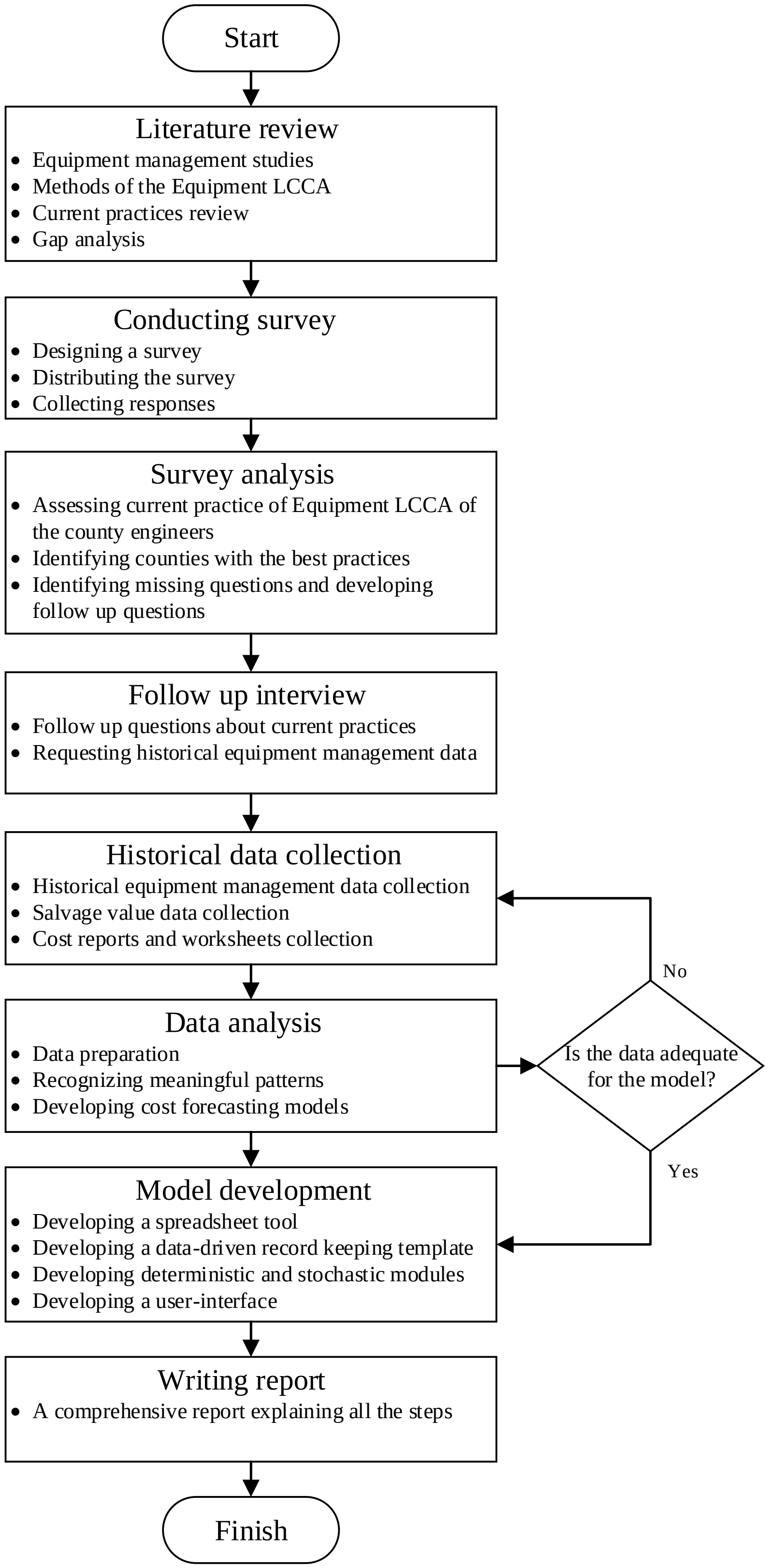


Figure 3.1. Flowchart of the research methodology

After reviewing the literature, a comprehensive survey was conducted to assess current county engineers' practices. Follow-up interviews were conducted to collect specific information and data about their practices that were not collected during the survey. The data collected from the counties was analyzed in order to create a spreadsheet-based equipment LCCA tool (E-L-T). Guidelines for equipment management data record keeping and for using the tool were then developed for county engineers.

3.1 Questionnaire Survey

To understand the current practices within Iowa counties, a web-based survey including 12 questions was conducted with a response rate of 54% (i.e., 54 counties out of 99 counties responded to the survey). The major items studied via survey are as follows:

- Equipment information
- Maintenance and repair information
- System/Software information
- Decision-making information

3.2 Follow-Up Interviews

Sixteen counties that have an equipment replacement process and also collect equipment usage and maintenance data were contacted and interviewed via phone. The interviews focused on understanding the counties' current replacement processes and identifying the most common types of equipment. In addition, the interviewees were asked to send their historical equipment maintenance data, trade-in values, and annual reports to the research team.

3.3 Data Analysis and Model Development

The data obtained from counties were collected to be prepared for data analysis. After data preparation, statistical analysis methods were applied to analyze the data. A framework for equipment LCCA and a spreadsheet-based model were developed, which was based on historical data analysis to determine the economic life and the optimum replacement year for equipment. The model uses two approaches of deterministic and stochastic analysis. A recommended template for equipment record keeping was also developed. The model was then tested and verified with testing data gathered from counties.

CHAPTER 4. CURRENT EQUIPMENT MANAGEMENT PRACTICES OF IOWA COUNTIES

This chapter discusses the results of the questionnaire survey and follow-up interviews and analyzes them to understand the current practices of Iowa counties in terms of equipment management. The survey collected data regarding (1) what types of equipment management data county engineers collect and store, (2) whether they have a specific equipment replacement process, (3) how the process works, (4) which software program is common for equipment management, and (5) the features of the software. Significant information required for developing equipment LCCA models was obtained through the survey. Follow-up interviews were conducted to better understand the current practices.

4.1 Survey Background

In this survey, equipment management was defined as the acquisition, operation, maintenance, repair, and disposal of a county's light- and heavy-duty equipment. It also included activities related to fleet management, such as planning and budgeting over the equipment life cycle. The survey questions were designed after reviewing a wide range of literature on surveys and questionnaires on equipment management. The language and terminology were then refined by the group of technical advisory committee (TAC) members, who were the sample population of Iowa county engineers. They reviewed the draft questionnaire and provided insights for refinement.

4.2 Survey Objectives and Main Questions

The main goal of the survey was the identification of current equipment management practices. To achieve this goal, the main questions included the following:

- What kind of equipment management data the agencies collect and store
- Whether they record required data for equipment LCCA
- Whether they use recorded historical data for future decision making
- How they decide on equipment replacement
- How efficiently the replacement process works

4.3 Survey Organization

The survey was administered by Iowa State University from February 28 to April 2, 2018. An invitation to participate in the survey was sent by e-mail from Iowa State University to Iowa county engineers. A communication campaign, including email notices and internal communication, was initiated to encourage participation in the survey. The questionnaire and the responses are provided in the appendix. The questionnaire included 14 questions and was categorized as follows:

- Equipment information
- Maintenance and repair information
- System/Software information
- Decision-making information

4.4 Survey Results

This section gives an overview and summary of key findings of the survey. The total number of counties across Iowa is 99. Out of which, 54 counties (54%) responded to the survey. In Figure 4.1, the highlighted areas are the counties that responded to the survey and the gray areas are the counties that didn't respond.

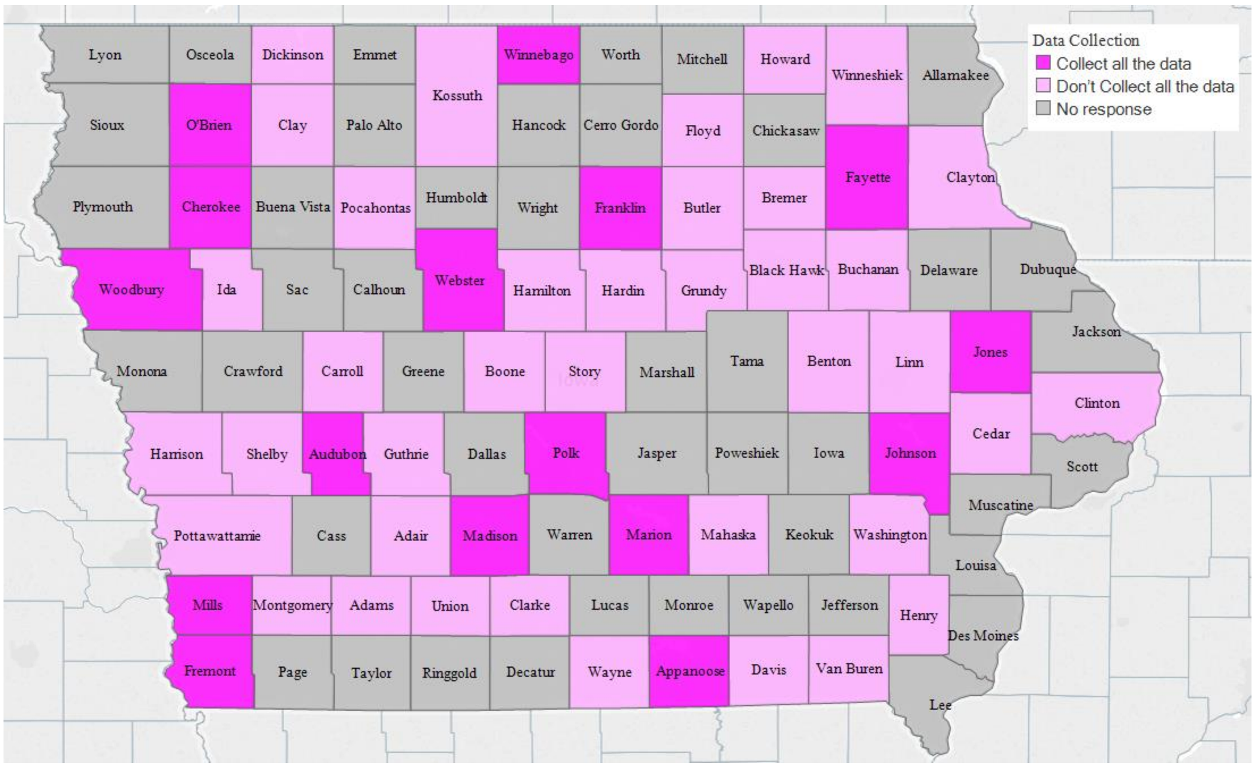


Figure 4.1. Responding counties and data collection status

The highlighted areas in darker pink are the 16 counties that collect equipment maintenance data (including repair date and cost, labor hours, and mileage), and the counties in lighter pink are the 38 counties that do not collect maintenance data or partially record data.

Figure 4.2 illustrates the percentage of the counties (among respondents) that collect different types of data.

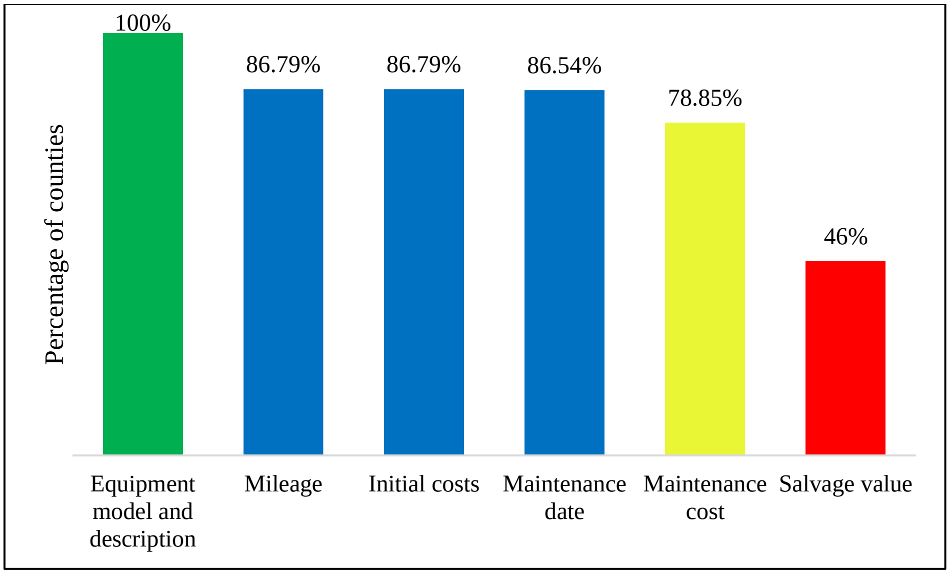


Figure 4.2. Types of data collected (percentage of the counties among respondents)

As the data was more difficult to collect, it tended to be collected less. Almost all counties collect information about equipment model and description. However, only 46% of the counties collect salvage value of their equipment.

The responding counties use different types of software programs for equipment management. According to Figure 4.3, 74% of the responding counties use a software tool, either a purchased software program or a customized spreadsheet software program, for equipment management.

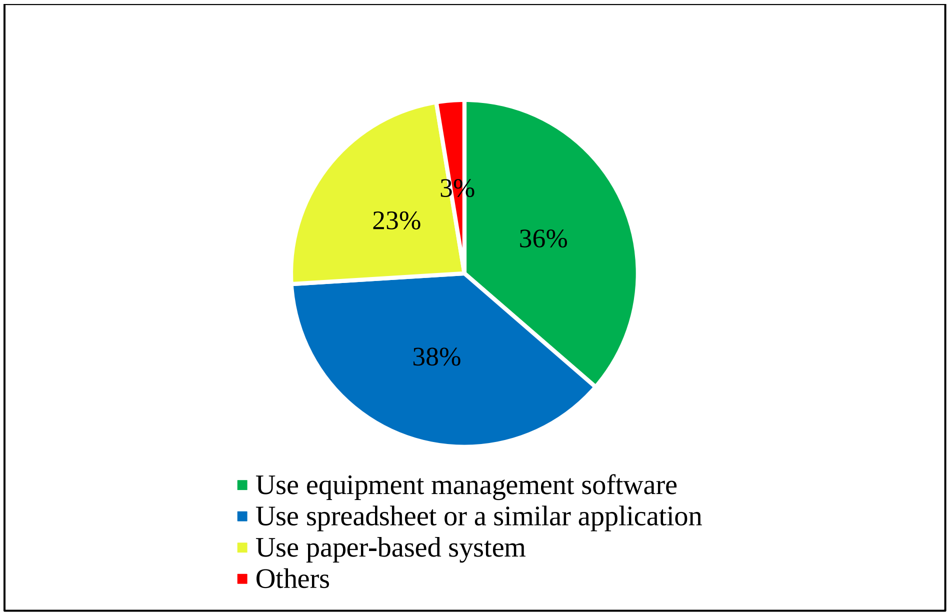


Figure 4.3. Equipment management software currently used in counties

However, 23% of the counties still use traditional paper-based methods.

Figure 4.4 presents counties in terms of (1) the types of collected data and (2) equipment replacement process used.

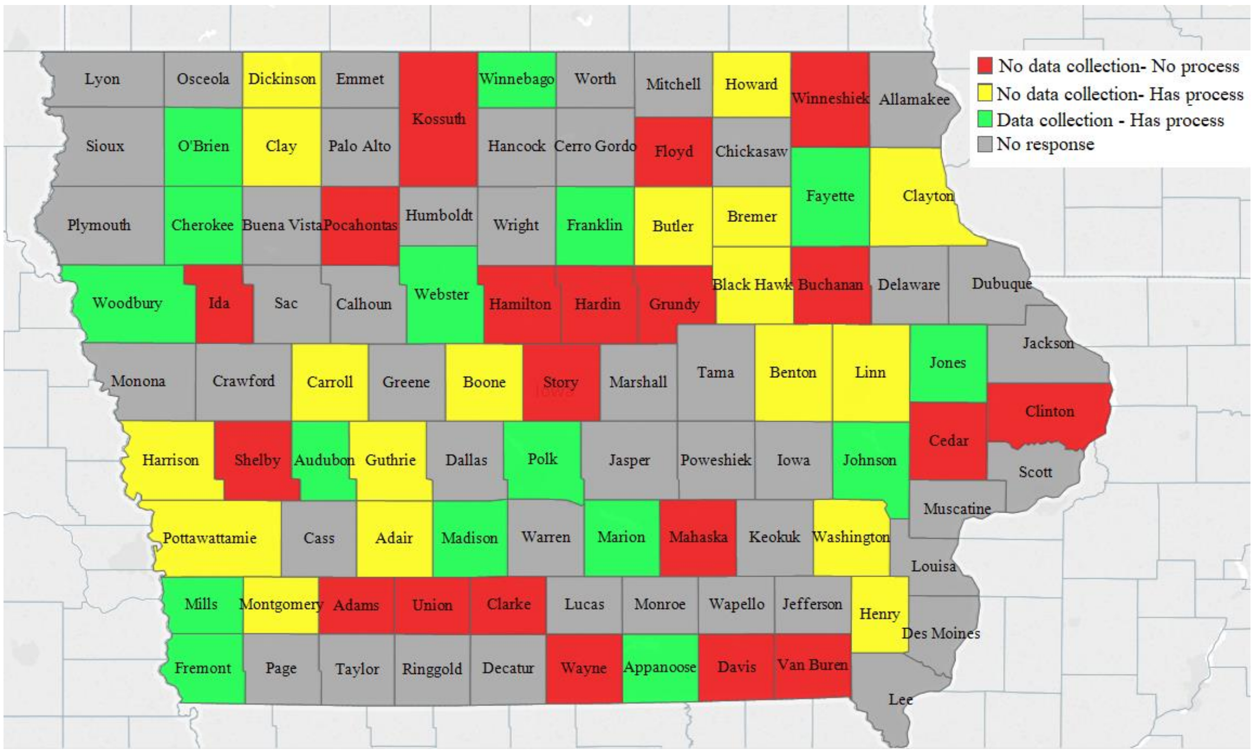


Figure 4.4. Data collection and replacement process status

The green areas show the 16 counties that collect equipment management data and also have a replacement process. The counties shown in yellow don't comprehensively collect data, but they have a replacement process. The counties shown in red don't collect data, and neither do they have a replacement process.

Out of the 54 counties, 34 counties (63%) have a process for equipment replacement decisions. Among them, 16 counties (47%) collect and utilize data to help make replacement decisions. However, as shown in the tornado diagram in Figure 4.5, 16 counties have both a replacement process and collect all the data but only one county (Polk County) employs a systematic method using a commercial software program for equipment replacement decision making.

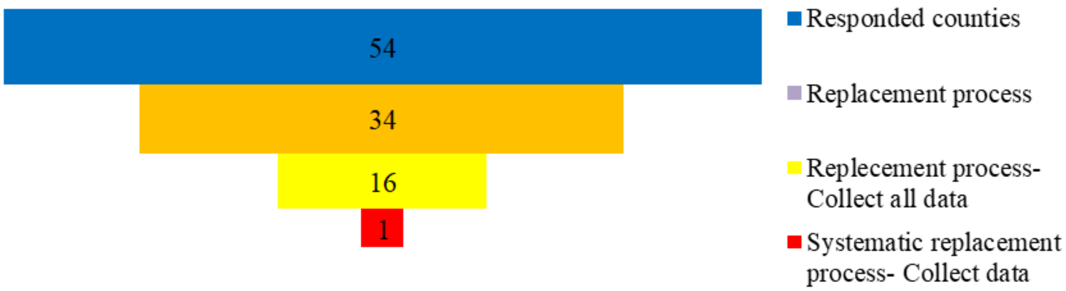


Figure 4.5. Number of counties and data collection/replacement process status

Figure 4.6 illustrates the percentage of equipment overdue for replacement in counties as they stated in the survey.

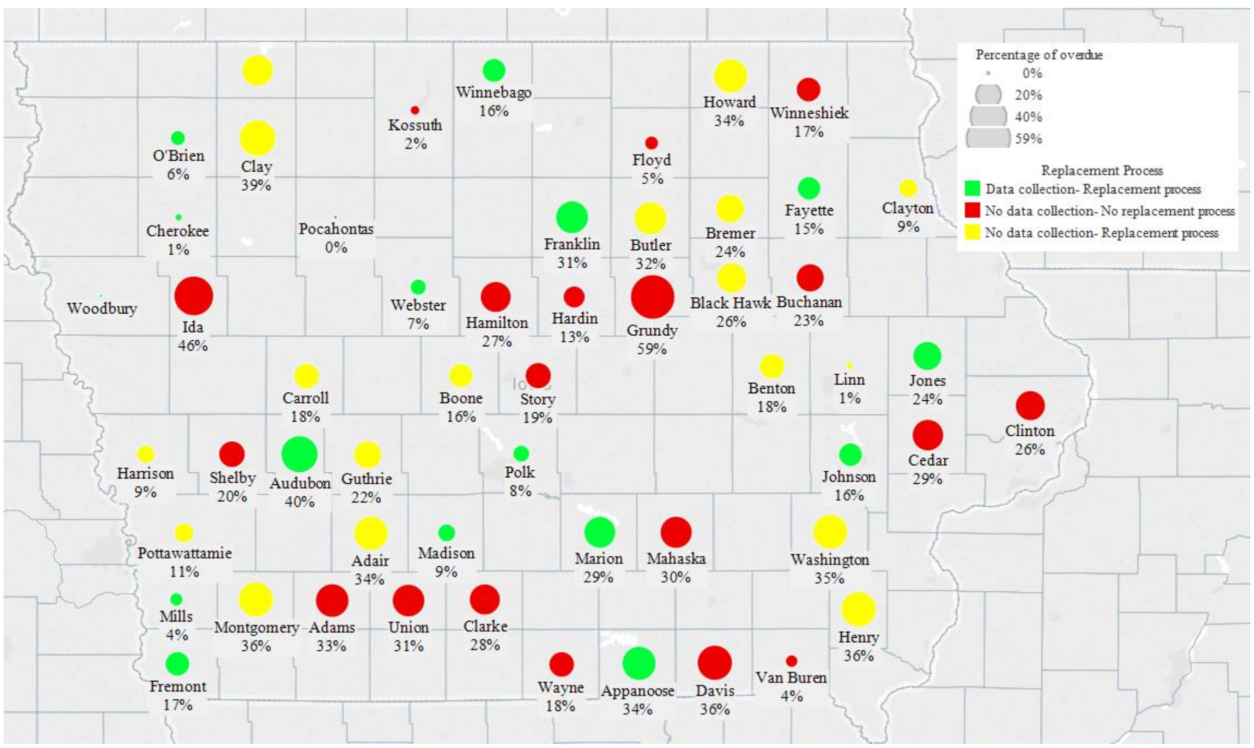


Figure 4.6. Percentage of equipment overdue for replacement

The size of the circles is proportional to the percentage of overdue equipment. The color of a circle, similar to Figure 4.4, shows the status of data collection and replacement process. One can see that counties that have some means of equipment replacement and collect or monitor most of the data have a smaller percentage of equipment overdue for replacement as shown in Figure 4.7.

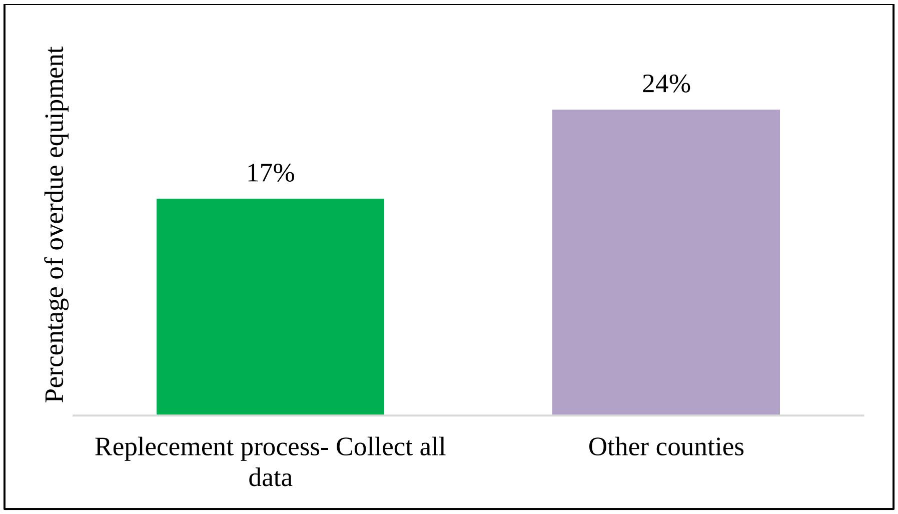


Figure 4.7. Effect of having a replacement process and data collection on the percentage of overdue equipment

Figure 4.8 illustrates different types of equipment and what percentage of them are overdue for replacement.

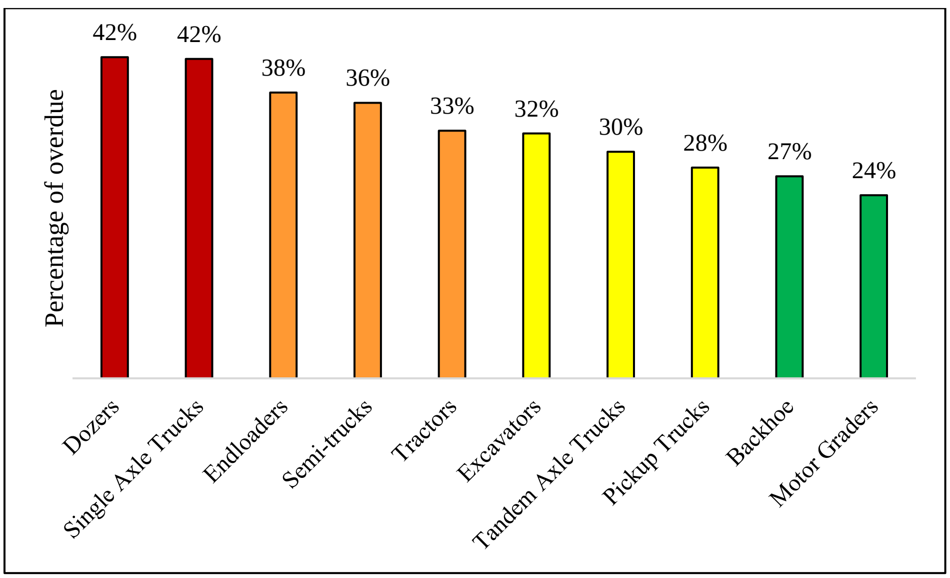


Figure 4.8. Different types of equipment and percentage overdue

According to the figure, motor graders have the least percentage overdue for replacement within the counties that participated in the survey, which means counties have a better plan for replacing motor graders in comparison with the other types of equipment. Based on discussions with the counties, the types of equipment with a higher percentage overdue for replacement have less usage and those types with a lower percentage overdue have higher usage in counties. For example, dozers are used rarely in some counties while motor graders are constantly used. Thus, counties have a better replacement plan for equipment with higher usage rather than equipment with less usage to keep them productive.

Some counties are using advanced technologies for their equipment management. Figure 4.9 shows the different types of advanced technologies they employ.

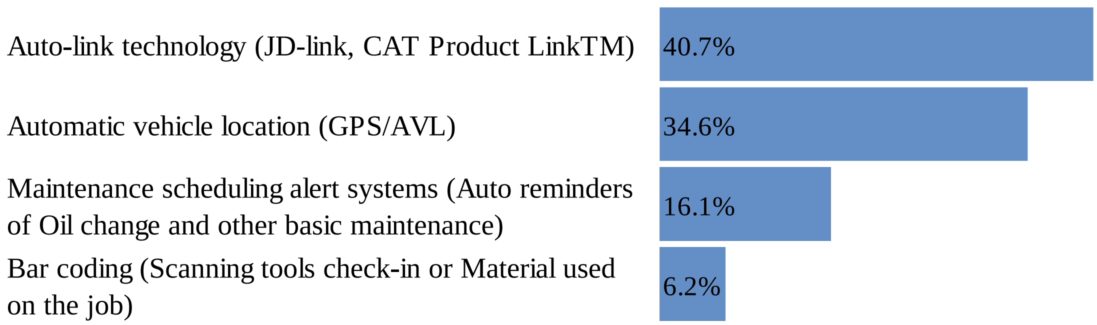


Figure 4.9. Common advanced technologies

Auto-link technology and automatic vehicle location detection are common. These technologies are mostly used to track equipment location, get information about equipment utilization, and monitor equipment downtime and operation time. Given such data, the counties can calculate and record the production rate for their equipment and monitor it for equipment management purposes.

In terms of dedicated maintenance personnel, counties have on average 3.5 repair staff members who are responsible for performing in-house maintenance activities. Figure 4.10 shows the percentage of in-house and outsourced repair works in terms of dollar value.

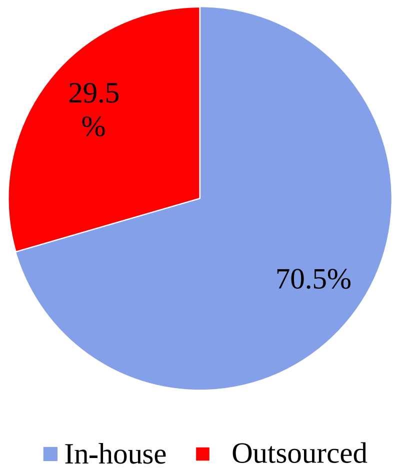


Figure 4.10. In-house and outsourced repair works

It can be inferred that counties have expertise in 70% of maintenance activities.

Figure 4.11 shows contributing factors and their level of influence on the equipment replacement decision making for three major types of equipment.

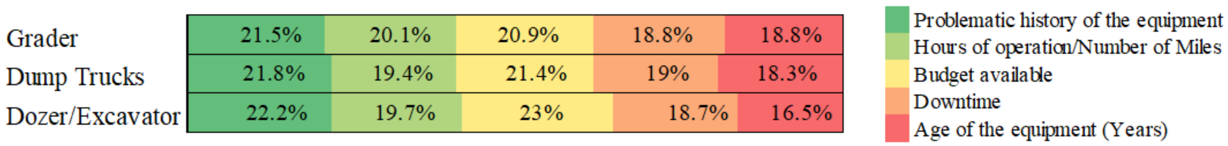


Figure 4.11. Important factors influencing equipment replacement decision making

For graders and dump trucks, the most important factor is the problematic history of the equipment, while for dozers and excavators, budget availability is the most significant factor. However, all five factors have a similar level of influence on equipment replacement decision making, as all percentages are near 20%.

Figure 4.12 illustrates the factors that are considered when counties decide to lease or purchase equipment.

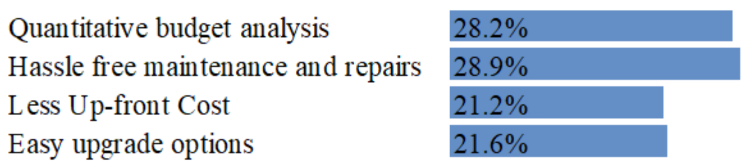


Figure 4.12. Important factors in leasing or purchasing decision making

The most important factors are the budget analysis and convenient repair. The LCCA tool in this research project, which considers both leasing and purchasing options, can help counties improve the acquisition decision-making process. When it comes to equipment leasing or purchasing decision making, county board members, county engineers, and the operations and maintenance team are the decision-makers, but county engineers play the main role. Figure 4.13 demonstrates how the counties dispose of their old equipment.

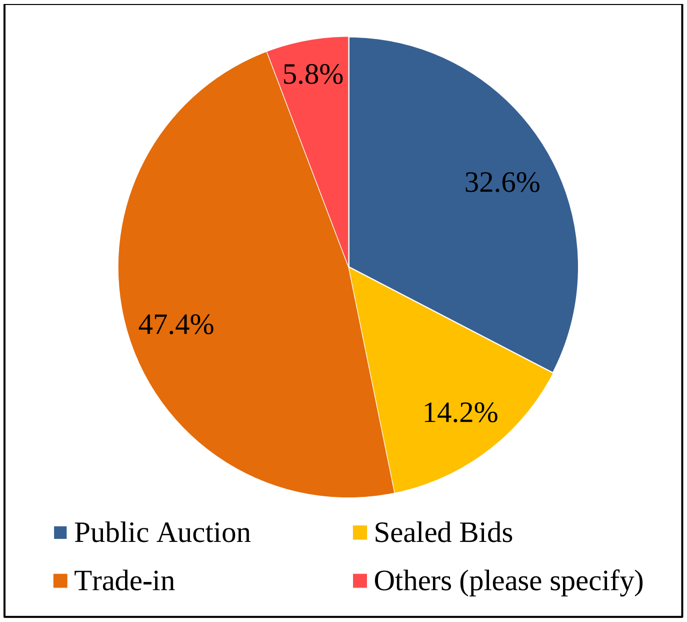


Figure 4.13. Different methods of equipment disposal

The most common method is trading in followed by public auction. For LCCA, in this research, trade-in value is considered as the value of the equipment at the time of disposal.

4.5 Survey Conclusion and Gap Analysis

The survey analysis results identified the following practices for equipment management:

- Counties that use a replacement process and collect all data have a lower percentage of equipment overdue for replacement
- Using commercial equipment management software and spreadsheet software is common for equipment management
- There are 16 counties that collect all the data needed for LCCA models
- Counties tend to execute most of the maintenance activities in-house
- Almost half of the counties trade in their old equipment
- A problematic history with the equipment and budget analysis are important factors in replacing an old piece of equipment with a new one

Follow-up interviews were conducted to clarify the following points:

- There are various types of equipment that counties utilize for road maintenance such as motor graders, loaders, trucks, excavators, backhoes, etc. To develop an inclusive LCCA tool for equipment management, a separate model for each type of equipment should be developed. However, some types of equipment account for most of the equipment budget. Thus, those types of equipment must be given higher priority if it is difficult to develop an equipment LCCA model for all types of equipment.

- Thirty-four counties have a replacement process and 16 counties collect equipment data. The current replacement process and equipment data should be collected and analyzed.

4.6 Follow-Up Interview Results and Analysis

Telephone interviews with 10 counties were conducted to learn about (1) the most common types of equipment, (2) equipment replacement process used, and obtain (3) historical equipment management data.

Table 4.1 shows the results of the interviews.

Table 4.1. Follow-up interview results

County	What are the most common types of equipment?	What percentage of the annual equipment maintenance budget?	Replacement process		Recording historical data status	Data collection for the research
			Method	Measurements	Yes/ No	Yes/ No
Polk	Motor graders & trucks	Big portion	Replacing periodically	MG: after 10,000 hrs, TR: after 200,000–250,000 miles	Yes	Yes
Hamilton	Motor graders & trucks	Big portion	Don't have a systematic process		Yes	Yes
Fremont	Motor graders & trucks	70%	Replacing periodically	MG: after 7 years, TR: after 5–7 years	Yes	Yes
Howard	Motor graders & trucks	60%	Replacing too old units	MG and TR: After 25 years	Yes (paper format)	No
Boone	Motor graders & trucks	50%	Replacing periodically	MG and TR: after 4,000 hours	Yes	Yes
Guthrie	Motor graders & trucks	60%	Replacing periodically	MG: after 10 years, TR: after 10–15 years	No	No
Henry	Motor graders & trucks	60%	Replacing periodically	MG: after 10–11 years or 11,000–15,000 hrs	Yes	Yes
Van Buren	Motor graders & trucks	Big portion	Replacing periodically	MG: after 15 years, TR: after 20 years	No	No
Butler	Motor graders & trucks	Big portion	Replacing periodically	MG and TR: after 12–15 years	No	No
Harrison	Motor graders & trucks	Big portion	Replacing periodically	MG: after 8–12 years, TR: after 15 years	No	No

MG: Motor grader; TR: Trucks

It can be concluded that motor graders and trucks are the two most common types of equipment used in counties and account for a large portion of the total annual equipment maintenance budget. Most of the counties that have a replacement process replace their equipment after a specific period of time or after specific equipment usage. Historical equipment operating data were also collected from some counties through the interview.

Counties use different types of equipment for road maintenance activities including motor grader, single-axle truck, tandem-axle truck, dump truck, excavator, loader, dozer, etc. Developing models for all types of equipment would require a huge amount of historical data for each type. The interview results show that two types of equipment, motor graders and different types of trucks, constitute a significant portion of the total equipment budget. Therefore, developing an equipment management tool for those two types of equipment would be enough to enhance the equipment management practice.

A common replacement method in counties is replacement after a certain amount of working hours, mileage, or time and there is not a systematic replacement process. Even the replacement periods vary significantly among counties and there is not a common standard replacement period. Figure 4.14 shows the range of replacement periods for motor graders and trucks.

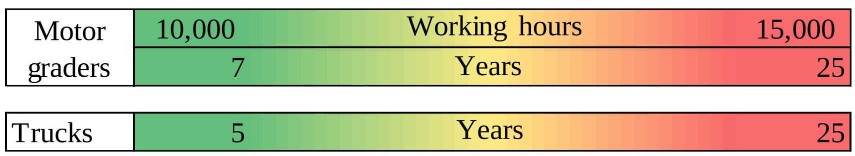


Figure 4.14. Ranges of equipment replacement periods

However, replacing equipment after a specific amount of time does not seem to be an efficient method because some pieces of equipment may have passed the replacement period but are still productive. In addition, there may be some pieces of equipment that have not passed the replacement time but are no longer productive and have a large maintenance cost.

As mentioned in the literature review section, the LCCA approach is a common way to efficiently estimate the LCC, forecast future costs, and plan for equipment replacement. Therefore, this research adopts a LCCA approach to develop a LCC model that can be applied to each piece of equipment to determine the current condition and the optimum replacement time.

CHAPTER 5. EQUIPMENT MANAGEMENT DATA COLLECTION AND ANALYSIS

5.1 Introduction

This chapter begins by describing the collection of equipment management data from Iowa counties and explains how the data was transformed into a spreadsheet to be prepared for data analysis. Then, it discusses the methodology of data analysis and the process of selecting a statistical model that best predicts the equipment life-cycle costs. It then describes the data preparation process and the method of handling missing and anomalous data. The adjustment process of monetary data to remove the impact of inflation on prices is also presented. Prepared data were then imported to the R software program for regression analysis. The selection of the best model and the validation procedure is described, and the deterministic and stochastic forms of the regression models for the two types of equipment, graders and trucks, are presented.

5.2 Data Collection

The data of 92 graders and 99 trucks were collected from Iowa counties in the form of cost reports and equipment management files. Table 5.1 presents the counties that provided data, the format of the data, the number of units in each county, and whether the data is historical.

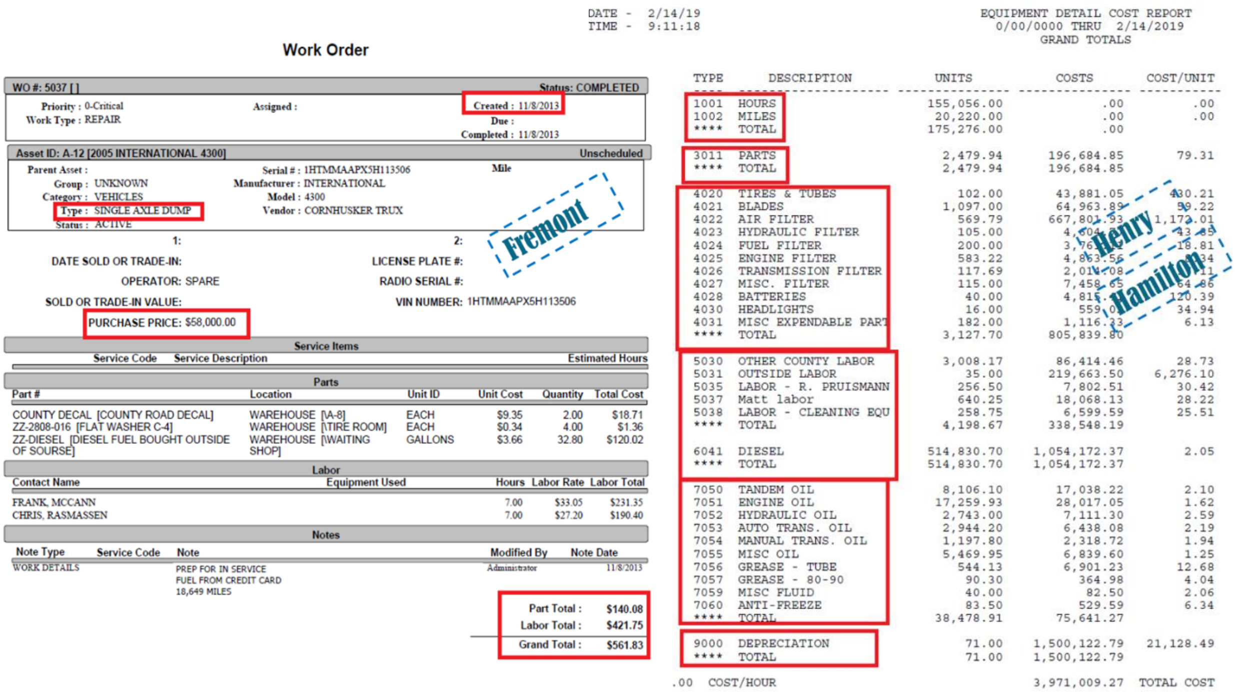
Table 5.1. Summary statistics for data of equipment management in counties

Titles		Hamilton	Henry	Fremont	Winnebago	Story	Madison	Marion	Audubon	Mills	Total
		Counties									
Data format		PDF (Cost report)	PDF (Cost report)	PDF (Work order)	Database files	PDF (Cost report)	Spreadsheet	Spreadsheet	Spreadsheet	Spreadsheet	
#s	Graders	11	9	7	11	9	17	13	9	6	92
	Trucks	4	10	10	15	-	43	-	17	-	99
Historical data		✓	✓	✓	✓	✓	×	×	×	×	

Historical data means that the data was available during the equipment utilization period while non-historical data means that the data was available only at a particular time. For example, Hamilton County provided historical data in the form of equipment cost reports in PDF format for 11 graders and 4 trucks since 1996.

5.3 Data Reading and Processing

Figure 5.1 shows different raw data formats and the respective counties.



Work Order

WO #: 5037 [ ] Status: COMPLETED

Priority : 0-Critical Assigned : Created : 11/8/2013
Work Type : REPAIR Due :
Completed : 11/8/2013

Asset ID: A-12 [2005 INTERNATIONAL 4300] Unscheduled

Parent Asset : Serial # : 1HTMMAAPX5H113506 Mile
Group : UNKNOWN Manufacturer : INTERNATIONAL
Category : VEHICLES Model : 4300
Type : SINGLE AXLE DUMP Vendor : CORNHUSKER TRUX
Status : ACTIVE

1: 2:

DATE SOLD OR TRADE-IN: LICENSE PLATE #:
OPERATOR: SPARE RADIO SERIAL #:
SOLD OR TRADE-IN VALUE: VIN NUMBER: 1HTMMAAPX5H113506
PURCHASE PRICE: $58,000.00

Service Items

Service Code	Service Description	Estimated Hours

Parts

Part #	Location	Unit ID	Unit Cost	Quantity	Total Cost
COUNTY DECAL [COUNTY ROAD DECAL]	WAREHOUSE [\A-8]	EACH	$9.35	2.00	$18.71
ZZ-2808-016 [FLAT WASHER C-4]	WAREHOUSE [\TIRE ROOM]	EACH	$0.34	4.00	$1.36
ZZ-DIESEL [DIESEL FUEL BOUGHT OUTSIDE OF SOURSE]	WAREHOUSE [\WAITING SHOP]	GALLONS	$3.66	32.80	$120.02

Labor

Contact Name	Equipment Used	Hours	Labor Rate	Labor Total
FRANK, MCCANN		7.00	$33.05	$231.35
CHRIS, RASMASSEN		7.00	$27.20	$190.40

Notes

Note Type	Service Code	Note	Modified By	Note Date
WORK DETAILS		PREP FOR IN SERVICE FUEL FROM CREDIT CARD 18,649 MILES	Administrator	11/8/2013

Part Total : $140.08
Labor Total : $421.75
Grand Total : $561.83

DATE - 2/14/19
TIME - 9:11:18

EQUIPMENT DETAIL COST REPORT
0/00/0000 THRU 2/14/2019
GRAND TOTALS

TYPE	DESCRIPTION	UNITS	COSTS	COST/UNIT
1001	HOURS	155,056.00	.00	.00
1002	MILES	20,220.00	.00	.00
****	TOTAL	175,276.00	.00	
3011	PARTS	2,479.94	196,684.85	79.31
****	TOTAL	2,479.94	196,684.85	
4020	TIRES & TUBES	102.00	43,881.05	430.21
4021	BLADES	1,097.00	64,963.89	59.22
4022	AIR FILTER	569.79	667,801.93	1,172.01
4023	HYDRAULIC FILTER	105.00	[illegible]	43.85
4024	FUEL FILTER	200.00	[illegible]	18.81
4025	ENGINE FILTER	583.22	4,863.56	[illegible]
4026	TRANSMISSION FILTER	117.69	2,014.08	[illegible]
4027	MISC. FILTER	115.00	7,458.65	64.86
4028	BATTERIES	40.00	[illegible]	120.39
4030	HEADLIGHTS	16.00	[illegible]	34.94
4031	MISC EXPENDABLE PART	182.00	1,116.33	6.13
****	TOTAL	3,127.70	805,839.80	
5030	OTHER COUNTY LABOR	3,008.17	86,414.46	28.73
5031	OUTSIDE LABOR	35.00	219,663.50	6,276.10
5035	LABOR - R. PRUISMANN	256.50	7,802.51	30.42
5037	Matt labor	640.25	18,068.13	28.22
5038	LABOR - CLEANING EQU	258.75	6,599.59	25.51
****	TOTAL	4,198.67	338,548.19	
6041	DIESEL	514,830.70	1,054,172.37	2.05
****	TOTAL	514,830.70	1,054,172.37	
7050	TANDEM OIL	8,106.10	17,038.22	2.10
7051	ENGINE OIL	17,259.93	28,017.05	1.62
7052	HYDRAULIC OIL	2,743.00	7,111.30	2.59
7053	AUTO TRANS. OIL	2,944.20	6,438.08	2.19
7054	MANUAL TRANS. OIL	1,197.80	2,318.72	1.94
7055	MISC OIL	5,469.95	6,839.60	1.25
7056	GREASE - TUBE	544.13	6,901.23	12.68
7057	GREASE - 80-90	90.30	364.98	4.04
7059	MISC FLUID	40.00	82.50	2.06
7060	ANTI-FREEZE	83.50	529.59	6.34
****	TOTAL	38,478.91	75,641.27	
9000	DEPRECIATION	71.00	1,500,122.79	21,128.49
****	TOTAL	71.00	1,500,122.79	

.00 COST/HOUR 3,971,009.27 TOTAL COST

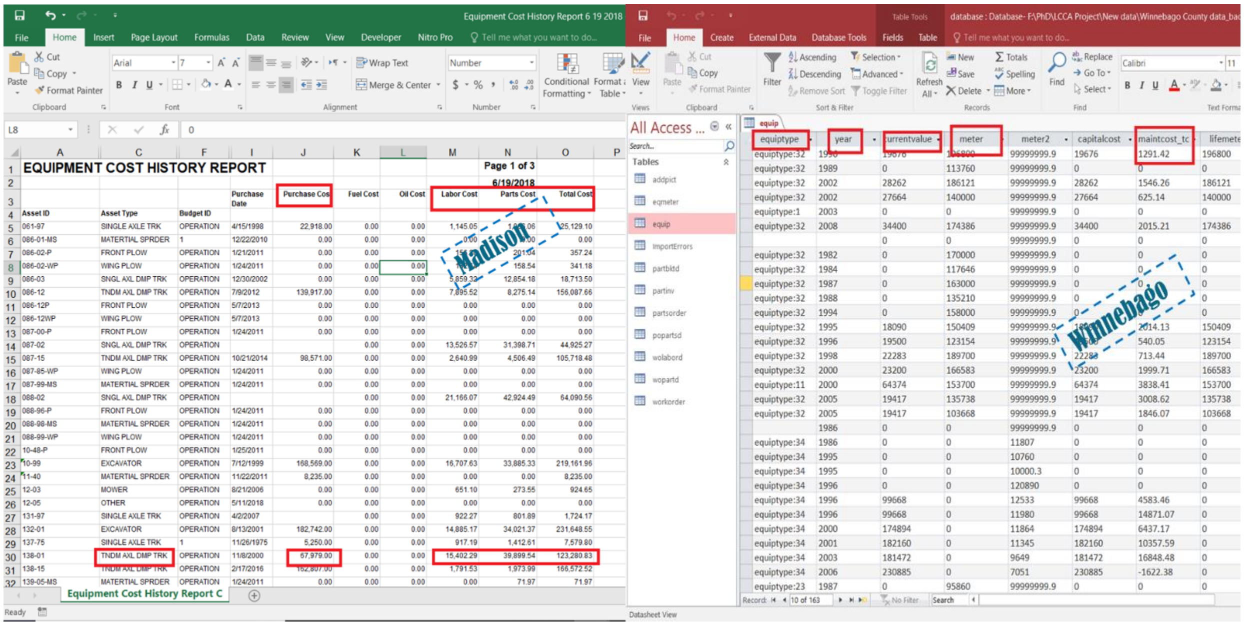


Figure 5.1. Different raw data of equipment management collected from counties of Fremont, Henry, Hamilton, Madison, and Winnebago

Required information for developing a LCCA tool is highlighted in the figure and were extracted from the raw data and entered into a spreadsheet. Due to the different types and formats of recorded data in counties, it took a significant amount of time for the research team to read and extract all the required data. Table 5.2 summarizes the information collected from the provided data.

Table 5.2. Equipment cost elements available in different counties

	Titles	Hamilton	Henry	Fremont	Winnebago	Story	Madison	Marion	Audubon	Mills
		Counties								
Equipment cost information	Working hours – mileage	✓	✓	×	✓	✓	×	✓	×	×
	Year	✓	✓	✓	×	✓	✓	✓	✓	✓
	Purchase price	×	×	✓	✓	×	✓	✓	✓	×
	Parts (engine and misc.)	✓	✓	×	×	✓	✓	✓	×	✓
	Blades, tires, and filters	✓	✓	×	×	✓	✓	✓	×	✓
	Labor	✓	✓	✓	×	✓	✓	✓	×	✓
	Diesel	✓	✓	×	×	✓	×	×	×	✓
	Oil	✓	✓	×	×	✓	×	×	×	✓
	Depreciation	✓	✓	×	×	✓	×	×	×	✓
	Total operation cost	✓	✓	✓	✓	✓	×	✓	×	✓

Some counties record equipment management data in more details (such as Henry and Hamilton). Table 5.3 represents different categories of equipment management data in these counties.

Table 5.3. Equipment maintenance information elements and description

Codes	Category	Description
*	Equipment description	Equipment number, type, and the model
*	Purchase price	The purchase price of the equipment
*	Purchase year	The time of equipment acquisition
1	Equipment usage	Cumulative working hours (for graders) or mileage (for trucks) at the time of maintenance activities
3	Equipment parts	Different repairable parts such as engine parts, brake parts, hoses & clamps, and miscellaneous parts
4	Replaceable parts	Regularly replaceable parts such as tires, filters, batteries, and blades
5	Labor	Wages for staff who repair the equipment
6	Diesel	The cost of fuel
7	Oil, grease, anti-freeze, etc.	The cost of different oils, grease, and anti-freeze
9	Depreciation	The amount of annual depreciation

Although the most accurate LCCA requires all the information included in Table 5.3, it was not possible to obtain this level of detail from all counties. Some counties don't collect data at this level or it was not feasible to extract this level of detail from the provided reports and files by the counties. Table 5.2 shows the equipment cost elements available in each county. According to this table, no county provides all the required information. A lot of missing information can be seen in this table.

Each cost item mentioned in Table 5.2 and Table 5.3 accounts for either ownership or operating cost. Ownership costs include purchase price and depreciation, while operating costs include equipment parts, replaceable parts, labor, diesel, oil, grease, anti-freeze, etc. (the codes of 3 to 6 in Table 5.3). Insurance and miscellaneous costs, a part of ownership costs, are not recorded in the cost reports. Also, the depreciation values and trade-in values are not accurately recorded in such reports. Since not all counties record data in detail, the research team decided to collect data at a general level. For example, Fremont and Winnebago counties do not collect operating costs in detail, but they collect the total operating cost (the last row of Table 5.2). The total operating cost can also be obtained from counties that collect data in more detail. Therefore, instead of breaking down the operating costs into detail, the total operating cost, which is obtainable from almost all counties, was collected and recorded for the LCCA. Table 5.4 is a sample spreadsheet created for data collection and shows the total maintenance cost along with other elements that were collected.

Table 5.4. A sample of the spreadsheet created for data collection

					Total maintenance cost					
					1st year		2nd year		Last year	
Equipment #	**County**	**Type**	**Purchase price**	**Purchase year**	Hours or mileage	Maintenance cost	Hours or mileage	Maintenance cost	Hours or mileage	Maintenance cost
770 GP	Fremont	Grader	$186,590	2016	-	$16,114	-	$34,174	-	$43,639
CAT 140H	Henry	Grader	-	2003	263	$454	1,504	$6,393	2,592	$24,190
0220 International	Hamilton	Truck	-	2017	18,445	$9,886	26,690	$12,441	-	-

Considering each row in Table 5.4 as one record, the total gathered data included 295 records of graders and 168 records of trucks belonging to 64 units of graders and 26 units of trucks mostly from 5 counties that provided historical data.

5.4 Data Preparation

Equipment management data, including operating cost information, acquisition year, and price, were transformed to spreadsheet format from the different counties' data formats. The next section explains how the missing data issues were handled and prepared for the data analysis.

5.4.1 Missing Data

Although some information such as operating costs is collected at a general level, there are still a significant amount of missing data (Table 5.2). For example, equipment purchase prices in Hamilton and the Henry counties and equipment working hours in Fremont County were missing. Missing data were estimated based on similar cases in other counties. For example, as shown in Figure 5.2, Henry County doesn't have purchase price information for a motor grader CAT 140H purchased in 2003.

Henry county						
EQUIPMENT # : CAT 140H 00P01 2003						
Year	2003	2004	2005	2006	2017	2018
Cum. Hours	263	1504	2592	3859	14695	15036
Total mainteneance cost	$ 454	$ 6,393	$ 24,190	$ 41,267	$ 236,702	239,790
Purchase price	?					

$ 176,500

Madison county		
Equipment description	Purchase date	Purchase price
Motor Grader CAT 140HV9TNO1464	7/28/2003	$ 176,500

Figure 5.2. A sample of filling missing data

There is a similar piece of equipment in Madison County that has a purchase price of $176,500. This price was considered for Henry County's grader to fill the missing data.

5.4.2 Anomalous Data

Anomalous data are recognized when the amount of one item significantly differs from most of the other items. For example, Figure 5.3 shows annual operating costs for a motor grader in Hamilton County.

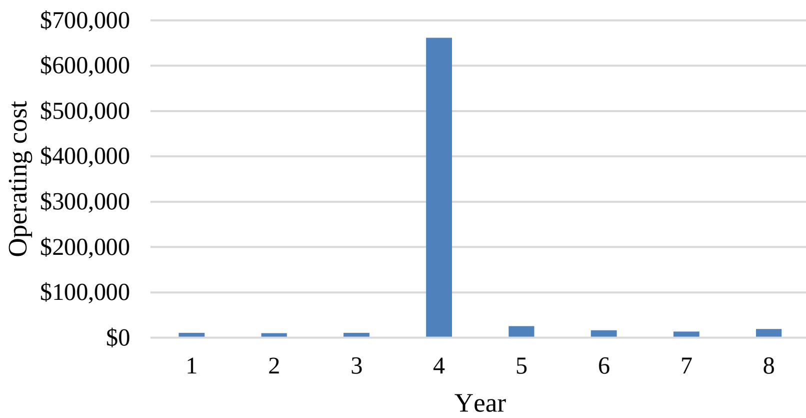


Figure 5.3. Annual operating cost for a motor grader in Hamilton County

Possible reasons for anomalies can be errors in recording data or may indicate an accident or another unpredictable event that caused a huge cost. In both cases, they significantly influence the regression model and need to be analyzed.

In this research, the cost prediction model aims to forecast predictable and normal costs, and the intention of the model is not to predict errors or other unpredictable situations. Therefore, anomalous data are eliminated in this research to make a clean database.

It can be seen that in the fourth year, the operating cost is suspected to be anomalous data. By reviewing Hamilton County's related cost report carefully, it was discovered that the cost of an air filter replacement was recorded as $647,724.34, which is unrealistic for an air filter and it must be an error (Figure 5.4).

7050	TANDEM OIL	136.00	345.44	2.54
7051	ENGINE OIL	58.00	79.21	1.37
7052	HYDRAULIC OIL	68.00	531.08	7.81
7053	AUTO TRANS. OIL	68.00	172.72	2.54
7055	MISC OIL	70.00	71.50	1.02
7056	GREASE - TUBE	1.00	3.80	3.80
****	TOTAL	401.00	1,203.75	
9000	DEPRECIATION	1.00	23,162.29	23,162.29
****	TOTAL	1.00	23,162.29	
35.56	COST/HOUR		31,789.11	TOTAL COST

EQUIPMENT # : 0190 MOTOR GRADER YEAR : 2005 CLASS : 32 LOCATION : WI

DATE	TYPE	PART NUMBER	UNITS	COST	DESCRIPTION
1/02/2015	4022		2.00	46.04	AIR FILTER
1/02/2015	4022		1.00	647,724.34	AIR FILTER
1/02/2015	4022		1.00	31.70	AIR FILTER
1/02/2015	5030		1.00	26.71	JOE W
1/06/2015	3011		1.00	130.32	PARTS

Figure 5.4. A part of the cost report of a motor grader in Hamilton County indicating anomalous data of a filter cost

To handle this issue, as Figure 5.4 shows, the cost of air filter replacement is obtained from similar cases ($23 and $31), and an estimated amount (the average of $23 and $31, which is $27) is considered for the anomalous data.

As another example of anomalous data, as Figure 5.5 shows, annual working hours for a motor grader in Hamilton County seems too high for the 12th year.

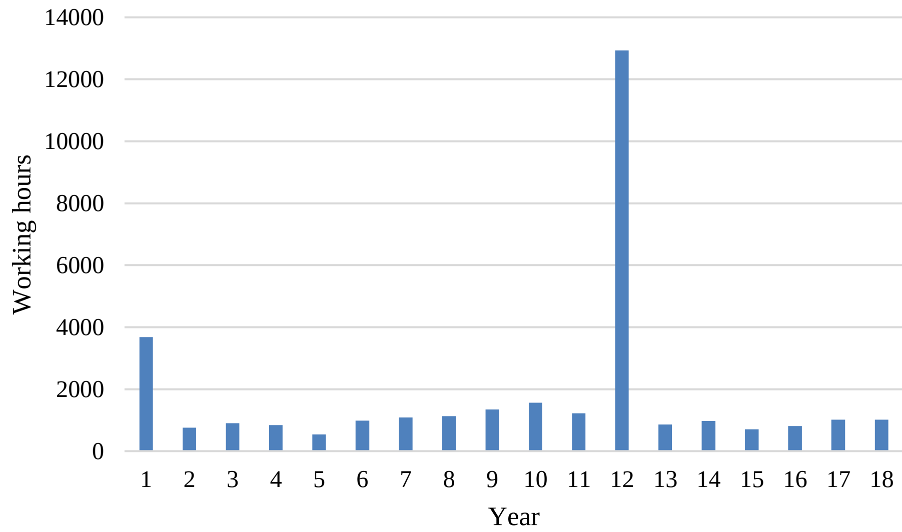


Figure 5.5. Annual working hours for a motor grader in Hamilton County

By referring to the related cost report (Figure 5.6), it is revealed that working hours for the 12th year is recorded as 12,931, while the average annual working hours for that motor grader is about 1,200.

EQUIPMENT # : 0040 MOTOR GRADER YEAR : 1997 CLASS : 32 LOCATION : WC

TYPE	DESCRIPTION	UNITS	COSTS	COST/UNIT
1001	HOURS	12,931.00	.00	.00
****	TOTAL	12,931.00	.00	
4022	AIR FILTER	6.00	231.29	38.55
4023	HYDRAULIC FILTER	1.00	9.43	9.43
4024	FUEL FILTER	1.00	5.20	5.20
4025	ENGINE FILTER	5.00	30.17	6.03
4026	TRANSMISSION FILTER	1.00	5.84	5.84
****	TOTAL	14.00	281.93	
5030	OTHER COUNTY LABOR	21.00	560.92	26.71
****	TOTAL	21.00	560.92	
6041	DIESEL	2,970.00	9,889.07	3.33
****	TOTAL	2,970.00	9,889.07	
7050	TANDEM OIL	136.00	327.76	2.41
7051	ENGINE OIL	113.00	334.60	2.96
7052	HYDRAULIC OIL	400.00	86.80	.22
7053	AUTO TRANS. OIL	48.00	115.68	2.41
7055	MISC OIL	8.00	17.44	2.18
7056	GREASE - TUBE	3.25	15.37	4.73
****	TOTAL	708.25	897.65	
.90	COST/HOUR		11,629.57	TOTAL COST

Figure 5.6. A part of the cost report of a motor grader in Hamilton County indicating anomalous data of working hours

It may have occurred as the result of an error in recording data. To handle this issue, the working hours for the motor grader was replaced with 1,200 hours for the 12th year. These examples of anomalous data are an indicator of other potential errors that might not have been caught in the data cleaning process.

5.5 Cost Adjustment

Figure 5.7 shows the year-based operating costs for 10 trucks of Fremont County.

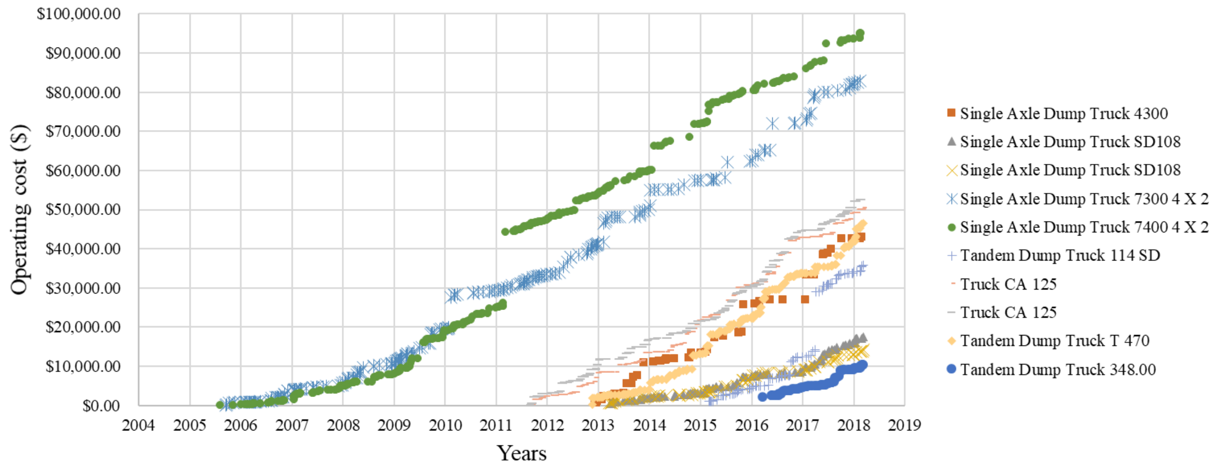


Figure 5.7. Year-based operating cost for 10 trucks of Fremont County

In order to develop a model that captures equipment usage as an input and estimates the associated operating cost, the historical operating cost data was required to be converted from year-based to age-based. That meant shifting all the curves in Figure 5.7 to a base time to have the operating cost based on the age of equipment (Figure 5.8 and 5.9).

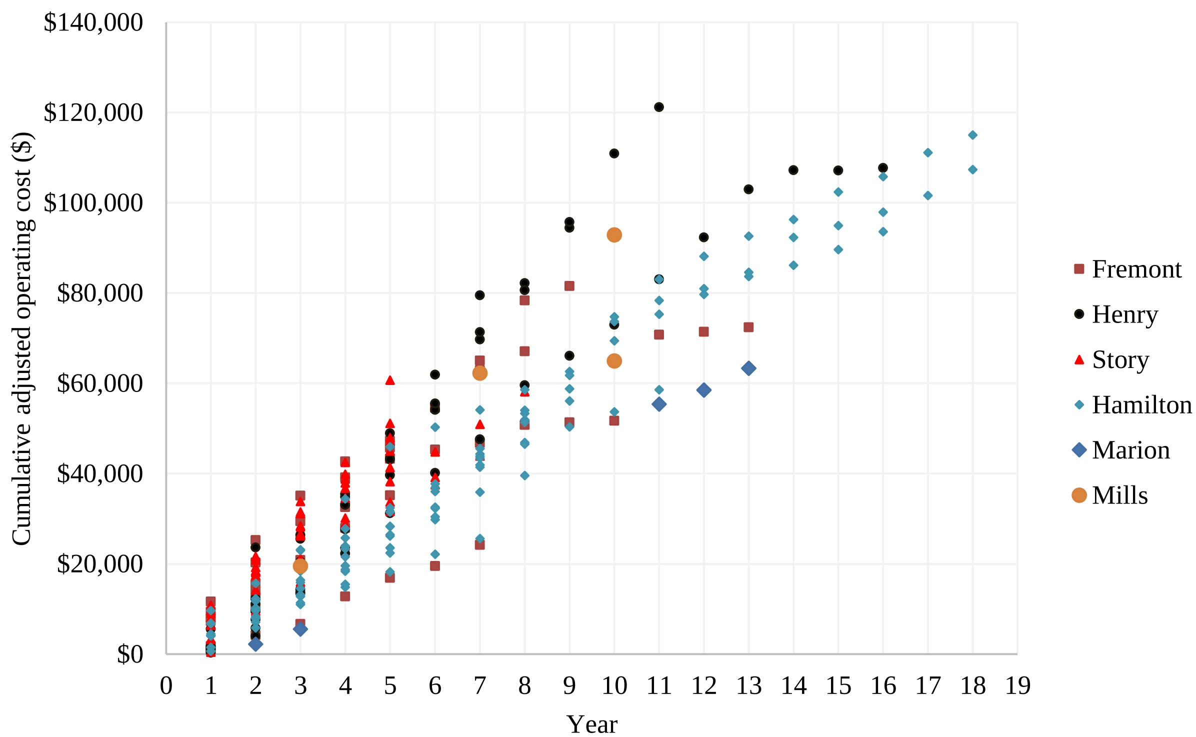


Figure 5.8. Age-based adjusted operating cost of the motor grader database

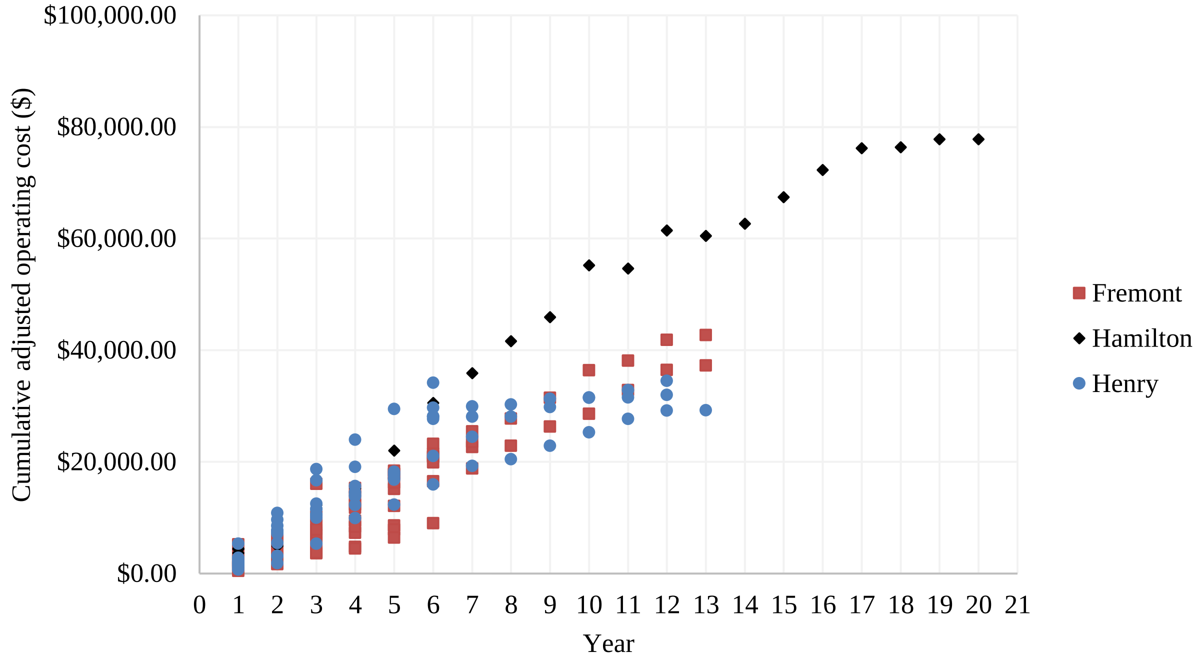


Figure 5.9. Age-based adjusted operating cost of the truck database

However, costs incurred at different times and the dollar value of events in earlier years are typically less than they are in later years due to inflation. Thus, the maintenance cost data should be adjusted for inflation. To adjust these costs, the construction machinery and equipment price index was used in this project.

5.5.1 Construction Machinery and Equipment Price Index (CMEPI)

The price index is an annual normalized average price for a given type of goods or service. It is used to adjust prices in different years to a common base year. In this project, price indexes were used to normalize costs in different years and remove the impact of inflation on prices. Federal Reserve Economic Data (FRED 2019) publishes the construction machinery and equipment price index considering the year of 1982 as the base year (Table 5.5).

Table 5.5. Construction machinery and equipment price index

Year	CMEPI	Year	CMEPI
1982	100.0	2001	149.9
1983	102.4	2002	150.6
1984	103.8	2003	153.3
1985	105.4	2004	158.5
1986	106.7	2005	168.3
1987	108.9	2006	175.5
1988	111.8	2007	179.6
1989	117.2	2008	185.4
1990	121.6	2009	191.0
1991	125.2	2010	191.4
1992	128.7	2011	197.4
1993	132.0	2012	205.4
1994	133.7	2013	210.7
1995	136.7	2014	214.3
1996	139.9	2015	216.9
1997	142.2	2016	218.9
1998	145.2	2017	220.8
1999	147.8	2018	222.5
2000	148.5		

Source: FRED 2019

FRED collects monetary data and all the revisions in real time from U.S. Bureau of Economic Analysis, U.S. Bureau of Labor Statistics, and U.S. Census Bureau to provide precise data that can be used for specific purposes such as equipment management planning. To adjust LCC using the price indexes, equation 5.1 is used:

$$\text{Adjusted price} = \text{Current price} \times \frac{PI_b}{PI_c} \qquad (5.1)$$

where, PI_b is the CMEPI in the base year (for example, for the base year of 1982, the CMEPI is 100), and PI_c is the CMEPI in the current year.

5.5.2 Adjusted Age-Based Equipment Operating Cost

After adjusting all the costs using price indexes, all of the data points representing the age of equipment and corresponding operating costs for each equipment type were gathered together. Figure 5.8 and 5.9 illustrate age-based adjusted operating cost for all 64 graders and 26 trucks, respectively, and indicate the respective county of each grader. A large variance in equipment operating cost can be recognized from Figure 5.8 and 5.9. The next section discusses this issue.

5.5.3 Large Variance of Data Points

Although all the equipment units belong to Iowa counties with similar road maintenance activities, a wide range of values of operating cost for each year can be recognized from Figure 5.8 and 5.9. For example, as shown in Figure 5.8, for graders in the 10th year, the cost varies between $55,000 and $110,000 (almost twice). One possible reason is that the repair cost of a piece of equipment is proportional to the price of the equipment. More expensive pieces of equipment tend to have more expensive repair costs. Therefore, to deal with the issue of large variance, the cumulative operating cost was divided by the purchase price and then adjusted using CMEPI to be considered as the response. Figure 5.10 shows the adjusted operating cost per purchase price for graders.

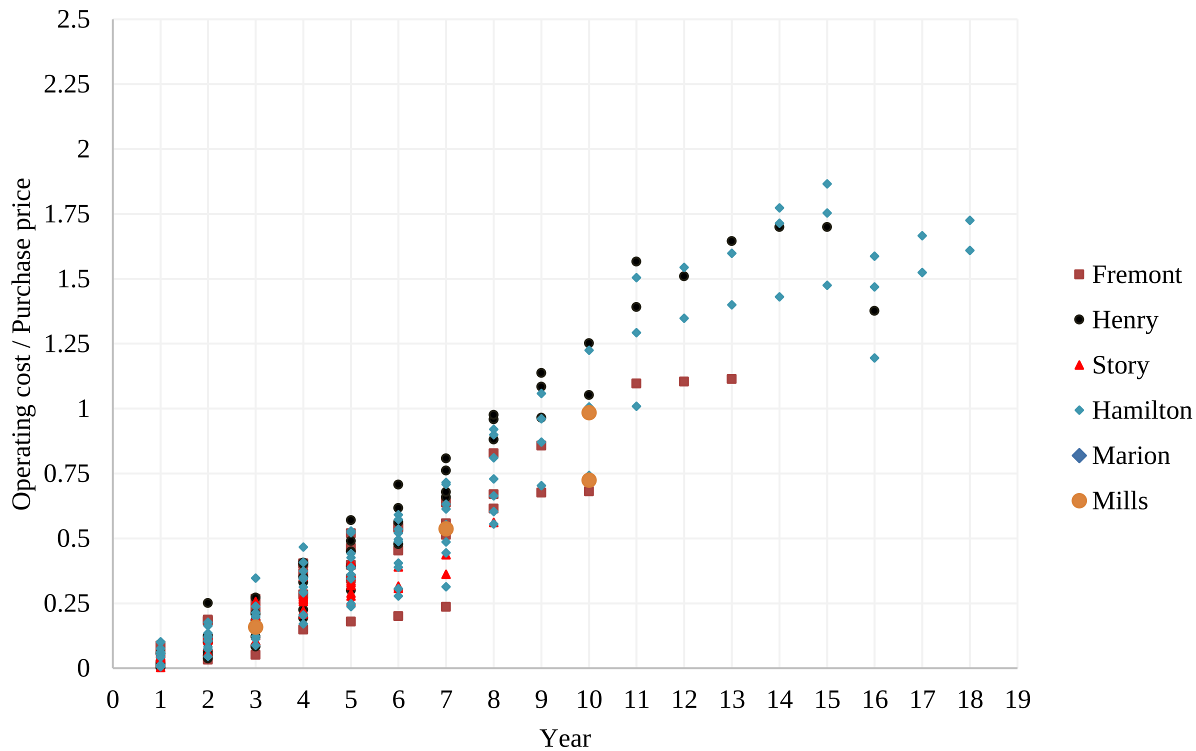


Figure 5.10. Age-based adjusted operating cost per purchase price for graders

It can be seen that the variance problem is alleviated. For example, in Figure 5.10, the ratio of adjusted operating cost per purchase price in the 10th year varies from 0.75 to 1.25 (1.6 times), indicating lower variance.

In addition, considering equipment age as a predictor variable is not accurate enough, because equipment usage varies in different years. There may be a piece of equipment that does not get used in one year but works a lot in another year. The operating cost is proportional to the amount of equipment operation rather than the age of equipment. Therefore, equipment usage must have a stronger correlation with the operating cost. Figure 5.11 illustrates adjusted operating cost per purchase price based on working hours for graders.

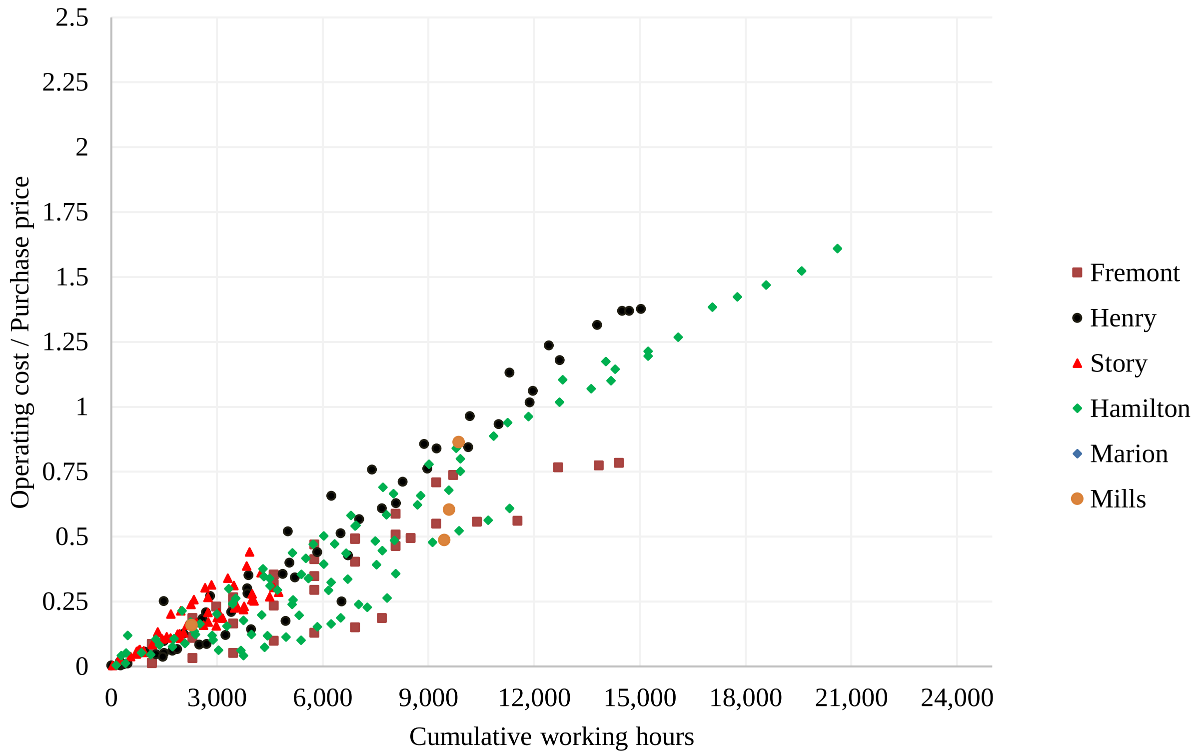


Figure 5.11. Adjusted operating cost per purchase price based on working hours for graders

It can be seen that the variance decreases in these cases. The next subsection explains mathematically how changing predictors and the response variables improves the correlation.

5.6 Data Analysis

The intention of data analysis was to develop cost forecasting models that are able to predict the ownership and operating cost of motor graders and trucks. The following section describes the regression analysis approach and the method of selecting the best regression model.

5.6.1 Regression Analysis

Regression analysis is a statistical method adopted to identify the relationship between one or more predictor variables and a response variable with a mathematical equation that is derived from the data. Based on different forms of predictors and the response, the regression analysis includes simple linear regression, multiple linear regression, and nonlinear regression (James et al. 2013).

In this research project, all of the analysis approaches were used and then the best model was selected based on assessing the association between the predictors and the response, goodness-of-fit of the regression model to the data, and its prediction abilities.

The association between predictors and response is measured based on the F-statistic of the model and P-value of the predictors. For a regression model, a large F-statistic of a model indicates that there is a relationship between predictors and the response. P-value is measured for each predictor, and a small P-value for each predictor indicates there is a relationship between the predictor and the response. The goodness-of-fit is measured by adjusted R2, in which the highest R2 specifies the best fit of the model to the data. The overall data set in this research was divided into two parts: the training part (80% of the data set) and the testing part (20% of the overall data set). F-statistic, P-values, and R2 were performed in the training data set. The prediction ability was measured on the test data set using mean square error (MSE). This research used the R software program for programming and conducting regression analysis.

There are two main predictor variables for the two types of equipment. For the graders, they are (1) the age of equipment and (2) equipment working hours. For the trucks, they are (1) the age of equipment and (2) equipment mileage. Also, two types of response can be considered: (1) the total operating cost and (2) total operating cost per purchase price. Different combination forms of predictors and responses, including linear and nonlinear, were considered for determining the best performing regression models. Table 5.6 summarizes the different variables for regression analysis, and Table 5.7 lists the different possible forms of regression models.

Table 5.6. Elements of predictors and responses for regression analysis

Equipment type	Predictors	Responses
Grader	Age Working hours (Hrs)	Total operating cost (OC) Total operating cost per purchase price (OC/PP)
Truck	Age Mileage (Mlg)	Total operating cost (OC) Total operating cost per purchase price (OC/PP)

Table 5.7. Alternative regression models

Number	Algebraic form of regression model
1	*Grader OC* = $\beta_0 + \beta_1.Age + \beta_2.Hrs$
2	*Grader OC* = $\beta_0 + \beta_1.Age + \beta_2.Age^2 + \beta_3.Hrs + \beta_4.Hrs^2$
3	*Grader OC/PP* = $\beta_0 + \beta_1.Age + \beta_2.Hrs$
4	*Grader OC/PP* = $\beta_0 + \beta_1.Age + \beta_2.Age^2 + \beta_3.Hrs + \beta_4.Hrs^2$
5	*Grader OC/PP* = $\beta_0 + \beta_1.Age + \beta_2.Age^2$
6	*Grader OC/PP* = $\beta_1.Hrs + \beta_2.Hrs^2$
7	*Truck OC* = $\beta_0 + \beta_1.Age + \beta_2.Mlg$
8	*Truck OC* = $\beta_0 + \beta_1.Age + \beta_2.Age^2 + \beta_3.Mlg + \beta_4.Mlg^2$
9	*Truck OC/PP* = $\beta_0 + \beta_1.Age + \beta_2.Mlg$
10	*Truck OC/PP* = $\beta_0 + \beta_1.Age + \beta_2.Age^2 + \beta_3.Mlg + \beta_4.Mlg^2$
11	*Truck OC/PP* = $\beta_0 + \beta_1.Age + \beta_2.Age^2$
12	*Truck OC/PP* = $\beta_0 + \beta_1.Mlg + \beta_2.Mlg^2$

OC: Operating cost, OC/PP: Operating cost per purchase price, Hrs: Working hours, Mlg: Mileage

All the possible regression forms were assessed, and the best model for each type of equipment was selected.

5.6.2 Prediction Models

Given a clear data set after data preparation, a regression analysis was performed to assess alternative regression models mentioned in Table 5.7. Two clear databases for graders and trucks were imported to the R software program for regression analysis. In Table 5.8, all the regression forms and the measurements are illustrated.

Table 5.8. F-statistic, adjusted R^2, P-values, and MSE of alternative regression models

Model #	Response	Measurements on training data set												Measure-ment on test data set
		F-statistic	Adjusted R2	β0		β1		β2		β3		β4		
				Amt	P-value	Amt	P-value	Amt	P-value	Amt	P-value	Amt	P-value	MSE
G1	Grader OC	593.1	0.816	10430	0.0109	9.65	0.0044	2679	2.00E-16	-	-	-	-	964,491,228
G2	Grader OC	317.9	0.826	-5278	0.20713	15730	3.65E-06	-638	4.51E-05	2.629	0.12367	0.0002	0.00375	984,415,038
G3	Grader OC/PP	731.2	0.8454	-0.0051	0.707	-0.01487	0.179	8.9E-05	<2e-16	-	-	-	-	0.0316
G4	Grader OC/PP	367	0.8458	-0.0295	0.178	0.02134	0.299	-0.00153	0.112	6.2E-05	4.32E-06	8E-10	0.247	0.0321
G5	Grader OC/PP	228.8	0.6305	-0.0582	0.139	0.079643	8.14E-07	0.00191	0.27	-	-	-	-	0.0756
G6	Grader OC/PP	727.3	0.8447	0.00605	0.597	6.74E-05	<2e-16	5.4E-10	0.0444	-	-	-	-	0.0317
T1	Truck OC	280.9	0.8284	-3065.3	0.0868	0.2234	8.29E-12	4036.8	1.33E-07	-	-	-	-	104,889,949
T2	Truck OC	143.3	0.8307	-4119	0.1529	6753	3.96E-05	-192.2	0.0696	0.06743	0.521	8E-07	0.1423	97,131,210
T3	Truck OC/PP	501	0.8961	-0.049	0.00181	0.05855	<2e-16	1.64E-06	5.48E-06	-	-	-	-	0.0065
T4	Truck OC/PP	274	0.904	-0.0525	0.03025	0.09619	4.76E-11	-0.00267	0.00292	-9E-07	0.29207	1E-11	0.00338	0.0054
T5	Truck OC/PP	436	0.8824	-0.0767	0.00276	0.102034	2.00E-16	-0.00196	1.01E-02	-	-	-	-	0.0086
T6	Truck OC/PP	175.4	0.7504	0.00924	0.795	4.17E-06	6.72E-05	7E-12	0.232	-	-	-	-	0.0174

For each predictor, the value of the coefficient of the predictor and the respective P-value are presented. In this table, measurements on the training data set determine whether predictors are associated with the response (F-statistic), the goodness of fit (adjusted R2), and the relationship between each predictor and the response (P-value). On the other hand, measurements on the test data set (MSE) validate the model and assess the prediction ability of the model.

The table is categorized into two sections for each type of equipment: the first six models belong to graders and the remaining six models belong to trucks. In each section, the response of the first two models is the equipment operating cost, and the response of the remaining four models is the operating cost per purchase price. The MSE is comparable among models with the same type of response.

All models have a large F-statistic indicating a relationship between predictors and the response. In each of the two sections, by changing the response from operating cost to the ratio of operating cost per purchase price, the goodness-of-fit was slightly improved. This conclusion is compatible with the fact that operational expenditures and maintenance costs of equipment are proportional with the price of equipment. For the graders, among the models of G3 to G6, the model of G6 had the lowest P-values, high adjusted R2, and low MSE, which was selected as the final grader regression model. Similarly, for the trucks, among the models of T3 to T6, the model of T4 had the highest R2, lowest P-values, and lowest MSE. The final regression models are represented as equations 5.2 and 5.3 for the graders and trucks, respectively.

$$\text{Grader's operating cost/purchase price} = 0.00605 + 0.0000674 \times (\text{Hours}) + 5.364e-10 \times (\text{Hours}^2) \quad (5.2)$$

$$\text{Truck's operating cost/purchase price} = -0.0525 + 0.909619 \times (\text{Age}) - 0.00267 \times (\text{Age}^2) - 9.27e\text{-}07 \times (\text{Mileage}) + 1.35\, e^{-11} \times (\text{Mileage}^2) \quad (5.3)$$

5.6.3 Deterministic and Stochastic Models

Equation 5.2 and 5.3 illustrate deterministic correlation between equipment usage variables and operating cost. For example, equation 5.2 captures working hours of graders and yields a single value as operating cost per purchase cost. However, estimating a single value cannot reflect the real practice due to uncertainties associated with the real practice. Stochastic regression models are able to better represent the uncertainties by considering probabilistic distribution of variables. The stochastic models determine confidence intervals, which are lower and upper limits, in which the true value of response lies within a range of confidence levels. Using a clean data set, the R software program was used to provide stochastic models to determine upper and lower limits. Equations 5.4 to 5.7 determines upper and lower bounds for graders and trucks with 95% level of confidence computed from the data set.

$$\text{Upper bound for Grader's operating cost/purchase price} = 0.00553 + 7.91e^{-5} \times (\text{Hours}) + 9.7e^{-10} \times (\text{Hours}^2) \quad (5.4)$$

Lower bound for Grader's operating cost/purchase price = –0.0434 + 5.57 e^{-5} × (Hours) + 1.0e^{-10} × ($Hours^2$) (5.5)

Upper bound for Truck's operating cost/purchase price = –0.0051 + 0.122× (Age) – 0.000931 × (Age^2) +8.08e^{-7}× (Mileage)+ 2.24 e^{-11}× ($Mileage^2$) (5.6)

Lower bound for Truck's operating cost/purchase price = –0.099 + 0.07× (Age) –0.0044 × (Age^2) –2.66 e^{-6}× (Mileage)+ 4357 e^{-12}× ($Mileage^2$) (5.7)

where,
Hours = cumulative equipment working hours
Mileage = cumulative equipment mileage
Age = equipment age in years

To illustrate the concept, Figure 5.12 shows the upper and lower bound and the main curve of the grader model on the grader's data points.

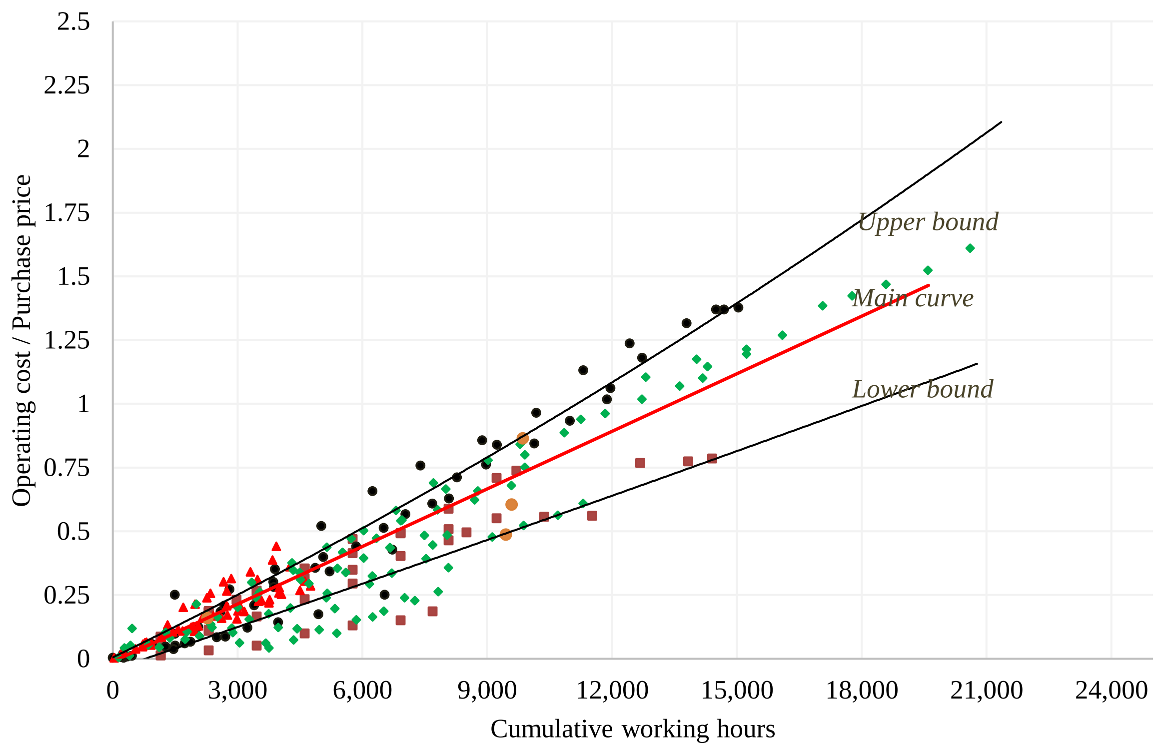


Figure 5.12. Grader regression model and the upper and lower bond on the grader data set

5.6.4 Linear Pattern Issue

According to equations 5.2 to 5.7, the coefficient values of nonlinear form of predictors are too small, which make the equations almost linear. Figure 5.12 also illustrates the linear correlation.

However, the linear growth of cumulative operating cost indicates that the hourly operation cost remains the same over time as the linear function derivative is a constant value. A constant hourly operating cost does not represent the real practice of equipment operation, because the cost of maintaining the equipment tends to increase over time due to deteriorating condition of the equipment. Research studies also confirm this fact by identifying polynomial equations for operating cost (Mitchell et al. 2011, Vance et al. 2014, Bayzid et al. 2016). However, the almost linear equations from the equipment data provided by counties do not support this fact. A possible reason is that counties tend to replace their equipment before the operating cost increases significantly. Therefore, the data points that represent high working hours and high operating cost are not available. From the interview analysis, it was revealed that counties tend to replace their graders after 10,000 to 15,000 working hours. The graders' data points in Figure 5.12 confirm this finding and show that most of the data points are available in the early life of graders, decrease with increasing working hours of equipment, and sparse after 15,000 working hours.

To obtain a polynomial regression model from available data points, the bootstrap resampling technique was used. Bootstrapping is a powerful statistical tool that can be used when there are uncertainties associated with parameters of the problem under study and has been used widely for cost estimation purposes (Sonmez 2008, Tsai and Li 2008, Sonmez 2011, Gardner et al. 2017). Bootstrap takes a random sample from the data set multiple times and performs a regression model on the sample data each time. Each regression model is recorded, and the best polynomial form of model that has a good fit to the data set is selected. Figure 5.13 shows the derived equation using this technique for graders.

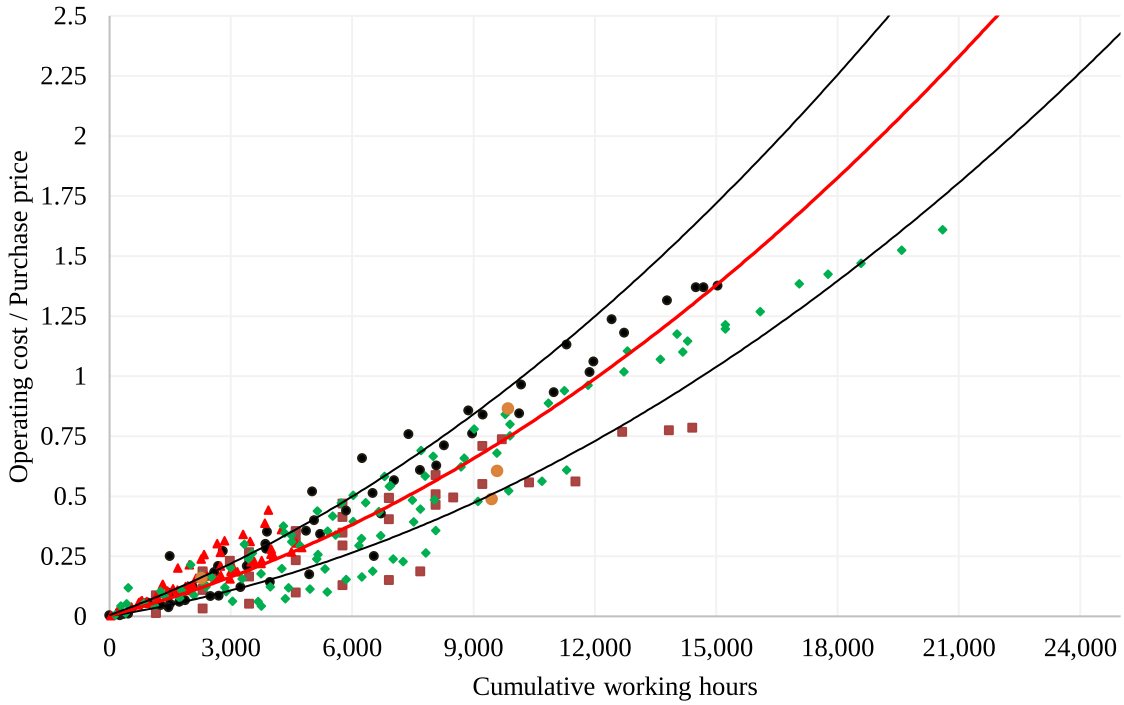


Figure 5.13. Bootstrapping on grader data set to obtain polynomial equations

5.7 Estimated Trade-In Values

As mentioned in Section 2.5.2, equipment is subject to depreciation as it operates, and the monetary value of equipment decreases gradually over time. In each year, the original value minus the depreciation value yields the salvage value or trade-in value. The annual trade-in value is usually considered as a declining curve across the equipment life. Based on the data collected from Iowa counties, it was found that the county engineers do not collect trade-in values precisely. Therefore, it was decided to estimate trade-in values based on literature and then validate it through discussion with experts. Lucko (2003) collected a great amount of historical trade-in data from four main manufactures: Caterpillar Inc., Deere & Company, Komatsu Ltd., and Volvo Group. Lucko analyzed 1,499 graders from 0–149 horsepower (HP) to 150+ HP as well as 3,105 trucks including different types and sizes of trucks. By analyzing the data, Lucko provided ratios of trade-in values per original purchase price for several equipment types at ages 0 to 15 years.

Based on Lucko's results and considering current graders and trucks in counties with different sizes, trade-in values were derived. For validation, the values were discussed with experts from Caterpillar in Iowa, and they confirmed the values. To more accurately address different trade-in values associated with different equipment sizes in each equipment type and other uncertainties, a beta-PERT distribution was used to determine a minimum, most likely, and maximum trade-in value for each year (Table 5.9).

Table 5.9. Estimated trade-in values for graders and trucks

Age (year)	Trade-in values for graders			Trade-in values for trucks		
	Minimum	Most likely	Maximum	Minimum	Most likely	Maximum
1	54.44%	62.69%	70.94%	69.00%	75.00%	81.00%
2	38.50%	46.50%	54.50%	60.62%	66.42%	72.22%
3	31.29%	39.04%	46.79%	44.98%	50.58%	56.18%
4	26.99%	34.49%	41.99%	36.29%	41.69%	47.09%
5	24.08%	31.33%	38.58%	30.68%	35.88%	41.08%
6	21.96%	28.96%	35.96%	26.75%	31.75%	36.75%
7	20.35%	27.10%	33.85%	23.82%	28.62%	33.42%
8	19.08%	25.58%	32.08%	21.57%	26.17%	30.77%
9	18.32%	24.32%	30.32%	19.77%	24.17%	28.57%
10	17.74%	23.24%	28.74%	18.32%	22.52%	26.72%
11	17.30%	22.30%	27.30%	17.12%	21.12%	25.12%
12	16.98%	21.48%	25.98%	16.13%	19.93%	23.73%
13	16.75%	20.75%	24.75%	15.28%	18.88%	22.48%
14	16.60%	20.10%	23.60%	14.56%	17.96%	21.36%
15	16.51%	19.51%	22.51%	13.95%	17.15%	20.35%
16	16.48%	18.98%	21.48%	13.42%	16.42%	19.42%
17	16.49%	18.49%	20.49%	12.97%	15.77%	18.57%
18	16.54%	18.04%	19.54%	12.57%	15.17%	17.77%
19	16.62%	17.62%	18.62%	12.23%	14.63%	17.03%
20	16.74%	17.24%	17.74%	11.94%	14.14%	16.34%
21	-	-	-	11.68%	13.68%	15.68%
22	-	-	-	11.46%	13.26%	15.06%
23	-	-	-	11.27%	12.87%	14.47%
24	-	-	-	11.11%	12.51%	13.91%
25	-	-	-	10.97%	12.17%	13.37%

Figure 5.14 illustrates the exponential decline of trade-in values with the greatest decrease in value occurring in the first years followed by a steady decrease in the remaining years.

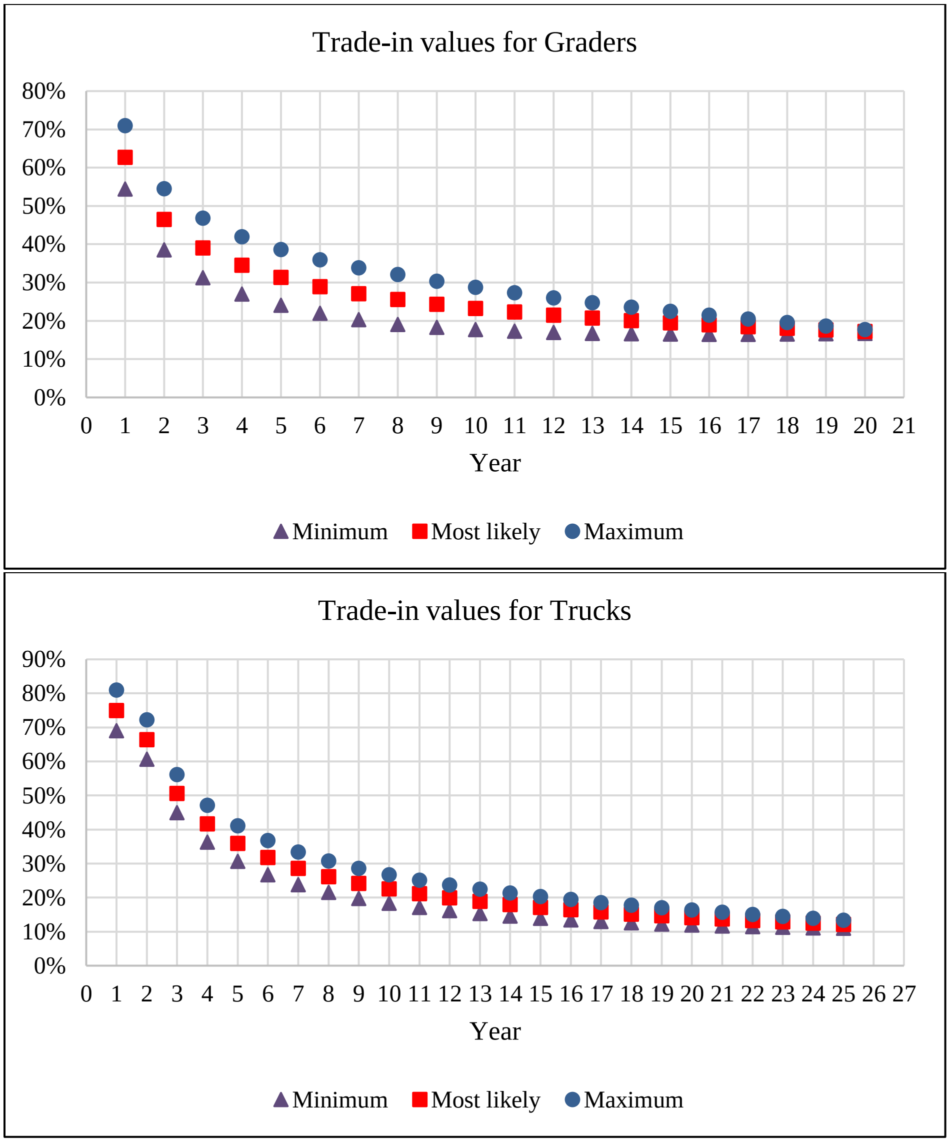


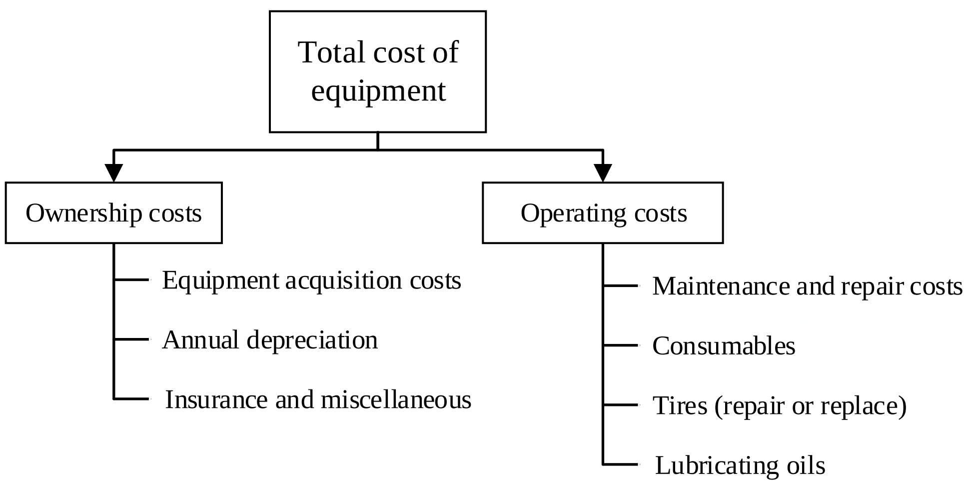
Figure 5.14. Visual representation of estimated trade-in values for graders and trucks

CHAPTER 6. PROPOSED TEMPLATE FOR DATA-DRIVEN EQUIPMENT RECORD KEEPING

The accuracy of the equipment LCCA relies on the quantity and quality of historical data. A reliable template for equipment record keeping will enable counties to collect their equipment data in a way that is suitable for data analysis and can be used to support future decisions. To develop a template for this purpose, all the current record-keeping practices were collected and reviewed to select the best practice that address the LCCA requirements. This chapter discusses the current record-keeping assessment and introduces the proposed record-keeping template.

6.1 Ideal Equipment Record Keeping Requirements

As discussed in the literature review section, the total cost of equipment can be divided into two general categories of ownership and operating costs. Figure 6.1 illustrates the breakdown of the total cost of equipment.



Sources: Gransberg et al. 2006, Schaufelberger and Migliaccio 2019

Figure 6.1. Types of ownership and operating costs

In this research study, due to the lack of full details in the records, a more general level of detail in cost items were used to identify the correlation between equipment usage and costs. However, to fully implement a data-driven LCCA, in which historical data is used to predict future costs, it is necessary to collect all the cost items mentioned in Figure 6.1 in detail, because different cost items may have different correlation with equipment usage or other predictors. For example, in consumable costs, fuel price does not follow similar trends as repair cost of the equipment. Several global economic factors affect the fuel price over time, and it is required to predict the fuel price using different methods separately.

6.2 Current Record Keeping Practices Assessment

Current record keeping practices in Iowa counties were collected and reviewed to select the best practice to address the LCCA requirements. As shown in Table 5.2, Henry County captures most of the data required for LCCA. Therefore, its practice was selected and modified to develop a spreadsheet template for record keeping.

6.3 Proposed Equipment Record Keeping Template

The proposed template considers the current best practice of equipment record keeping, while addressing the primary items typically necessary for equipment LCCA. Figure 6.2 shows a summary form of the template using sample data from a grader in Henry County, and Table 6.1 summarizes different cost items of the template.

Equipment data Record Keeping Template

Date: *02/06/2019* As of: *12/31/2018*

Equipment information

Equipment #: *00P01* *CAT 140H Grader* Year: *2003* Class: *15* Purchase price: *$ 120,000*

Expense detail

Code Description	<-------- Month to date -------->			<-------- Year to date -------->			<-------- Life to date -------->		
	Units	Costs	Cost/Unit	Units	Costs	Cost/Unit	Units	Costs	Cost/Unit
**** Equipment usage total	20.00			205.00			15,036.00		
**** Equipment parts total				3.00	$ 338.79		431.00	$ 18,619.06	
**** Replaceable parts total	8.00	$ 147.26		12.00	$ 639.55		388.00	$ 29,169.96	
**** Labor total	2.50	$ 91.65		9.50	$ 340.10		790.75	$ 25,738.58	
**** Diesel total				248.39	$ 517.49		64,901.60	$ 157,817.47	
**** Oil, grease, and anti-freeze total	9.00	$ 52.20		9.00	$ 52.20		1,326.00	$ 7,222.10	
**** Depreciation total							15.00	$ 162,223.00	
**** Ins. and misc. total	60.00	$ 400.00		36.00	$ 6,000.00		45.00	$ 99,000.00	
* **Operating cost**		$ 291.11			$ 1,888.13			$ 238,567.17	
* **Ownership cost**		$ 400.00			$ 6,000.00			$ 261,223.00	
* **Total costs**		$ 691.11			$ 7,888.13			$ 499,790.17	
* ***Operating cost / Hours or Mileage***		$ 14.56			$ 9.21			$ 15.87	
* ***Ownership cost / Hours or Mileage***		$ 20.00			$ 29.27			$ 17.37	
* ***Total costs / Hours or Mileage***		$ 34.56			$ 38.48			$ 33.24	

Figure 6.2. Summary form of the proposed template for data record keeping

Table 6.1. Different sections and explanation of the record keeping template

Part	Codes	Category	Description
A	_	Equipment description	Equipment number, type, and model
	_	Purchase price	The purchase price of the equipment
	_	Purchase year	The time of equipment acquisition
B	1	Equipment usage	Cumulative working hours (for graders) or mileage (for trucks) at the time of maintenance activities
	3	Equipment parts	Different repairable parts such as engine parts, brake parts, hoses & clamps, and miscellaneous parts
	4	Replaceable parts	Regularly replaceable parts such as tires, filters, batteries, and blades
	5	Labor	Wages for staff who repair the equipment
	6	Diesel	The cost of fuel
	7	Oil, grease, anti-freeze, etc.	The cost of different oils, grease, and anti-freeze
	9	Depreciation	The amount of annual depreciation
	A	Ins. and misc.	The insurance and miscellaneous costs
C	-	Operating cost	Summing up the codes of 3 to 7
	-	Ownership cost	Summing up the codes of 9 and A
	-	Total cost	Summing up the operating and ownership costs
	-	Costs per equipment usage	Dividing the costs per working hours (for graders) or mileage (for trucks)

In Table 6.1, parts A, B, and C, represent corresponding sections in Figure 6.2, and describe cost items with their codes and categories. In Figure 6.2, part A records general equipment information. Part B records month to date, year to date, and life to date information for equipment expenses. The code #9 in this section records the depreciation of the equipment. It is the actual amount of depreciation, which is obtained by subtracting the actual trade-in value from the purchase price. The life to date section in this template accounts for cumulative values since the equipment acquisition. The user can keep track of total cost elements in part C. They include the operating and ownership costs, total cost, and costs per equipment usage, which can be used as an index reflecting the economic condition the equipment. Figure 6.3 shows an extended form of the template illustrating more details.

Equipment data Record Keeping Template

Date: *02/06/2019* As of: *12/31/2018*

Equipment information

Equipment #: *00P01* *CAT 140H Grader* Year: *2003* Class: *15* Purchase price: *$ 120,000*

Expense detail

Code	Description	<-------- Month to date -------->			<-------- Year to date -------->			<-------- Life to date -------->		
		Units	Costs	Cost/Unit	Units	Costs	Cost/Unit	Units	Costs	Cost/Unit
1001	Hours	20.00			205.00			15,036.00		
1002	Mileage									
****	Equipment usage total	20.00			205.00			15,036.00		
3011	Misc. Part & Hardware							415.00	$ 16,226.50	39.10
3012	Brake parts				2.00	$ 172.20	86.10	4.00	$ 206.96	51.74
3013	Engine parts							4.00	$ 1,585.24	396.31
3014	Transmission parts							2.00	$ 162.66	81.33
3017	Hoses & Clamps				1.00	$ 166.59	166.59	6.00	$ 437.70	72.95
3019	Front end parts									
3020	Exhaust									
****	Equipment parts total				3.00	$ 338.79		431.00	$ 18,619.06	
4020	Tire & Tubes							16.00	$ 12,963.68	810.23
4021	Blades							85.00	$ 7,661.90	90.14
4022	Air filters				2.00	$ 52.50	26.25	66.00	$ 1,932.48	29.28
4023	Hydraulic filter	1.00	$ 11.37	11.37	1.00	$ 11.37	11.37	18.00	$ 314.64	17.48
4024	Fuel filter	2.00	$ 36.22	18.11	2.00	$ 36.22	18.11	62.00	$ 1,731.04	27.92
4025	Engine filter	1.00	$ 8.05	8.05	1.00	$ 8.05	8.05	60.00	$ 1,040.40	17.34
4026	Transmission filter	1.00	$ 21.96	21.96	1.00	$ 21.96	21.96	19.00	$ 526.30	27.70
4027	Misc. filter	3.00	$ 69.66	23.22	3.00	$ 69.55	23.18	48.00	$ 1,171.68	24.41
4028	Batteries	0.00	$ -	0.00	2.00	$ 439.90	219.95	7.00	$ 1,547.63	221.09
4030	Head lights	0.00	$ -	0.00	0.00	$ -	0.00	7.00	$ 280.21	40.03
****	Replaceable parts total	8.00	$ 147.26		12.00	$ 639.55		388.00	$ 29,169.96	
5030	County labor	2.50	$ 91.65	36.66	9.50	$ 340.10	35.80	778.75	$ 22,490.30	28.88
5031	Outside labor							12.00	$ 3,248.28	270.69
****	Labor total	2.50	$ 91.65		9.50	$ 340.10		790.75	$ 25,738.58	
6041	Diesel				248.39	$ 517.49	2.08	64,901.60	$ 157,817.47	2.43
****	Diesel total				248.39	$ 517.49		64,901.60	$ 157,817.47	
7050	Engine oil changed	9.00	$ 52.20	5.80	9.00	$ 52.20	5.80	698.80	$ 3,731.59	5.34
7051	Engine oil added							155.00	$ 282.10	1.82
7053	Auto trans. Oil							191.00	$ 1,056.23	5.53
7055	Anti-freeze							20.50	$ 174.05	8.49
7056	Grease - Tube							77.00	$ 190.19	2.47
7057	Gear oil							9.30	$ 54.41	5.85
7058	Hydraulic oil changed							174.40	$ 1,733.54	9.94
****	Oil, grease, and anti-freeze total	9.00	$ 52.20		9.00	$ 52.20		1,326.00	$ 7,222.10	
9000	Depreciation							15.00	$ 162,223.00	10,814.87
****	Depreciation total							15.00	$ 162,223.00	
A001	Insurance	20.00	$ 200.00	10.00	12.00	$ 4,000.00	333.33	15.00	$ 63,000.00	4,200.00
A002	Storage	20.00	$ 100.00	5.00	12.00	$ 1,000.00	83.33	15.00	$ 18,000.00	1,200.00
A003	Miscellaneous costs	20.00	$ 100.00	5.00	12.00	$ 1,000.00	83.33	15.00	$ 18,000.00	1,200.00
****	Ins. and misc. total	60.00	$ 400.00		36.00	$ 6,000.00		45.00	$ 99,000.00	
*	**Operating cost**		$ 291.11			$ 1,888.13			$ 238,567.17	
*	**Ownership cost**		$ 400.00			$ 6,000.00			$ 261,223.00	
*	**Total costs**		$ 691.11			$ 7,888.13			$ 499,790.17	
*	***Operating cost / Hours or Mileage***		$ 14.56			$ 9.21			$ 15.87	
*	***Ownership cost / Hours or Mileage***		$ 20.00			$ 29.27			$ 17.37	
*	***Total costs / Hours or Mileage***		$ 34.56			$ 38.48			$ 33.24	

Figure 6.3. Extended form of the proposed template for data record keeping

CHAPTER 7. EQUIPMENT LIFE-CYCLE COST ANALYSIS TOOL (E-L-T)

7.1 Introduction

After studying the current practices of equipment management in counties, data collection, and equipment data analysis, a spreadsheet tool was developed to support county engineers' decision making in terms of equipment management. The tool was designed to capture basic information for each piece of equipment and analyze it to estimate future associated costs and the optimal replacement year. This chapter introduces the tool, describes fundamental assumptions of it, and provides a case study for using the tool. A manual for using the tool is provided as a standalone document associated with this research project.

7.2 Framework for the E-L-T

Figure 7.1 shows a schematic form of the tool.

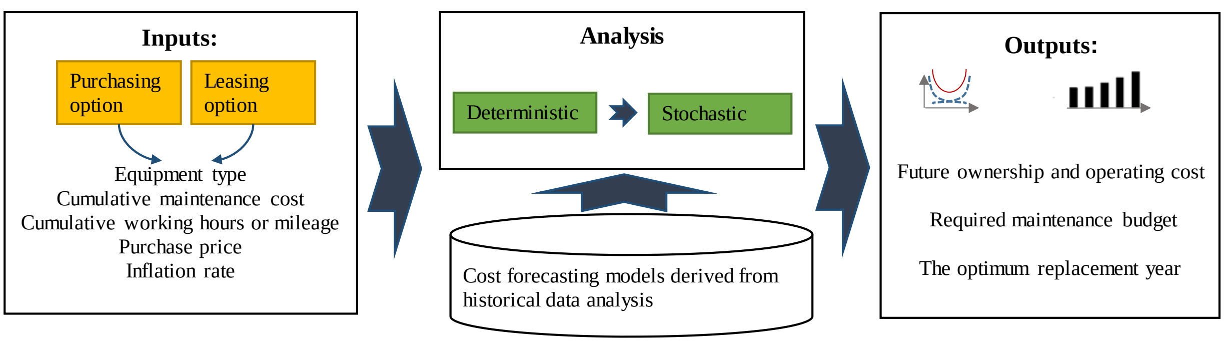


Figure 7.1. Schematic form of the tool

The tool takes as its inputs general economic information and basic equipment information considering both purchasing and leasing acquisition options. Input variables include purchase price, purchase year, cumulative maintenance cost, cumulative working hours or mileage, as well as leasing term, down payment, warranty period, and ultimate residual value. It then analyzes the information and estimates future costs using cost forecasting models derived from historical data analysis to determine the optimal economic life of the equipment.

According to the results from the follow-up interviews, motor graders and different types of trucks, including single-axle trucks, tandem-axle-trucks, and dump trucks, are the most common types of equipment in the counties. The three types of trucks are treated as one equipment type, since all the trucks' activities are similar. Therefore, the tool was developed for the two most common types of equipment, motor graders and trucks.

The tool has two modules of deterministic and stochastic analysis. It was developed in Microsoft Excel software and uses Visual Basic for Applications (VBA) coding for computation and analysis. The tool consists of three main worksheets. They are (1) the home page, (2) deterministic analysis, and (3) stochastic analysis. Two different methods were designed to receive input variables from the user: (1) entering inputs directly into the deterministic or stochastic worksheet to receive one-point estimation of results in deterministic analysis or probabilistic results from the stochastic analysis and (2) using the user interface launching from a button on the home page to capture the data in a more user–friendly way that provides both deterministic and stochastic results. The main results of the tool are provided as graphs and tables in the two sheets of deterministic and stochastic analysis.

7.3 Cost Prediction Models

The cost prediction models use equations derived from the data analyses described in Chapter 5. For motor graders, the equation relates the grader's working hours to the cumulative operating costs. Similarly, the truck's equation relates the truck's age in years and the truck's cumulative mileage to the cumulative operating costs.

Since the cost prediction models are obtained from the counties' data over a specific period of time (i.e., from 1990 to 2018), the models will gradually lose their prediction capability over time in the future. To keep the predictions as accurate as possible, it is recommended that the equipment data be analyzed periodically to update the cost prediction models. The need for redefining the prediction models depends on several factors. For example, the advanced technologies adopted in new equipment tend to make equipment more productive, while requiring lower costs for maintaining the equipment. This factor may change the relationship between equipment usage and the associated operating costs. In addition, the current prediction models used a limited amount of data (295 records of graders and 168 records of trucks for 64 units of grader and 26 units of truck). This amount of data was the most achievable amount of data at the time of the research. However, it is recommended to strengthen the reliability of the prediction model by deriving the cost prediction models using more historical data.

7.4 Deterministic and Stochastic Analysis Modules

The deterministic analysis captures predetermined and single input variables and can consistently yield one-point estimation. However, one-point estimations are not realized in practice due to the randomness in actual equipment operations. The stochastic analysis addresses this issue by considering inherent uncertainties associated with input variables by assigning a range of values for variables including (1) inflation rate, (2) estimated working hours or mileage, (3) insurance and miscellaneous costs, (3) trade-in values, and (4) cost forecasting models. The tool then runs the Monte Carlo simulation and provides a range and confidence intervals for results by 95% level of confidence.

7.5 Purchasing and Leasing Options

There are two types of equipment acquisition options, purchasing and leasing. In both options, it was assumed that the user can provide certain information such as the acquisition year, the cumulative working hours (for graders), cumulative mileage (for trucks), and cumulative maintenance cost. It was also assumed that the user can estimate the normal equipment usage (working hour or mileage) per year. In the leasing option, it was assumed that there is a down payment and installment payments. It was also assumed that during the warranty period, the leasing company handles all the required maintenance activities without any payment from the user. The residual value is the ultimate price of the equipment at the end of the leasing period. At this moment, the user can either return the equipment back to the leasing company without any extra payment or keep the equipment by paying the residual value. In the tool, it is assumed that the user pays the residual value, keeps the equipment, and handles all the maintenance activities afterward.

7.6 Trade-In Value Estimation

The estimated trade-in values explained in Section 5.7 were used in the tool. The values can be modified in the background sheet based on agency requirements.

7.7 Inflation Rate

It was assumed that the user can estimate a number for inflation. A range of 3% to 5% is common for the inflation rate.

7.8 Case Study

In this section, the information about a real case of a motor grader from Henry County is used to illustrate how the tool works. Table 7.1 shows the information of Henry County's grader.

Table 7.1. Equipment management information of a motor grader from Henry County

Item	Amount
Equipment type	Motor grader
Model and size	CAT 12 M3
Acquisition option	Purchased
Acquisition year	2016
Cumulative hours (hr)	2,501
Cumulative operating cost ($)	$30,514
Work hours/year	1,600
Purchase Price ($)	$230,000
Insurance and miscellaneous ($)	$5,261

The purchase price and insurance and miscellaneous costs were missing information, and so the purchase price was estimated using Madison County's data, and the insurance and miscellaneous cost were estimated based on literature.

The tool starts from the home page. Figure 7.2 shows the home page in which a short summary instruction on the tool is provided.

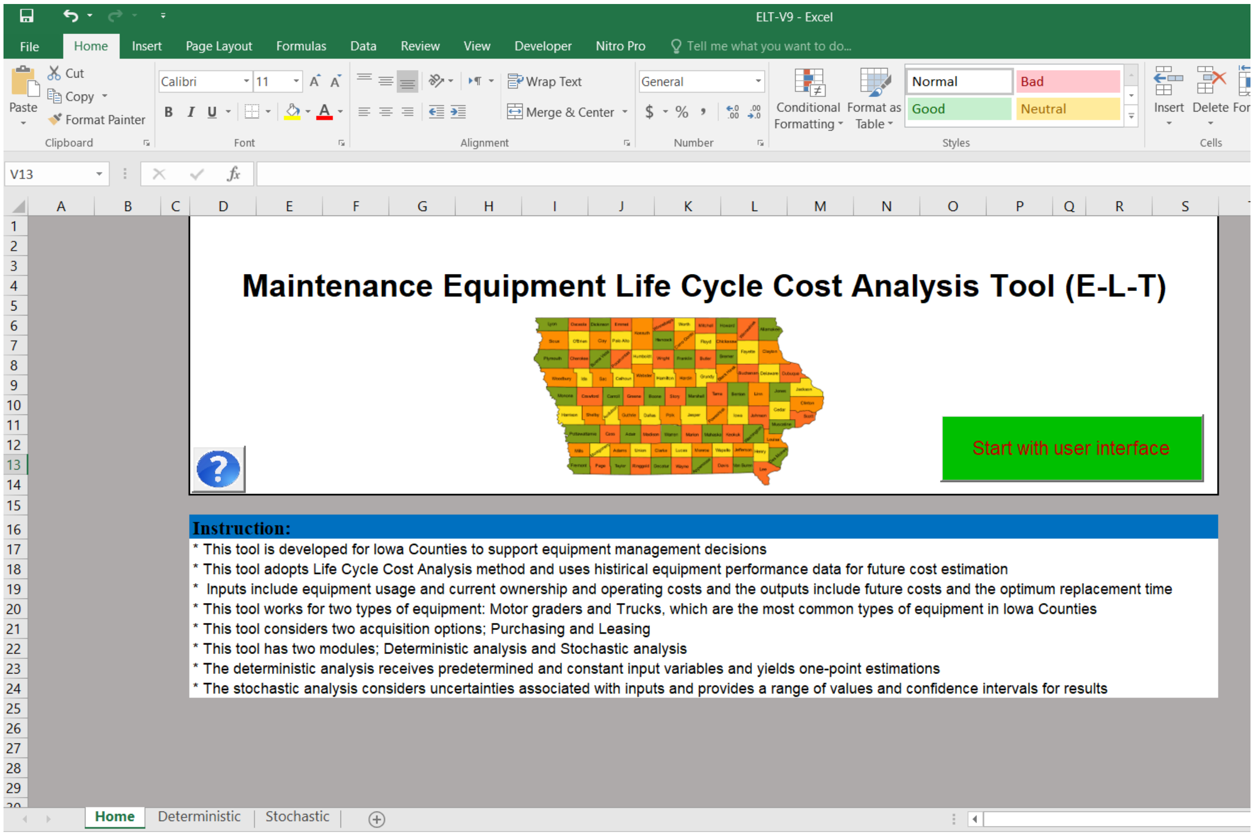
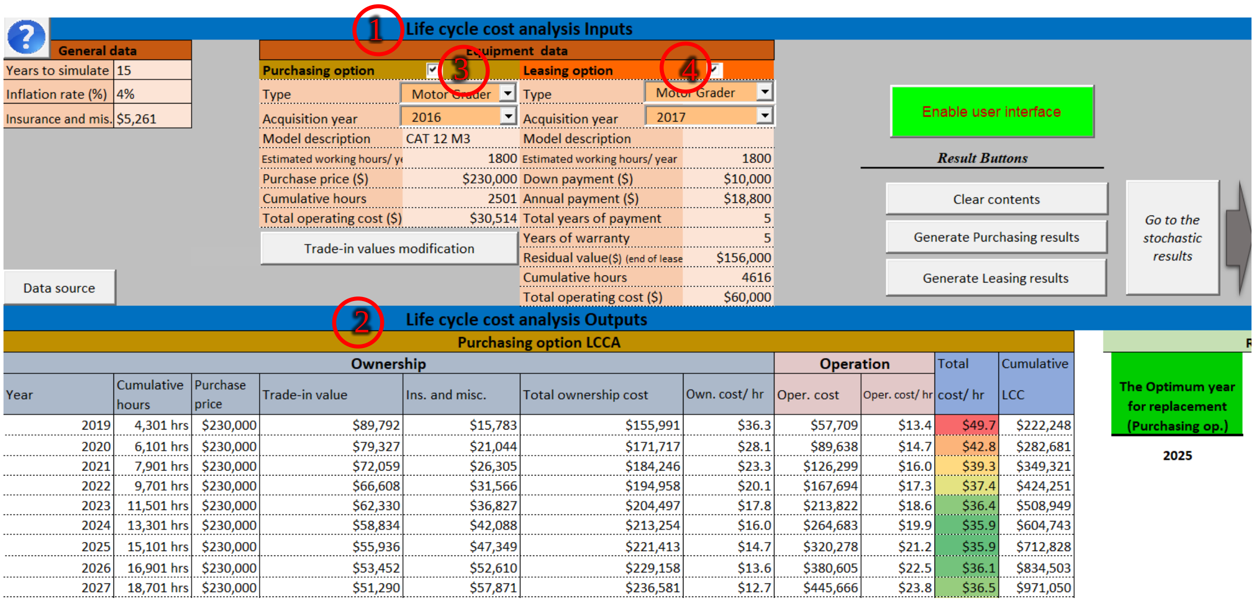


Figure 7.2. Home page of E-L-T

A comprehensive instruction is provided by clicking on the help button, which is the blue question mark on the left center in the figure. By clicking the “Start with user interface” button, the user interface is launched, which permits the user to enter input data more easily. However, the user can also directly go to the deterministic and stochastic sheets to enter data, as shown by the tabs at the bottom left in the figure.

7.8.1 Deterministic Analysis

Figure 7.3 shows the deterministic analysis page.

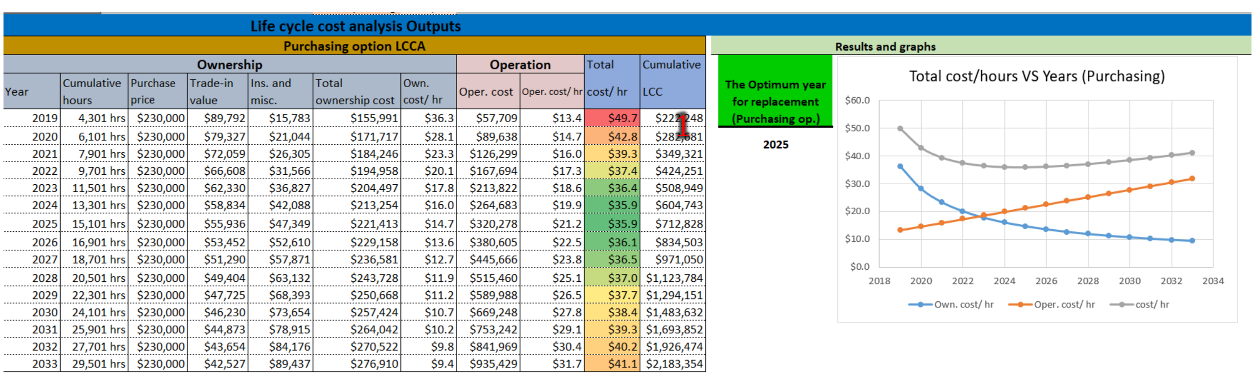


Year	Cumulative hours	Purchase price	Trade-in value	Ins. and misc.	Total ownership cost	Own. cost/ hr	Oper. cost	Oper. cost/ hr	Total cost/ hr	Cumulative LCC
2019	4,301 hrs	$230,000	$89,792	$15,783	$155,991	$36.3	$57,709	$13.4	$49.7	$222,248
2020	6,101 hrs	$230,000	$79,327	$21,044	$171,717	$28.1	$89,638	$14.7	$42.8	$282,681
2021	7,901 hrs	$230,000	$72,059	$26,305	$184,246	$23.3	$126,299	$16.0	$39.3	$349,321
2022	9,701 hrs	$230,000	$66,608	$31,566	$194,958	$20.1	$167,694	$17.3	$37.4	$424,251
2023	11,501 hrs	$230,000	$62,330	$36,827	$204,497	$17.8	$213,822	$18.6	$36.4	$508,949
2024	13,301 hrs	$230,000	$58,834	$42,088	$213,254	$16.0	$264,683	$19.9	$35.9	$604,743
2025	15,101 hrs	$230,000	$55,936	$47,349	$221,413	$14.7	$320,278	$21.2	$35.9	$712,828
2026	16,901 hrs	$230,000	$53,452	$52,610	$229,158	$13.6	$380,605	$22.5	$36.1	$834,503
2027	18,701 hrs	$230,000	$51,290	$57,871	$236,581	$12.7	$445,666	$23.8	$36.5	$971,050

Figure 7.3. Deterministic analysis page of E-L-T

This sheet is divided into two sections, input and output, which are indicated by the dark blue rows labeled 1 and 2 in the figure. The user inserts input variables in the cells highlighted in orange. Two equipment acquisition options are available for analysis, purchasing and leasing. Each option can be enabled or disabled by clicking the checkmarks, as shown by 3 and 4 in Figure 7.3. The "Years to simulate" cell is the total number of years the user wants to run the analysis. Clicking the "generate results" button will perform the LCCA based on the input values to generate the results in the output section.

After inserting input variables according to Table 7.1 in the related sections and by clicking on the "Generate results" of the purchasing option, the LCCA results are generated. Figure 7.4 shows the results when the model is run for 15 years.



Year	Cumulative hours	Purchase price	Trade-in value	Ins. and misc.	Total ownership cost	Own. cost/ hr	Oper. cost	Oper. cost/ hr	Total cost/ hr	Cumulative LCC
2019	4,301 hrs	$230,000	$89,792	$15,783	$155,991	$36.3	$57,709	$13.4	$49.7	$222,248
2020	6,101 hrs	$230,000	$79,327	$21,044	$171,717	$28.1	$89,638	$14.7	$42.8	$282,681
2021	7,901 hrs	$230,000	$72,059	$26,305	$184,246	$23.3	$126,299	$16.0	$39.3	$349,321
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2024	13,301 hrs	$230,000	$58,834	$42,088	$213,254	$16.0	$264,683	$19.9	$35.9	$604,743
2025	15,101 hrs	$230,000	$55,936	$47,349	$221,413	$14.7	$320,278	$21.2	$35.9	$712,828
2026	16,901 hrs	$230,000	$53,452	$52,610	$229,158	$13.6	$380,605	$22.5	$36.1	$834,503
2027	18,701 hrs	$230,000	$51,290	$57,871	$236,581	$12.7	$445,666	$23.8	$36.5	$971,050
2028	20,501 hrs	$230,000	$49,404	$63,132	$243,728	$11.9	$515,460	$25.1	$37.0	$1,123,784
2029	22,301 hrs	$230,000	$47,725	$68,393	$250,668	$11.2	$589,988	$26.5	$37.7	$1,294,151
2030	24,101 hrs	$230,000	$46,230	$73,654	$257,424	$10.7	$669,248	$27.8	$38.4	$1,483,632
2031	25,901 hrs	$230,000	$44,873	$78,915	$264,042	$10.2	$753,242	$29.1	$39.3	$1,693,852
2032	27,701 hrs	$230,000	$43,654	$84,176	$270,522	$9.8	$841,969	$30.4	$40.2	$1,926,474
2033	29,501 hrs	$230,000	$42,527	$89,437	$276,910	$9.4	$935,429	$31.7	$41.1	$2,183,354

Figure 7.4. Deterministic analysis results for the case study

The tool estimates the ownership cost per hour, operating cost per hour, and total cost per hour of the equipment under analysis. Since counties tend to record the equipment's working hours for graders and the equipment's mileage for trucks, the tool estimates costs per hour for graders and costs per mileage for trucks. The ownership cost per hour has a decreasing trend mainly because the trade-in value decreases over time. As the equipment operates, the operating cost increases because the equipment requires repair and maintenance activities. As shown in Figure 7.4, the total cost per hour (ownership cost per hour + operating cost per hour) first decreases to reach its minimum amount before starting to increase again. The best year to replace a piece of equipment is the year in which the total cost per hour is the minimum, which is 2025 in this case.

Cumulative LCC, labeled 1 in Figure 7.4, indicates the total cost of the equipment considering the inflation rate and estimates the entire budget for the equipment in future years.

The deterministic analysis determines the future costs and replacement year. However, the user may still want to know how uncertainties could affect the results. By clicking on the "Go to the stochastic analysis" button, the stochastic analysis page is activated.

7.8.2 Stochastic Analysis

As explained previously, the stochastic analysis asks the user to insert a range for some uncertain factors. Table 7.2 shows these ranges for the case study.

Table 7.2. Ranges for stochastic items

Stochastic items	Min	Most likely	Max
Inflation rate (%)	3.5%	4.0%	4.5%
Insurance and misc. ($)	$4,200	$5,261	$5,800
Working hours /year	1700	1800	1900

Similar to the deterministic analysis sheet, this sheet is also divided into two sections, input and output. This sheet captures three probabilistic input variables in which a minimum, most likely, and maximum value are considered for these variables. The tool runs the Monte Carlo simulation to consider the probability distribution of defined variables and calculates results over and over, each time using different randomly selected values from the probability functions of input variables and provides range of values as results. Input variables are entered using real cases of equipment from counties and results are obtained as shown in Figure 7.5.

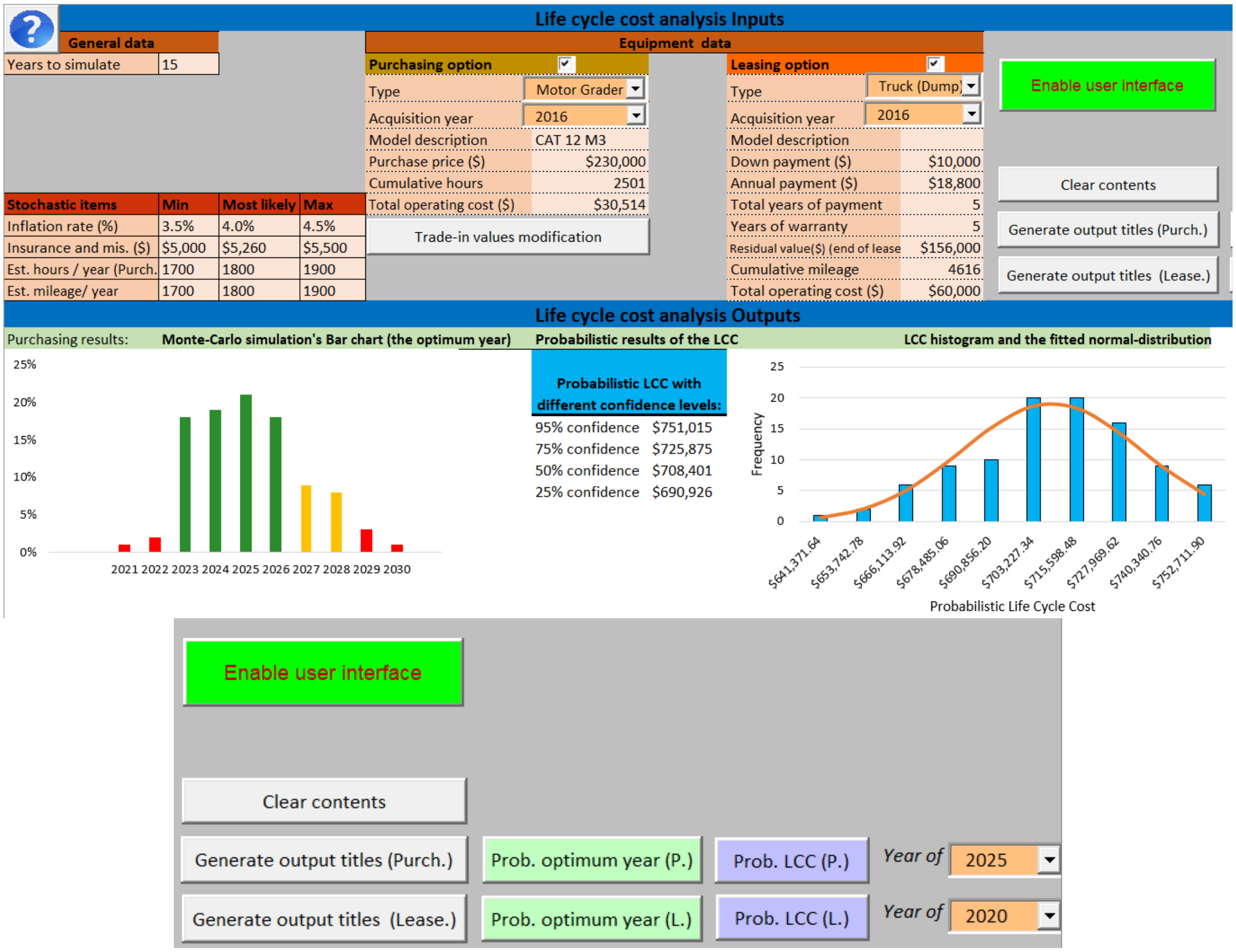

Figure 7.5. Stochastic analysis sheets, inputs, and results

After inserting input values in the designated cells, the tool provides results and graphs. The bar chart indicates alternative years for equipment replacement, in which green years are the best, yellow ones are medium, and red years are not recommended for replacement. Future total LCC of the equipment for different years can be generated. The tool runs the Monte Carlo simulation for future costs and fits a normal curve to provide a table to indicate probable total cumulative LCC with different levels of confidence in the specified year providing better insights for budget planning.

CHAPTER 8. CONCLUSIONS

This research project developed a data-driven spreadsheet-based tool to estimate replacement time and future cost of motor graders and trucks currently used in Iowa counties to enhance equipment management practice. This study conducted a comprehensive survey to understand the current practice of equipment management in Iowa counties and collected and analyzed historical equipment management data to derive cost estimating models for use in the proposed tool. The research project reviewed advanced methods in LCCA and studied current application of LCCA by DOTs across the US that have similar duties as in Iowa counties. The tool adopts advanced LCCA techniques and captures current ownership and operating costs of a piece of equipment to estimate future costs and determine the economic life and the optimal replacement year. The research project also proposed an equipment record-keeping template to improve current practice. Using the outputs of this research can contribute to local agencies making justifiable decisions and bring about large savings in terms of their equipment budget.

The project conducted a comprehensive survey to assess the current practice of equipment management in Iowa counties. Local agencies in 54 counties out of Iowa's 99 counties responded to the survey. Motor graders and trucks were reported as the most common types of equipment in use and that their associated costs constitute a large portion of an agency's total equipment maintenance budget. Just 30% of respondents collect equipment data and have a replacement process. The current replacement process included periodic equipment replacement in which after a certain amount of equipment usage, the equipment is replaced with a new one. The follow-up interviews showed that county engineers replace their motor graders after 10,000 to 15,000 working hours or 7 to 25 years and replace their trucks after 5 to 25 years depending on the condition of the equipment.

However, a general standard of periodic replacement is not efficient, since there may be a piece of equipment that has passed the replacement period, but it is still productive. In addition, there may be some pieces of equipment that have not passed the replacement time, but they are not productive and have a large maintenance cost. Findings from the survey confirm this situation as 33% of current equipment is overdue for replacement. In addition, the current method cannot predict future costs and determine the optimal life for each piece of equipment individually. Respondents noted that in replacing a piece of equipment with a new one, budget analysis and the history of problematic maintenance activities play essential roles. In terms of equipment disposal, 47.4% of counties prefer to trade in their equipment at the end of the life, and 32.6% of counties sell them in a public auction.

To develop cost estimation models, the historical equipment data of 64 types of graders and 26 types of trucks including 295 records of graders and 168 records of trucks was collected from 9 counties and transferred to a spreadsheet and reviewed carefully. Missing data and anomalous data were detected and replaced using information from similar pieces of equipment from other counties to prepare a clean database for data analysis. Regression analysis was performed to identify the relationship between equipment usage and operating cost. Since the preliminary regression yielded a linear model, the bootstrapping technique was used to recognize a polynomial pattern representing the correlation between equipment usage and operating cost. To better reflect scatter data points and address uncertainties associated with variables, stochastic analysis was performed to obtain an upper and lower boundary of model. The final derived equations were used in the tool to estimate future operating cost based on equipment usage. To predict ownership costs, trade-in values (or salvage values) for graders and trucks were extracted using Lucko's study (2003), in which the researcher identified trade-in values using data from 1,499 graders and 3,105 trucks, and tested using validated trade-in values from counties. The data analysis was concluded by obtaining cost estimation models.

The proposed spreadsheet-based tool was developed in the Microsoft Excel software program using VBA coding for computation and analysis. The tool has two modules (1) deterministic analysis in which the tool captures single values as inputs and provides one-point estimation and (2) stochastic analysis in which a range of values are captured from the user and Monte Carlo simulation is used to provide a range of values as results. Stochastic analysis provides insights about the effect of uncertainties associated with variables and better reflects actual practice.

It is recommended that the equipment data be analyzed periodically to update the cost prediction models. The current cost prediction models were derived from the counties' equipment for a specific period of time (i.e., from 1990 to 2018). The prediction capability of the models will decrease over time in the future and using the same cost prediction models for a long time is not recommended. It is recommended that counties use the proposed record-keeping template to enhance the quality and quantity of historical data over time and update the cost prediction models accordingly to not only keep the prediction capability but also gradually increase the accuracy of predictions and the results.

A simple rule for replacing equipment is that when the annual cost for maintenance and operating exceed the trade-in value of the equipment, it is the time to replace the equipment. Therefore, keeping track of trade-in values is essential in equipment management. The trade-in values can be recorded and tracked using the proposed template. More accurate trade-in values lead to increase the accuracy of the cost prediction models and the results.

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APPENDIX. CONDUCTED SURVEY AND RESPONSES

This section consists of the complete survey questions and the collected responses.

Q1. How does your agency store equipment data?
Instructions: You can select multiple options.

Fifty-five individuals responded to one or more parts of this question. These respondents represent 54 counties. As noted in the instruction of Question 1, the survey indicated that each participant could select multiple options.

Answer	%	Count
A purchased equipment management system (Please specify the name of the software)	31.17%	24
A custom developed equipment management system	5.19%	4
A spreadsheet or a similar application	37.66%	29
A paper-based system	23.38%	18
Others	2.60%	2
Total	100%	77

Follow-up: Please specify the name of the Software.
Free responses among those who answered "A purchased equipment management system:"

Software	Count
A combination of Softworks and VisionLink	1
Antero	1
Collective Data - collectiveFleet Client 6.1	5
Dossier	3
Dudesolutions	1
FASTER	1
manager plus pro	1
Networkfleet	1
Qqest	2
Solutions	3
TATUMS	1
Truck Tracker	1
Work Management	2
New World	1

Follow-up: Others.
Free responses among those who answered "Others:"

Others - Text
Paper duplicates and excel for fuel usage

Q2. Equipment information: Is the following equipment data available to your agency?
Instructions: Please read the attribute and its description and select your answer.

Fifty-four individuals responded to one or more parts of this question.

Question	Yes		No		Total
Make Description - Manufacturer Name (CAT for example)	100.00%	54	0.00%	0	54
Model- Focus or Civic for example	100.00%	54	0.00%	0	54
Fuel Type- Self-explanatory	96.23%	51	3.77%	2	53
Meter Reading- A reported reading of the odometer or hour meter depending on whether it is a light or heavy vehicle.	96.30%	52	3.70%	2	54
Life Hours/Life Miles- A total cumulative value of hours or miles. Sometimes hour meters and odometer must be replaced, and this accumulates usage prior to the change of the meter.	92.31%	48	7.69%	4	52
Total Cost- The sum of the purchase price, costs to prep the vehicle for use and improvements to the vehicle.	86.79%	46	13.21%	7	53
Salvage Value- A dollar figure established at the time we receive the equipment. It is a prediction of the sale price.	46.00%	23	54.00%	27	50

Q3. Does your agency have a process of estimating the equipment replacement year? (Years, hour/miles)

Fifty-four individuals responded to this question.

Answer	%	Count
Yes	66.67%	36
No	33.33%	18
Total	100%	54

Q4. Maintenance and Repair Information: Does your agency collect the following data?
Instructions: Please read the attribute and its description and select the option.

Fifty-four individuals responded to one or more parts of this question.

#	Question	Yes		No		Total
1	Cost Year- Year in which a cost was incurred	86.54%	45	13.46%	7	52
2	Labor Hrs- Hours worked on the maintenance event.	73.58%	39	26.42%	14	53
3	Repair Date- Date that a repair was indicated as complete	87.04%	47	12.96%	7	54
4	Transaction Type- This is a generalization of the type of expense experience in an event.	80.39%	41	19.61%	10	51
5	Transaction Type Description- Does a fair job of describing the transaction type.	79.17%	38	20.83%	10	48
6	Event Cost- This is the cost for this event.	78.85%	41	21.15%	11	52
7	Miles or Hours- This is the reading of how many miles or hours were recorded at the time of the event.	86.79%	46	13.21%	7	53
8	Warranty events and costs- Do you track warranty events and costs?	54.00%	27	46.00%	23	50

Q5. System/Software and Data collection (If you do not have an electric system skip this question)

Thirty-four individuals responded to one or more parts of this question.

Question	Yes		No		Total
Is your equipment management system or software capable of assisting in making equipment replacement decisions?	16.00%	4	84.00%	21	25
Does your agency use the equipment replacement decision feature of the software?	7.14%	2	92.86%	26	28
Does your system or software have the option to record equipment utilization such as operating hours, mileage, etc.?	54.84%	17	45.16%	14	31
Does your system or software record routine inspection?	40.63%	13	59.38%	19	32

Q6. How many dedicated in-house maintenance and repair staff members do your agency currently have? (Please exclude operators from this number)

Fifty-four individuals responded to this question

The average number is 3.425. The highest is 30, and the least is 0.

Q7. In your perception, what percentage of your agency's equipment is currently overdue for replacement?

Fifty-four individuals responded to one or more parts of this question.

#	Field	Minimum	Maximum	Mean	Std. Deviation	Variance	Count
1	Motor Graders	0	70	24.18	17.93	321.35	50
2	Single Axle Trucks	1	100	42.18	31.43	987.74	39
3	Tandem Axle Trucks	2	100	29.92	19.88	395.12	48
4	Semi-trucks	0	100	36.38	31.42	987.06	29
5	Backhoe	0	100	26.68	28.83	831.29	28
6	Dozers	0	100	42.41	37.87	1433.8	32
7	Excavators	0	77	32.34	20.71	429.04	32
8	Tractors	2	70	32.7	17.83	317.97	33
9	Skidloaders	0	100	33.61	32.58	1061.35	18
10	Endloaders	0	100	37.74	23.48	551.16	35
11	Pickup Trucks	1	70	27.83	17.89	320.18	52
12	Others (Please specify)	0	100	39.75	28.45	809.19	8
13	Others (Please specify)	0	100	62.5	41.46	1718.75	4
14	Others (Please specify)	100	100	100	0	0	1

Follow-up: Others (Please specify) 1.
Free responses among those who answered "Others (Please specify) 1:"

Others (Please specify) - Text
Service Trucks
service truck
Trailers
Brush Mower
Roadside mowers and brush cutters
roller/compactor
trailers rock

Follow-up: Others (Please specify) 2.
Free responses among those who answered "Others (Please specify) 2:"

Others (Please specify) - Text
Street Brooms
sign truck
lowboy trailer

Follow-up: Others (Please specify) 3.
Free responses among those who answered "Others (Please specify) 3:"

Others (Please specify) - Text
side dump trailer

Q8. Please select which advanced technologies your agency uses to improve its equipment data and management.
Instructions: You can select multiple options.

Forty individuals responded to one or more parts of this question.

#	Answer	%	Count
1	Automatic vehicle location (GPS/AVL)	34.57%	28
2	Auto-link technology (JD-link, CAT Product LinkTM)	40.74%	33
3	Tire telemetry (Heat and speed data collected with tire sensors)	0.00%	0
4	Bar coding (Scanning tools check-in or Material used on the job)	6.17%	5
5	Maintenance scheduling alert systems (Auto reminders of Oil change and other basic maintenance)	16.05%	13
6	Others (please specify)	2.47%	2
	Total	100%	81

Follow-up: Others (Please specify)
Free responses among those who answered "Others (Please specify):"

Others (please specify) - Text
Only JD-Link, not fleetwide
none

Q9. Approximately what percentage of equipment repair work is done in-house or outsourced in terms of dollar value?

Fifty-five individuals responded to one or more parts of this question.

#	Field	Minimum	Maximum	Mean	Std. Deviation	Variance	Count
1	In-house	10	95	70.53	17.91	320.69	55
2	Out-sourced	5	90	29.51	17.98	323.2	55

Q10#1. Please evaluate on a scale of 1 to 5 the level of influence each factor has in making equipment replacement decisions? - Motor Grader

Fifty-five individuals responded to one or more parts of this question.

Question	1Not Important		2Less Important		3Somewhat Important		4 Important		5Very Important		Total
Age of the equipment (Years)	0.00%	0	7.27%	4	20.00%	11	50.91%	28	21.82%	12	55
Problematic history of the equipment	0.00%	0	1.82%	1	5.45%	3	40.00%	22	52.73%	29	55
Budget available	1.82%	1	3.64%	2	7.27%	4	36.36%	20	50.91%	28	55
Hours of operation/Number of Miles	0.00%	0	5.45%	3	14.55%	8	40.00%	22	40.00%	22	55
Downtime	1.82%	1	14.55%	8	12.73%	7	36.36%	20	34.55%	19	55
Others (Please specify)	0.00%	0	0.00%	0	33.33%	2	0.00%	0	66.67%	4	6
Others (Please specify)	100.00%	1	0.00%	0	0.00%	0	0.00%	0	0.00%	0	1

Q10#2. Please evaluate on a scale of 1 to 5 the level of influence each factor has in making equipment replacement decisions? - Dump Trucks

Fifty-four individuals responded to one or more parts of this question.

Question	1Not Important		2Less Important		3Somewhat Important		4 Important		5Very Important		Total
Age of the equipment (Years)	1.85%	1	12.96%	7	24.07%	13	38.89%	21	22.22%	12	54
Problematic history of the equipment	0.00%	0	1.85%	1	5.56%	3	46.30%	25	46.30%	25	54
Budget available	1.85%	1	1.85%	1	9.26%	5	38.89%	21	48.15%	26	54
Hours of operation/Number of Miles	0.00%	0	12.96%	7	18.52%	10	35.19%	19	33.33%	18	54
Downtime	1.85%	1	14.81%	8	11.11%	6	44.44%	24	27.78%	15	54
Others (Please specify)	0.00%	0	20.00%	1	40.00%	2	0.00%	0	40.00%	2	5
Others (Please specify)	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0

Q10#3. Please evaluate on a scale of 1 to 5 the level of influence each factor has in making equipment replacement decisions? - Specialty Equipment (Dozer/Excavator)

Fifty-two individuals responded to one or more parts of this question.

Question	1Not Important		2Less Important		3Somewhat Important		4 Important		5Very Important		Total
Age of the equipment (Years)	7.69%	4	19.23%	10	36.54%	19	28.85%	15	7.69%	4	52
Problematic history of the equipment	0.00%	0	3.85%	2	15.38%	8	42.31%	22	38.46%	20	52
Budget available	1.92%	1	0.00%	0	11.54%	6	38.46%	20	48.08%	25	52
Hours of operation/Number of Miles	0.00%	0	13.46%	7	25.00%	13	40.38%	21	21.15%	11	52
Downtime	3.85%	2	23.08%	12	15.38%	8	34.62%	18	23.08%	12	52
Others (Please specify)	0.00%	0	33.33%	2	16.67%	1	16.67%	1	33.33%	2	6
Others (Please specify)	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0

Follow-up: Others (Please specify) 1
Free responses among those who answered “Others (Please specify) 1:”

Others (Please specify) - Text
Parts Availability
Service response time
resale
Cost to Maintain
Warranty remaining
CAT

Follow-up: Others (Please specify) 2
Free responses among those who answered “Others (Please specify) 2:”

Others (Please specify) - Text
Deere

Q11. Please evaluate on the scale of 1 to 5, the factors considered when your agency decides to lease or purchase equipment?

Forty-nine individuals responded to one or more parts of this question.

Question	1 Not Important		2 Less Important		3 Somewhat Important		4 Important		5 Very Important		Total
Quantitative budget analysis	8.51%	4	10.64%	5	19.15%	9	31.91%	15	29.79%	14	47
Less Up-front Cost	15.22%	7	28.26%	13	28.26%	13	23.91%	11	4.35%	2	46
Easy upgrade options	14.89%	7	29.79%	14	23.40%	11	25.53%	12	6.38%	3	47
Hassle free maintenance and repairs	4.17%	2	8.33%	4	20.83%	10	43.75%	21	22.92%	11	48
Others (Please specify)	11.11%	1	11.11%	1	11.11%	1	22.22%	2	44.44%	4	9

Follow-up: Others (Please specify)
Free responses among those who answered "Others (Please specify):"

Others (Please specify) - Text
Part Costs
Life-Cycle Value / ROI / Productivity
Location of warranty facilities and repair shop
parts and service availability
Hours per year equipment will be operated
We've never leased
We don't lease equipment

Q12. How does your agency dispose of the old equipment (please select the approximate percentage)?

Fifty-five individuals responded to one or more parts of this question.

#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Public Auction	0.00	100.00	39.49	25.63	656.96	51
2	Sealed Bids	0.00	60.00	17.17	15.26	232.94	30
3	Trade-in	5.00	100.00	57.42	24.30	590.70	53
4	Others (please specify)	1.00	10.00	7.00	4.24	18.00	3

Follow-up: Others (Please specify)
Free responses among those who answered "Others (Please specify):"

Others(please specify) - Text
Scrap
Scrapyard
Junk

Q13#1. Who are the main decision makers when it comes to equipment purchase or lease decision? - Purchasing Decision

Fifty-five individuals responded to one or more parts of this question.

#	Question	High		Medium		Low		Total
1	Board members	20.37%	11	42.59%	23	37.04%	20	54
2	County engineer	80.00%	44	14.55%	8	5.45%	3	55
3	Operations and Maintenance team	47.27%	26	47.27%	26	5.45%	3	55

Q13#2. Who are the main decision makers when it comes to equipment purchase or lease decision? - Leasing Decision

Forty individuals responded to one or more parts of this question.

#	Question	High		Medium		Low		Total
1	Board members	27.50%	11	27.50%	11	45.00%	18	40
2	County engineer	75.00%	30	17.50%	7	7.50%	3	40
3	Operations and Maintenance team	30.00%	12	32.50%	13	37.50%	15	40

Q14 - Please provide your contact information:

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