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# Major equipment life cycle cost analysis

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# Major equipment life cycle cost analysis

by

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MASTER OF SCIENCE

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Program of Study Committee:
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Iowa State University

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# NOMENCLATURE

| | |
|---|---|
| $A_{IC}$ | Annual Initial Cost |
| API | American Petroleum Institute |
| $A_{SV}$ | Annual Salvage Value |
| CF | Consumption Factor |
| CIP | Capital Improvement Program |
| DOT | Department of Transportation |
| LRRB | Local Road Research Board |
| EF | Engine Factor |
| EUAC | Equivalent Uniform Annual Cost |
| F | Future Worth |
| FC | Fuel Cost |
| FOG | Filter, Oil, and Grease |
| FP | Fuel Price |
| gal/fwhp-hr | Gallon of fuel per flywheel horsepower hour |
| i | Interest Rate |
| IC | Initial Cost |
| LC | Life Cycle |
| LCC | Life Cycle Costs |
| LCCA | Life Cycle Cost Analysis |
| LRRB | Local Road Research Board |
| MPWFSD | Minneapolis Public Works Fleet Services Division |
| MV | Market Value |

| | |
|---|---|
| N | Years of Calculation |
| NPV | Net Present Value |
| P | Present Worth |
| PSM | Peurifoy and Schexnayder Model |
| R&MC | Repair and Maintenance Cost |
| $S_N$ | Market Value at the end of the Ownership period |
| SV | Salvage Value |
| TC | Tire Cost |
| TF | Time Factor |
| TRC | Tire Repair Cost |
| VCI | Vehicle Condition Index |

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I would like to thank Dr. Gransberg for all the support and guidance that he has offered me throughout my entire time as a graduate student at Iowa State University.  I am extremely grateful for the opportunity that he gave me, and I owe a great deal of my success to him.

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# ABSTRACT

Managing a public agency's equipment fleet is rife with conflicting priorities. One of the most important aspects is the economic trade-off between the capital cost of replacing a piece of equipment and the ownership costs of operating and maintaining the machine in question if retained for another year. Therefore, determining life cycle costs and the economic life is vital for fleet managers to optimize equipment funds. Currently, most public agencies apply deterministic methods to make fleet management decisions. These methods do not account for uncertainty within the input parameters, such as volatility in fuel prices that potentially impact the replace-or-retain decision. Thus, the objective of this study is to develop a stochastic equipment life cycle cost analysis (LCCA) model to optimize equipment economic life based on life cycle costs for a public agency's fleet.

A public agency does not have financial flexibility; consequently, the constraints on the use of available funding can affect the replacement and repair cycles for its equipment fleet. Public sector financial constraints have the potential to put an agency's fleet into continuous decline if needed repairs cannot be made and old equipment cannot be replaced when it reaches the end of its economic life. This research will show that from the public perspective, there is a predisposition to retain a piece of equipment for as long as possible before replacing it because of the administrative burden required to get purchase authority. Thus, it is essential for the fleet manager to have a tool that will provide the accurate information to assist in making major equipment repair and replacement decisions. The public fund authorization process may require the agency to identify the need to replace a given piece of equipment a year or more in advance of the need, making the results of this research both timely and valuable for implementation.

The proposed stochastic equipment LCCA model is the result of a comprehensive literature review, national survey, case study analysis, and a software content analysis. Data from the Minneapolis Public Works Fleet Services Division (MPWFSD) was obtained during the case study analysis to utilize in this thesis. Also, a viable equipment LCCA model, the Peurifoy and Schexnayder model (PSM), was used in the analysis in addition to the use of engineering economics. The model utilizes stochastic inputs to quantify uncertainty and determine a given piece of equipment's optimum economic life.

# CHAPTER 1.
# INTRODUCTION

The objective of this research is to develop a stochastic equipment LCCA model to determine the economic life of equipment for a public agency's fleet. The MPWFSD equipment fleet data was utilized in the LCCA. This thesis has three main areas of focus:

- Impact of Fuel Volatility on Equipment Economic Life
- Determination of the Most Sensitive Inputs to a LCCA Model for Equipment
- Stochastic Equipment LCCA Model to Calculate the Economic Life that Varies from Deterministic Methods

## Background

In order to develop an effective and reliable equipment LCCA model the stages of equipment life had to be established. Also, the equipment LCCA methods had to be examined to determine the most applicable LCCA method. Therefore, this section presents the fundamental information from the literature as a basis upon which the analyses were performed. The content within this chapter is used to complement and support the information found in Chapters 3, 4, and 5.

### Equipment Life

Equipment life can be mathematically defined in three different ways: physical life, profit life, and economic life (Mitchell 1998). Physical and economic life both must be defined and calculated when considering equipment life because they provide two important means to approach a replacement analysis and to ultimately make an equipment replacement decision (Douglas 1975). The concepts of depreciation, inflation, investment, maintenance and repairs, downtime, and obsolescence are all integral to a replacement analysis (Gransberg, Popescu, and Ryan 2006). Combining these concepts and processes allows the equipment manager to properly perform a replacement analysis and make reasonable equipment replacement decisions.

Figure 1 shows the relationship between the three stages of each life cycle (Douglas 1978). The graph shows that over the physical life of the machine, it takes some time for the new machine to earn enough to cover the capital cost of its procurement. It then moves into a phase where it earns more than it costs to own, operate, and maintain. A machine finishes its life in a stage where the costs of keeping it going and the productive time lost to repairs it is greater than what it earns during the periods when it is operational. Thus, an equipment fleet manager needs tools to identify the point in time where retaining a given piece of equipment is no longer profitable, and the machine can be replaced by either purchasing a new piece or by leasing an equivalent piece.

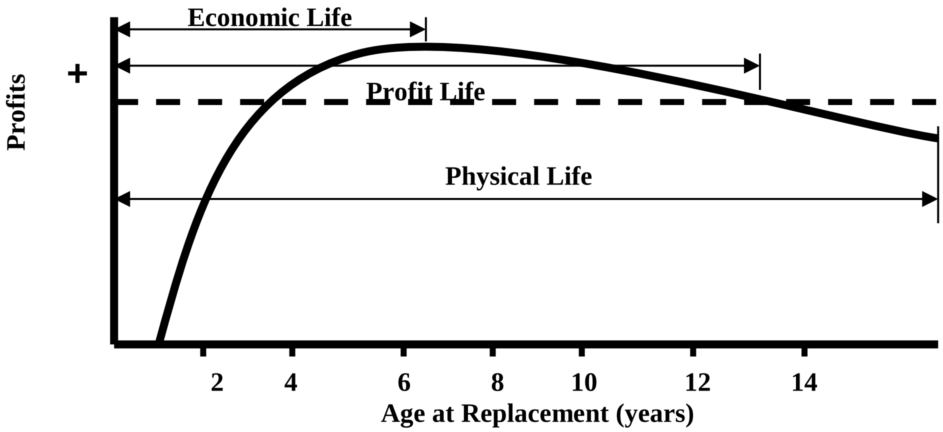

**Figure 1. Equipment Life (Douglas 1978).**

Figure 1 also graphically illustrates three different definitions for the useful life of a given machine: economic life, profit life, and physical life. These are explained in the following sections.

### Physical life

For this research, the physical life of equipment will be identified as the service life. This time period ends when equipment can no longer be operated. This stage is greatly impacted by the repair and maintenance attention that the machine has received over its lifespan (Gransberg et al. 2006). A piece of equipment that has not been given adequate maintenance throughout its lifespan will deteriorate faster than a machine that was been given substantial preventative maintenance. Thus, the service lives will vary depending on the piece of equipment and the amount of upkeep it received.

### Profit life

Profit life is the time period where equipment is generating a profit (Gransberg et al. 2006). This is the most desired stage of the equipment life because after this point in time the equipment will operate with a loss (Douglas 1978). “Increasingly costly repairs exacerbate this as major components wear out and need to be replaced” (Gransberg et al. 2006). Thus, this is a critical stage in the equipment life to maximize on profitability and efficiencies. Also, the equipment fleet manager must be able to determine this time period to implement a replacement plan for a new machine while the components are useful (Gransberg et al. 2006).

## Economic life

Economic life is based on decreasing ownership costs with the increase in operating costs (Mitchell 1998). The time period where these costs are equivalent is called the economic life. When the operating costs exceed the ownership costs, a piece of equipment is costing more to operate than to own. To maximize profits, the replacement of a piece of equipment should occur before the economic life is reached. “The proper timing of equipment replacement prevents an erosion of profitability by the increased cost of maintenance and operation as the equipment ages beyond its economic life” (Gransberg et al. 2006).

The economic life will be the primary tool applied in the research to determine the replacement time period. The usage of engineering economics will be utilized to calculate the optimal economic life based on principles laid down by Park (2011) and Peurifoy and Schexnayder (2002). Of the equipment life cycle cost models proposed Peuifoy and Schexnayder (2002), one will be extended by incorporating stochastic inputs to the economic life determination calculation.

## Life Cycle Cost Analysis

Equipment LCCA is comprised of life cycle costs, equipment decision procedures, replacement analysis, and replacement models. The decision to repair, overhaul, or replace a piece of equipment in a public agency’s fleet is a function of ownership and operating costs. This research explores the impact of commodity price volatility, as well as normal variation, in the costs of tires and repair parts. The accuracy of the life cycle costs can be improved by implementing stochastic functions. Thus, this research employed a stochastic model to better depict life cycle costs and compute optimal economic life to improve equipment fleet decisions.

Life cycle costs for equipment have two components: ownership costs and operating costs. Ownership costs include initial costs, depreciation, insurance, taxes, storage, and investment costs (Peurifoy and Schexnayder 2002). Operating costs include repair and maintenance, tire, tire repair, fuel, operator, and any other consumable equipment cost (Gransberg et al. 2006). The MPWFSD provided equipment fleet data which was used in the research to evaluate equipment life and answer the research questions in a quantitative manner.

## Stochastic Modeling

"A quantitative description of a natural phenomenon is called a mathematical model of that phenomenon" (Pinsky and Karlin 2011). A deterministic phenomenon or model predicts a single result from a set of conditions (Pinsky and Karlin 2011). A stochastic phenomenon does not always lead to the same outcome but to different results regulated by statistical regularity (Haldorsen and Damselth 1990). The prediction of a stochastic model is built by articulating the likelihood or probability of a given result (Pinsky and Karlin 2011).

Pinsky and Karlin (2011) hold that stochastic modeling has three components:

1. A phenomenon under study,
2. A logical system for deducing implications about the phenomenon, and
3. A connection or equation which links the elements of the system under study together.

In order to create stochastic phenomena, considerations must be selected within a given model because phenomena are not naturally stochastic (Pinsky and Karlin 2011). This allows the versatility of stochastic models for an abundant of applications.

A critical part of the stochastic models is the probability functions used to determine the outcome of a phenomenon. The equally likely approach, originated in 1812, "was made to define the probability of an event A as the ratio of the total number of ways that A could occur to the total number of possible outcomes of the experiment" (Pinsky and Karlin 2011). This approach is the basis for the utilization of the distributions of probabilities in the stochastic models.

The stochastic process utilizes random variables within a model to determine the most likely outcome. The random variables are generated using Monte Carlo simulations. Monte Carlo simulations perform iterations, using random variables, on the output of a stochastic model. The results are then obtained from the simulation based on statistical data. The equipment LCCA model proposed in this thesis is a stochastic process applied to the economic life of equipment and calculate life cycle costs.

## Peurifoy and Schexnayder Equipment LCCA Model

The PSM to calculate life cycle costs for equipment was employed for this research. R.L. Peurifoy is considered by many to be the father of modern construction engineering (Gransberg 2006). Thus, the model was selected for the equipment LCCA. The parameters of the model are explained below.

The PSM equipment LCCA model utilizes cost factors that are separated into ownership and operating costs. The initial cost is defined as the purchase amount of a piece of equipment minus the tire cost (Peurifoy and Schexnayder 2002). Taxes, insurance, and storage costs are calculated as a single percentage of initial costs. Ownership costs are determined by computing the equivalent uniform annual cost (EUAC) of the initial costs and the estimated salvage value.

The PSM operating costs include the fuel costs; repair and maintenance costs; filter, oil, and grease (FOG) costs; tire cost; and tire repair costs. Fuel costs include a function “of how a machine is used in the field and the local cost of fuel” (Peurifoy and Schexnayder 2002). To calculate the fuel costs, a consumption rate is multiplied by the fuel price, engine horsepower, time, and engine factor. The time factor is based on the production rate in an hour, and engine factor is based on the percentage of horsepower utilized.

The repair and maintenance costs are calculated as a percentage of the annual depreciation. This method uses the straight-line method for depreciation. The percentage for the repair and maintenance cost is a function of the machine type and work application. Also, the tire repair cost is a percentage of the tire cost.

## Public Agency Financial Constraints

The PSM was selected because it is a well-accepted approach to the development of an equipment ownership cost model and contained all the elements necessary to allow it to be transformed into a stochastic LCCA model for use in this research. However, the PSM was originally developed for use in private industry by construction contractors (Peurifoy and Schexnayder 2002), and as a result must be adapted for application to public agency equipment fleet management decisions. For example, since public agencies do not pay sales or property taxes, the tax component was dropped from the PSM to adapt it to the final deterministic model for the public sector. The subsequent paragraphs in this section will discuss the other adjustments made to make the PSM fully applicable to the typical public agency’s financial environment.

Private contractors operate with access to requisite funding when it is time to repair or replace a specific piece of equipment. This is not the case in the public sector. The major source of funding for public equipment fleet expenses comes from tax revenues that feed capital budgets (Antich 2010). Public purchases of capital equipment must often gain approval from an appropriate authority and be paid for from tax revenues that were collected for this purpose. This creates a constraint on expenditures that is often referred to as the “color of money,” where it is possible to have surplus funds that were designated for one purpose in the public coffers while at the same time have insufficient funds to make purchases for another specific purpose (Lang 2008). The most common situation is a strict separation of capital expenditures for the purchase of new pieces of equipment from operations and maintenance expenses, which are designated to pay for routine expenses such as fuel and repair parts (Lang 2008). Often major capital expenses must pass through an appropriations process where the governing authority reviews and approves a specific sum of money to purchase a specific item. This process may require the agency to identify the need to replace a given piece of equipment a year or more in advance of the need, making the results of this research both timely and valuable for implementation.

The City of Minneapolis, whose equipment fleet records are used in the subsequent analysis, provides an excellent example of the constraints faced by public agency equipment fleet managers. Its operating budget is established to “ensure maintenance of capital assets and infrastructure in the most cost-efficient manner” (COM 2014). Within that budget, the equipment fleet will be repaired and replaced from current revenues “where possible” (COM 2014). Minneapolis maintains a five-year capital improvement program (CIP) that provides funding for capital projects (COM 2014). Equipment fleet is not “the [appropriate] asset nature to fund through the City’s CIP process” (COM 2014). Thus, Minneapolis maintains a separate five-year funding plan to address major equipment purchases (COM 2014). Theoretically, to get the purchase of a piece of equipment into this budget, the equipment fleet manager is required to make replacement decisions at least five years in advance of the need to provide the time for the City to appropriate the necessary funding. While private contractors often have long-term equipment replacement plans of their own, they are not constrained to executing deviations from that plan because they are in full control of what and when available financial resources are expended. Minneapolis’ five-year plan for equipment forces its equipment fleet manager to make decisions in conditions of greater uncertainty than that faced by its private-sector counterpart. Thus, using a stochastic LCCA model to inform these decisions is more appropriate for the public sector because of the length of the decisions’ time horizon.

Some public agencies avail themselves of other funding mechanisms to partially support their fleet operations. Examples are grant acquisitions, purchasing of used parts, and leasing agreements (Antich 2010). Private contractors normally have an immediately available line of credit upon which they can draw to finance large purchases whether planned or unexpected (The Bond Exchange 2010). A public agency does not have the same financial flexibility; consequently, the constraints on the use of available funding can affect the replacement and repair cycles for equipment fleet. For example, the City of Macomb, Michigan deferred all vehicle and equipment purchases for one year in 2010 due to budget deficits. As a result, in 2011 they were faced with substantially higher maintenance and repair costs (Antich 2010). While choosing the null option of not spending money on the equipment fleet may have been an unavoidable fiscal reality, the consequence was that the decision effectively extended the service life of the equipment scheduled to be replaced in 2010 beyond its economic life. The result conceivably could be equipment that is unable to be productively employed because of unacceptably high repair costs and could end up being disposed of at a salvage value far below the unit's possible market value if it had been repaired the previous year (Antich 2010).

The other issue is purely mechanical as experience has shown that idle equipment deteriorates if it is not operated as designed. Things like gaskets and seals dry out causing fluid to leak or the gasket to blow when the machine is operated for the first time after a long period of being idle (Moss 2014). Thus, the public sectors financial constraints have the potential to put an agency's fleet into a virtual demise if needed repairs cannot be made, and old equipment cannot be replaced when it reaches the end of its economic life. One can infer from this discussion that from the public's perspective, there is a strong tendency to keep a piece of equipment for as long as possible before replacing it because of the administrative burden required to get purchase authority. Therefore, it is critical that the fleet manager have a tool that will provide the most accurate information to assist in making major repair and replacement decisions. Developing that tool is the objective of this research.

## Research Motivation

Managing an agency's major equipment fleet is rife with conflicting priorities. One of the most important is the economic trade-off between the capital cost of replacing a piece of equipment and the ownership costs of operating and maintaining the machine in question if retained for another year. Therefore, determining life cycle costs and the economic life is vital for fleet managers to optimize equipment funds.

Many studies have been completed on equipment replacement optimization. For example, Fan and Jin (2011) applied a decision tree to determine the significant factors in the economic life determination of construction equipment. The utilization of EUAC was used to find the replacement age of equipment within the North Carolina Department of Transportation (DOT) fleet (Kauffman et al. 2012). Previous studies do not have a stochastic function that models volatility in commodity pricing for input variables like diesel fuel to determine the economic life of equipment. This research has developed a robust method permitting equipment fleet managers to maximize the cost effectiveness of the fleet by optimizing the overall life cycle value of each piece in the fleet.

## Problem Statement

The effective management of equipment fleet is a vital part of a public agency. A public agency's equipment fleet decisions are often made years in advance of actual purchases and usually involve a mandate to minimize costs (COM 2014). Therefore, the need to accurately determine the life cycle costs and replacement age is significant. Additionally, fleet management software based on basic engineering economic theory oversimplifies this complex relationship by failing to account for non-financial input parameters, such as the agency's sustainability goals, volatility of fuel prices, actual annual usage rates for seasonal equipment, etc.

Deterministic equipment LCCA models only provide results based on discrete input parameters while a stochastic model utilizes a distribution of values to improve the accuracy of the output (Pinsky and Karlin 2011). By taking into account operating costs and non-financial parameters, better decisions may be made by fleet managers with an expanded understanding of how each input parameter impacts the final decision. A stochastic equipment LCCA model will be proposed for use by equipment fleet managers to sell, purchase, or repair pieces of equipment within their fleets.

The primary question this research seeks to answer is as follows:

*How does uncertainty in the input variables to the classic LCCA methodology impact equipment economic life?*

The primary research question is addressed by answering the following three specific questions:

1. *How does volatility in fuel costs and variation in interest rates impact equipment economic life?*
2. *How does uncertainty in other input parameters impact equipment life cycle cost and, hence, equipment economic life?*
3. *Can stochastic models be used to determine equipment economic life in a manner that is different than current deterministic models?*

## Thesis Organization

This thesis contains three journal papers in chapters 3, 4, and 5. Each paper is related to equipment LCCA, but each is intended to provide the answers to one of the three specific questions detailed in the previous section. Chapter 1 provides complementary information that is needed to understand the concepts that were utilized throughout this thesis. Chapter 2 contains the research methodology and supplemental information that was completed for this thesis.

Chapter 3 discusses the influence of fuel volatility and interest rate variation within the stochastic equipment LCCA model. Chapter 4 determines which equipment LCCA input parameters have the greatest impact on equipment life cycle costs by utilizing a sensitivity analysis of the stochastic model. Finally, Chapter 5 applies a stochastic equipment LCCA model to determine the economic life that is different than the deterministic methods.

Chapter 6 contains the conclusion and limitations of the thesis based on the previous chapters. Chapter 7 encompasses the recommendations for future research related to the work that has been completed in this thesis. After Chapter 7, the appendices contain supplemental information and details of the output results pertaining to the research.

# CHAPTER 2.

# OVERALL APPROACH TO RESEARCH METHODOLOGY AND VALIDATION

Chapter 2 contains the research methodology that is functional in Chapters 3, 4, and 5. Figure 2 displays the research methodology that was employed for this study. This is the overall approach in the development of the stochastic model and economic life determination used to implement equipment LCCA.

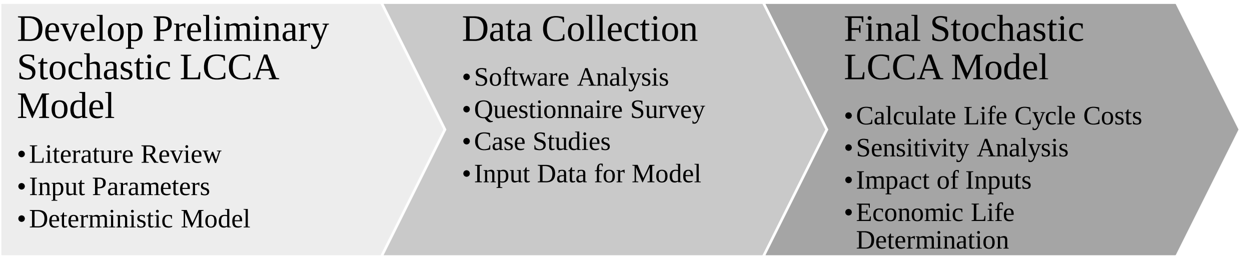

**Figure 2. Research Methodology**

## Methodology

The research steps and instruments are detailed within each paper in Chapters 3, 4, and 5. This chapter contains the stochastic model that was developed based on the PSM to calculate equipment life cycle costs (2002). The use of engineering economics is detailed to explain the economic life calculation based on the works of Park (2011). Additionally, the statistical F-test is defined because it was applied to determine the historical fuel price range in Chapters 4 and 5.

### Software Analysis

Current LCCA and fleet management software is extensive and diverse. Each platform has unique abilities for varying applications. This research conducted an analysis of twenty-eight individual, commercial products to differentiate between software packages. The purpose of this research effort was to determine if any existing packages would serve as viable software programs for use by the Minnesota Local Road Research Board (LRRB) members. Each piece of software was analyzed on its features, capabilities, and functionality. Based on this analysis, a determination of the viability of the software and its ability to satisfy the needs articulated in the request for proposals for the current project was made.

The primary research instrument was a formal content analysis of the features, capabilities, and functions found in the marketing and specification literature available on the Internet. A content analysis can be used to develop "valid inferences from a message, written or visual, using a set of procedures" (Neuendorf 2002). Based on the equipment LCCA capabilities, the most viable software programs were Fleet Maintenance Pro, Fleet & Equipment Manager, FleetFocus, J. J. Keller's Maintenance Manager™ Software, and collectiveFleet™. The programs were found to have the highest capabilities to apply to the LCCA of the equipment fleet.

## Benchmarking Survey

An online survey was distributed to benchmark the usage of LCCA and other parameters in agency fleet management programs. The questionnaire was developed from the literature review and assembled in accordance with the thirteen-point protocol established by Oppenheim (1992). The questionnaire design protocol is summarized as follows:

1. "Deciding the *aims* of the study."
2. General aims must then lead to a statement of specific aims, and these should be turned into *operationalized* aims; that is, a specified set of practical issues or hypotheses to be investigated.
3. [Developing] a statement of the *variables* to be measured, and…a set of questions, scales, and indicators will have to be formulated.

4. Reviewing the relevant *literature*.
5. Preliminary *conceptualization* of the study, followed by a series of exploratory in-'depth' interviews; revised conceptualization and research objectives.
6. Deciding the *design* of the study and assessing its feasibility.
7. Deciding which *hypotheses* will be investigated.
8. Making these hypotheses specific to the situation… [i.e.] *operational*.
9. Listing the *variables to be measured.*
10. Designing… the necessary *research instruments* and techniques.
11. Doing the necessary *pilot work* to try out the instruments.
12. Designing the *samplers.*
13. Drawing the sample: *selection of the people* to be approached." (Oppenheim 1992).

The survey was distributed by the City of Minneapolis to solicit a substantial amount of respondents. The questionnaire consisted of seven questions pertaining to equipment fleet management. The main objective of the survey was to gather information about input parameters, fleet data, budget information, and the decision-making processes for equipment. The survey results were found to be inconclusive based on the limited number of respondents and varied results.

## Minnesota Case Study Analysis

The case study analysis for this research involved three agencies: the City of Eagan, the City of Minneapolis, and Dodge County. The candidates were selected by the research team because they comprise three different levels of equipment fleet sizes and practices. Minneapolis is a large city; Eagan is a small city, and Dodge is a county. The case studies were conducted through structured interviews of the stakeholders in each agency. The objective of the case studies was to capture current practices and obtain data.

**City of Eagan:** Eagan utilizes a vehicle rating policy to determine repair and replacement decisions. The policy is based on the age of the vehicle and a rating system. Once the piece of equipment reaches a certain criteria, the vehicle is evaluated and reviewed to determine if a replacement is required. The repair decisions for pieces of equipment are related to the rating system as well. Pieces of equipment are repaired and maintained until they reach the minimum criteria for replacement.

**City of Minneapolis:** Minneapolis utilizes various methods and techniques to make major equipment fleet decisions. The utilization of the M5 software program, minimum cost method, and maximum number of hours are some of the components that aid in equipment decisions. The replacement evaluation has three major sets of information that are analyzed including equipment life cycle, equipment utilization, and the business need of the equipment. The repair process is specified by 50% to 60% of the original value of a piece of equipment. If a piece of equipment is above the optimal range of 50% to 60% of the initial value then the equipment is repaired. Utilization and agency need are vital in the repair and replacement decision process of equipment.

**Dodge County:** Dodge County does not utilize any formal decision making techniques to make equipment fleet decisions. The replacement process is based on the needs and allowable budget. Also, repairs for both light and heavy pieces of equipment are performed on an as-needed basis without any analysis of the economics of the repair.

The City of Minneapolis and the City of Eagan have the most dynamic equipment fleet replacement and repair policies. Dodge County’s absence of overall structure within the equipment fleet management is mostly due to the lack of data recording and policy implementation. The City of Minneapolis and the City of Eagan are the most significant case studies for this research project. Therefore, the data used for this research is from the City of Minneapolis. Chapters 3, 4, and 5 all use equipment fleet data that was provided from the City of Minneapolis.

## Equipment Data

Two options were evaluated when deciding on the data to use for this thesis. The first option was to use data gathered from the MPWFSD, and the second option was obtaining data from the literature review. The MPWFSD provided historical equipment fleet data dating back to 2009. Some of the data was able to be utilized in this thesis, such as service lives, acquisition costs, and salvage values. However not all the data was able to be exploited such as the repair, maintenance, tire, tire repair, and depreciation cost. Regression analysis was performed to determine if the data could be employed; however, with the lack of historical data, this option was found to be inapplicable. The quality of the data from the MPWFSD was not consistent, and the data for the equipment had to be derived from the literature review.

## Deterministic and Stochastic Equipment LCCA Model

The equipment LCCA model was built on the components of the PSM and engineering economics. The model was employed in all the papers found in Chapters 3, 4, and 5. The model uses Equation 1 to determine the life cycle costs of equipment.

$$LCC = Operating\ Cost + Ownership\ Cost \tag{1}$$

Where:
$LCC = Life\ cycle\ cost$
$Operating\ Cost = R\&MC + FC + TC + TRC$
$R\&MC = Repair\ and\ maintenance\ cost$
$FC = Fuel\ cost$

$TC = \text{Tire cost}$
$TRC = \text{Tire repair cost}$

The operating costs are based on Equations 2 through 6 (Peurifoy and Schexnayder 2002, Atcheson 1993). Equation 3 is used to calculate the repair and maintenance costs at a constant rate each year, while Equation 4 is used to calculate the repair and maintenance costs in a given year. Equation 4 is used in the economic life determination because it may be applied stochastically and increases as the machine ages.

$$\text{Straight-line depreciation} = (IC - SV)/N \qquad (2)$$

Where:
$IC = \text{Initial Cost}$
$SV = \text{Salvage Value}$
$N = \text{Useful Life}$

$$R\&MC = (\text{Repair factor})\ x\ (\text{straight-line depreciation cost}) \qquad (3)$$

$$\text{Years } R\&MC = \left(\left(\frac{Year\ Digit}{Sum\ of\ Years\ Digit}\right) x\ Total\ repair\ Cost\right) + R\&MC \qquad (4)$$

Where:
Year Digit = Year taken in ascending order
Sum of Years Digit = Sum of years' digit for the depreciation period
Total Repair Cost = Repair Factor x (List Price – Tire Cost)
Repair Factors given by Table 1

**Table 1. Repair Factors (Atcheson 1993)**

| Equipment Type | Operating Conditions | | |
|---|---|---|---|
| | Favorable | Average | Unfavorable |
| Scrapers-All Types | 42% | 50% | 62% |
| Front-End Loaders-Rubber-Tired | 45% | 55% | 62% |
| Haulers | 37% | 45% | 60% |
| Bottom Dumps | 30% | 35% | 45% |
| Crawler Tractors (by Application) | | | |
| Industrial | 10% | 25% | 75% |
| General Contracting | 40% | 60% | 80% |
| Quarrying | 50% | 85% | 115% |
| Mining | 70% | 110% | 150% |

$$FC = TF \times EF \times CF \times hp \times FP \tag{5}$$

Where:
$TF$ = Time factor, based on the minutes of productivity within an hour utilized as a percent
$EF$ = Engine factor, based on the percent of horsepower utilized
$CF$ = Consumption factor, units of gallon of fuel per flywheel horsepower hour (gal/fwhp-hr)
$hp$ = Engine horsepower
$FP$ = Fuel price, units of \$/gal

$$TRC = \% \text{ of } TC \tag{6}$$

The ownership costs for the model utilize Equations 7 and 8 (Peurifoy and Schexnayder 2002, Park 2011).

$$\text{Ownership Cost} = (IC - SV)A_P \tag{7}$$

$$A_P = P[(i(1+i)^N)/((1+i)^N-1] \tag{8}$$

Where:
$IC$ = (list price – tire cost)
$SV$ = % of the initial cost
$N$ = Year of calculation
$i$ = Interest rate
$P$ = Present worth

$A_P$ = often shown as $(A/P, i, N)$ (Park 2011)

## Equipment Economic Life Calculation

The economic life calculation is used in Chapters 3 and 5. The EUAC takes into account the operating and ownership cost differently than the life cycle cost calculations, shown in Equations 9 through 12 (Park 2011). The ownership costs utilize the market value of the vehicle in a given year, displayed by Equation 11 (Park 2011). The operating costs must also be calculated, using Equation 10, on an annual basis in a given year to properly calculate the EUAC (Park 2011).

$$EUAC = LCC = Operating\ Cost + Ownership\ Cost \tag{9}$$

$$Operating\ Cost = (\textstyle\sum_{n=1}^{N} Ownership\ Cost_n (P_F)(A_P) \tag{10}$$

$$Ownership\ Cost = (IC - S_N)A_P + i(S_N) \tag{11}$$

$$P_F = P[F(1+i)^{-N}] \tag{12}$$

*Where:*
$IC$ = (list price – tire cost)
$S_N$ = Market value at the end the ownership period of $N$ years
$N$ = Year of calculation
$i$ = Interest rate
$P$ = Present worth
$F$ = Future worth

$P_F$ = often shown as $(P/F, i, N)$ (Park 2011)

## Determining Historical Fuel Cost Sampling Ranges

The statistical F-test was applied to determine the historical fuel cost sampling ranges for Chapters 4 and 5. "The F-test evaluates the ratio of two variances as evidence to test the null hypothesis that two population variances are equal" (LeBlanc 2004). The data used for the F-test must be obtained from "unbiased study design" to create a population variance and a normal distribution (LeBlanc 2004). A major assumption of the test is that both populations under investigation have a normal distribution (LeBlanc 2004). The F-test uses Equation 13 to determine the ratio (LeBlanc 2004). This equation is based on the variances, $S$, within two populations.

$$F_{test} = S^2{}_1/S^2{}_2 \tag{13}$$

The larger of the two variances is placed in the numerator and the smaller in the denominator (LeBlanc 2004). The null hypothesis is true if the ratio is calculated to be 1.0, but the larger the ratio the "stronger the evidence that the two population variances are unequal" (LeBlanc 2004).

The F-test may be employed for a one or two-tailed test, with the p-value determining the significance of the data. The p-value represents the area on the right and left end of a normal distribution for a two-tailed test (LeBlanc 2004). If $p \leq 0.05$, "the probability associated with the random-variation explanation for the observed difference between the two sample variances is sufficiently low to reject this explanation" (LeBlanc 2004). Thus, if the p-value was greater than 0.05 the null hypothesis could be rejected and the two samples do not have significantly similar data. This logic will be employed to determine the appropriate choice, in months, for the historical fuel prices in Chapters 4 and 5.

# CHAPTER 3.
# IMPACT OF FUEL VOLATILITY ON EQUIPMENT ECONOMIC LIFE

O'Connor, E.P. and D.D. Gransberg, "Impact of Fuel Volatility on Equipment Economic Life," (to be submitted for publication in the *Journal for Construction Engineering and Management*, ASCE, in 2014).

## Abstract

Diesel fuel prices are currently more volatile than in any time in the past two decades. As a result, its impact on public agency equipment fleet management decisions is more prominent than ever before. Therefore, the purpose of this research is to quantify the impact of fuel volatility on the economic life of equipment and provide guidance on how to factor this major operating cost into public agency fleet repair, overhaul, and replacement decisions. The authors demonstrate the impact using both deterministic and stochastic equipment economic life cost models. An example utilizing a 2002 Sterling LT9500 dump truck is provided to demonstrate the difference between the two models. When the stochastic model is used, the equipment management decision can be enhanced by associating a confidence level with the economic life determination. The researchers find that a 50% increase in fuel costs creates a 32% increase in the life cycle cost, which reduces the economic life of the truck. It was also concluded that the life cycle cost model is most sensitive to the interest rate used and the fuel costs.

## Introduction

Equipment replacement decisions are critical to the success of public agency fleet management. If a piece of equipment is not replaced at the end of its economic service life, the maintenance, repair, and fuel consumption costs will outweigh the value of its purpose (Jensen and Bard 2002), eating more than its fair share of the agency's limited operations budget. The issue is exacerbated by the fact that in most cases purchases of new equipment are made using the agency's capital budget, which typically requires approval from authorities in the fleet manager's chain of command (Gransberg et al. 2006). Therefore, if a machine is selected for replacement before it literally stops running, the fleet manager must be able to justify the purchase to those individuals. To do so often requires a means to demonstrate the business case for buying a new machine rather than keeping the old one for another year.

The purpose of this paper is to demonstrate the usage of a deterministic and stochastic model to quantify equipment life cycle costs, economic life, and the impact of fuel volatility. The usage of commercial software will be employed to perform Monte Carlo simulations to calculate the stochastic life cycle costs. Also, a sensitivity analysis will be performed to determine the impact of fuel fluctuation. An example using a dump truck from the MPWFSD equipment fleet will be used to demonstrate the fuel impact and the difference between the deterministic and stochastic models.

## Background

Past research has provided a number of options to base the replacement decision on accepted financial terms that are easily understood by nontechnical personnel with limited fleet management expertise or experience. According to Fan and Jin (2011), the most widely accepted approach is called the "cost minimization method" which was first proposed by Taylor (1923). Schexnayder (1980) describes it as "the most appropriate analysis method" and proposes that it "yields an optimum replacement timing cycle and a corresponding equivalent annual cost." The method was adapted for public transportation agencies by Gillerspie and Hyde

(2004). All three models use life cycle cost analysis based on engineering economics to identify a point in a given machine's life where the cumulative cost of operating and ownership is at its minimum. Figure 3 graphically illustrates the basis of this theory. It shows that as a piece of equipment ages, its capital value decreases while its operation and maintenance costs increase. The theoretical optimum service life is the point where cumulative costs are at the minimum and defines the economic life (Kauffman 2012).

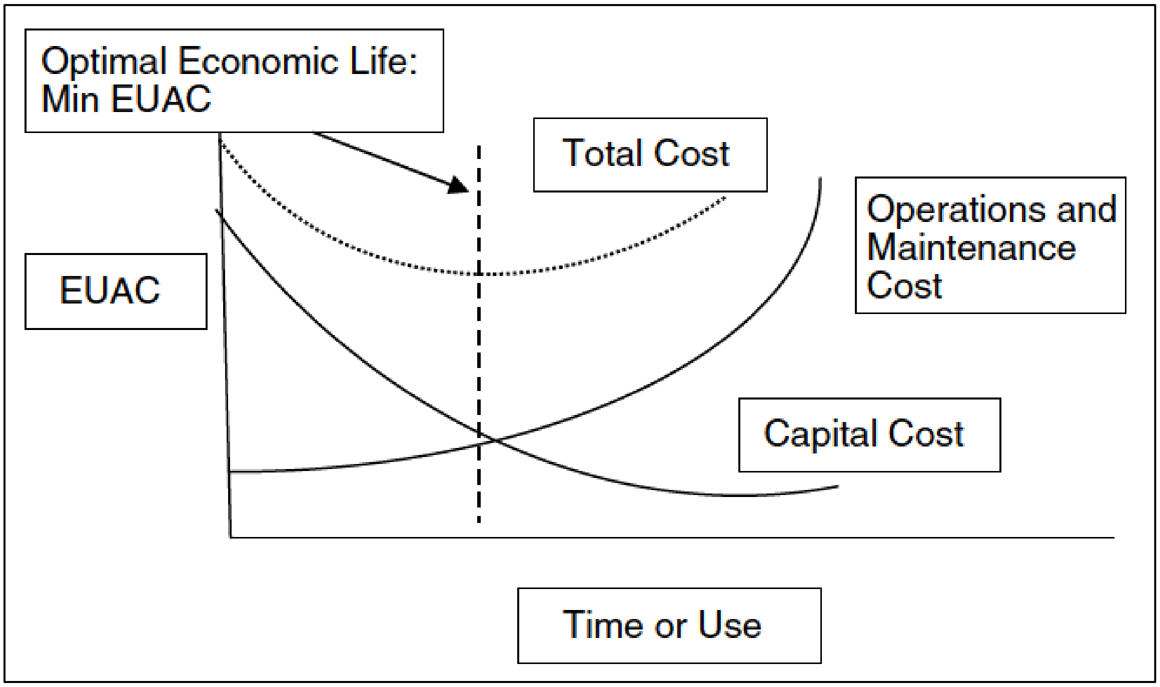

**Figure 3. Economic Life of Equipment Based on the Cost Minimization Method (Kauffman 2012)**

Each of the models described above are deterministic models that require the analyst to develop single values for each input variable. Thus, the economic life is really a snapshot based on the values used at the time of the analysis. While all models are merely mathematical analogs for real conditions, assuming a given cost for a significant variable like fuel prices makes the output used by the decision-maker highly dependent on the quality of the assumptions used in the analysis. Two key input variables are the interest rate used in the model and the values used for operating costs that are highly volatile, like fuel prices. According to Schexnayder (1980), "because the analysis process incorporates [engineering economics] procedures it was necessary to establish the correct interest rate factor." The interest rate assumption issue was validated by several other studies (Pittenger et al. 2012, Gransberg 2009, Gransberg and Kelly 2008, Gransberg and Scheepbouwer 2010), and in each case the value of allowing the interest rate to be modeled as a stochastic value rather than a single assumption was demonstrated.

Diesel fuel prices are also an input variable that fluctuate within a wide range and are "considered as a significant input to the annual operating costs" (Richardson 2007). Therefore, understanding the impact of fuel prices is vital to optimize the life cycle equipment fleet management decisions. Figure 4 depicts the monthly diesel fuel prices from January 2011 to March 2014 (U.S. Department of Energy 2014). The quantities shown in the figure were used for the creation of the stochastic model. The fuel prices are shown to fluctuate from three to four dollars with no certain pattern. Thus, this volatility impacts the life cycle costs and equipment decisions substantially. The fluctuation in the fuel costs directly impacts the life cycle costs of equipment because life cycle costs will increase along with the fuel prices, which directly impact the calculated economic life of the equipment. By allowing the fuel price input variable to vary over its historic range, a better life cycle cost may be achieved. Consequently, making fuel costs a stochastic input will allow for a more realistic calculation in the economic life determination.

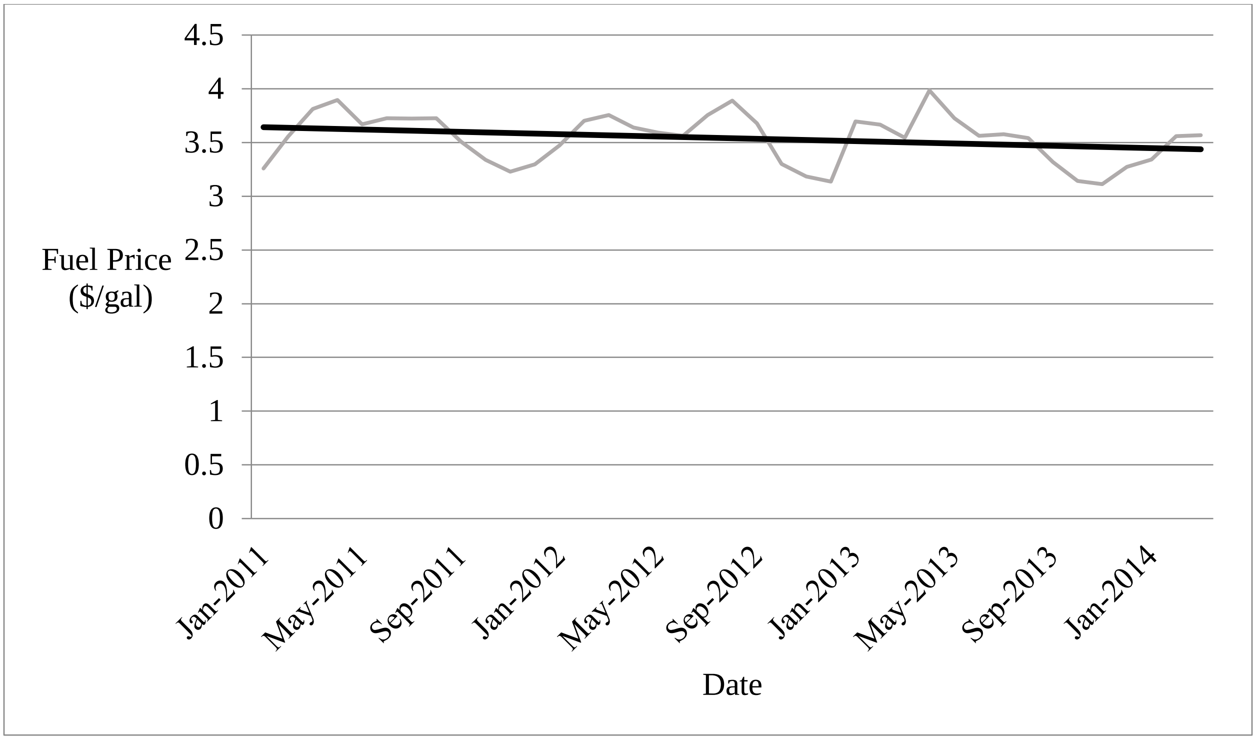

**Figure 4. Historical Fuel Costs (U.S. Department of Energy 2014)**

## Methodology

The methodology for this study is based on the deterministic and stochastic models to calculate equipment life cycle costs. A stochastic economic life determination is applied to further examine replacement ages and aid the public agency's equipment fleet managers.

### Deterministic and Stochastic Models

Both models were developed using equipment ownership cost inputs prescribed by Peurifoy and Schexnayder (2002) and engineering economic LCCA to determine the economic life of equipment. The overall goal of the model was to optimize the life cycle costs and the economic life of equipment for a pubic agency's fleet. To accomplish this the fuel volatility, interest rate fluctuation, and changing market values were made to be stochastic inputs for the model. Monte Carlo simulations were then run to produce probability distributions which allow the development of probability output.

The PSM was determined to be the most thorough and applicable method that could be applied in the development of the model. The method was adapted to apply to a public agency. For example, since public agencies don’t pay sales or property taxes, that component was dropped in the formulation of the final deterministic model illustrated in the remainder of this paper.

The input parameters utilized in the PSM to formulate the deterministic and stochastic models consist of solely cost variables. The costs are analyzed on an annual basis for all the parameters. Therefore, the final output for the life cycle cost is an annual amount. Since most agency budgets are based on the fiscal year, using EUAC analysis provides output in a form that correlates with the purpose for conducting the analysis: to determine the required equipment replacement capital budget (Pittenger et al. 2012). The model uses Equation 1 to determine the life cycle cost of equipment.

The operating costs for the deterministic and stochastic models are based on Equations 2 through 6 (Peurifoy and Schexnayder 2002, Park 2011). Equation 4 is used to calculate the repair and maintenance cost in a given year, while Equation 3 is used to calculate the repair and maintenance costs at a constant rate each year. The ownership costs for the deterministic and stochastic models utilize Equation 7 (Peurifoy and Schexnayder 2002).

For this study, Equation 5 used a 50-minute productive hour for the time factor, which equates to 0.83. Also, for Equation 5, 0.04 gal/fwhp-hr was used for the consumption factor and 1.0 was used for the engine factor. For Equation 3, 37% was used for the repair and maintenance factor, and 16% was used for the tire repair factor in equation 6 (Peurifoy and Schexnayder 2002).

Figure 5 summarizes the stochastic LCCA model based on the adapted public sector version of the PSM. The stochastic inputs are the fuel costs within the operating costs and the interest rate used in the ownership costs. The deterministic inputs include the initial cost, salvage value, useful life, depreciation, tire cost, and tire repair costs.

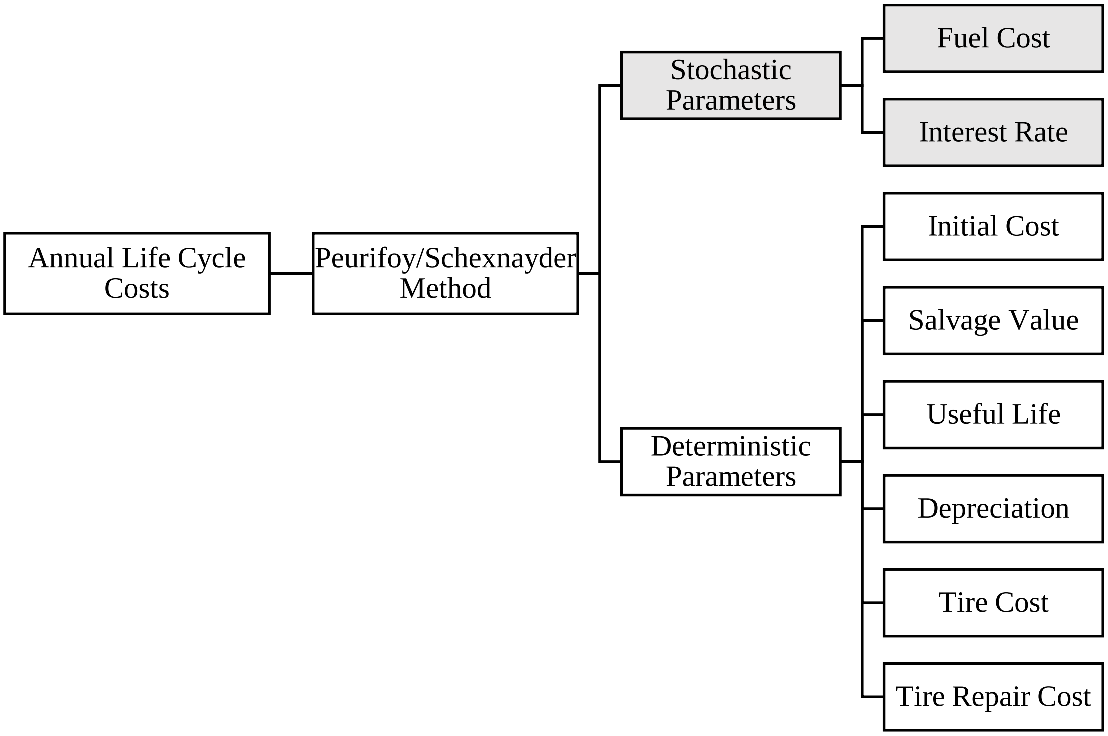

**Figure 5. Flow Chart of LCCA Method**

## Optimal Economic Life Cycle Analysis

The determination of the economic life for equipment fleet is a critical component of the LCCA. The economic life, or the optimal time to sell a piece of equipment, requires the usage of EUAC calculations. To properly use the EUAC, the ownership costs and operating costs must be calculated on an annual basis in the correct year. The life cycle costs must also be calculated, using Equation 9, on an annual basis in a given year to properly calculate the EUAC (Park 2011). Additionally, Equations 10 and 11 are utilized for the operating and ownership costs within the EUAC (Park 2011).

Schexnayder (1980) found that in the private sector that “the proper interest rate is the cost-of-capital rate for the particular firm making the analysis.” Public agencies may or may not be able to determine its own cost-of-capital. However, if the replacement equipment will be funded by the sale of municipal bonds or some other financial instrument, then that rate would be appropriate. Therefore, the need to evaluate life cycle cost using a stochastic interest rate is no longer necessary.

The calculation of the EUAC is done over the entire life span for a piece of equipment. The lowest EUAC in a given year will be the optimal economic life. This will be the point in time in which the piece of equipment has the lowest combined operating and ownership costs.

Figure 6 summarizes the stochastic inputs that were utilized during the economic life calculations. Since the interest rate is a stochastic input, all the calculations for the economic life employ a stochastic function. Additionally, the market value has been applied stochastically within the economic life calculation.

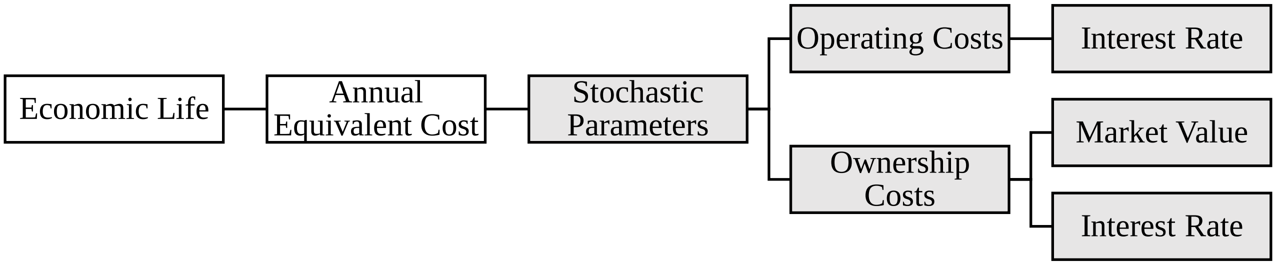

**Figure 6. Equipment Economic Life Flow Chart**

## Results

The results contain the output from the deterministic and stochastic equipment example. A sensitivity analysis quantified the impact of fuel volatility associated with the LCCA. Additionally, the stochastic model is compared with the deterministic model to illustrate the discrepancies.

### Deterministic Equipment Example

A 2002 Sterling LT9500 dump truck was employed in an example to demonstrate the deterministic method. The data for the dump truck was derived from the records furnished by the MPWFSD. Table 2 shows the information that was used during the formation of the model for the dump truck. The dump truck was chosen for this demonstration because it is a typical piece of equipment used in public agencies.

**Table 2. Deterministic LCCA for the 2002 Sterling LT9500 Dump Truck**

| Parameters | 2002 Sterling LT9500 Dump Truck |
|---|---|
| Initial Cost | $96,339 |
| Annual Usage in Hours | 1000 |
| Annual Initial Cost ($A_{IC)}$ | $11,265 |
| Tire Cost | $3,240 |
| Salvage Value (12%) | $11,561 |
| Annual Salve Value ($A_{SV)}$ | $1,456 |
| Useful Life | 14 |
| Sum of Years Digit | 105 |
| Change in Market Value | 10.60% |
| Interest Rate | 7.38% |
| Depreciation | $6,056 |
| Tire Repair Costs | $518 |
| R&MC | $2,241 |
| Fuel Price | $3.54/gal |
| Fuel Costs | $50,523 |
| Total Operating Costs | $56,522 |
| Ownership Costs | $9,809 |
| Annual Life Cycle Cost | $66,330 |

Figure 7 depicts the plot of the annual life cycle costs for the 2002 Sterling LT9500 dump truck versus varying fuel prices.  As fuel prices increase, the annual life cycle cost of the dump truck increases.  The figure shows the drastic impact of the fuel pricing to the life cycle costs of a piece of equipment. This figure stresses the importance of accurately calculating the fuel costs to optimize the LCCA of equipment.

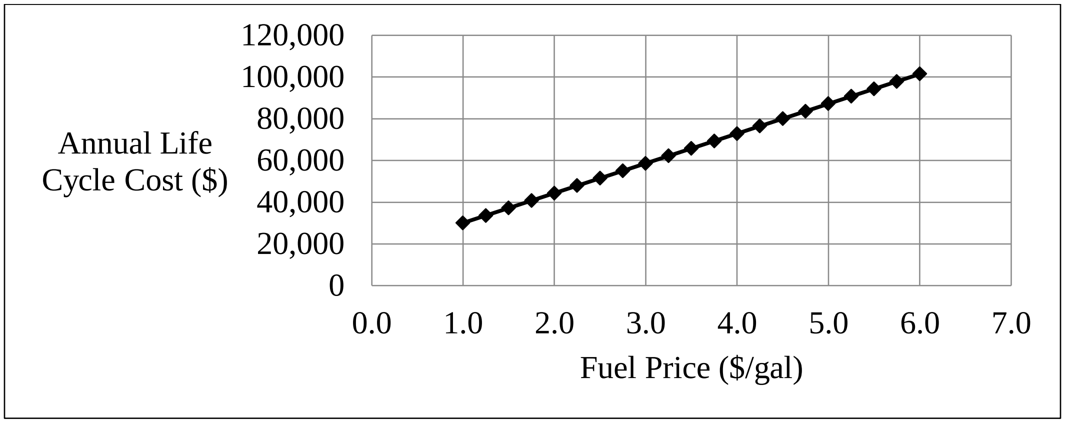

**Figure 7. Fuel Impact to Equipment Life Cycle Cost**

Figure 8 shows the optimal economic life of the dump truck.  The plot consists of the annual costs versus replacement age of the dump truck with the associated cost parameters.  The economic life of the dump truck is depicted by the dashed line at year 12, this is the optimal point where the R&MC are increasing while the ownership costs are decreasing.

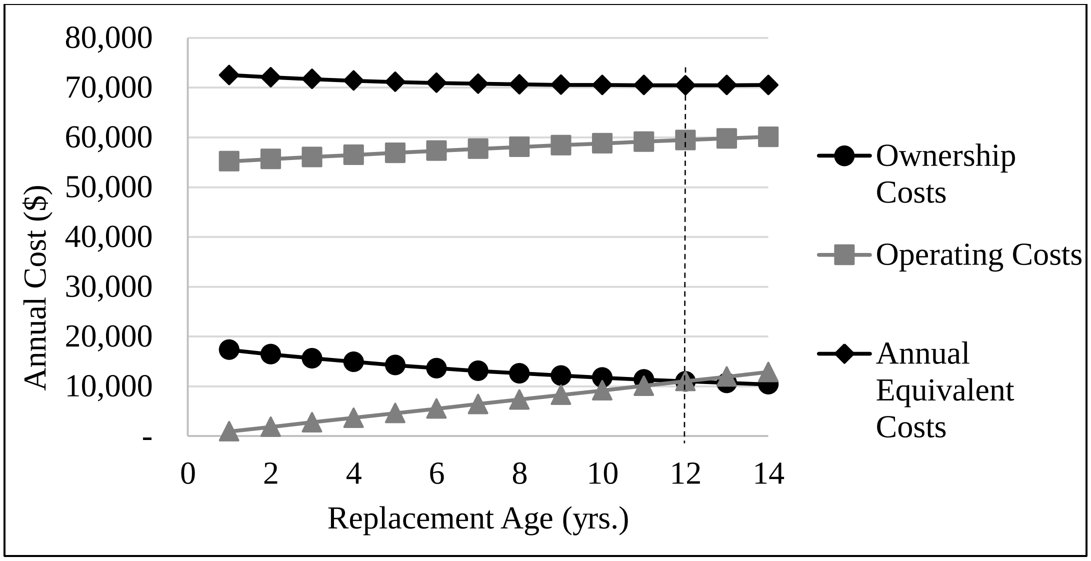

**Figure 8. Economic Life of the Dump Truck Using Deterministic Model**

## Stochastic Equipment Example

After the creation of the deterministic model, input values for the variables of interest are allowed to vary within their historic ranges in the stochastic model. The first priority was to create probability distributions for the stochastic inputs. Utilizing the 2002 Sterling LT9500 dump truck, the fuel prices, interest rate, and market value were made to be stochastic inputs. After creating distributions for the stochastic inputs, the stochastic model was created. The model ran Monte Carlo simulations to calculate the expected life cycle costs. Table 3 summarizes the parameters of the stochastic model and the output. The fuel cost, interest rate, market value, and annual life cycle costs are shown in Table 3 by the output that was calculated in the simulation. The market value was only utilized in the economic life calculations.

**Table 3. Stochastic LCCA for the 2002 Sterling LT9500 dump truck**

| Parameters | 2002 Sterling LT9500 dump truck |
|---|---|
| Initial Cost | $96,339 |
| Annual Usage in Hours | 1000 |
| Annual Initial Cost ($A_{IC}$) | $11,049 |
| Tire Cost | $3,240 |
| Salvage Value (12%) | $11,561 |
| Annual Salve Value ($A_{SV}$) | $1,300 |
| Useful Life | 14 |
| Sum of Years Digit | 105 |
| Change in Market Value | 10.78% |
| Interest Rate | 7.05% |
| Depreciation | $6,056 |
| Tire Repair Costs | $518 |
| R&MC | $2,241 |
| Fuel Costs | $50,813 |
| Total Operating Costs | $56,812 |
| Ownership Costs | $9,749 |
| Annual Life Cycle Costs | $66,560 |

Figure 9 shows the model's sensitivity to both interest rates and fuel prices. This diagram depicts the relationship between the input values and the impact to the annual life cycle costs. According to this simulation, the interest rate is shown to have a higher financial impact than the fuel prices in the calculation of the life cycle costs for the dump truck.

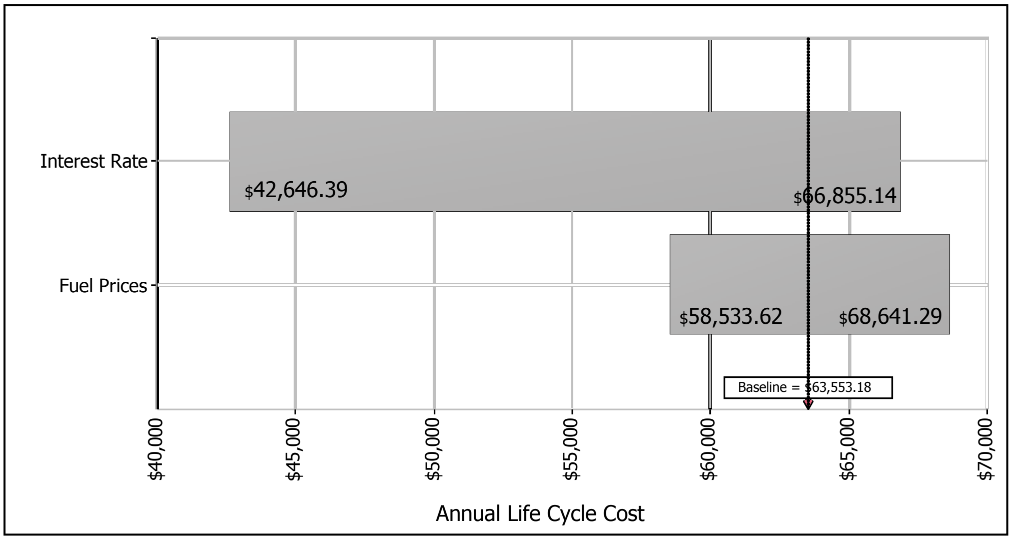

**Figure 9. Input Sensitivity for the 2002 Sterling LT9500 dump truck**

Figure 10 shows the economic life of the dump truck using the output from the stochastic model. The yellow triangle specifies the optimal economic life (i.e. the replacement age) of the 2002 Sterling LT9500 dump truck. The figure shows that as the level of confidence increases both the EUAC and the economic life increase. With a 90% confidence, an economic life of fourteen years was determined, which is equal to the service life of the dump truck.

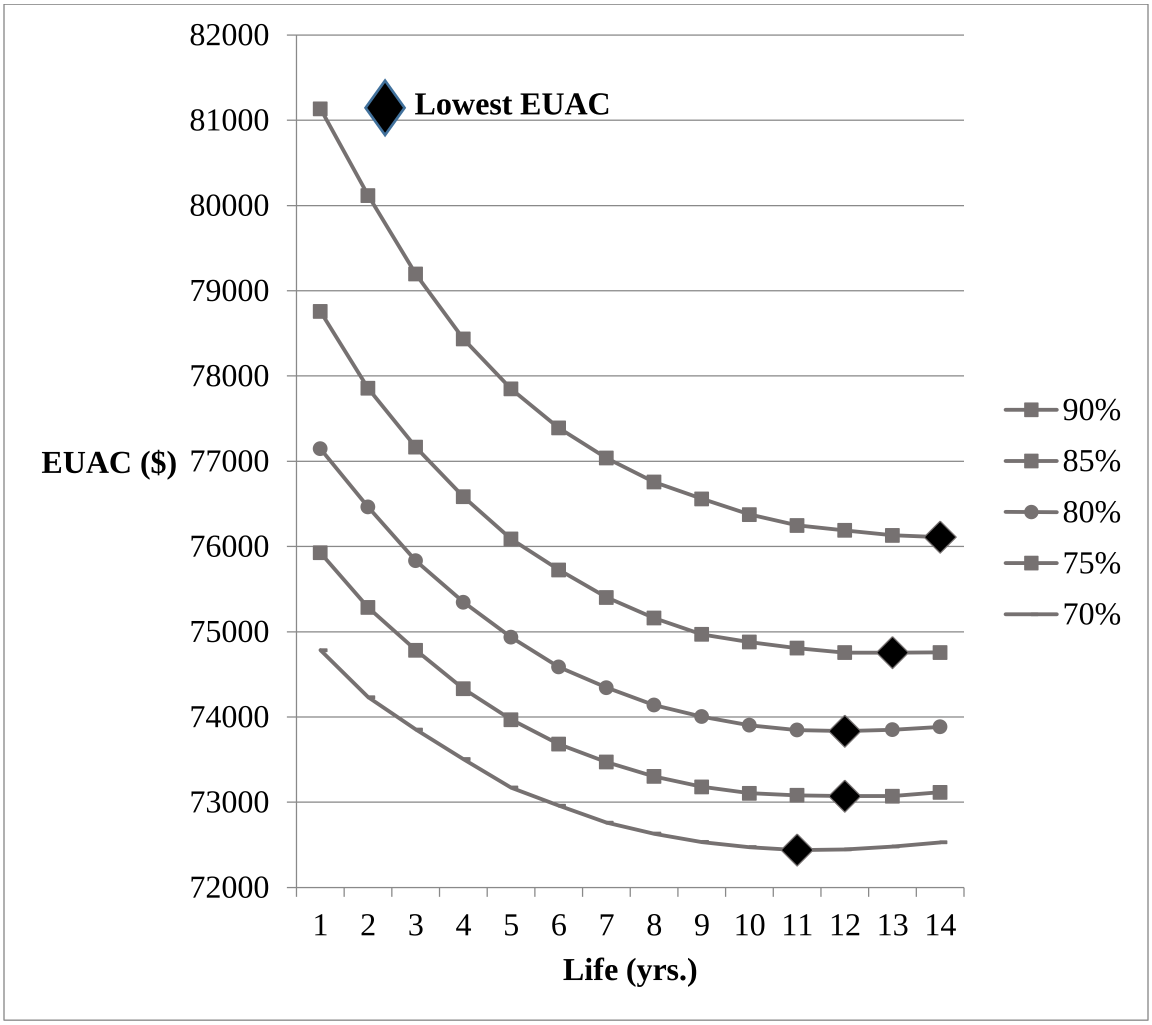

Figure 10. Economic Life of the dump truck using the Stochastic Model

Figure 10 provides the equipment fleet manager with information not available in a deterministic model's output. The range of 70% confidence to 90% confidence translates to an economic life between 11 and 14 years. Thus, if the equipment fleet manager wants to be completely sure that a piece of equipment has achieved its maximum economic life, then the truck would be retained in the fleet for 14 years. However, that desire to get the most value out of each capital equipment investment would be offset by the potential loss if the equipment had been replaced with the most current technology at an earlier point in its service life. Therefore, the best way to interpret the output shown in Figure 10 is to use it as a trigger point to begin a detailed evaluation of the costs and benefits of retaining the current piece of equipment for another year or replacing it with a comparable new machine. Taking this approach to decision-making would then trigger the fleet manager to begin an annual retain-replace analysis starting in year 11 and repeat it in years 12 and 13 with a replacement occurring in year 14 if the analysis did not show it should be replaced in a previous year.

Implementing the proposed model would allow the fleet manager to be able to forecast several years in advance the need for equipment replacement for the entire fleet. The manager would be able to generate a rational annual equipment replacement budget for the agency over a period of 3 to 5 years with relatively increased confidence that the decisions can be justified.

## Comparison of the Models

The change from deterministic to stochastic modeling is evident in the fuel costs and life cycle costs displayed in Table 4. The fuel cost for the deterministic model used a unit price of \$3.54/gal, while the stochastic model used a statistic distribution of the historical fuel costs. Additionally, the deterministic model utilized a fixed interest rate which the stochastic model did not. Based on the confidence levels, the life cycle costs differ. For example, the stochastic model determined a life cycle cost of \$68,467 with an 80% confidence, and the cost only increases as the confidence increases. Thus, the costs are separated by a larger quantity when the confidence levels are introduced.

**Table 4. Comparison of Deterministic Model vs. Stochastic Model**

| **Parameters** | **Deterministic** | **Stochastic** |
|---|---|---|
| Deterministic Life Cycle Costs (LCC) | $66,330 | - |
| 95% Confidence of the LCC | - | $70,631 |
| 90% Confidence of the LCC | - | $69,705 |
| 85% Confidence of the LCC | - | $69,040 |
| 80% Confidence of the LCC | - | $68,467 |

The economic life of the dump truck was determined to be 12 years for the deterministic model. Whereas, the stochastic model demonstrated that the truck's economic life could be as much as 14 years. The value added by the stochastic analysis directly relates to public agency funding constraints discussed in Chapter 2 and provides quantified justification for potentially retaining a piece of equipment past the point identified in the deterministic model.

## Conclusions

Deterministic and stochastic models were developed to calculate life cycle costs and the optimal economic life of equipment. An example was demonstrated, using a dump truck to show the usage of the models and to determine the impact of fuel volatility. This was achieved by applying the PSM and basic engineering economics principals to find the optimal life cycle cost solutions. The deterministic and stochastic models were then compared to examine the impact of the inputs.

When the stochastic model was applied to a piece of equipment, the sensitivity of the model's input variables were determined. The interest rate was found to have a greater impact on economic life output than fuel prices. Thus, the assumption of selecting an arbitrary interest rate with which to evaluate all alternatives is faulty. One author describes the issue in this manner: “engineering economics textbooks have over-simplified the [LCCA] process…” (Gransberg and Scheepbouwer 2010).

The confidence levels associated with the stochastic model demonstrates a difference from the deterministic calculations. The deterministic model determined an economic life of 12 years while the stochastic model determined a range from 11 to 14 years, with 14 years being the most certain time frame. Once again, this proves that allowing fuel prices to range probabilistically in the analysis provides a means to quantify the certainty of the equipment replacement decision.

To put the above analysis in the perspective of the public agency fleet manager, the interest rate chosen for the calculation is less important than the impact of fuel prices because the funding for the replacement alternative comes from the capital expense budget and the funding for fuel consumption comes from the agency’s operations and maintenance budget. Additionally, many agencies have mandated interest rates that must be used in LCCA (Gransberg and Scheepbouwer 2010), which effectively forces the fleet manager to use a deterministic rate in order to receive approval to purchase the new equipment. Therefore, the results argue that the fuel price is probably the most critical input when determining the economic life of equipment since fuel will be funded from the operations and maintenance budget. The capital budget will either contain funding for a purchase or not, but the operations and maintenance budget must purchase the fuel that the equipment fleet needs for the given fiscal year. Hence, with the increasing cost of diesel fuel, the issue of upgrading to a more fuel-efficient model of equipment using the latest technology has become an increasingly important element of the replace/repair decision. Therefore, employing the stochastic inputs allows the analyst to determine the impact of the most volatile component of the model.

# CHAPTER 4.

# EQUIPMENT LIFE CYCLE COST ANALYSIS INPUT VARIABLE SENSITIVITY ANALYSIS USING A STOCHASTIC MODEL

O’Connor, E.P. and D.D. Gransberg, “Equipment Life Cycle Cost Analysis Input Variable Sensitivity Analysis using a Stochastic Model,” (to be submitted for publication in the *International Journal of Construction Engineering and Management*, SAP, in 2014).

## Abstract

Deterministic life cycle cost models force the analyst to select a discrete value for every input variable even when past history has shown most of the inputs will vary over time. The important issue is the sensitivity of the model’s output to the values assumed for the input variables. To improve equipment LCCA models, each variable’s sensitivity must be known. This paper presents a comprehensive stochastic sensitivity analysis. Data from the MPWFSD equipment fleet was used to determine the impact of nine stochastic input variables. The authors find that the engine and time factors had the greatest impact on the output of the equipment life cycle costs.

## Introduction

Deterministic equipment LCCA models are employed to calculate various costs associated with equipment fleet. The input parameters utilize a fixed quantity to calculate the costs; however, fluctuation within an input is not taken into account. “In the deterministic model, each variable has a single ‘best’ value that is used” (Gransberg et al. 2006). This may not reflect the actual costs associated with a piece of equipment, especially with volatile inputs. A stochastic model is employed for a more accurate analysis. “[A] stochastic model predicts a set of possible outcomes weighted by their likelihood or probabilities” (Pinsky and Karlin 2011).

This paper will illustrate the usage of an equipment LCCA model with a large number of the input variables being stochastic. The usage of a sensitivity analysis will identify the most vital input parameters to the model. The MPWFSD equipment fleet data was applied to the study to use actual information from a public agency. Therefore, managers will be able to make equipment fleet decisions with the identification of the essential equipment characteristics. These decisions are especially critical to public agencies because they must minimize the costs of owning, operating, and maintaining equipment due to the lack of profit motive within public agencies equipment replacement policies (Gransberg et al. 2006).

A sensitivity analysis will be applied to the stochastic model using the Monte Carlo simulations. The analysis will determine the most sensitive inputs to the model by highlighting "the parameters that have the greatest influence on the results of the model" (McCarthy et al. 1995). Additionally, the analysis will allow for a more accurate depiction of the actual life cycle costs because a "sensitivity analysis can highlight model parameters that ought to be the most accurately measured so as to maximize the precision of the model" (McCarthy et al. 1995).

## Background

Most common stochastic models utilize Monte Carlo simulations (Gransberg et al. 2006). Monte Carlo simulations use "random samples from known populations of simulated data to track a statistic's behavior" (Mooney 1997). The first step in creating a simulation would be to define the data to be analyzed and, more importantly, the deterministic and stochastic variables (Mooney 1997). The next step is to create probability distributions for the stochastic or random variables. Next, an output variable must be created using a logarithm or mathematical equation utilizing the stochastic functions. Finally, the output variable is used to run the Monte Carlo simulations.

The common assumption is that repair and maintenance costs are the most influential parameters to equipment life cycle costs (Peurifoy and Schexnayder 2002). This is due to the uncertainty associated with the cost item. Equipment may need routine maintenance, minor repairs, or complete overhauls whose costs are hard to predict for each type of equipment. Additional influential cost parameters to equipment life cycle costs are depicted in Table 5.

**Table 5. Breakdown of Machine Cost over its Service Life (Peurifoy and Schexnayder 2002).**

| Cost Parameter | Percentage of Total Cost (%) |
|---|---|
| Repair | 37 |
| Depreciation | 25 |
| Operating | 23 |

The following input variables that were portrayed as stochastic in the model: annual usage, engine factor, time factor, fuel price, interest rate, salvage value, tire repair factor, repair and maintenance cost, and tire cost. Each was selected to determine the uncertainty associated with the inputs and to determine the impact of each parameter on the model.

The engine factor is a parameter that affects fuel efficiency and fuel cost. Engine factors "depend on the engine horsepower, engine type, fuel type, and operating conditions" (Atcheson 1994). Atcheson (1994) categorizes operating conditions in three degrees: low, medium, or high. Under standard conditions a gasoline engine will operate with a 0.06 gal/fwhp-h, and a diesel engine will operate with a 0.04 gal/fwhp-h (Peurifoy and Schexnayder 2002). These are deterministic factors utilized in the model, but the engine factor was made stochastic to account for the variations in operating conditions and equipment type.

The MPWFSD portrays salvage values as a percentage of capital cost, and the analysis uses this value to maintain consistency with the other data provided by the MPWFSD. The MPWFSD maintains equipment fleet data on a variety of both construction equipment and administrative vehicles. Administrative vehicles and construction equipment use percentages for salvage values shown in Table 6. The percentages for the construction equipment reflect values from only loaders, dump trucks, and bobcats. The administrative vehicles' salvage values are from sedans and pick-ups from the fleet data.

**Table 6. Salvage Values used for the Stochastic Model**

| Equipment Type | Salvage Values Utilized |
|---|---|
| Administrative Vehicles | 10%, 12&, 15%, 20%, 25% |
| Construction Equipment | 5%, 10%, 12%, 15%, 30% |

The tire repair factor is associated with the tire repair cost. Tire costs include the replacement of the tires, while tire repair cost takes into account the repairs on the tires (Gransberg et al. 2006). The tire costs were obtained from dealers within Minnesota to provide an accurate depiction of the costs associated with the MPWFSD's equipment fleet. The tire repair factors and annual usage for the stochastic model range from 12% to 16% (Gransberg et al. 2006, Atcheson 1993, Peurifoy and Schexnayder 2002). Additionally, the annual usage for the equipment ranges from 1,560 hours to 2,600 hours (Atcheson 1993, Peurifoy and Schexnayder 2002).

The interest rate was characterized by a range of values found in the literature in addition to Minnesota municipal bond rates to establish a relationship with a public agency. Table 7 displays the source for each of the interest rate values utilized within the stochastic model.

**Table 7. Interest Rate Sources for the Stochastic Model**

| Source | Interest Rate (%) |
|---|---|
| Atcheson 1993 | 8 |
| Caterpillar Inc. 2011 | 16 |
| Gransberg et al. 2006 | 6.75 |
| Kauffman et al. 2012 | 3 |
| Minnesota Municipal Bonds (May 20, 2014) | 3, 3.38, 2.5, 4, 5 |
| Park 2011 | 12, 16 |
| Peurifoy and and Schexnayder 2002 | 8 |
| Sabetghadam 2012 | 12 |

## Methodology

The stochastic equipment LCCA model was developed using equipment cost inputs prescribed by the Peurifoy and Schexnayder (2002) and engineering economics. The following input variables for the model were made stochastic: fuel prices, interest rates, repair and maintenance factors, tire costs, tire repair factors, engine and time factors, salvage values, and annual usage. Monte Carlo simulations were then run to produce probability distributions which allow the development of the probability output. Based on the output, a sensitivity analysis was performed by a commercial software to quantify the impact of the input variables.

The PSM was selected as a widely accepted equipment ownership cost methodology and used as the basis for the stochastic model. The PSM was developed for construction contractors and needed to be adapted for application by a public agency. For example, since public agencies do not pay sales or property taxes, that component was dropped in the formulation of the model.

The equipment costs were calculated on an annual basis using Equations 1 through 8. Equation 1 was employed to determine the annual life cycle costs, and Equations 2 through 8 were employed to calculate the operating and ownership costs.

The stochastic model that was employed for this research includes nine stochastic inputs that range from direct quantities to factors within an equation. Table 8 shows the stochastic parameters that were applied for the analysis. The values that utilized a deterministic variable were the initial cost, useful life, depreciation, and fuel consumption factors.

**Table 8. Stochastic Inputs: Range of Values**

| Parameter | | Range of Values |
|---|---|---|
| Fuel Price* | Gas | \$2.91 - \$3.96 |
| | Diesel | \$3.38 - \$4.13 |
| Interest Rate | | 3% - 16% |
| Time Factor | | 25% - 100% |
| Engine Factor | | 17% - 100% |
| Salvage Value | | 5% - 30% |
| R&MC | | 35% - 80% |
| Tire Cost | | Varied by Machine |
| Tire Repair Cost | | 12% - 16% |
| Annual Usage | | 1560hrs. - 2600hrs. |
| *\$/gal. | | |

The selection of historical fuel data is a significant issue within the stochastic model to ensure accuracy. Applying an abundance of historical fuel data may disrupt the model and take into account economic influences that are not present in this research. Also, the selection of only a few data points may not correctly quantify the fuel prices. Thus, finding the most appropriate time period for the data is vital to the accuracy of the model.

The historical fuel data was assessed every sixth month to determine a variation within the data points. The F-test and the P-value determination were used to define the most appropriate time period for the fuel data. Tables 9 and 10 show the mean, standard deviation, variance, and P-value for each specified month for gasoline and diesel fuel prices. The P-value is used to determine an appropriate time period for the fuel price sample population by calculating the significance to the null hypothesis. “P-values simply provide a cut-off beyond which we assert that the findings are ‘statistically significant’ (Davies and Crombie 2009). The null hypothesis is the assumption that there is no difference between two sample populations (Davies and Crombie 2009).

**Table 9. Historical Diesel Prices with Statistical Analysis**

| **Parameters** | **Number of Months** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **6** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **54** | **60** |
| Mean | $3.89 | $3.93 | $3.93 | $3.92 | $3.91 | $3.90 | $3.88 | $3.86 | $3.77 | $3.67 |
| Std. | $0.06 | $0.10 | $0.10 | $0.11 | $0.14 | $0.17 | $0.20 | $0.23 | $0.35 | $0.45 |
| Variance | $0.00 | $0.01 | $0.01 | $0.01 | $0.02 | $0.03 | $0.04 | $0.05 | $0.13 | $0.20 |
| P-Value (%) | | | 94.22 | 51.64 | 5.52 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 10. Historical Gasoline Prices with Statistical Analysis**

| **Parameter** | **Number of Months** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **6** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **54** | **60** |
| Mean | $3.66 | $3.63 | $3.63 | $3.62 | $3.61 | $3.60 | $3.58 | $3.57 | $3.49 | $3.41 |
| Std. | $0.11 | $0.18 | $0.17 | $0.18 | $0.19 | $0.21 | $0.23 | $0.25 | $0.34 | $0.40 |
| Variance | $0.01 | $0.03 | $0.03 | $0.03 | $0.04 | $0.04 | $0.05 | $0.06 | $0.11 | $0.16 |
| P-Value (%) | | | 93.79 | 87.40 | 58.12 | 29.63 | 9.64 | 2.59 | 0.00 | 0.00 |

Tables 9 and 10 show that the cut-off point where adding additional data points does not increase the statistical significance of the sample is in the 42nd month. By convention, five percent significance was applied to the study to determine the statistical significance (Davies and Crombie 2009). Thus, any P-value less than five percent is found “unlikely to have arisen by chance, and we reject the idea that there is no difference between the two treatments (reject the null hypothesis)” (Davies and Crombie 2009). For the diesel prices the 45-month time period was found to be the cut-off range, and for the gasoline prices the 47-month time period was found to be the most significant. Consequently, the 45- and 47-month ranges were applied for the fuel analysis.

## Results

Various types of equipment from the MPWFSD equipment fleet were employed in the stochastic model to determine the most sensitive variables. The following pieces of equipment were applied to the model: 2008 Ford F250, 2007 Chevrolet Impala, 2006 Ford Escape XLT, 2005 Sterling LT9513 tandem dump truck, 2006 Volvo L90F Art loader 2.5 yard, and a 2006 Volvo L150E Art loader 5 yard. The Chevrolet Impala, Ford F250, and Ford Escape are grouped into the administrative vehicles, and the Sterling dump truck and the two Volvo loaders are grouped as construction equipment.

The determination of the most sensitive inputs to the stochastic model used a sensitivity analysis within a commercial software. Figure 11 displays the sensitivity analysis output for the 2008 Ford F250. The range in the values is represented in dollar amounts, where a wider the range represents a more volatile input. The sensitivity of each variable is related to the mean of the annual life cycle cost associated with the piece of equipment. For the 2008 Ford F250 the time factor was the most fluctuating input to the stochastic model with a range from $9,645 to $35,495. Therefore, the time factor variable alone could make the annual costs vary by about $25,000.

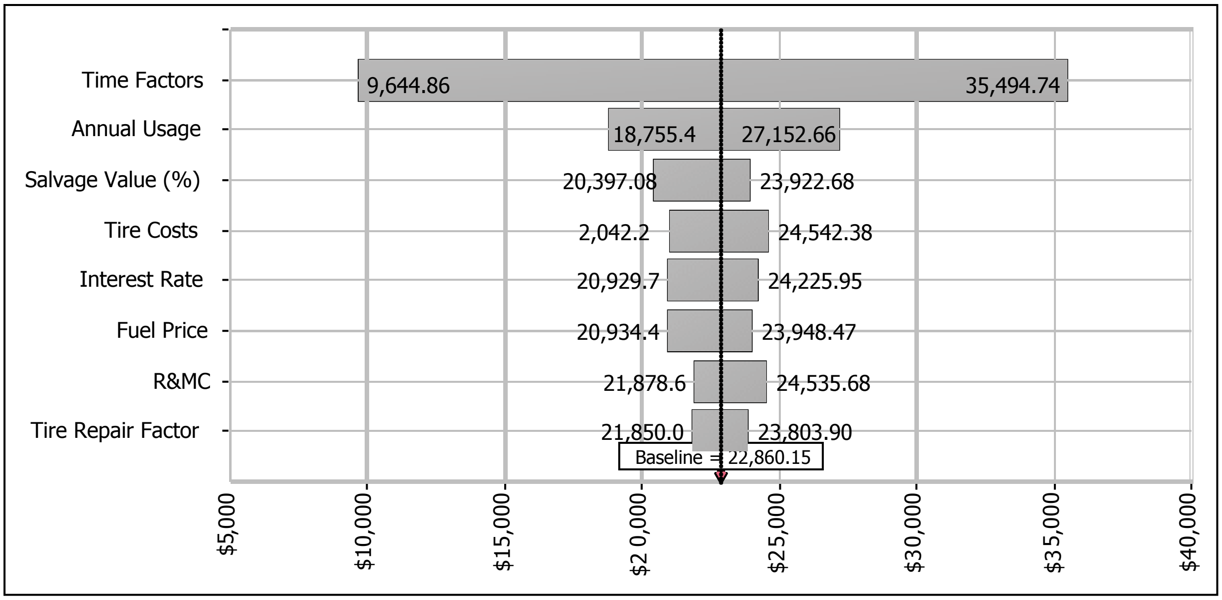

**Figure 11. Sensitivity Analysis for the 2008 Ford F250**

Next, a ranking system was employed to further examine the sensitivity analysis. Since there are a total of nine input variables for the construction equipment and eight variables for the administrative vehicles, each stochastic input will be ranked with one being the most sensitive and eight or nine being the least sensitive. This will allow the determination of the most sensitive variable to each piece of equipment. Table 11 displays the ranking for each machine.

**Table 11. Sensitivity Ranking of each Variable within the Sensitivity Analysis**

| Input Variable | Piece of Equipment | | | | | |
|---|---|---|---|---|---|---|
| | 2008 Ford[1] | 2007 Chevrolet[2] | 2006 Ford[3] | 2005 Dump Truck[4] | 2006 Volvo Loader[5] | 2006 Volvo Loader[6] |
| Time Factor | 1 | 1 | 1 | 2 | 2 | 1 |
| Engine Factor | N/A | N/A | N/A | 3 | 1 | 2 |
| Interest Rate | 5 | 4 | 5 | 1 | 4 | 4 |
| Salvage Value | 3 | 6 | 4 | 4 | 5 | 5 |
| Annual Usage | 2 | 2 | 2 | 9 | 6 | 9 |
| Tire Costs | 4 | 7 | 8 | 7 | 3 | 3 |
| Tire Repair Costs | 9 | 8 | 6 | 8 | 9 | 8 |
| R&MC | 8 | 5 | 7 | 6 | 7 | 7 |
| Fuel price | 7 | 3 | 3 | 5 | 8 | 6 |

[1]F250, [2]Impala, [3]Escape XLT, [4]Sterling LT9513, [5]L90F Art 2.5yd., [6]L150E Art 5yd.

The ranking from each piece of equipment was averaged to find the most significant input factors. Table 12 contains the results from the average ranking for each stochastic input factor. These results are directly related to Table 11 and the sensitivity analysis that was performed.

**Table 12. Ranking of the Input Variables from the Sensitivity Analysis**

| Input Variable | Average Ranking of Input Variables |
|---|---|
| Time Factor | 1.2 |
| Engine Factor | 1.7 |
| Interest Rate | 4.2 |
| Salvage Value (%) | 4.5 |
| Annual Usage | 4.3 |
| Tire Costs | 5.2 |
| Tire Repair Costs | 7.8 |
| R&MC | 7.0 |
| Fuel price | 6.0 |

The results from Tables 11 and 12 indicate that the time and engine factors are the most sensitive variables to the stochastic life cycle cost model for the construction equipment. The two factors are utilized in the same calculation and have a major impact on the life cycle costs. For the administrative vehicles, the time factor and annual usage are the most sensitive to the model. Once again, the annual usage is applied in the same calculation as the time factor so they may influence each other. The time factor is vastly unknown due to variability with idle time and productivity. Thus, the engine and time factors displayed significant uncertainty due to such things as downtime and harsh working conditions.

The percent of total horsepower used, which is a component of the engine factor, may vary extensively from project to project within an agency's fleet. Also, the amount of total horsepower may vary depending on the usage of a machine. For example, if a dump truck is hauling heavy material this may cause more usage of the engine horsepower. Thus, the uncertainty associated with the input is considerable and is evident in the sensitivity analysis.

The two sedans displayed inputs that were closely related when ranking the sensitivities. However, the repair and maintenance costs were one of the least influential inputs to the model for all pieces of equipment. The results contradict the common assumption about repair and maintenance costs, “repair cost normally constitutes the single highest operating cost” (Atcheson 1993). Also, both of the Volvo loaders exhibited tire costs as the third most influential input due to the relative high cost of tires for that piece of equipment when compared to the cost of the sedan and dump truck tires.

Within the stochastic model, fuel costs are a function of annual usage, fuel price, engine factor, horsepower, time factor, and the fuel consumption factor. Thus, the size of the engine and the time factor directly impact fuel costs and are related to fuel efficiency because the consumption factor goes down as an engine’s fuel efficiency increases. The engine and time factors are variables that a fleet manager may not directly control. Therefore, applying the inputs deterministically would allow for the analysis of the other variables that managers may influence.

Table 13 displays an example of the impact that the engine and time factor, along with the annual usage, have on equipment costs. In this example, the fuel costs were calculated with varying horsepower, either 400 hp or 300 hp, and a varying combined factor consisting of the engine and time factor. Additionally, the fuel consumption factor and annual usage were applied uniformly for all the pieces of equipment. The results displayed by Machines B and D show that the fuel costs are drastically lower when applying a piece of equipment with less horsepower and a lower combined factor consisting of the engine and time factor. Therefore, this further reinforces the importance of engine efficiency and life cycle costs.

**Table 13. Fuel Consumption Factor Comparison of Engine Efficiency**

| Fuel Cost ($/gal) | Equipment A[1] | EquipmentB[2] | EquipmentC[3] | EquipmentD[4] |
|---|---|---|---|---|
| $3.00 | $48,000 | $24,000 | $36,000 | $18,000 |
| $3.50 | $56,000 | $28,000 | $42,000 | $21,000 |
| $4.50 | $64,000 | $32,000 | $48,000 | $24,000 |
| $4.50 | $72,000 | $36,000 | $54,000 | $27,000 |
| $5.00 | $80,000 | $40,000 | $60,000 | $30,000 |
| [1]400hp 0.5 factor, [2]400hp 0.25 factor, [3]300hp 0.5 factor, [4]300hp 0.25 factor | | | | |

## Conclusions

Based on the results obtained from the Monte Carlo simulation, the time and engine factors were the most sensitive input variables to the equipment taken from the MPWFSD. The uncertainty associated with each factor was one of the major reasons that discrepancy occurred during the simulations. The sensitivity of the time and engine factors is not vital for a fleet manager since they cannot control the input of each element. Thus, each factor has a major impact on the LCCA but is not significant in equipment fleet decisions concerning repairs and overhauls.

Equipment fleet managers may use the sensitivity results of the time and engine factor to determine equipment purchases. When deciding to replace a piece of equipment, engine efficiency should be a high priority due to the costs associated with the time factor, engine factor, and annual usage. Equipment that is able to perform well in all work conditions, has a lower horsepower, and has a high engine efficiency should be considered.

For a public agency's equipment fleet manager, the influence of the time and engine factors are not essential to fleet decisions. Idle time, working conditions, and engine efficiency are not variables that an equipment fleet manager can influence. Thus, employing the inputs as deterministic is the most practical solution.  Inputs such as the repair and maintenance uncertainty are more vital to equipment decisions because the fleet manager can control those inputs more closely.  These inputs should remain stochastic within the model to optimize the results.  Consequently, the study identified variables to be deterministic and stochastic within an equipment LCCA model to aid public agency equipment fleet managers.

# CHAPTER 5.

# OPTIMIZING PUBLIC AGENCY EQUIPMENT ECONOMIC LIFE USING STOCHASTIC MODELING TECHNIQUES

O’Connor, E.P. and D.D. Gransberg, “Optimizing Public Agency Equipment Economic Life Using Stochastic Modeling Techniques” (to be submitted for publication in the *Journal for Construction Engineering and Management*, ASCE, in 2014).

## Abstract

Public agency funding constraints force equipment fleet managers to identify the need to replace a given piece of equipment a year or more in advance to be able to obtain authorization to purchase the replacement piece of equipment. By definition, deterministic equipment LCCA models do not account for uncertainty within input parameters. This research proposes a methodology to determine an optimal replacement age based on a stochastic equipment LCCA model, taking into account the variation within the input variables. Using the MPWFSD’s equipment fleet data, an optimal replacement age was determined based on confidence levels ranging from 70% to 90%. A trigger point was formulated by analyzing the sensitivity between the change in market value and the repair and maintenance costs. Using the stochastic model, along with a sensitivity analysis, an economic life was determined that was different than that obtained by deterministic methods for the same piece of equipment.

## Introduction

A public agency’s equipment fleet consists of many different types of machines, for example the Texas Department of Transportation’s (TxDOT’s) fleet ranges from compact sedans to motorized ferries (TxDOT 2008). Also, many agencies have “a uniform process in [their] approach to determine equipment replacement criteria” (TxDOT 2008). The methods for determining a replacement age are based on deterministic approaches that do not account for uncertainty with inputs that affect equipment LCCA (West et al. 2013). To take into account uncertainty, a stochastic approach has been employed to define a viable economic life of equipment within a public agency.

The maintaining and monitoring of the equipment fleet is a vital role of the equipment fleet managers, especially when the fleet becomes older (Antich 2010). This issue is stressed due to the budget constraints in public agencies andalso typically means more maintenance and repair. Implementing extended, modified, or enhanced preventative maintenance has been employed in public agencies to ensure equipment fleet is in operating condition (Antich 2010). Therefore, not only is the funding different for private and public entities' equipment fleet but the maintenance and repair costs are drastically different to manage. As a result, the PSM has been modified to be implemented for public agency usage to aid in equipment fleet decisions.

For this research the MPWFSD's equipment fleet data was utilized. To determine the economic life of the equipment, a stochastic model was used. The EUAC was applied to calculate the economic life of equipment based on the work completed by Park (2011). The calculation of the life cycle costs was based on the PSM. Additionally, Monte Carlo simulations were used to make the model stochastic and determine the sensitivity of the input parameters.

## Background

Many studies have been completed on equipment replacement optimization. A study using dynamic programming, based on the Bellman and Wagner approaches, was employed to determine the replacement age of vehicles (Fan et al. 2013). The Florida Department of Management Services uses a minimum equipment replacement standard to determine the replacement age of the equipment (2009). Fan and Jin (2011) applied a decision tree to determine the significant factors in the economic life determination of construction equipment.

Research completed by Mitchell (1998, 2011) applied cumulative cost models to aid managers with determining repair costs for equipment. His work focused on the private sector and used regression models to analyze the repair costs for an equipment fleet. Also, the use of regression models was employed by Ghadam (2012) to determine the economic life of earth moving equipment. Soft computing methods using LCCA tools were applied to transportation infrastructure management to aid in management decisions (Flintsch and Chen 2004). Additionally, LCCA for infrastructure systems were established with the optimal service life and safety level characteristics (Furuta et al. 2003).

The utilization of EUAC was employed to determine the optimal disposal age, or economic life, of six equipment classes for the North Carolina DOT (Kauffman et al. 2012). The research included the following varied input parameters to the EUCA model: interest rate, initial market value (MV), MV decline rate, mileage decline, cost per mile, and annual cost increase rate (Kauffman et a. 2012). A sensitivity analysis was performed for each of the varied parameters and was evaluated based on mean, standard deviation, coefficient of variation, and magnitude of the slopes for each response line (Kauffman 2012).

Barringer (1997) performed Monte Carlo simulations to calculate life cycle costs for the American Petroleum Institute (API) pumps. The work included failure costs found by Monte Carlo simulations and net present value (NPV) calculations to determine the life cycle costs (Barringer 1997). Barringer's work was completed using commercial software, similar to this research, but it was finalized for process equipment not construction equipment. Also, Barringer completed research based on reliability principles and computing life cycle costs in 2001.

## Methodology

The calculation of the equipment life was performed using deterministic and stochastic input variables. The usage of the PSM was employed to calculate the life cycle costs. The method was altered to reflect public agency practices. This was done because the PSM is operated by private entities, and public agencies operate with different constraints.

The input parameters utilized in the PSM to formulate the stochastic model consist of solely cost variables. The costs are analyzed on an annual basis for all the parameters. The stochastic and deterministic LCCA models use Equation 2 through 6 to determine the operating costs for the equipment (Peurifoy and Schexnayder 2002, Park 2011).

### Economic Life Analysis

The determination of the economic life for an equipment fleet is a critical component of the LCCA. The economic life, or the optimal time to sell a piece of equipment, requires the usage of EUAC calculations. To properly utilize EUAC, the ownership costs and operating costs must be calculated on an annual basis in the correct year, using Equations 9 through 12 (Park 2011).

The calculation of the EUAC is done over the entire life span for a piece of equipment. In most instances the lowest EUAC in a given year will be the optimal economic life. This will be the value used in the deterministic and stochastic evaluation of the equipment fleet. The stochastic model will use confidence levels associated with the output. Also, the stochastic economic life evaluation will use the same equations as the deterministic method but apply stochastic inputs.

The last 47 months were used for the range of the diesel fuel prices, determined by the F-test and P-value statistical assessment (see Table 9 from Chapter 4). Table 14 summarizes the stochastic inputs that were applied to the economic life calculations. Other than the fuel prices and the tire cost, the values displayed in Table 14 were obtained from the literature (Gransberg et al. 2006, Atcheson 1993, Puerifioy and Schexnayder 2002, Park 2011).

**Table 14. Stochastic Values for the Inputs used in the Economic Life Determination**

| Parameter | Range of Values |
|---|---|
| Interest Rate | 3% - 16% |
| Tire Cost | Varied by Machine |
| R&MC | 35% - 80% |
| Change in Market Value | 8% - 15% |
| Diesel Fuel Prices | \$3.38/gal. - \$4.13/gal. |
| Tire Repair Factor | 12% - 16% |

The stochastic economic life will be determined by a range of confidence levels associated with the EUAC. The range for the confidence levels will be from 70% - 90%. Then a sensitivity analysis will be applied to determine the sensitivity of the change in market value and the repair and maintenance costs. When the sensitivity for the repair and maintenance costs exceeds the sensitivity of the change in market value, it will be an indicator for equipment fleet managers. Figure 12 shows an example of the trigger point based on the sensitivity analysis.

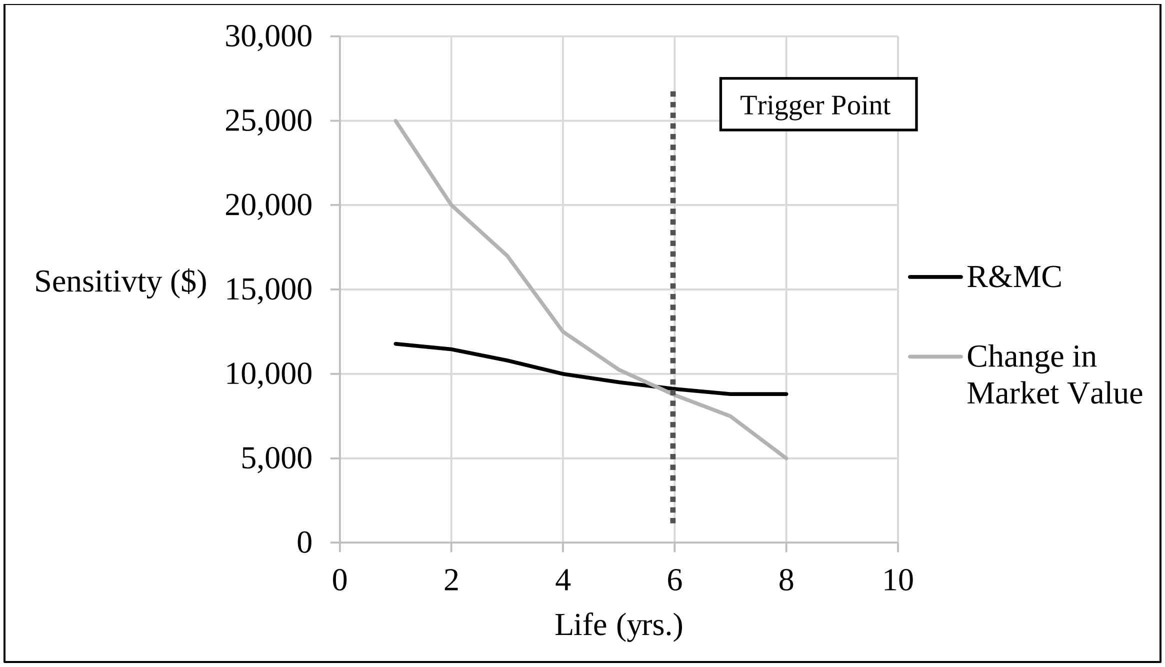

**Figure 12. Trigger Point Determination Based on Sensitivity Analysis**

The trigger point in Figure 12 is identified by the dashed line at year 6. This is the point in time when the sensitivity of the repair and maintenance costs intersects with the sensitivity of the change in market value. The trigger point signifies that the repair and maintenance costs are more uncertain at this point in time than the market value.

## Results

The results for the research include deterministic and stochastic economic life calculations, and a sensitivity analysis of the stochastic output. An example using a loader, from the MPWFD equipment fleet, is provided to demonstrate the results that were obtained. Lastly, the usage of the stochastic economic life is discussed and compared with the deterministic method.

## Deterministic Economic Life

The deterministic economic life was calculated to compare the results with the stochastic determination. Figure 13 displays the deterministic economic life of a 2006 loader, a piece of equipment within the MPWFD fleet. The economic life of the loader was found to be 4 years using the lowest EUAC. The variation between the two methods of calculating the economic life is discussed later in the research.

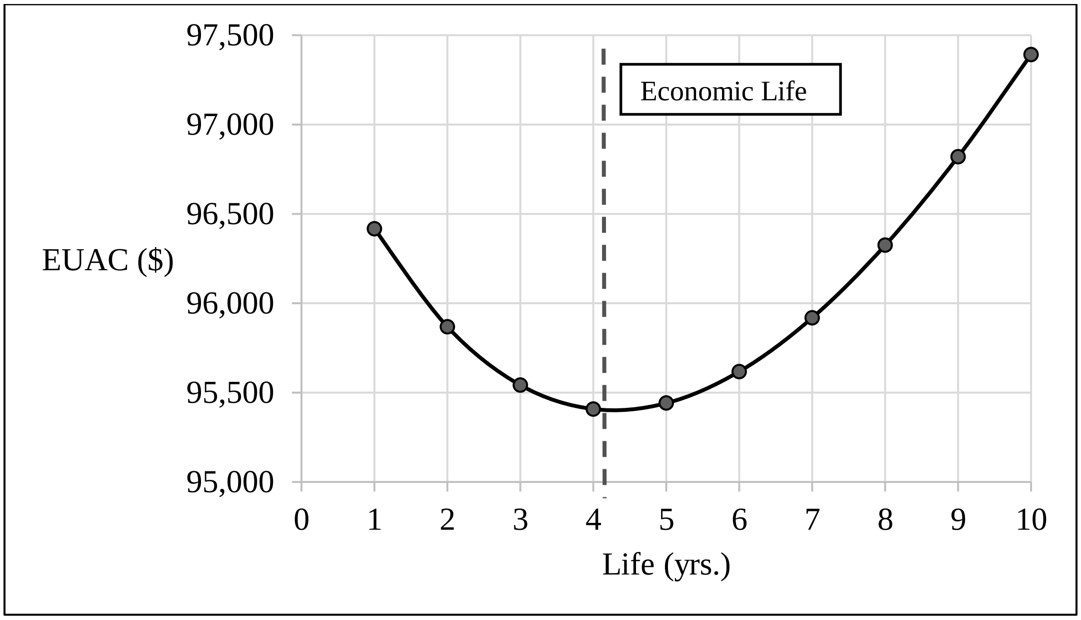

**Figure 13. Deterministic Economic Life of the 2006 Volvo Loader**

## Stochastic Economic Life

The stochastic determination of the economic life for the 2006 Volvo loader is depicted in Figure 14. The confidence levels are shown with the optimal replacement age specified by the lowest EUAC. The economic life for the loader varies from year 5 to 8 depending on the confidence level.

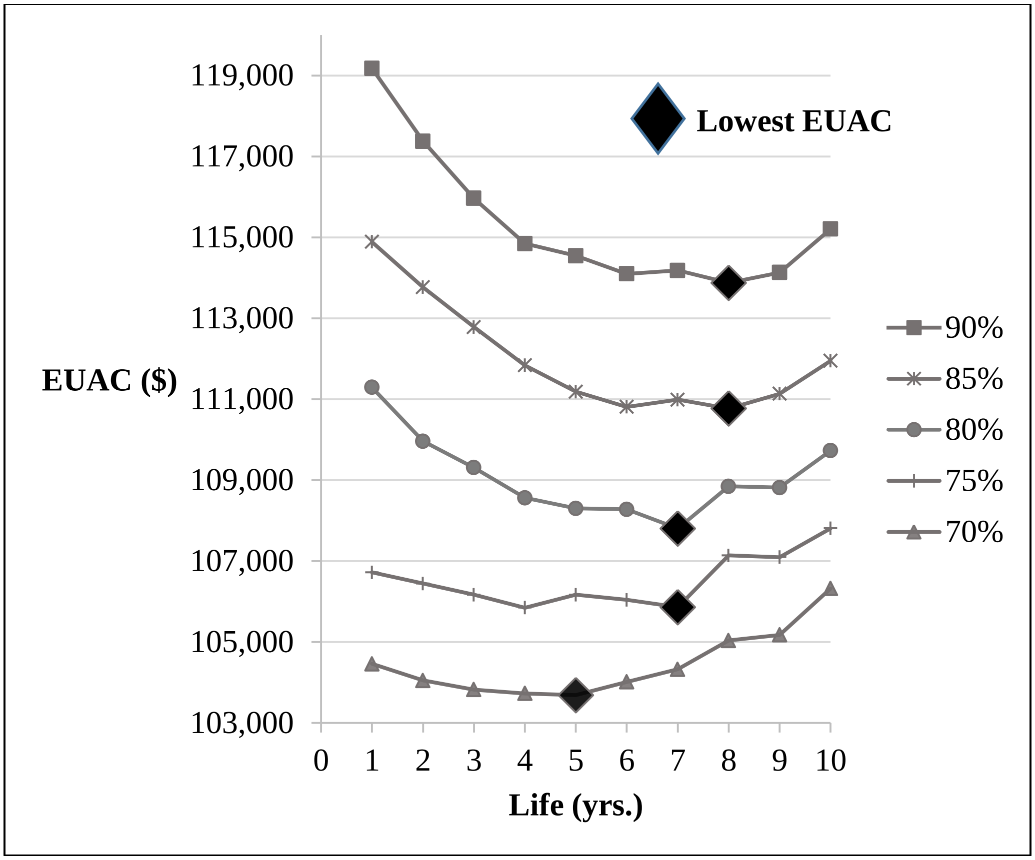

**Figure 14. Stochastic Economic Life of the 2006 Volvo Loader**

The stochastic economic life range for the loader supplies more detail than a deterministic determination. Using the range of values for the input parameters provides a more certain calculation of the economic life. Additionally, the range offers the fleet manager options to assess the replacement of equipment.

## Sensitivity Analysis

Monte Carlo simulations were employed to determine the sensitivity of the inputs for the economic life calculation. Based on the sensitivity results of the change in market value and repair and maintenance costs, a trigger point for the machines was established. The sensitivity of each variable is related to the mean of the annual life cycle cost associated with the piece of equipment. The range in the values is represented in dollar amounts. The wider the range the more sensitive the input is to the mean.

Figure 15 displays the results from the sensitivity analysis performed in the seventh year of the 2006 Volvo loader. The results show that the change in market value is more sensitive than the repair and maintenance costs given the year under investigation.

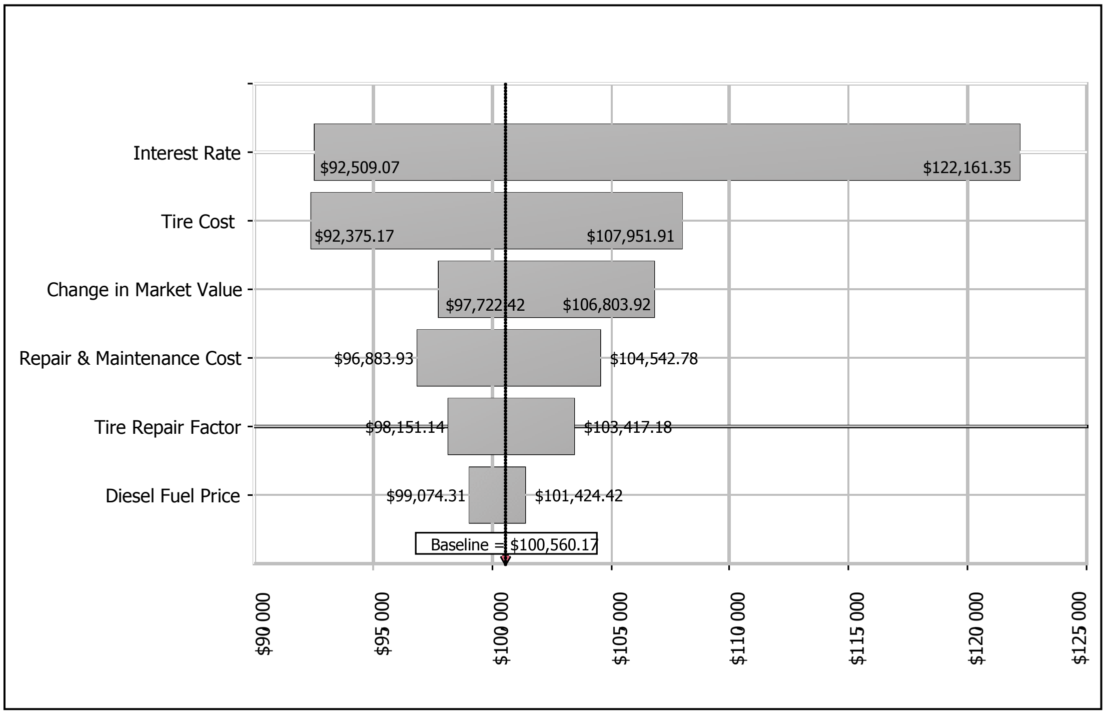

**Figure 15. Sensitivity Analysis for the 2006 Volvo Loader in Year 7**

Figure 16 contains the results from the sensitivity analysis performed in the eighth year of the Volvo loader. The results indicate that the repair and maintenance costs are more sensitive than the change in market value. This would indicate that the trigger point would be in year 8, due to the results differing from Figure 15.

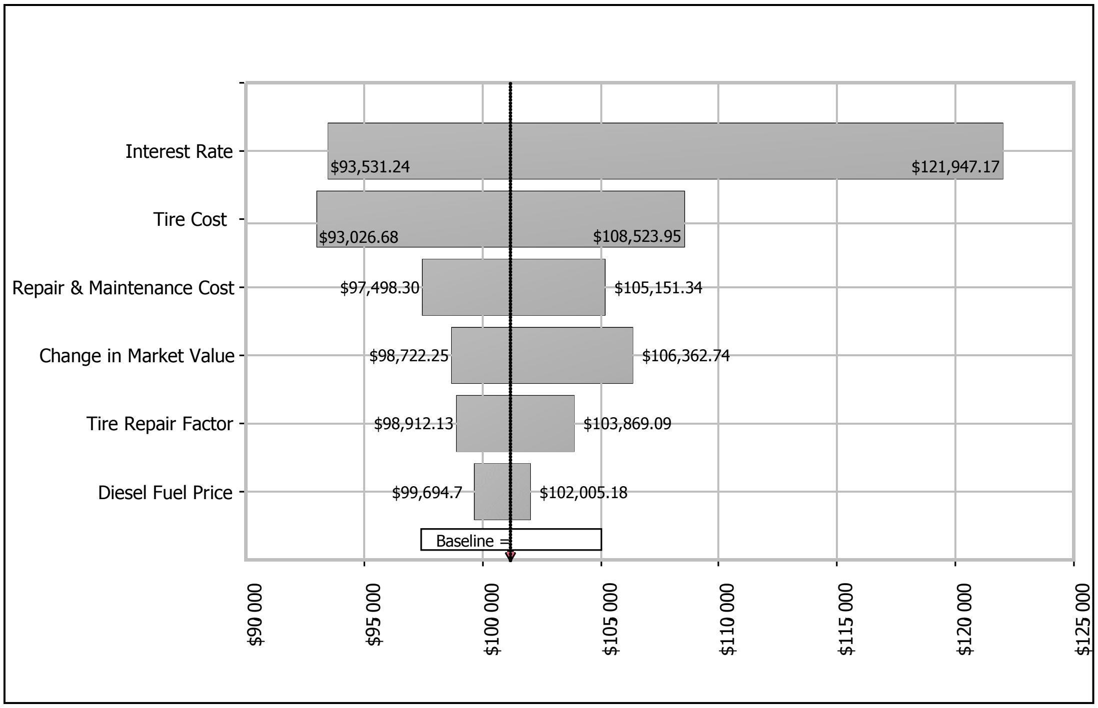

Figure 16. Sensitivity Analysis for the 2006 Volvo Loader in Year 8

Figure 17 contains the plot of the sensitivity fluctuations for the change in market value and the repair and maintenance costs for the 2006 Volvo loader. The results correlate with the Figures 15 and 16, indicating a trigger point in the eighth year.

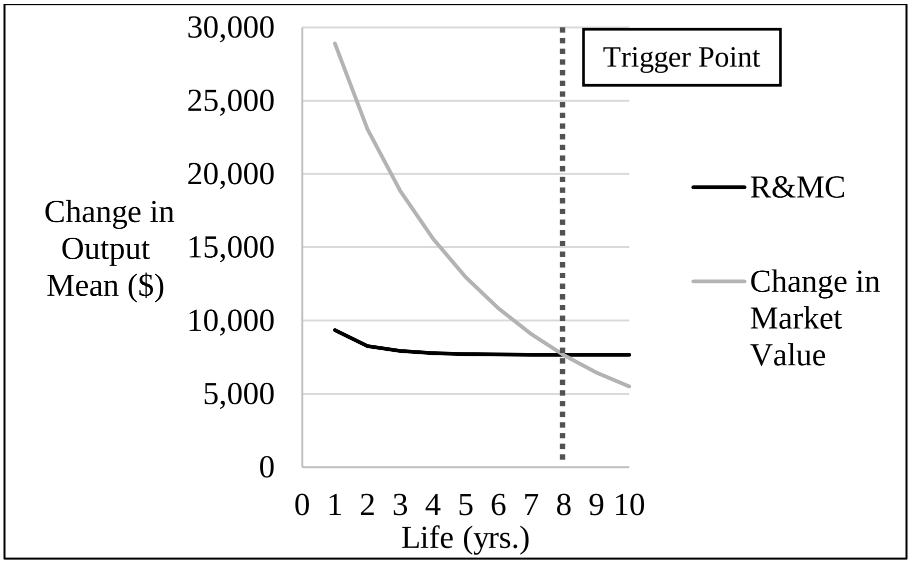

Figure 17. Change in the Output Mean for 2006 Volvo Loader 5 yd.

The results displayed in Figure 17 indicate that the sensitivities of the two inputs intersect at year 8, signifying the change in the sensitivity. The intersection of the two parameters is the trigger point for equipment fleet managers. Fleet managers may use this information to aid in equipment decisions.

Table 15 contains the results of the machines that were investigated within the MPWFD fleet. The economic life is shown with the deterministic and the stochastic methods for comparison. Also, the sensitivity analysis trigger year is displayed, and the service life of each machine is displayed.

**Table 15. Economic life of the MPWFD Equipment Fleet**

| Equipment | Deterministic Economic Life (yrs.) | Stochastic Economic Life Range (yrs.) | Sensitivity Analysis Trigger (yrs.) | Service Life (yrs.) |
|---|---|---|---|---|
| 2002 Dump Truck | 13 | 11 - 14 | 13 | 14 |
| 2012 Loader | 4 | 3 - 8 | 6 | 10 |
| 2006 Loader 2.5 yd. | 4 | 3 - 7 | 7 | 10 |
| 2006 Loader 5 yd. | 4 | 5 -8 | 8 | 10 |

Since public agencies must make equipment replacement decisions years in advance, 5 years for the MPWFD, the economic life range allows fleet managers to plan the replacement with certain levels of confidence. For example, if the fleet manager uses an 80% confidence associated with the economic life for the 2006 loader 5 yd., the manager may plan the replacement at year 2, because at 80% confidence the economic life would be at year 7.

Based on the results from Table 15, the sensitivity analysis of the economic life determination may be used as a trigger point for equipment fleet managers. The sensitivity of the maintenance and repair costs is higher than the market value at the trigger point. Indicated by the shift in the two input parameters, the likelihood of a major failure for a piece of equipment increases as the machine ages. Therefore, implementing the trigger point would allow fleet managers to identify the correct age to implement preventative maintenance steps or support a replacement decision.

The budget constraints within a public agency's equipment fleet result in strict replacement policies. This results in keeping equipment past the optimal economic life, increasing the repair and maintenance costs during the service life of equipment. The fleet manager has to manage these costs and identify the correct maintenance strategy at the correct time period. By having a trigger point within the service life of the fleet, it allows for the management of the repair and maintenance costs and use of resources.

## Conclusions

A stochastic equipment LCCA model was applied to determine the economic life of equipment within a public agency. Using the PSM and engineering economics with stochastic functions, the optimal replacement age was determined. The results displayed a different output than traditional deterministic methods. The model accounts for uncertainty within input parameters, different than deterministic methods that only have discrete input values. Accounting for the uncertainty within the input parameters allows the fleet managers to make more confident equipment decisions because a more certain output is obtained.

The use of Monte Carlo simulations provided a sensitivity analysis to be performed during the stochastic economic life determination. The outcomes displayed a change in the sensitivity from year to year because of the change in market value and the repair and maintenance costs. The variation between the two input variables occurred within the optimal replacement age which is indicated from the confidence levels calculated. The sensitivity of the change in market value becomes less over time while the repair and maintenance cost increases over time. The point in time is an indicator that replacement of the equipment should be considered because repair and maintenance costs are more uncertain. Therefore, the confidence levels along with the sensitivity analysis provide a viable range to replace a piece of equipment.

Fleet managers may use this method as an indicator for replacement or as a trigger point to implement preventative maintenance strategies. Since public agencies must make equipment replacement decisions years in advance, the economic life range allows fleet managers to plan the replacement with certain levels of confidence. Also, due to budget constraints, public agencies must maximize the life of equipment fleet. By implementing a trigger point based on the stochastic economic life determination, this may aid fleet managers more effectively than deterministic methods.

# CHAPTER 6.
# CONSOLIDATED CONCLUSIONS AND LIMITATIONS

## Conclusions

Deterministic and stochastic models were developed for public agencies to calculate equipment fleet life cycle costs and the optimal economic life. This was achieved by modifying the PSM to fit the public agency's equipment fleet environment and applying basic engineering economics principles to find optimal life cycle cost solutions. When the stochastic model was applied to a piece of equipment using fluctuating interest rates and fuel prices, the sensitivity of the model's input variables was determined. The interest rate was found to have a greater impact on economic life output than fuel prices for a dump truck illustrated in Chapter 3. The fuel volatility did impact the life cycle costs when applying the stochastic confidence levels. Therefore, allowing fuel prices to range probabilistically in the analysis provided a means to quantify the certainty of the equipment replacement decision.

With the increasing cost of diesel fuel, the issue of upgrading to a more fuel-efficient model of equipment using the latest technology has become an increasingly important element of the replace/repair decision. Therefore, employing the stochastic inputs allows the analyst to determine the impact of the most sensitive component of the model. This was illustrated in Chapter 4, where common input values were made stochastic to determine their impact on the public sector-adapted PSM equipment LCCA model. Based on Monte Carlo simulation sensitivity analysis results, the time factor and engine factor were the most sensitive input variables to the LCCA model. This leads to the conclusion that when deciding to replace a piece of equipment, engine efficiency should be a high priority due to the costs associated with the time factor, engine factor, and its subsequent annual usage.

Applying that conclusion to the public sector, one must realize that once a given piece of equipment is added to public agency's equipment fleet, the equipment fleet manager can no longer influence many of the model's variables. These include the equipment's idle time, its working conditions, and its engine efficiency. While accounting for uncertainty was shown to add value to the overall decision, making all the input variables stochastic introduces a level of complication that is not necessary. Therefore, it is concluded that employing the inputs as deterministic is the most practical determination. Inputs such as the repair and maintenance uncertainty are more critical to equipment decisions because the fleet manager can control those inputs more closely. Consequently, the researchers determined which variables should be included in the equipment LCCA model as deterministic values and those better portrayed as stochastic variables to aid public agency equipment fleet managers, as shown in Chapter 4.

Finally, Chapter 5 contained a stochastic equipment LCCA model that produced different output results than the deterministic methods for a public agency's fleet. The stochastic model accounted for uncertainty within input parameters, unlike deterministic methods that only use discrete input value assumptions. A range for the optimal replacement age was formulated within a 70% to 90% confidence level. Since public agencies must make equipment replacement decisions years in advance, the economic life range allows fleet managers to plan the replacement with certain levels of confidence. The usage of Monte Carlo simulations provided for a sensitivity analysis performed in conjunction with the stochastic economic life determination. The outcomes displayed a change in the sensitivity from year to year due to the change in market value and the repair and maintenance costs. The variation between the two input variables occurred within the economic life range developed by the confidence levels. Therefore, the confidence levels along with the sensitivity analysis provide a trigger point that signals when the equipment manager should consider replacing a piece of equipment as it nears the end of its optimum economic life.

## Limitations

The results of this research have several important limitations that must be considered before attempting to generalize it. The PSM model used to generate the results of the research has been altered to account for a public agency's constraints on equipment fleet funding. Additionally, since the equipment fleet data used in the analyses sprung from the MPWFD fleet, the input parameters were altered to match. The proposed model and methodology is not applicable to a LCCA of a private entity's equipment as it is missing certain factors, such as tax considerations. Additionally, the historical fuel prices were taken from the state of Minnesota, and interest rates were taken from municipal bond rates in Minnesota. Consequently, applying the same input parameters for equipment fleet outside of Minnesota would yield inaccurate results.

The range of historical fuel prices for the research has been determined for the present time period. To apply the same fuel prices in the future may be inaccurate. The F-test and P-value determination would have to be completed to determine the appropriate range for fuel prices if this study is applied in the future.

Another limitation within this thesis has to do with the repair and maintenance costs. The costs do not take into account a major failure of a machine. This was not included in the cost parameter as it is impossible to estimate the potential amount based on the data obtained. This amount could vary substantially based on the type of machine being analyzed. Thus, the analysis uses only routine repair and maintenance costs and not complete overhaul costs within the models.

# CHAPTER 7.

# CONTRIBUTIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

## Contributions

The main contribution of this thesis is the development of a stochastic equipment LCCA method into the public sector. The uncertainty within the input parameters is not taken into account when applying deterministic methods to calculate the life cycle costs and determine the economic life. Stochastic models account for uncertainty, like volatility in fuel costs, and quantify the impact of that uncertainty to equipment life cycle cost. This was demonstrated using a public agency's equipment fleet to accurately calculate life cycle costs and a replacement age.

Chapter 3 demonstrated the impact of fuel volatility to the determination of the economic life for equipment. The stochastic model was able to quantify the impact of fuel fluctuation to aid equipment fleet managers in replacement decisions. Therefore, public agencies may use the stochastic model as a decision tool to make more certain decisions within the equipment fleet.

Chapter 4 quantified the uncertainty of each input variable to the equipment LCCA. This provided a rational method for deciding which of the input variables to make deterministic and stochastic within an equipment LCCA model to optimize results. This research applied a sensitivity analysis to determine the uncertainty with each variable. For example, the engine and time factors were deemed deterministic because fleet managers cannot directly control these variables. This approach was different than previous research, such as Kauffman (2012), because the sensitivity analysis was performed on the stochastic LCCA results.

Chapter 5 provided the stochastic model to determine the economic life of equipment for a public agency. This method determined results that were different than traditional deterministic equipment LCCA models. The results take into account uncertainty within each input, calculating a more realistic depiction of the actual costs. A trigger point for equipment fleet managers was discovered based the sensitivities of the change in market value and repair and maintenance costs. Therefore, the research developed a robust tool to aid equipment fleet managers in the public sector.

## Recommendations for Future Research

Due to the nonexistence of stochastic modeling for equipment LCCA within public agencies this research is the first of its kind. Thus, the expansion for this thesis is critical to increase the knowledge of equipment fleet management. The following is a list of possible research projects that may be formulated from this thesis:

- Using the stochastic equipment LCCA model, the development of a replacement time period may be established for public agency’s equipment fleet. The time period could replace current replacement plans, such as the 5-year replacement plan used by the MPWFD. The adjusted replacement period would be based on the confidence levels associated with the stochastic economic life determination. For example, the 70% to 90% economic life range is between year 11 and 14 for the dump truck illustrated in Chapter 3. The three year range, from year 11 to 14, could be the determination of a three year replacement plan for the MPWFD.
- Applying the stochastic equipment LCCA for private entities. Adjusting the model for the private sector, and using the confidence levels to develop an optimal replacement age.
- Case study analysis using the stochastic equipment LCCA from this thesis for other public agencies. Since this research has been adapted for the MPWFD, the model could be analyzed for a different equipment fleet to justify the results obtained in this thesis.

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# APPENDIX A.
# CASE STUDY RESULTS

The case study results were obtained from a structured interview questionnaire. Three agencies were investigated for the case study analysis: City of Minneapolis, City of Eagan, and Dodge County. This section contains the questionnaire that was applied and the results from each case study.

## Structured Case Study Questionnaire

The following contains the questions that were used during the case study analysis.

CONDITIONS: This interview can either be conducted in person or via telephone. The following protocol shall be followed during its administration:

1. The questionnaire shall be sent to the respondent at least 1 week prior to the interview via email.
2. To maximize the quality and quantity of information collected, the primary respondent should be encouraged to invite other members of his/her organization to be present during the interview. Thus, a single transportation agency response can be formulated and recorded.
3. The interviewer will set the stage with a brief introduction that emphasizes the purpose of the research, the type of information expected to be collected, and the ground rules for the interview.
4. Once the interviewees indicate that they understand the process at hand, the interview will commence.
5. The interviewer will read each question verbatim and then ask if the interviewee understood the question before asking the interviewee to respond.
6. Each question contains a specific response that must be obtained before moving to the next question. Once that response is obtained, the interviewer can record as text additional cogent information that may have been discussed by the interviewees in working their way to the specific response.
7. Upon conclusion of the interview, the interviewer will ask the interviewees if they have additional information that they would like to contribute and record those answers as text.
8. The interviewer will assemble a clean copy of the final interview results and return them to the interviewee for verification.

## STRUCTURED INTERVIEW:

### I. Agency and Interviewee General Information:

1. Interviewee name:
2. Interviewee job position in the agency:
3. Interviewee telephone number:
4. City and state in which the respondent agency is headquartered:

    A. Name of Agency:

5. What type of organization do you work for?

☐ State DOT ☐ Other public transportation agency

☐ Other: {explain}

6. Approximate number of pieces of heavy machinery and equipment:
7. Approximate number of pieces of light vehicles (sedan, pickups, vans, etc):
8. Approximate average annual budget for equipment purchase:
9. Approximate average annual budget for equipment repair, rehabilitation, and maintenance:

### II. Equipment Decision Techniques:

1. Does your agency currently use a formal decision-making process to make equipment maintenance, repair, and/or replacement decisions on individual pieces of equipment?

☐ Yes ☐ No ☐ Don't Know

2. If yes, which methods are used? What process best describes your procedures?

☐ Life Cycle Cost Analysis

☐ Minimum Cost Method

☐ Mathematical Modeling Method

☐ Payback Period Method

☐ Other(s)

☐ Economic life of the investment

☐ Maximum number of hours

☐ Output from software-based analysis

☐ Don't know

3. If your agency utilizes a software-based analysis for fleet management decisions, what software program is used?

## III. Major Equipment Decision Tool:

1. How does your agency decide when to replace a piece of equipment?

2. How does your agency decide when to repair a piece of equipment?

3. How does your agency decide between replacing and repairing a piece of equipment?

4. How long in advance does your agency need to know when to buy a new piece of equipment?

5. What is your definition of economic life?

6. What is your definition of service life?

7. What information do you need to make equipment management decisions based on the life cycle of the equipment?

8. What are the major life cycle components that factor into replacement or maintenance decisions for heavy equipment?

☐ Acquisition Costs
☐ Annual Usage
☐ Depreciation
☐ Equipment Horsepower
☐ Fuel Costs
☐ Insurance Costs
☐ Interest Costs
☐ Lubrication Costs
☐ Operator Costs
☐ Purchase Price
☐ Maintenance Costs
☐ Tire Costs
☐ Tire Maintenance Costs
☐ Tire Life Expectancy
☐ Total Expected Life
☐ Salvage Value

☐ Oil Costs

☐ Oil Life Expectancy

☐ None

☐ Other(s):

9. What are the major life cycle components that factor into replacement or maintenance decisions for light equipment?

☐ Acquisition Costs

☐ Annual Usage

☐ Depreciation

☐ Equipment Horsepower

☐ Fuel Costs

☐ Insurance Costs

☐ Interest Costs

☐ Lubrication Costs

☐ Oil Costs

☐ Oil Life Expectancy

☐ Operator Costs

☐ Purchase Price

☐ Maintenance Costs

☐ Tire Costs

☐ Tire Maintenance Costs

☐ Tire Life Expectancy

☐ Total Expected Life

☐ Salvage Value

☐ None

☐ Other(s):

## IV. Equipment Data:

1. What are the most common pieces of heavy equipment that your agency owns (5-6)?

2. What are the most common pieces of light equipment that your agency owns (5-6)?

3. Which pieces of equipment would be most beneficial for Life Cycle Cost Analysis?

4. Is there anything you would like to add that you think would be valuable to the researchers in this study?

## Case Study Analysis Results

The following section contains the results for each of the case studies that was completed for this thesis.  Each of the case studies has three parts: replacement evaluation process, repair evaluation process, and equipment life cycle information.

### City of Minneapolis

**Replacement Evaluation Process:** The replacement evaluation process for the City of Minneapolis includes three major aspects including; equipment life cycle, equipment utilization, and business need of equipment. The equipment life cycle requirement is based on 50% to 60% of the initial value of the piece of equipment. If a piece of equipment is below or at the optimal value than it would be considered for replacement. The equipment utilization factor is based on the usage and need for certain tasks. For example, a police vehicle may be utilized more than a snow plow in the summer. The business need is the least important factor in the replacement evaluation process. An example of business need for the City of Minneapolis would be that a specific type of excavator is needed to build ponds, and now the City needs a different type of excavator to maintain the ponds. Therefore, the replacement of an excavator which is needed to build ponds would not be necessary.

The replacement evaluation entails a ten-, five-, and two-year replacement plan. These plans are developed to specify replacement needs and when the replacement will be executed. The ten-year plan is a rough estimate of what will be replaced in the future. The five-year plan has a firm idea of what pieces of equipment will be replaced. The five-year plan includes changes due to accidents and repairs. The two-year plan includes the specific data for replacement. The two-year plan finalizes and calculates all the replacement decisions that will be made.

**Repair Evaluation Process:** The repair process is specified by 50% to 60% of the original value of a piece of equipment. If a piece of equipment is above the optimal range of the initial value then the equipment is repaired. This is standard for all pieces of equipment within the fleet. Utilization of the equipment fleet is a major driving force in the determination between repairing and replacing a piece of equipment.

**Equipment Life Cycle Information:** The most vital pieces of information that are needed to make equipment decisions based on the life cycle of equipment for the City of Minneapolis include age, utilization, and fuel consumption. The major life cycle components that factor into replacement or maintenance decisions for heavy pieces of equipment include:

- Acquisition Costs
- Depreciation
- Insurance Cost (same for all pieces of equipment)
- Maintenance Costs (includes tire cost and tire maintenance cost)
- Total Expected Life
- Salvage Value
- Up-fitting Costs

The major life cycle components that factor into replacement or maintenance decisions for light pieces of equipment include:

- Acquisition Costs
- Annual Usage
- Insurance Cost (same for all pieces of equipment)

- Operator Costs
- Purchase Price
- Maintenance Costs (includes tire cost and tire maintenance cost)
- Total Expected Life
- Salvage Value
- Safety Factors

The most common pieces of heavy equipment that the City of Minneapolis owns are dump trucks, loaders (3yd and 5yd), skid steer loaders, and numerous others. The most common pieces of light equipment include sedans, particularly the Ford Escape and Ford Focus.

## City of Eagan

**Replacement Evaluation Process:** The City of Eagan utilizes a minimum replacement standard for all pieces of equipment. The standard entails a specific age, mileage, or hour requirement that must be met before a piece of equipment can be replaced. An example for a light piece of equipment is a sedan that must reach 10 years old or 100,000 miles before it may be classified for replacement consideration. An example of a heavy piece of equipment is a backhoe that must reach 20 years old or 6,000 hours of operation before it may be replaced.

After the minimum standards have been met, the replacement evaluation process includes the following pieces of information: Vehicle Condition Index (VCI), age (years, mileage, or operating hours), and operational considerations. The VCI takes into account the following parameters: age, mileage or hours, reliability, maintenance and repair costs, condition, cost per mile, and risk factor. These considerations will be reviewed by city employees to make the replacement decision. Furthermore, deviations from this policy must be reviewed and approved by city administrators.

The time frame for future replacement decisions for the equipment fleet is dictated by the budget period. The budget period for the City of Eagan is from May through December which allows for most of the replacement decisions to take place in December.

**Repair Evaluation Process:** All pieces of equipment are repaired and maintained until they reach the minimum standards set by the replacement evaluation process. This is true for both light and heavy pieces of equipment.

**Equipment Life Cycle Information:** All information and data regarding decisions based on the life cycle of equipment is generated from FleetFocus, an equipment fleet software program. The major life cycle components that factor into replacement or maintenance decisions for both heavy and light pieces of equipment include:

- Acquisition Costs
- Purchase Price
- Maintenance Costs
- Tire Costs
- Tire Life Expectancy

The most common pieces of heavy equipment that the City of Eagan owns are snow plows and fire trucks. The City currently has approximately 40 snow plows and 20 fire trucks within their equipment fleet. The most common pieces of light equipment includes sedans and light pick-ups.

### Dodge County

**Replacement Evaluation Process:** Pieces of equipment are replaced based on the needs of the County and the allowable budget. Once a piece of equipment needs to be replaced, the County decides if the budget has the funds to replace the equipment.

**Repair Evaluation Process:** Pieces of equipment are repaired when they are broken or need fixing. There is no standard policy for the repair evaluation process.

**Equipment Life Cycle Information:** The information that Dodge County needs to make equipment management decisions based on the life cycle of equipment are repair costs and costs to replace. The major life cycle components that factor into replacement or maintenance decisions for both heavy and light pieces of equipment include:

- Acquisition Costs
- Annual Usage
- Depreciation
- Purchase Price
- Maintenance Costs
- Salvage Value

The most common pieces of heavy equipment that Dodge County owns are snow plows, loaders, excavators, and graders. The most common pieces of light equipment light pick-ups.

# APPENDIX B.
# NATIONAL SURVEY RESULTS

An online survey was distributed to benchmark the usage of LCCA and other parameters in agency fleet management programs. The following contains the questionnaire and results that for the survey that was completed for this thesis.

## Survey Questionnaire

1. Please specify the following pieces of information.

| | Response |
|---|---|
| Agency Name | |
| City | |
| Approximate number of pieces of heavy machinery and equipment | |
| Approximate number of pieces of light vehicles (pickup, vans, etc.) | |
| Approximate average annual budget for equipment purchase | |
| Approximate average annual budget for equipment repair, rehabilitation, and maintenance | |

2. Does your agency currently use a formal decision-making process to make equipment maintenance, repair, and/or replacement decisions on individual pieces of equipment?

☐ Yes ☐ No ☐ Don’t Know

3. If yes, which methods are used? What process best describes your procedures?

☐ Life Cycle Cost Analysis
☐ Minimum Cost Method
☐ Mathematical Modeling Method
☐ Payback Period Method
☐ Other(s)

☐ Economic life of the investment
☐ Maximum number of hours
☐ Output from software-based analysis
☐ Don’t know

4. Which of the following fleet management software programs are or have been utilized by your agency? Please check all that apply.

☐ collectiveFleet
☐ Maintenance Connection
☐ eMaint $X_3$
☐ Maintenance Coordinator
☐ Maintenance5000
☐ Maintenance Pro
☐ Accruent 360Facility
☐ Fleetmatics
☐ Fleet Maintenance Pro
☐ J.J. Keller’s Maintenance Manager™
☐ collectiveShop™
☐ Service Pro Field Service and Repair Center
☐ AgileAssets® Fleet & Equipment Manager™

☐ Infor EAM
☐ 4Site
☐ Guide TI
☐ ManagerPlus
☐ TMT Fleet Maintenance
☐ iMaint
☐ Maintenance Assistant CMMS
☐ TMT Fleet Maintenance Software
☐ FleetFocus
☐ collectiveFleet™
☐ MH Fleet
☐ MS Excel
☐ None

☐ Other(s):

5. Which of the parameters listed in the table does your agency collect and maintain in your equipment fleet management database? For those parameters in your database, please rate your sense of how reliable the data in the database is currently.

| Parameters | Available Electronically | Available on Paper | Not Available | Data Reliability | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Totally Unreliable | Mostly Unreliable | Mostly Reliable | Reliable | Very Reliable | Don't Know |
| Purchase Price | | | | | | | | | |
| Acquisition Costs | | | | | | | | | |
| Annual Usage in Hours | | | | | | | | | |
| Total Expected Life | | | | | | | | | |
| Equipment Horsepower | | | | | | | | | |
| Salvage Value | | | | | | | | | |
| Maintenance Costs | | | | | | | | | |
| Insurance Costs | | | | | | | | | |
| Interest Costs | | | | | | | | | |
| Depreciation | | | | | | | | | |
| Operator Costs | | | | | | | | | |
| Tire Cost | | | | | | | | | |
| Tire Maintenance Cost | | | | | | | | | |
| Tire Life Expectancy | | | | | | | | | |
| Oil Life Expectancy | | | | | | | | | |
| Oil Costs | | | | | | | | | |
| Fuel Costs | | | | | | | | | |
| Lubrication Costs | | | | | | | | | |

6. Which of the following parameters do you use when making equipment fleet management decisions, like purchases, major repairs, etc.? Please rate the impact on the final decision for each parameter that you use. For example, if the original purchase price for the piece of equipment carries the heaviest weight in a decision to invest in a major repair or to purchase a new piece of equipment, then rate it as “highest impact.” On the other hand if it is not considered, rate its impact as “none.”

| Parameter | Decision-making Impact | | | | |
|---|---|---|---|---|---|
| | None | Little | Some | High | Highest |
| Purchase Price | | | | | |
| Acquisition Costs (i.e. plates, licensing, etc.) | | | | | |
| Annual Usage in Hours | | | | | |
| Total Expected Life | | | | | |
| Equipment Horsepower | | | | | |
| Salvage Value | | | | | |
| Maintenance Costs | | | | | |
| Insurance Costs | | | | | |
| Interest Costs | | | | | |
| Depreciation | | | | | |
| Operator Costs | | | | | |
| Tire Cost | | | | | |
| Tire Maintenance Cost | | | | | |
| Tire Life Expectancy | | | | | |
| Oil Life Expectancy | | | | | |
| Oil Costs | | | | | |
| Fuel Costs | | | | | |
| Lubrication Costs | | | | | |

7. Would you be willing to allow the researchers to use the information in your database and allow them to interview you on your program?

☐ Yes ☐ No

If yes, please indicate the name, phone number and email address of your agency’s point of contact.

## Survey Results

The subsequent tables contain the results of the survey. Table 16 shows the agency respondents and the corresponding equipment fleet information. The number of pieces of equipment and budget are shown in the table. Also, the last column of the table shows if the agency uses a formal decision-making process for the equipment fleet.

Table 16. Agency Responses and Equipment Fleet Information

| Agency Name: | City: | Approximate number of pieces of heavy machinery and equipment: | Approximate number of pieces of light vehicles (sedans, pickups, vans, etc.): | Approximate average annual budget for equipment purchase: | Approximate average annual budget for equipment repair, rehabilitation, and maintenance: | Does the Agency Utilize a Formal Decision-Making-Process for Equipment Decisions? |
|---|---|---|---|---|---|---|
| Village of Algonquin | Algonquin | 50 | 100 | $150,000-$250,000 | $850,000 | Yes |
| City of Woodland | Woodland | 100 | 200 | $600,000 | $1,000,000 | No |
| City of Solon | Solon | 25 | 10 | $80,000 | $20,000 | No |
| Central Fleet | Manchester, NH | 220 | 240 | $3,000,000 | $3,000,000 | No |
| Department of Public Works | City of Largo, FL | 75 | 300 | $3,500,000 | $2,000,000 | Yes |
| City of Durham, NC | Durham, NC | 578 | 937 | $5,500,000 | $2,300,000 | Yes |
| City Of West Des Moines | West Des Moines | 100 | 200 | $1,200,000 | $1,600,000 | Yes |
| Pierce County Public Works Equipment Services | Tacoma, WA | 223 | 201 | $3,500,000 | $4,581,000 | Yes |
| City of Decatur | Decatur | 151 | 210 |  | $2,715,547 | No |
| City of Dubuque | Dubuque | 160 | 100 | $500,000 | $500,000 | Yes |
| City of Dubuque | Dubuque |  |  |  |  | Yes |
| City of Troy | Troy | 70 | 200 | $1,600,000 | $2,900,000 | Yes |

Table 17 corresponds to the methods utilized within the formal decision-making process that the agency has in place. Since eight of the eleven respondents utilize a formal decision-making process, Table 17 has the results of only those eight. The respondents were allowed to pick more than one method, and the percent column is based on the total percent for that method, not cumulative of all the methods.

**Table 17. Methods Utilized for Equipment Fleet Decision-Making**

| Method | Responses* | % |
|---|---|---|
| Life Cycle Cost Analysis | 8 | 100% |
| Minimum Cost Method | 0 | 0% |
| Mathematical Modeling Method | 3 | 38% |
| Payback Period Method | 1 | 13% |
| Economic Life of Investment | 6 | 75% |
| Maximum Number of Hours | 4 | 50% |
| Output from Software-based Analysis | 5 | 63% |
| Don't Know | 0 | 0% |
| Other(s) | 0 | 0% |

*Respondents were allowed to pick more than one method

Based on the results from Table 17, the life cycle cost analysis method is the most prominent method utilized by the responding agencies. The second highest response rate was the economic life of investment, and following that was output from software-based analysis.

Table 18 contains the results from the software programs that are being utilized by the various agencies that responded to the survey. The respondents were allowed to pick more than one software program, thus the percentages are not cumulative of all software programs. The most prominent software programs were MS Excel and Faster as shown in the table.

**Table 18. Fleet Management Software Programs that have been or are being Utilized**

| Software | Results* | % |
|---|---|---|
| MS Excel | 5 | 36% |
| collectiveFleet | 1 | 7% |
| None | 2 | 14% |
| Other: | 11 | 79% |
| Faster, CCGSystems | 6 | 55% |
| Jetfleet | 1 | 9% |
| Sungard | 1 | 9% |
| RTA | 1 | 9% |
| C.F.A. Computerized fleet analysis | 1 | 9% |
| PRECISION | 1 | 9% |

*Respondents picked more than one software if applicable

Table 19 shows the availability of the input data for the LCCA model. The parameters are the input data for the model and the other columns are the availability based on electronically availability, paper availability, or not available. A total of eleven agency responses are contained in Table 19, and they were allowed to pick more than one availability option.

**Table 19. Availability of Input Data for LCCA Model**

| Parameter | Available Electronically | Available on Paper | Not Available | Total Responses |
|---|---|---|---|---|
| Purchase Price | 9 | 6 | 0 | 15 |
| Acquisition Costs (i.e. plates, licensing, etc.) | 7 | 6 | 1 | 14 |
| Annual Usage in Hours | 9 | 2 | 1 | 12 |
| Total Expected Life (in hours or years) | 9 | 4 | 0 | 13 |
| Equipment Horsepower | 5 | 2 | 2 | 9 |
| Salvage Value | 9 | 2 | 2 | 13 |
| Maintenance Costs | 10 | 2 | 1 | 13 |
| Insurance Costs | 3 | 3 | 4 | 10 |
| Interest Costs | 2 | 2 | 4 | 8 |
| Depreciation | 5 | 1 | 3 | 9 |
| Operator Costs | 4 | 2 | 4 | 10 |
| Tire Maintenance Cost | 8 | 2 | 1 | 11 |
| Tire Life Expectancy | 4 | 2 | 3 | 9 |
| Oil Life Expectancy | 6 | 3 | 2 | 11 |
| Oil Costs | 8 | 3 | 1 | 12 |
| Fuel Costs | 9 | 2 | 1 | 12 |
| Lubrication Costs | 8 | 1 | 2 | 11 |

Table 20 contains the results of the reliability characteristics of the available data for the LCCA model inputs. The parameters for the table are the LCCA model inputs, and the other columns relate to the reliability. Each agency could pick one characteristic for a given parameter. Most of the results for each data point were mostly reliable as shown.

**Table 20. Reliability of Input Data for LCCA Model**

| Parameter | Totally Unreliable | Mostly Unreliable | Mostly Reliable | Reliable | Very Reliable | Don't Know | Total Responses |
|---|---|---|---|---|---|---|---|
| Purchase Price | 1 | 0 | 5 | 1 | 3 | 0 | 10 |
| Acquisition Costs (i.e. plates, licensing, etc.) | 1 | 1 | 4 | 2 | 2 | 0 | 10 |
| Annual Usage in Hours | 0 | 0 | 6 | 1 | 2 | 0 | 9 |
| Total Expected Life (in hours or years) | 0 | 0 | 6 | 1 | 2 | 0 | 9 |
| Equipment Horsepower | 1 | 0 | 4 | 1 | 1 | 1 | 8 |
| Salvage Value | 1 | 5 | 1 | 1 | 2 | 0 | 10 |
| Maintenance Costs | 0 | 2 | 5 | 1 | 2 | 0 | 10 |
| Insurance Costs | 1 | 2 | 2 | 1 | 1 | 0 | 7 |
| Interest Costs | 0 | 1 | 3 | 1 | 0 | 1 | 6 |
| Depreciation | 1 | 1 | 3 | 1 | 1 | 1 | 8 |
| Operator Costs | 0 | 1 | 3 | 1 | 2 | 1 | 8 |
| Tire Maintenance Cost | 0 | 1 | 5 | 1 | 2 | 0 | 9 |
| Tire Life Expectancy | 1 | 1 | 3 | 1 | 1 | 1 | 8 |
| Oil Life Expectancy | 1 | 2 | 3 | 1 | 2 | 0 | 9 |
| Oil Costs | 0 | 1 | 6 | 1 | 2 | 0 | 10 |
| Fuel Costs | 0 | 1 | 6 | 1 | 2 | 0 | 10 |
| Lubrication Costs | 0 | 2 | 5 | 1 | 2 | 0 | 10 |

Table 21 is the impact of the input data for the LCCA model. Each agency was to rank the impact from no impact to highest impact. The parameters that received the most responses with the highest impact were purchase price, annual usage in hours, and total expected life. The parameters that received the most responses corresponding with no impact included acquisition costs, insurance costs, interest costs, and depreciation.

**Table 21. Impact of Input Data for LCCA Model**

| Parameter | No Impact | Little Impact | Some Impact | High Impact | Highest Impact | Total Responses |
|---|---|---|---|---|---|---|
| Purchase Price | 0 | 0 | 2 | 1 | 6 | 9 |
| Acquisition Costs | 5 | 1 | 2 | 1 | 1 | 10 |
| Annual Usage in Hours | 0 | 0 | 3 | 4 | 2 | 9 |
| Total Expected Life | 0 | 0 | 3 | 4 | 3 | 10 |
| Equipment Horsepower | 1 | 4 | 4 | 0 | 1 | 10 |
| Salvage Value | 2 | 5 | 1 | 2 | 0 | 10 |
| Maintenance Costs | 0 | 0 | 2 | 8 | 0 | 10 |
| Insurance Costs | 7 | 1 | 1 | 0 | 0 | 9 |
| Interest Costs | 5 | 2 | 2 | 0 | 0 | 9 |
| Depreciation | 4 | 2 | 3 | 0 | 0 | 9 |
| Operator Costs | 1 | 2 | 4 | 2 | 0 | 9 |
| Tire Costs | 2 | 2 | 4 | 1 | 0 | 9 |
| Tire Maintenance Costs | 1 | 3 | 4 | 1 | 0 | 9 |
| Tire Life Expectancy | 2 | 2 | 4 | 1 | 0 | 9 |
| Oil Life Expectancy | 2 | 1 | 6 | 0 | 0 | 9 |
| Oil Costs | 1 | 2 | 6 | 0 | 0 | 9 |
| Fuel Costs | 0 | 0 | 4 | 5 | 0 | 9 |
| Lubrication Costs | 2 | 2 | 6 | 0 | 0 | 10 |

# APPENDIX C.
# SOFTWARE ANALYSIS

Table 22 contains the results of the content analysis and differentiates the capabilities of each software program.  A check in a capability column indicates that the software program performs that certain task. This was completed to indicate which software programs are most apt to provide meaningful output for equipment fleet LCCA.

## Table 22. Software Capabilities

| Software | Capability | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Multiple facilities** | **Network support** | **Import/ Export** | **Auto Email** | **Maintenance Scheduler** | **Work order/ Request** | **Parts Inventory** | **Equipment log** | **Depreciation** | **Inspections** | **Life cycle costs** | **Accident Reports** | **Multi-site** |
| Fleetmatics | x | | | | x | | | | | | | | x |
| TMT Fleet Maintenance Software | | | x | | | | x | x | | | | | |
| Fleet Maintenance Pro (by IMS) | | x | x | | x | x | x | x | x | x | | | |
| (AgileAssets®) Fleet & Equipment Manager™ | | | | | x | x | x | | x | | x | | |
| FleetFocus (by AssetWorks) | | x | | | x | x | x | | | x | x | x | |
| J. J. Keller's Maintenance Manager™ Software | | | x | | x | x | x | x | | | | | |
| collectiveFleet™ | | | x | x | x | x | x | | x | x | x | x | |
| MH Fleet by MH Equipment | | x | | | x | | | | | | | | |
| Maintenance Connection | x | | | | | | | | | | | | |
| eMaint $X_3$ | x | x | | x | x | x | x | x | x | | | x | |
| Maintenance Coordinator | x | x | x | x | x | x | x | x | x | | | | |
| Maintenance5000 | | | | | x | x | | | | | | | |
| Maintenance Pro | | x | x | | x | x | x | x | | x | | | |
| Accruent 360Facility | | | | | x | x | x | | | x | x | x | |
| Infor EAM | | | | | x | x | x | x | | x | x | | |
| 4Site | | | | | x | | x | x | | | | | |
| Guide TI | | | x | | | | | x | | | | | |
| ManagerPlus | | | x | | x | x | x | | | | | x | |
| iMaint (Fleet) | | | | | x | x | x | | | | | x | |
| Maintenance Assistant CMMS | | | x | x | x | x | | x | | x | | | x |
| MSI Service Pro Repair Center and Field Service | | | | | x | x | x | x | | | | | x |
| Fleetio | | | | x | x | | | | | | | | |
| TATEMS | | | | | x | x | x | | | | | | |
| FleetCommander | | | | | | x | | | | | | | |
| Arsenault, Dossier Fleet Maintenance | | | | | x | x | x | x | | | x | x | |
| RTA Fleet Management | | | | | | x | x | x | | | | | |
| FleetWave/RoadBASE | | | x | | x | x | x | | | x | | | |
| FleetWise VB | | | | | x | | x | x | | | | | |

# Table 22. Software Capabilities Cont'd

| Software | Capability | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cost Tracking/ Control | Customiz-able | Bar code | Fuel Mgnt | Risk Mgnt | Integrate with CAD | Equipment Tracking | History Recording | MX Mobile Solution | Track Vehicle Maint History | Track Tires | Integration GPS | Mobile Wireless Handheld |
| Fleetmatics | x | | | x | | | x | x | | x | | x | |
| TMT Fleet Maintenance Software | x | x | x | x | | | x | | | | x | x | |
| Fleet Maintenance Pro (by IMS) | x | | | x | | | x | x | | x | x | | |
| (AgileAssets®) Fleet & Equipment Manager™ | | | | x | | | x | | | | | x | x |
| FleetFocus (by AssetWorks) | x | | x | | | | | | | | | x | x |
| J. J. Keller's Maintenance Manager™ Software | | | | x | | | x | | | x | x | | |
| collectiveFleet™ | | | | | | | | | | | | | |
| MH Fleet by MH Equipment | | | | | | | x | | | | | | |
| Maintenance Connection | | | | | | | | | | | | | |
| eMaint $X_3$ | | | | | | | | x | x | | | | |
| Maintenance Coordinator | | | | | | | | | | | | | |
| Maintenance5000 | x | | | | | | | x | | | | | |
| Maintenance Pro | | | | | | | x | x | | | | | |
| Accruent 360Facility | x | | | | | x | | | | | | | |
| Infor EAM | x | | | | x | | | | | | | | |
| 4Site | x | | | | | | | | | | | | |
| Guide TI | | | x | | | | | x | | | | | |
| ManagerPlus | x | | x | | | | | | | | | | |
| iMaint (Fleet) | x | x | x | x | | | | | | | | | |
| Maintenance Assistant CMMS | | x | | | | | | | | | | | |
| MSI Service Pro Repair Center and Field Service | | | | | | | x | | | | | | |
| Fleetio | x | | | x | | | x | x | | x | | | |
| TATEMS | | | | x | | | | | | | | | |
| FleetCommander | x | x | | x | x | | | | | | | x | |
| Arsenault, Dossier Fleet Maintenance | x | | | x | | | | x | | x | | | |
| RTA Fleet Management | x | | | x | | | x | | | | x | | |
| FleetWave/RoadBASE | | | | | | | | x | | | | | |
| FleetWise VB | | | | x | | | | | | | | | |

Based on the results from Table 22, further examination of the software programs was conducted. Table 23 depicts the results of the examined software programs premised on the life cycle (LC) capabilities and the functionality for this project. The life cycle capabilities were broken down into three categories: generates LC, could generate LC based on input data, and no viable inputs to compute LC. Next, the software was categorized into definitely functional, maybe functional, and not functional. The functionality is dependent on how applicable the software is to the project.

Table 23. Software Categorization and Utilization

| Equipment Fleet Software | Life Cycle (LC) Capabilities | | | Functionality | | |
|---|---|---|---|---|---|---|
| | Generates LC | Could Generate LC (ie. Generates Input Data) | No Viable Inputs for LC | Definitely Functional | Maybe Functional | Not Functional |
| Fleetmatics | | x | | | x | |
| TMT Fleet Maintenance Software | | x | | | x | |
| Fleet Maintenance Pro (by IMS) | | x | | x | | |
| (AgileAssets®) Fleet & Equipment Manager™ | x | | | x | | |
| FleetFocus (by AssetWorks) | x | | | x | | |
| J. J. Keller's Maintenance Manager™ Software | | x | | x | | |
| collectiveFleet™ | x | | | x | | |
| MH Fleet by MH Equipment | | | x | | | x |
| Maintenance Connection | | | x | | | x |
| eMaint $X_3$ | | x | | | x | |
| Maintenance Coordinator | | x | | | x | |
| Maintenance5000 | | | x | | | x |
| Maintenance Pro | | x | | | x | |
| Accruent 360Facility | x | | | | x | |
| Infor EAM | x | | | | x | |
| 4Site | | | x | | | x |
| Guide TI | | | x | | | x |
| ManagerPlus | | | x | | | x |
| iMaint (Fleet) | | | x | | | x |
| Maintenance Assistant CMMS | | | x | | | x |
| MSI Service Pro Repair Center and Field Service | | | x | | | x |
| Fleetio | | | x | | | x |
| TATEMS | | | x | | | x |
| FleetCommander | | | x | | | x |
| Arsenault, Dossier Fleet Maintenance | x | | | | x | |
| RTA Fleet Management | | x | | | x | |
| FleetWave/RoadBASE | | | x | | | x |
| FleetWise VB | | | x | | | x |