Optimal Replacement Cycles of Highway Operations Equipment

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 879

Optimal Replacement Cycles of Highway Operations Equipment

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Amir N. Hanna
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Optimal Replacement Cycles of Highway Operations Equipment is essentially both a handbook on equipment replacement concepts and an instruction manual for making cost-effective replacement decisions. The research report presents a process for determining replacement needs for highway operations equipment, identifying candidate equipment units for replacement, and preparing an annual equipment replacement program. The products include a guide and an Excel-based replacement optimization tool to support the equipment replacement process and facilitate its implementation.

The guide will help fleet managers determine optimal life cycles and implement systematic replacement processes supported by sound data-driven analysis. In this manner, the guide should help fleet managers determine replacement needs and prepare replacement budgets to provide a highway operations program with a high-quality and dependable fleet to support the agency's mission. The information contained in the research report should be of interest to fleet managers and state maintenance engineers and to others involved in the replacement aspects of equipment fleet assets.

State highway agency equipment fleet assets are vital to the delivery of agency programs, projects, and services. These fleets represent a significant capital investment and require recurring maintenance, operational expenditures, and timely replacement to achieve the desired level of performance, reliability, and economy. A variety of practices have been used by highway agencies for deciding on the replacement cycles of highway operations equipment. However, there is no widely accepted process on which to base decisions. Therefore, there was a need to identify current practices, review relevant information, and develop rational processes to provide a realistic means for determining optimal replacement cycles. There was also need to prepare a guide for optimal replacement cycles to facilitate use of these processes. In this manner, highway equipment managers and administrators can better deal with the task of equipment replacement.

Under NCHRP Project 13-04, "Guide for Optimal Replacement Cycles of Highway Operations Equipment," Dye Management Group, Inc. worked with the objective of developing a guide for optimal replacement cycles of highway operations equipment that includes processes and tools for consideration in making decisions regarding the optimal replacement cycles of on- and off-road highway operations equipment used by state highway agencies. To accomplish this objective, the researchers reviewed literature pertaining to equipment replacement methodologies particularly related to highway operations equipment replacement, identified the factors relevant for determining optimal replacement cycles, and presented approaches and processes involved in equipment replacement decisions. The researchers then developed a systematic process that uses life cycle cost analysis for determining replacement needs, identifying candidate equipment units for replacement, and preparing an annual equipment replacement program. Finally, the researchers prepared a guide document (included as Part II of the research report) to facilitate use of the developed replacement process together with an Excel-based optimization tool for performing life cycle cost analysis in support of the replacement process and a user manual (Part III) that provides step-by-step instructions for its use. The optimization tool is available for download from TRB's website at www.trb.org by searching on *NCHRP Research Report 879*.

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Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

PART I

Research Overview

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PART I Research Overview

SUMMARY

Optimal Replacement Cycles of Highway Operations Equipment

Fleet assets are vital resources for highway agency programs and service delivery. Highway agencies make huge capital investments each year to replace equipment and spend equally large sums of money to operate and maintain the fleet. Replacing equipment at the right time reduces the overall cost of equipment ownership. When equipment is kept too long, the costs of maintenance and repairs increase, as does downtime. Higher downtime has a direct impact on service delivery and diminishes the agency's ability to accomplish its mission. When equipment is unavailable due to downtime, critical services are underperformed or are performed inefficiently. However, there is no widely accepted process for determining optimal replacement cycles. NCHRP Project 13-04 was performed to accomplish the following two objectives:

- Develop rational processes that will provide a realistic means of determining optimal replacement cycles.
- Include processes and tools for consideration in making decisions regarding the optimal replacement cycles.

Three products resulted from the project: a guide for optimal replacement cycles of highway operations equipment (the guide), a Microsoft Excel-based replacement optimization analysis tool, and the tool user manual. The guide promotes life cycle cost analysis (LCCA) for determining optimal life cycles and advocates a systematic equipment replacement decision process that incorporates LCCA with real-world considerations of the highway operations environment. The optimization tool is accompanied by a user manual that provides step-by-step instructions for its use. The guide and user manual are Parts II and III of this report, respectively.

Fleet managers often face difficult challenges in securing sufficient funds to replace their fleet at optimal cycles. Maintaining an old fleet because of replacement budget cuts and immediate reductions in expenditures costs the agency and the public more over time because of higher equipment ownership cost, higher costs of highway operations, and reduced service levels.

The research effort focused on developing processes and tools that are rational and realistic. There is a large amount of literature advocating LCCA for determining optimal equipment replacement cycles. Although similar in concept, there are varying approaches for equipment LCCA and different factors used in the analysis. The research team evaluated the approaches and sought to mesh prevailing economic theory with the real-world operating environment and considerations to arrive at a practical solution.

The most important aspect recognized in the guide is that making equipment replacement decisions is a process. Determining optimal life cycles and making replacement decisions are

two distinctly different exercises. Keeping with the project objectives, the project sought to develop processes and tools that are rational and realistic to help fleet managers and administrators with the task of equipment replacement.

The equipment replacement process can be summarized in three phases.

Data Collection. As with any asset management system, quality data are keys to obtaining dependable cost analysis results. In practice, there appear to be wide variations among fleet agencies in data accuracy, detail, and consistency. These limitations were considered as the project sought to develop practical and rational processes.

Analysis. Equipment is an asset and should be subjected to data-driven replacement analysis using LCCA, combined with systematic and methodical processes to determine optimal life cycles, identify potential replacement candidates, perform condition assessments, and prioritize replacement needs.

Decision Making. Ultimately, fleet managers must combine analysis results with practical knowledge and experience to make replacement decisions and develop an annual equipment replacement program that optimizes the use of available replacement funding. Many considerations come into play, including life cycle cost, condition, mission criticality, available replacement budgets, and others.

Quality data are extremely important in equipment replacement. Several highway agencies were contacted for equipment information and data so that the project could develop the processes and tools based on actual equipment cost data. While sufficiently good data were obtained, it became apparent that more work is needed by the highway industry to standardize equipment reporting and data collection.

A large amount of the data reviewed in the project was incomplete or contained many errors. A key shortcoming in the data was the lack of a complete database of equipment history. In many cases, detailed historical data did not exist because agencies have implemented new systems for tracking equipment cost, either through their financial or equipment management systems. When new systems are implemented, historical data are lost or are carried forward into the new system as a lump sum life-to-date quantity, thus losing annual cost data for the early years of a unit's life.

Additionally, many agencies do not record and track downtime. Downtime is a significant cost in equipment operations. It does not directly affect the fleet budget because there is no direct monetary outlay by the fleet agency. However, downtime has a real and significant cost impact on highway operations that is manifested in higher infrastructure maintenance costs and reduced service levels.

The mechanic hourly rate is another data element that bears consideration. Most agencies do not fully account for direct and indirect overhead in the labor cost for maintenance and repairs. When this is the case, the equipment operating cost is undervalued. In one case example, an agency charging $35 per hour for mechanic labor should have been charging $53 when accounting for all direct and indirect overhead costs.

Using LCCA to determine equipment life cycles requires complete, accurate, and consistent data, and a coordinated effort is needed to improve equipment data quality. Recognizing the need for complete and accurate data, the guide provides suggested guidelines that agencies can use for reporting equipment cost, utilization, and downtime.

From the literature search, the following 11 factors were initially identified as possible contributors to LCCA and the equipment replacement process.

- Age,
- Utilization,
- Depreciation,
- Maintenance and repair cost,
- Fuel cost,
- Downtime,

- Obsolescence,
- Replacement cost,
- Purchase price,
- Cost of money, and
- Soft cost.

Each of these factors was evaluated to determine its relevance to highway operations equipment.

The cost of money is not considered as a significant factor for highway operations equipment. Using cost of money as a factor assumes that there are alternative uses for the replacement funds, such as investment. This is not a pragmatic assumption, primarily because there is no practical alternative use of the funds.

Subsequently, the following three additional factors were identified as significant and relevant:

- Physical condition
- Mission criticality
- Overhead cost

Not all of these factors are used to perform LCCA. For instance, equipment condition and mission criticality do not affect the economic analysis for equipment, but they are important factors in making equipment replacement decisions.

The LCCA concept is illustrated in Figure 1. Performing LCCA for an individual unit of equipment can be helpful in making equipment replacement decisions; however, there are two practical limitations in the interpretation and application of a unit-level cost analysis. First, the point at which the unit reaches its economic life cannot be known until after the fact. Second, if annual cost data are not available for the unit's early years, which is often the case, the analysis cannot be performed.

Recognizing these limitations, the guide uses life-to-date (LTD) equipment history to compute averages for all units in a particular class. In effect, the approach models the life cycle cost of an average unit to determine optimal life cycles at the equipment class level.

In real life, equipment cost trends rarely follow the stylized graphic depicted in Figure 1. Most often, the cost curves are erratic and require interpretation. The optimal life is seldom a point in time but is more appropriately considered as a window of time.

Although LCCA concepts are fairly straightforward, the process for determining optimal life cycles and making replacement decisions is challenging, sometimes involving as much art as science. Making replacement decisions is a process. It combines cost analysis with

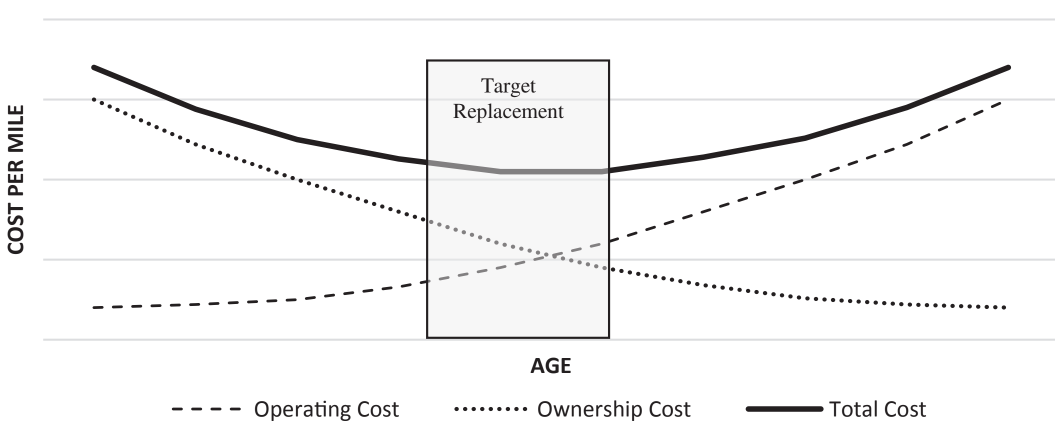

Figure 1. Equipment LCCA concept.

other factors and considerations to arrive at the best decision. The process is time consuming and requires continual effort.

Measuring asset conditions is a fundamental principle of asset management that applies to equipment assets in much the same way as infrastructure assets. Performing equipment condition assessments is an important step in an effective replacement process but has been largely ignored in practice. Recognizing its importance, the guide outlines recommended procedures for performing condition assessments, assigning mission criticality levels to equipment units, and incorporating the condition/criticality scores into the decision process. The optimization tool includes an Excel spreadsheet to support the condition assessments.

The guide presents a systematic, 12-step process comprising the following major activities:

- Start with good quality data. Download data from the agency's equipment information systems. Clean up the data by correcting errors and eliminating units that do not have sufficient cost history to represent a valid cost trend.
- Make sure that there are enough units in the class to provide a statistically valid sample of units for the class-level LCCA. Perform the class-level LCCA to determine optimal life cycles. If there are not enough units to perform a class-level LCCA and if complete historical data are available, a unit-level LCCA can analyze the costs of individual units.
- Identify replacement candidates based on a unit's LTD miles, hours, or cost.
- Perform condition assessments on the candidate units and prioritize units for replacement based on mission criticality, condition, and cost analysis.
- Make final replacement decisions based on available replacement funding and other agency-specific factors and considerations.
- Develop a 5-year plan and analyze the cost consequences of various replacement scenarios to provide the fleet manager with information to make a business case for future funding levels.

The Excel-based optimization tool performs LCCA and supports the annual equipment replacement process with analysis and outputs to assist in making replacement decisions. The tool is a set of spreadsheets with the following features:

- It provides a configuration file with preloaded replacement factors and default values that the user agency may choose to adopt or override with agency-specific values.
- It performs class-level LCCA to determine optimal life cycles for 40 major equipment classes.
- It performs unit-level LCCA to analyze the equipment cost of individual pieces of equipment.
- It identifies potential replacement candidates based on utilization and LTD cost derived from LCCA.
- It provides a spreadsheet for performing condition assessments and computes a condition score based on condition and mission criticality.
- It prioritizes equipment replacements by using a priority ranking system based on a unit's LTD cost and condition.
- It develops a 5-year plan of future replacement needs and budgets based on the projected replacement year of individual equipment units.
- It analyzes cost consequences of various equipment replacement cycles.

The accompanying tool user manual provides step-by-step instructions for using the optimization tool.

Although the project achieved its objectives, more effort is needed to make equipment replacement easier and provide more reliable cost analysis results.

The project research identified data quality as a major concern. An effort should be made to develop standards or guidelines for reporting and tracking equipment maintenance and repair cost. The guidelines should incorporate recommended data quality control procedures.

Excel was chosen for development of the optimization tool because of its ready availability. The Excel-based tool provided the appropriate features to support equipment replacement. However, the tool's functionality could be enhanced with more robust software that would make the tool more user-friendly.

Guidelines should be developed for determining the true cost of mechanic labor rates. Prevailing practices fail to account fully for direct and indirect overhead expenses, and equipment operating costs are being understated.

Guidelines should also be developed for measuring, reporting, and tracking equipment downtime. It appears that most agencies do not currently track downtime, resulting in the true cost of equipment operations being understated.

The guide developed in this project addresses all of these concerns and provides guidelines and recommended procedures for cleaning up data, reporting maintenance cost, accounting for overhead expenses, and tracking downtime. The guidelines contained in the guide should be considered as starting points for future refinement with the goal of achieving more standardized practices.

User training is necessary when any new software system is implemented in an agency. Such is the case with the equipment replacement processes and optimization tool contained in Parts II and III. Implementation of the tool will require training to understand the recommended processes supported by the tool and how to apply the tool in performing LCCA and making effective replacement decisions. System training is a normal and important step for successful system implementation.

Also, ongoing system support will be required and is a natural step in the implementation and ongoing use of the tool. An organization such as AASHTO is most likely the best organization to provide the ongoing support.

CHAPTER 1

Introduction

1.1 Background

Equipment is an essential resource in highway operations. The quality of the equipment fleet has a direct impact on the agency's cost of operations and ability to achieve its mission. Without a high-quality fleet, highway maintenance costs go up and service levels go down. An effective equipment replacement program is a key component in providing a high-quality fleet.

Highway agencies make large capital investments each year to replace equipment. A survey performed as part of *NCHRP Synthesis 452: State Department of Transportation Fleet Replacement Management Practices* (*1*) found that the average agency expenditure in 2011 was $18.5 million; however, survey respondents believed that amount was 40% lower than needed.

Replacing equipment at the right time lowers the total ownership cost, reduces downtime, and allows highway operations to be performed more efficiently. However, there is no widely accepted process for determining optimal equipment replacement cycles. There is a need to develop rational processes that will (a) provide a realistic means for determining optimal replacement cycles and (b) help equipment managers and administrators with the task of equipment replacement.

1.2 Project Objective

The objective for NCHRP 13-04 was to develop a guide for optimal replacement cycles of highway operations equipment. The guiding principle was to develop rational and realistic processes. There is considerable literature dealing with the economic theory of equipment replacement analysis. The intent of this project was to mesh theory with real-world operating considerations to achieve practical results that can be applied in a highway operations environment.

The project also recognizes the need for processes and tools. Making equipment replacement decisions is a process that recognizes the real-life operating environment. The tool developed in the project is Excel based, which is easy to obtain, does not require proprietary software, and supports the replacement processes.

1.3 Research Approach

The project was accomplished in two phases. Phase I encompassed a literature search to identify and evaluate current practices related to equipment replacement processes, determining replacement cycles, and proposing a plan for preparing the guide and developing the optimization tool. The plan was executed in Phase II.

1.4 Organization of the Report

The report consists of Parts I, II, and III. Part I is a research report describing the work performed to prepare the guide and develop the optimization tool. It consists of four chapters and two appendices.

Chapter 1 introduces the project and discusses its background, objectives, and research approach. Chapter 2 discusses the project approach in detail and presents the literature search findings on prevailing practices. Chapter 3 presents the overall project results, including discussions on

- Replacement factors and how they are quantified and used in highway operations,
- The LCCA approach for highway operations equipment,
- Equipment replacement processes presented in the guide, and
- An overview of the optimization tool used to perform LCCA and support the replacement processes.

Chapter 4 presents a summary of the findings and offers suggested future research. Appendix A contains the default depreciation schedules used in the optimization tool and Appendix B presents a flowchart of the equipment replacement process. Part II is the guide for optimal replacement cycles of highway operations equipment and Part III is the user manual for the optimization tool. The optimization tool is not included herein. The tool is available for download from TRB's website at www.trb.org by searching on *NCHRP Research Report 879*.

CHAPTER 2

Research Approach and Findings

NCHRP 13-04 was conducted in two phases. Phase I consisted of a comprehensive literature search to identify current replacement practices relevant to the project scope. In Phase II, the findings from the literature search were evaluated, equipment data from public and private sources were gathered and analyzed, and promising practices were synthesized and adapted to develop processes and tools for practical application in a highway operations environment.

2.1 Literature Search

The research found a large volume of literature on equipment LCCA methodologies and replacement practices. Most of the LCCA methodologies were similar in concept but tended to have slight variations in their approach and the factors used in the cost analysis. The aim of the literature search was to identify current promising practices, methods, and tools and to evaluate their applicability to highway operations equipment.

A wide variety of sources including academia, state, federal highway and other government agencies, professional associations, research institutions, and equipment industry periodicals were researched through the internet, libraries, personal contacts, and bibliography reviews. These sources included TRB; NCHRP; FHWA; AASHTO; International Road Federation; International Bridge, Tunnel and Turnpike Association; professional fleet management associations (e.g., National Association of Fleet Administrators, Municipal Fleet Managers Association, Association of Equipment Management Professionals, and American Public Works Association); the U.S. military, equipment manufacturers; and private contractors.

In addition to published material and manuscripts, relevant information from fleet management conferences conducted by AASHTO, TRB, Rocky Mountain Fleet Management Association, academia, and others were identified and reviewed. More than 80 potential documents were examined to identify their relevance to the project scope based on the following criteria:

- **Replacement factors.** Does the literature identify factors for performing replacement analysis? Does it define how the factors should be measured? Do the factors appear to be applicable to highway operations equipment?
- **Process.** Does the literature discuss how to structure replacement programs? Does it describe replacement decision-making processes applicable to highway operations equipment? Does the literature represent current industry appropriate practices?
- **Tools.** Does the literature describe software or automated tools that support LCCA and equipment replacement processes?

With these criteria, the most relevant literature was selected and reviewed in detail.

The literature search also identified and reviewed several software products and tools used in replacement analysis. However, access to commercial products dealing with asset management in general and equipment replacement in particular was not available to allow a detailed evaluation of their methodologies but literature describing the product features provided a general understanding of their replacement approaches.

2.2 Data Collection and Analysis

Data were collected from public and private sources for use in analyzing equipment replacement factors and developing and testing the optimization tool. Several state departments of transportation (DOTs) provided valuable information and data including

- Original equipment purchase costs;
- Equipment disposal data on age, miles/hours at sale, and salvage values;
- Data sets containing equipment history on utilization, operating cost, and downtime;
- Classification and equipment numbering conventions;

- Hourly rental rates; and
- Age and utilization replacement targets.

Information was also obtained from several other government agency and private sources to help analyze replacement factors related to depreciation, fuel costs, and hourly operating costs.

2.3 Prevailing Practices

The literature search on equipment replacement found that replacement practices vary widely between private and public agencies. Three general approaches emerged as those most commonly used:

- Replacement based on target age or utilization,
- Replacement based on maintenance and repair thresholds, and
- Replacement based on formal LCCA.

An agency's replacement practices seldom fit neatly into any one approach. Rather, the prevailing practices seemed to combine parts of all three.

NCHRP Synthesis 452 (*1*) presented the findings of fleet replacement practices in state DOTs. Table 1 presents the respondents' answers to the questions most pertinent to this project. Of the 38 states that responded, 32 had some form of LCCA, multi-year planning, methodology to prioritize replacements, or repair versus replace analysis. Five DOTs reported that LCCA was the most important tool used for replacement decisions. Most agencies indicated that they used either criteria-based methods (miles or hours) or thumb rules based on past practices and judgment.

2.3.1 Replacement Based on Target Age or Utilization

In this approach, replacement targets are established for each major equipment class. The targets establish thresholds for age and utilization (miles or hours). When a vehicle is at or near the replacement target, it is evaluated for replacement. This replacement practice has the advantage of simplicity, but it may not result in the optimal economic cost.

2.3.2 Replacement Based on Maintenance and Repair Thresholds

This approach compares an equipment unit's maintenance and repair (M&R) cost with established thresholds to determine when replacement is warranted. The thresholds are established at two levels:

- When the M&R LTD costs exceed a specified threshold or
- When a major overhaul or rebuild exceeds a specified threshold.

In the first method, M&R costs are tracked throughout the life of the vehicle. When M&R costs reach the specified threshold, they are targeted for replacement. Dolce suggests targeting a unit for replacement when (a) the cumulative M&R costs reach the original purchase price of the unit or (b) when annual M&R costs reach 30% of a unit's residual value (*2*).

Flagship Fleet Management, LLC suggests that the optimal replacement point is that where cumulative maintenance cost starts to out run the market value of the asset (*3*).

The second method targets a vehicle for replacement if a major repair or rebuild is required in which the cost exceeds a given percentage of the unit's original cost. Figure 2 illustrates the concept adopted by the Naval Facilities Command for its civil engineering equipment (*4*). It establishes the maximum one-time repair cost based on three factors: original purchase price, expected life (target replacement), and actual age.

2.3.3 Life Cycle Cost Analysis

The literature suggests that LCCA is the best method for determining optimal replacement cycles because it uses economic analyses to determine the time in a unit's life at which its total cost is at a minimum (see Figure 1 in the Summary).

In concept, LCCA is rather straightforward and, when performed effectively, it provides data-driven results for determining optimal life cycles. However, LCCA is difficult and time consuming and many agencies have not committed to its application. The difficulty arises not in the model's complexity but rather in the time and resources required to capture complete and accurate data and then to incorporate LCCA into a robust equipment replacement process.

Plotting the life cycle cost of an individual unit is not likely to yield the stylized smooth curve depicted in Figure 1. Bibona noted that establishing replacement cycles is both an art and a science (*5*). It involves judgment, prediction, forecasts, and assumptions on one hand and analysis of available data on the other hand.

The findings from the literature search were used in determining how to treat LCCA and develop a realistic approach for highway operations equipment.

Table 1. Prevailing DOT practices.

State	Formal Life-Cycle Cost Analysis?	Multi-Year Fleet Plan?	Methodology to Prioritize Assets When Budget not Sufficient?	Repair vs. Replace Policy or Tools?	LCCA Most Important Tool for Replacement?		Fleet Replacement Studies	
					Most Important Tool?	How Often Used?	Within last 10 Years?	Available to Public?
AL	Yes				LCCA	Always	Yes	Don't Know
AK		Yes	Yes	Yes			Yes	Yes
AR	Yes	Yes	Yes					
AZ	Yes	Yes	Yes	Yes				
CA	Yes						Yes	Don't Know
CT		Yes	Yes					
DE	Yes	Yes		Yes	LCCA	Most times		
FL							Yes	Yes
GA	Yes		Yes	Yes				
HI	Yes	Yes	Yes	Yes				
IA				Yes				
ID		Yes						
IL			Yes				Yes	No
IN								
KY							Yes	Yes
MD								
ME	Yes	Yes	Yes	Yes			Yes	Don't Know
MI	Yes	Yes	Yes	Yes				
MN							Yes	Don't Know
MS			Yes					
MT	Yes		Yes					
NC				Yes			Yes	Don't Know
NE								
NH		Yes						
NJ	Yes	Yes	Yes	Yes	LCCA	Always		
NM	Yes	Yes	Yes	Yes	LCCA	Always	Yes	Don't Know
NY				Yes			Yes	Yes
OH		Yes	Yes	Yes			Yes	Yes
OR		Yes	Yes				Yes	Yes
PA	Yes	Yes	Yes				Yes	No
SC	Yes		Yes	Yes	LCCA	Seldom	Yes	Yes
SD	Yes	Yes	Yes	Yes			Yes	Don't Know
TN		Yes		Yes				
TX			Yes	Yes			Yes	Yes
UT			Yes					
VT								
VA			Yes					
WY			Yes					

	Maximum Economic Repair Cost as a Percent of Purchase Price																			
	ACTUAL AGE - YEARS																			
EXPECTED LIFE - YEARS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
3 YR	75	48	20																	
4 YR	75	57	38	20																
5 YR	75	61	47	33	20															
6 YR	75	64	53	42	31	20														
7 YR	75	65	56	47	38	29	20													
8 YR	75	67	59	51	43	35	27	20												
9 YR	75	68	61	54	47	40	33	26	20											
10 YR	75	69	63	57	51	45	39	33	24	20										
11 YR	75	70	65	60	55	50	44	36	32	26	20									
12 YR	75	70	65	60	55	50	45	40	35	30	25	20								
13 YR	75	70	65	60	55	50	45	40	36	32	28	24	20							
14 YR	75	71	67	63	59	55	51	47	43	38	32	28	24	20						
15 YR	75	71	67	63	59	55	51	47	43	39	35	31	26	23	20					
16 YR	75	71	67	63	59	55	51	47	43	39	35	32	29	26	23	20				
17 YR	75	71	67	63	59	55	51	47	44	41	38	35	32	29	26	23	20			
18 YR	75	72	67	63	59	56	53	50	47	44	41	38	35	32	29	26	23	20		
19 YR	75	72	69	66	63	60	57	54	51	48	45	42	35	36	33	30	27	24	20	
20 YR	75	72	69	66	63	60	57	54	51	48	45	42	39	36	33	30	27	24	22	20

Figure 2. Repair cost thresholds (4).

CHAPTER 3

Project Results

The three primary products of the project are:

- A guide for optimal replacement cycles of highway operations equipment,
- An Excel-based optimization tool for performing LCCA and supporting replacement processes, and
- A user manual for the replacement optimization analysis tool.

The guide and tool user manual are included as Parts II and III in this report, respectively. The optimization tool is available for download from TRB's website at www.trb.org by searching on *NCHRP Research Report 879*. The project results are described in the following sections.

3.1 Equipment Classification Scheme

For the optimization tool to be universally applicable, it is necessary to adopt a standardized equipment classification and numbering scheme within the tool. Table 2 lists the 40 major equipment classes that are preloaded in the optimization tool. The numbering scheme closely follows the equipment classification codes adopted by the National Association of Fleet Administrators (*6*).

The tool class codes are used solely by the optimization tool and are not meant to replace the user agency's class codes. In the initial tool setup, the agency's internal class codes are cross-referenced to the preloaded tool class codes.

Most of the class code descriptions in Table 2 are self-explanatory; however, two class codes may need further clarification:

- Class 8786, Bottom Dump, is used to describe the full bottom dump truck unit, including the tractor and bottom dump trailer. Although few agencies have these units in their fleet, this class was included to allow those agencies that do have them to analyze life cycle costs of the units.
- Class 0110, Salt Spreader, uses the same number as the general NAFA class for "Snow Removal" units. For the purposes of analyzing life cycle cost in the optimization tool, this class code was adopted from NAFA and represents a generic type class description for salt spreaders, regardless of the configuration or type of salt spreader used by the agency. The 0110 class code may be used for tailgate spreaders, drop-in spreaders, or any other configuration that is most prevalent within the agency. Because these units typically do not have hour meters, their utilization is measured by hours of usage reported daily by maintenance crews.

Most agencies have unique classification and numbering schemes. Some schemes are very detailed and have many class codes, while other schemes are more generalized. The optimization tool adopts a more generalized scheme.

Using the ½-Ton Pickup Class as an example, the optimization tool performs LCCA for all pickup types under one universal code listed in Table 3. In the example, six different pickup configurations are included under Class 1521, ½-Ton Pickup. A 2WD extended cab gas pickup, for instance, is analyzed in the same way as a 4WD regular cab diesel pickup. The replacement factors considered by the LCCA are similar for all pickup types, leading to similar optimal life cycles. Each of the six pickup types may be analyzed individually or all six may be analyzed under one pickup class. The tool also allows analysis of various equipment groupings such as manufacturer. It is important to note that the equipment class or subgroup must have a sufficient number of units in the fleet to render a statistically valid sample for analysis.

With the cross-reference table, the agency's cost history for all pickups is combined under the 1521 class code so that the optimal life cycle determined by the tool applies to all six of the agency's classes. The tool allows the user to analyze each of the six pickup classes individually. However, breaking

Table 2. Optimization tool equipment classes, codes, and descriptions.

Equipment Group	Equipment Class	
	Tool Code	Description
Passenger Vehicles	1300	Sedan
	1600	SUV
	1348	Police Cruiser
Light Trucks	1521	½-Ton Pickup
	1531	¾-Ton Pickup
	1523	½-Ton Crew Cab
	1533	¾-Ton Crew Cab
	1424	Vans
Medium Duty Trucks	3514	Mechanic Shop Truck
	2513	1-Ton Crew Cab
	3711	Flat Bed Truck
	3744	Scissor-Bed Truck
Large Trucks	6712	Single-Axle Dump
	8712	Tandem Dump
	8785	Tri-axle Dump
	8786	Bottom Dump
	8810	Tractor/Trailer
	8743	Bucket Truck
Specialty Trucks	8744	Bridge Snooper Truck
	8771	Roadway Sweeper Truck
	8741	Mobile Crane
	8773	Culvert Cleaner/Vacuum Truck
	8778	Asphalt Distributor
	8731	Wrecker Truck
	9452	Striping/Paint Truck
Heavy/Off-Road Equipment	9132	End Loader, Wheeled
	9220	End Loader, Track
	9110	Loader, Skid Steer
	9160	Motor Grader
	9440	Roller, Pneumatic
	9441	Roller, Steel Wheel
	9150	Excavator, Wheeled
	9250	Excavator, Track
	9230	Dozer
	9290	Dragline
	9142	Backhoe
Maintenance Equipment	9431	Asphalt Paver
	9426	Pavement Profiler
	9623	Tractor, Mower
	0110	Salt Spreader

equipment classes down too finely can affect the quality of the LCCA results if there are not enough equipment units in the class to render a realistic cost analysis.

3.2 Equipment Replacement Factors

The following 11 factors were initially identified from the literature search as being potentially relevant to highway operations: Each factor was evaluated to determine if and how it applies to highway operations equipment.

Table 3. Equipment types in tool class 1521.

Equipment Types Included in Tool Class 1521 ½-Ton Pickup	
Optimization Tool Class	Equipment Types Included
½-Ton Pickup	– 2WD – 4WD – Regular Cab – Extended Cab – Diesel – Gas

- Age,
- Utilization,
- Depreciation,
- Maintenance and repair cost,
- Fuel cost,
- Downtime,
- Obsolescence,
- Replacement cost,
- Purchase price,
- Cost of money, and
- Soft cost.

In addition to these factors, the guide suggests three additional factors as significant to performing LCCA and making equipment replacement decisions. These are

- Physical condition,
- Mission criticality, and
- Overhead costs.

Not all of the factors are monetary. For instance, physical condition and mission criticality do not impact LCCA, but they are important for prioritizing equipment replacement in the decision-making process. The following sections describe the factors and how they are used by the tool and in the replacement processes.

3.2.1 Age

Most highway agencies have established equipment replacement targets or criteria based on age and utilization. According to *NCHRP Synthesis 452* (*1*) a large percentage of agencies use age and utilization as the primary criteria for equipment replacement. Example replacement targets are shown in Table 4.

Table 4. Example of replacement targets.

Equipment Class	Replacement Target Years	Miles	Hours
Sedan	6	90,000	
½-Ton Pickup	6	110,000	
¾-Ton Crew Cab	8	110,000	
Single-Axle Dump	12	120,000	
Mobile Crane	15	120,000	
Loader, Wheel	12		5,000
Motor Grader	15		5,000

The guide does not propose making replacement decisions based solely on age. However, age is an important factor to be considered in the replacement process and is used in three basic ways:

- To express optimal replacement cycles in years,
- As a planning value to identify equipment units as potential replacement candidates, and
- To project the year that an equipment unit will reach its planned replacement life.

The optimization tool contains preloaded default planning values for target replacement age for each of the 40 equipment classes. These are only target planning values and are not hard-and-fast replacement standards. In the initial tool setup, the user can review the preloaded default values and opt to use them or override them with values specific to the agency.

3.2.2 Utilization

Utilization normally goes hand in hand with age, although utilization can vary significantly between equipment classes and from year to year for individual units. Figure 3 shows the average annual utilization for all pickup trucks in the fleets of three DOTs. The trend for lower utilization in later years was found to be consistent for nearly all equipment classes, including Dump Truck and Heavy Equipment. Older units tend to be used less because operators prefer to operate new equipment, and older units normally incur higher downtime.

Repair costs are tied more directly to utilization than to age; the more a unit is operated, the more it requires maintenance. Likewise, utilization, not age, generally dictates the true depreciated value of a unit. Utilization is used in equipment replacement in three ways:

- In LCCA to calculate LTD cost per mile/hour;
- As a planning value to identify potential replacement candidates; and
- To express optimal replacement cycles by miles/hours.

As with age, the optimization tool contains preloaded default planning values for replacement utilization targets based on miles or hours for each equipment class. The user may opt to use the default values or override them with values specific to the agency.

3.2.3 Depreciation

Depreciation is a major factor to be considered in LCCA and is generally made up of between 30% and 40% of the total cost to own and operate equipment over its lifetime. Most LCCA methodologies define depreciation in accounting terms that determine the book value of an asset over its life. Within the project, various data sources were analyzed to evaluate how depreciation by accounting methods can be applied to highway operations equipment.

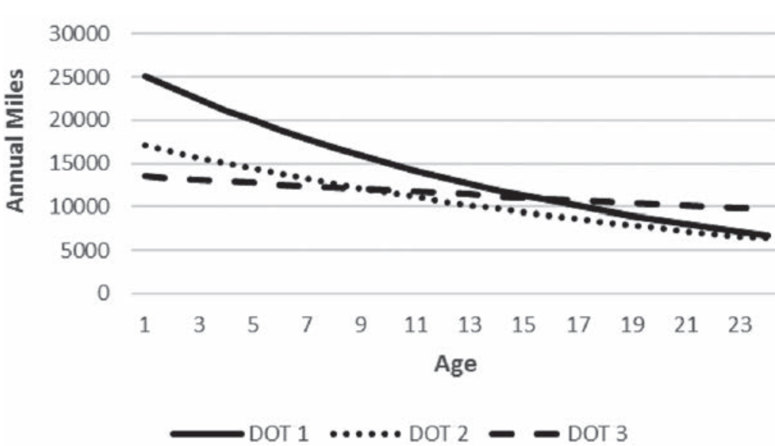

Figure 3. Utilization for pickup trucks, by age.

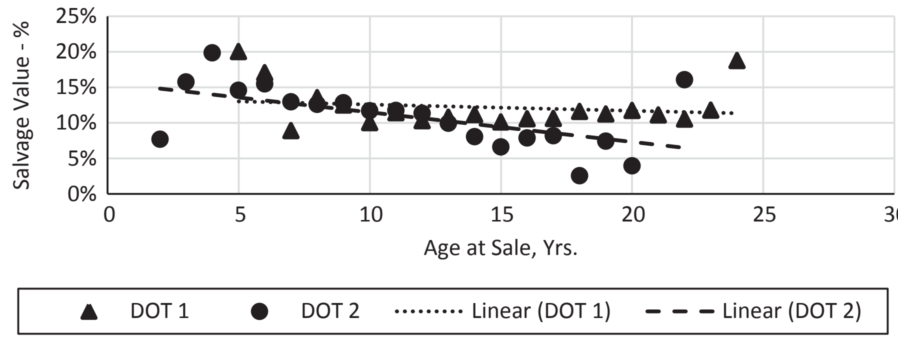

Figure 4. Salvage value for pickups, by age.

Analysis of DOT Salvage Values

State DOTs do not keep records that show salvage values during each year of a unit's life, and thus no data exist with which to analyze year-over-year depreciation. However, for this project, DOT data were obtained and analyzed for end-of-life salvage values for three equipment classes: Pickup Truck, Dump Truck, and End Loader.

Pickup Trucks. Figures 4 and 5 were developed from records provided by two DOTs and show the salvage values of the pickup class for 319 and 2,084 units designated DOT 1 and DOT 2. The vehicles were grouped by age and utilization, and the average salvage value of all units in the group was computed.

Figure 4 shows that the trend of pickups class salvage values in the sample is downward with age, as expected for both DOTs. Figure 5 shows that the salvage values trend is downward with miles for DOT 2 but upward for DOT 1. For example, vehicles in DOT 1 with an average of 50,000 miles when sold had a salvage value of approximately 6.5%, while vehicles with 200,000 miles had a salvage value of about 11%. Looking at the details of the data, the same variability of salvage values is observed within mileage and age groups. For example, 16 vehicles with utilization between 150,000 and 160,000 miles when sold ranged from a low of 3% to a high of 13% salvage value.

8-Yard Dump Trucks. The same type of analysis was performed for the 8-Yard Dump Truck Class from the DOT data. The results are shown in Figures 6 and 7.

Salvage values trend for the 8-Yard Dump Truck sample from DOT 1 is upward, with both age and miles but downward with age and upward with miles for DOT 2. As with the pickup class, there was considerable variability in salvage values between units with the same age and miles.

End Loaders. The same analysis was performed for the End Loader Class using the DOT data, representing 99 and 176 units for DOT 1 and DOT 2. The results are shown in Figures 8 and 9.

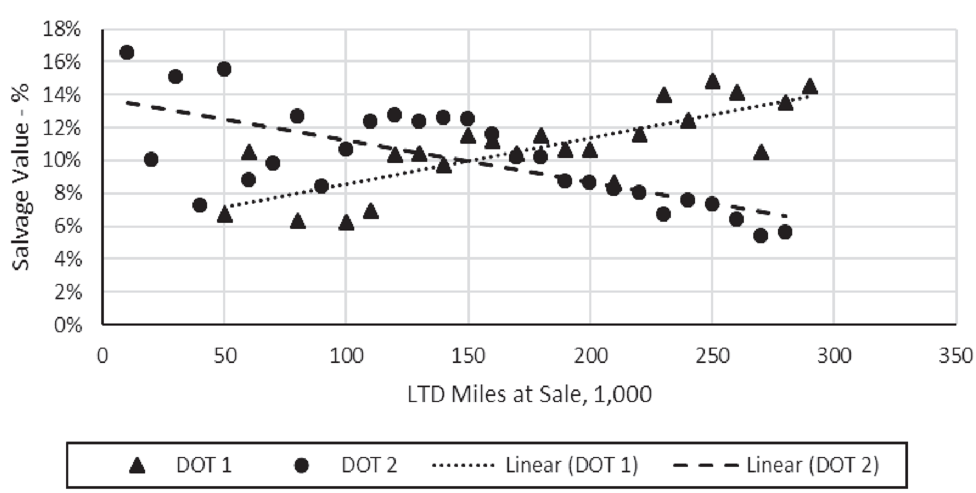

Figure 5. Average salvage value for pickups, by miles.

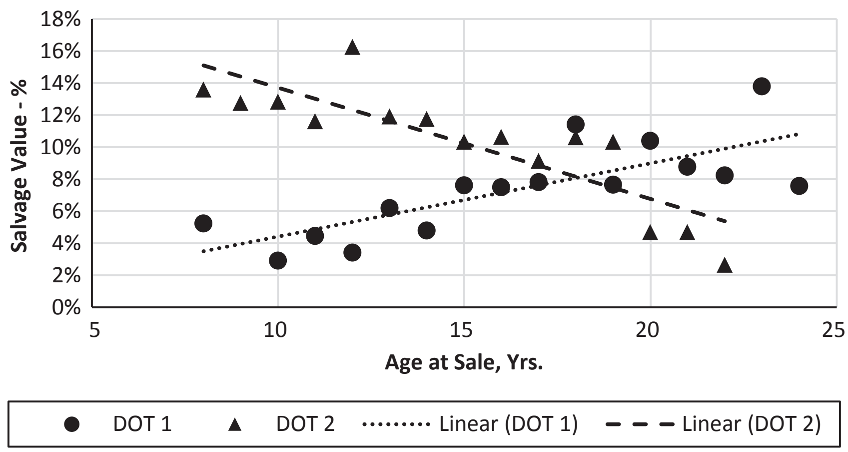

Figure 6. Salvage value for dump trucks, by age.

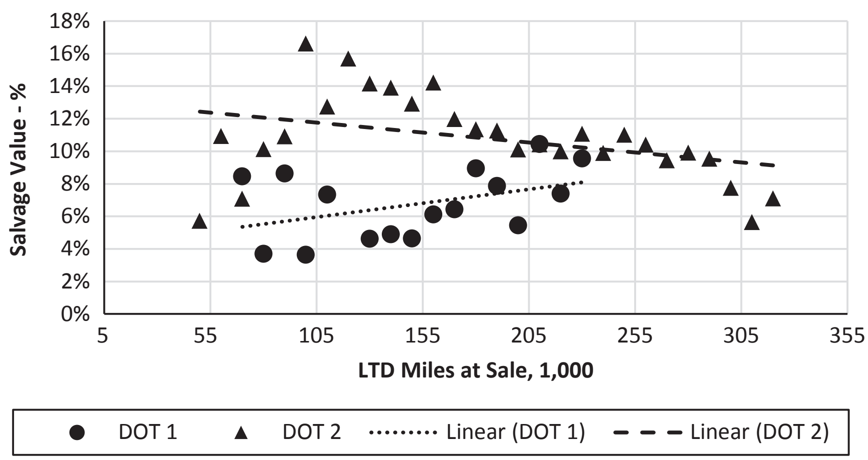

Figure 7. Salvage value for dump trucks, by miles.

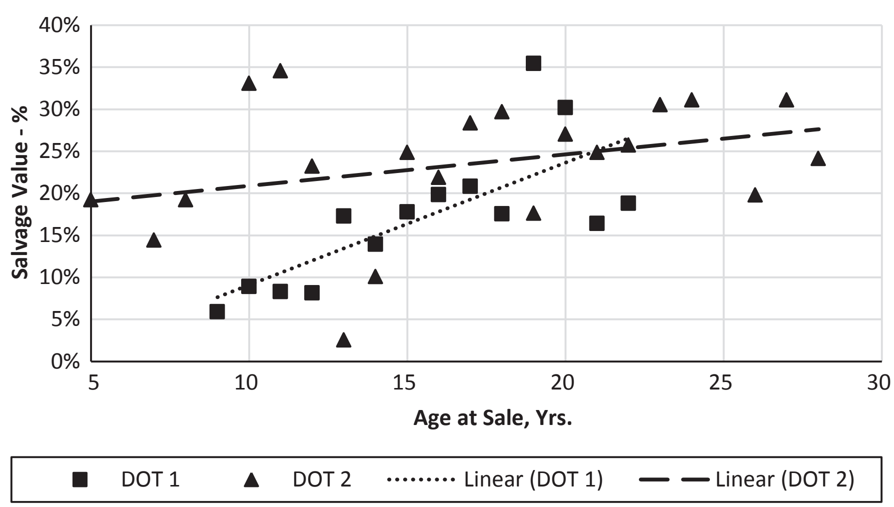

Figure 8. Salvage value for end loaders, by age.

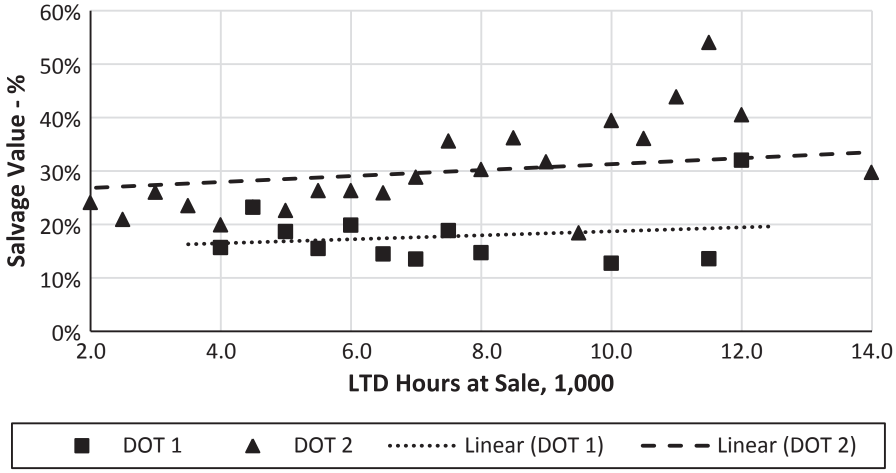

Figure 9. Salvage value for end loaders, by hours.

Figures 8 and 9 show that the salvage values trend with age and hours for both DOTs is upward, and the values are considerably higher than would be expected. For example, the average salvage value for 20-year-old end loaders was about 24% for both agencies but approximately 20% for DOT 1 and 32% for DOT 2 for end loaders with 12,000 hours.

Two important conclusions can be derived from the analysis of DOT salvage values:

- Salvage values tended to be higher than expected and exceeded the 10% value normally projected in accounting depreciation methods.
- There is considerable variability in salvage values among units of similar age and utilization, most likely due to the individual conditions of the units and market conditions at the time of resale.

PennDOT Data

A recent report by Vance & Renz, LLC, Pennoni Associates, Inc., and SF & Company further illustrates evidence of salvage value variability (*8*). Table 5, extracted from the report, shows actual resale values in relation to PennDOT's conventional accounting depreciation values. Salvage value percentages in the last column were added for this report. Two key observations were derived from the data:

- Actual depreciated values do not match accounting depreciation.
- Salvage values are generally higher than what might intuitively be expected; loader salvage values are consistent with the results found in the two-state analysis described in the previous section.

Interpretation of the DOT Data

The salvage value analyses performed in the project and presented in the PennDOT report (*8*) show no direct correlation between a unit's salvage value and its age or utilization. Salvage values varied quite significantly for units with similar age and miles and tended to be higher than expected. While no data exist to explain the variation in salvage values or the high resale values, consideration of the operating environment of highway operations may provide some insight. First,

Table 5. PennDOT salvage values.

Equipment Type	No. of Units	Avg. Acquisition Price	Avg. Months Owned	Avg. Sale Price	Avg. PennDOT Depreciation at Sale	Avg. Difference, Sale-Depreciated Value	Salvage Value
Backhoes	54	$52,897	199	$10,765	$8,960	$1,805	20.4%
Crew Cabs	36	$28,208	122	$1,943	$9,208	-$7,265	6.9%
Gradall Excavators	32	$144,897	204	$8,526	$23,306	-$14,780	5.9%
Loaders	243	$69,203	180	$20,218	$14,477	$5,741	29.2%
Single-Axle Trucks	177	$66,634	153	$8,089	$17,516	-$9,427	12.1%
Tandem-Axle Trucks	546	$75,046	152	$17,241	$18,552	-$1,311	23.0%
Tri-Axle Trucks	19	$90,719	133	$22,188	$26,022	-$3,834	24.5%

DOTs are often able to purchase equipment units at a significantly lower cost than the private sector. However, DOT vehicles are sold at auction at prices equal to or higher than private sector vehicles. Because the DOT paid significantly less to purchase the vehicle, the amount of depreciation will be lower. Second, many DOTs have gained a reputation for maintaining their equipment units in good condition and are able to realize better resale values than might otherwise be the case for private vehicles.

These results of the salvage value analysis were an important input into developing realistic depreciation tables for use in performing LCCA.

Salvage Values from Industry Data

Salvage value data were evaluated from industry sources to supplement the DOT salvage value analysis. The industry data sources are not entirely applicable to highway operations equipment in terms of absolute dollar values, because DOTs typically purchase equipment considerably below retail cost.

For transportation vehicles such as cars and trucks, the data sources were the *Kelley Blue Book Car Values* (*9*) and the National Appraisal's *NADA Guides* (*10*). Hypothetical units for sedans, pickups, and vans were constructed to see how they would depreciate based on miles and average condition at sale. Although the dollar values cannot be compared, the annual percentage depreciation of privately owned vehicles would be expected to follow a similar trend as that for state DOT vehicles.

An example of the results for ½-Ton Pickups is shown in Figure 10. With an average annual usage of 15,000 miles, the results show that a pickup would normally depreciate about 18%, which is in line with the first-year depreciation rate found for state DOT vehicles. The rate of annual depreciation declines with the vehicle's age and flattens in later years.

Depreciation Calculations in LCCA

In LCCA, depreciation costs must be calculated for each year of a vehicle's life and predicted into the future. For LCCA to provide accurate results, depreciation must be defined as the true cost of ownership. The analysis presented in this section demonstrates that the true cost of depreciation is not necessarily the same as the depreciation computed by accounting methods.

To model true depreciation costs as closely as is practical, default depreciation tables were developed for the project based on the results of the salvage value analysis. The optimization tool contains default depreciation schedules for each of the 40 equipment classes. The full depreciation table is shown in Appendix A and excerpted in Table 6. Because utilization is a better predictor of depreciation than age is, the tool computes depreciation based on a unit's LTD utilization. The user may choose to use the default depreciation values preloaded in the tool or override them with values specific to the agency.

3.2.4 Maintenance and Repair Cost

M&R cost is a required factor for LCCA. The costs used by the optimization tool to perform LCCA are obtained from the user agency's internal equipment data source.

M&R costs can fluctuate significantly from year to year, as illustrated in Figures 11 and 12. Figure 11 shows the annual M&R costs for an individual dump truck. Figure 12 shows the average annual M&R costs for all units in a sample of motor

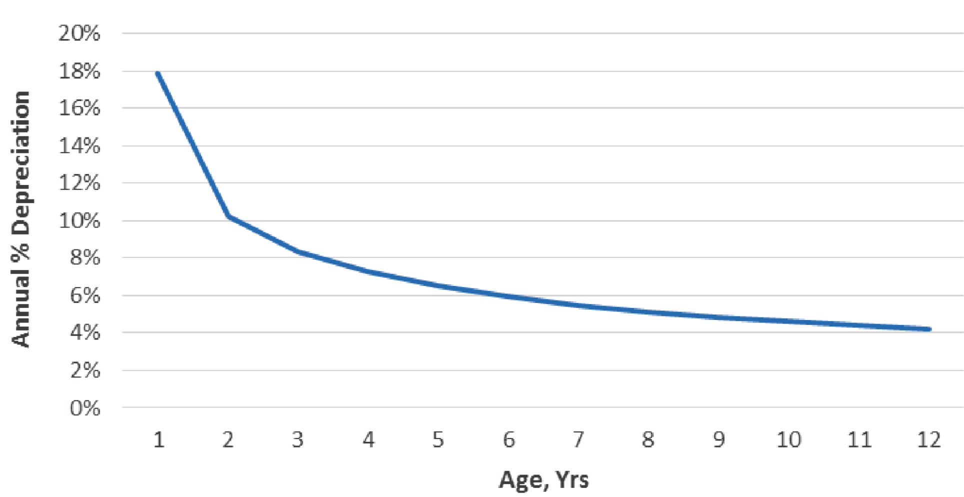

Figure 10. Annual depreciation for ½-ton pickups.

Table 6. Excerpt of optimization tool depreciation schedule.

Class Code	Description	Accumulated Depreciation at Miles or Hours											
	Utilization, 1,000 Miles →	10	20	30	40	50	60	70	80	90	100	110	120
	Utilization, Hours →	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
1300	Sedan	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%
1600	SUV	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%
1348	Police Cruiser	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%
1521	1/2 Ton Pickup	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1531	3/4 Ton Pickup	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1523	1/2 Ton Crew Cab	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1533	3/4 Ton Crew Cab	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1424	Vans	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%

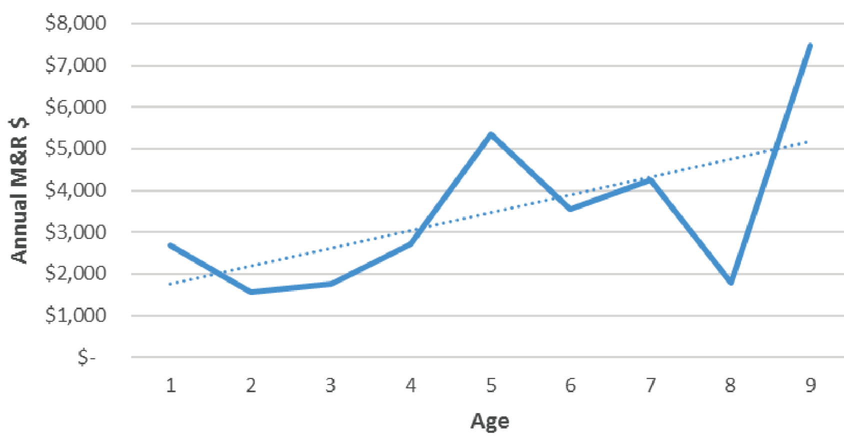

Figure 11. Example of annual M&R cost for a dump truck.

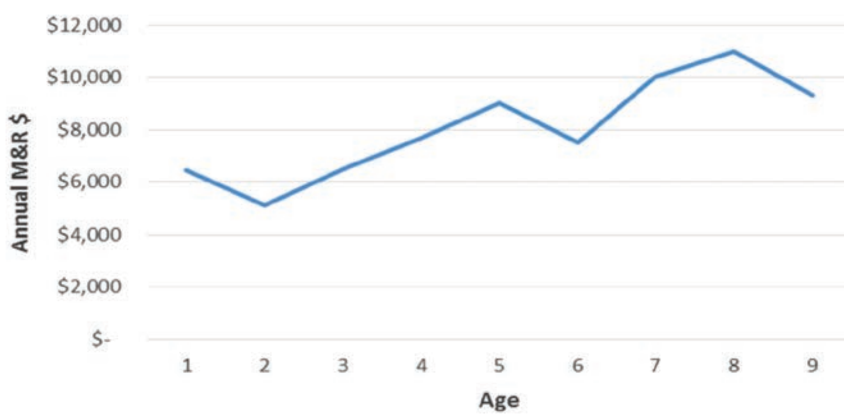

Figure 12. Example of average annual M&R cost for motor graders.

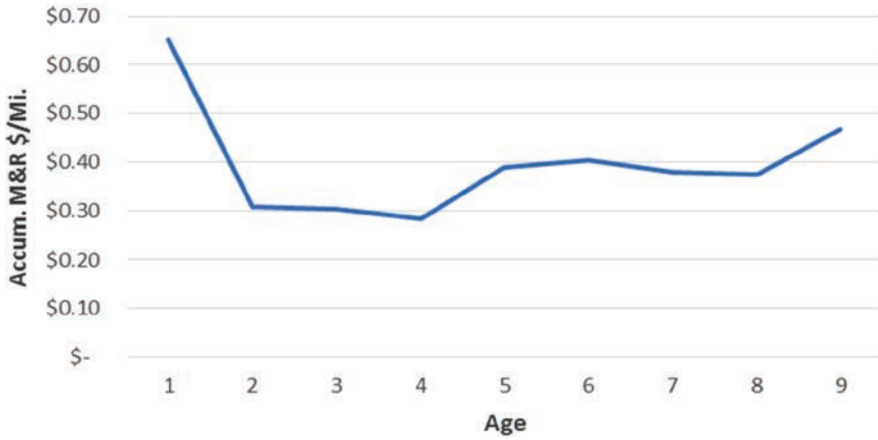

Figure 13. Example of accumulated M&R cost for dump trucks.

graders. The similar annual fluctuations were consistently observed for other equipment samples.

The annual fluctuations of M&R costs occur over a unit's life. Units may go a year or two with only preventive maintenance and minor repairs, followed by a year with a sharp rise in cost due to a major repair or service, such as tire replacement, and then experience low M&R costs in the following years. Although these annual cost fluctuations occur, the graphs show that M&R costs tend to increase over a unit's life.

M&R costs are included in LCCA as part of the operating cost component and are analyzed on a per-mile or per-hour basis. Using the same cost data for the dump truck and motor graders and the units' LTD miles/hours, the accumulated cost per mile/hour for the data samples is shown in Figures 13 and 14. In both cases, the cost per mile/hour is relatively higher in the first year. This high first-year cost is commonly attributed to expenditures for preparing and outfitting the equipment prior to field deployment, coupled with the typically low utilization in the first year because units are received at varying times throughout the year.

The first-year anomaly in M&R costs warrants careful consideration when performing LCCA. Units that have a substantially higher first-year cost per mile/hour should be evaluated to determine if they should be included in the LCCA for determining optimal life cycles. For instance, a unit with only 50 miles and $1,500 in prep cost would not represent a typical first-year cost in the life cycle.

M&R Calculations in LCCA

The LCCA in the optimization tool models M&R costs by averaging the historical costs of all units in a specific equipment class. Past-year costs are normalized to current-year constant dollars by using the inflation factor input in the configuration file of the optimization tool.

M&R Cost Data Consistency

Review of the M&R cost data provided by the DOTs revealed some issues with respect to data consistency and detail. To ensure that consistent and complete maintenance data

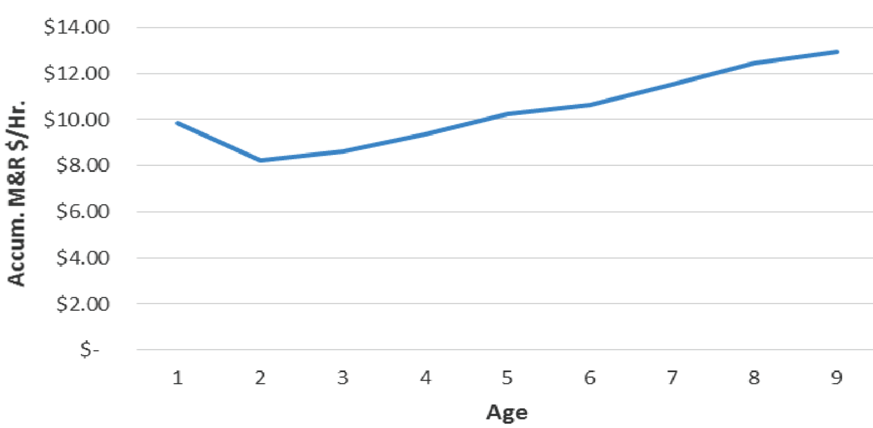

Figure 14. Example of accumulated M&R cost, graders.

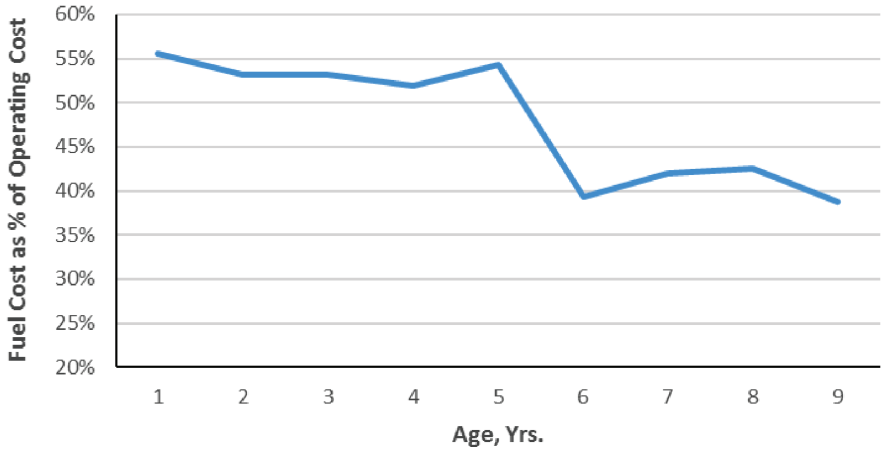

Figure 15. Annual fuel cost as percent of operating cost for single-axle dump trucks.

are used to perform LCCA, the guide outlines recommended guidelines for tracking and allocating M&R costs. Generally, the guide recommends the following:

- All services and repairs performed on a vehicle should be captured on a shop work order so that M&R costs are fully tracked, including
  - Preventive maintenance,
  - Scheduled and unscheduled repairs,
  - Accident repairs and body work, and
  - Rebuilds and overhauls.

  The literature varies on how to treat accident repairs. From a practical consideration, it can be difficult for an agency to separate accident repairs from other work, and the cost of accident repairs generally tends to be very small when averaging all units in a class.
- Vehicle prepping and outfitting prior to field deployment for items such as decals, safety striping, light bars, and radios should be considered in the vehicle's capital cost and not counted as M&R costs;
- Mechanic and technician time charged to work orders should only include actual services and repairs. Activities such as training, shop cleanup, safety meetings, and other nonmaintenance activities should be included in overhead and not charged to a repair work order; and
- All parts and fluids used for services and repairs should be charged on a repair work order.

3.2.5 Fuel Cost

Fuel costs make up 20% to 40% of the cost to own equipment over its lifetime. In a unit's early years, fuel costs can often exceed M&R costs. Figure 15 shows the proportion of operating cost attributable to fuel from a sample of 300 single-axle dump trucks. Fuel costs in the early years make up more than half of the operating cost, declining to about 39% in the later years.

Fuel cost is an important replacement factor but must be considered somewhat differently from the other factors because of wide fluctuations in fuel prices. Figure 16 shows average fuel prices for 10 years (from 2006 to 2016) from Bureau of Labor Statistics data (*11*). A report on analysis

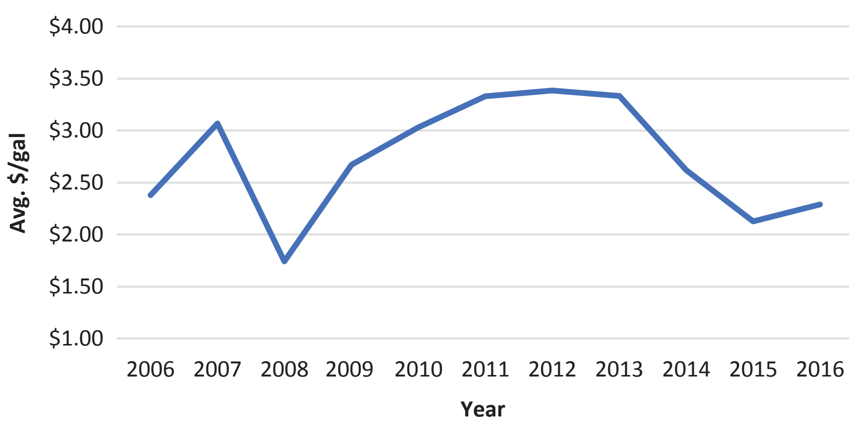

Figure 16. Historical average fuel prices in the United States.

of fleet replacement life cycle for the South Florida Water Management District (*7*) proposes that fuel costs can be estimated based on averages over time and price trends.

Fuel Cost Calculations in LCCA

The LCCA methodology used in the optimization tool assumes that the historical price trends for fuel can be used to predict future trends, which allows the LCCA to model future operating costs. The approach uses average per-mile/hour fuel costs for all equipment units in the class based on cost history downloaded from the agency's internal data source. Past-year costs are normalized to current-year constant dollars. Fuel cost is also used as the basis for determining obsolescence costs, as discussed in Section 3.2.9.

3.2.6 Downtime

Equipment downtime can be a significant operating cost factor, especially in a unit's later years when downtime increases substantially. It is often overlooked because it does not result in a direct outlay of money by the agency. However, downtime has a direct and significant impact on highway agency costs to perform maintenance and provide services.

Quantifying Downtime Costs

There are two generally accepted methods for computing downtime cost:

- **Lost production time.** In this method, the actual cost of lost production is determined for each downtime occurrence. Lost production costs can be very high in instances when a large maintenance crew is interrupted because a critical equipment unit goes down. While this is the most accurate method for determining downtime cost, it requires both rigorous reporting and an accurate accounting mechanism for determining the hourly crew cost. This method is not practical in a highway operations environment.
- **Hourly rental rates.** This method assumes that the cost of equipment downtime is the cost of either having additional units in the fleet to cover downtime occurrences or the cost to rent equipment. Downtime cost is computed by multiplying downtime hours by an hourly rental rate. For agencies with an established rental rate system, the hourly rental rates can be used. Recognizing that not all DOTs have established equipment rental rates, the optimization tool is preloaded with default hourly downtime rates for each equipment class. The default hourly downtime rates represent averages derived from information provided by DOTs. The user agency may use the default rates or override them with hourly rates specific to their agency.

Figure 17 shows how downtime cost can affect life cycle cost. In this example, downtime hours were extracted from the work order history of an individual dump truck. The downtime cost was calculated using a rental rate of $38 per hour. The analysis shows that adding downtime to the operating cost can have a significant impact on the accumulated cost. In this case, a 9-year-old dump truck had accumulated 879 hours of downtime over its life. The accumulated operating cost per mile at the end of nine years was $0.70 without downtime and $1.20 when downtime is added, an increase of 70%.

Guidelines for Tracking and Recording Downtime

Tracking downtime hours can be challenging, and practices for reporting downtime vary among state DOTs. The project found that many agencies do not maintain downtime history.

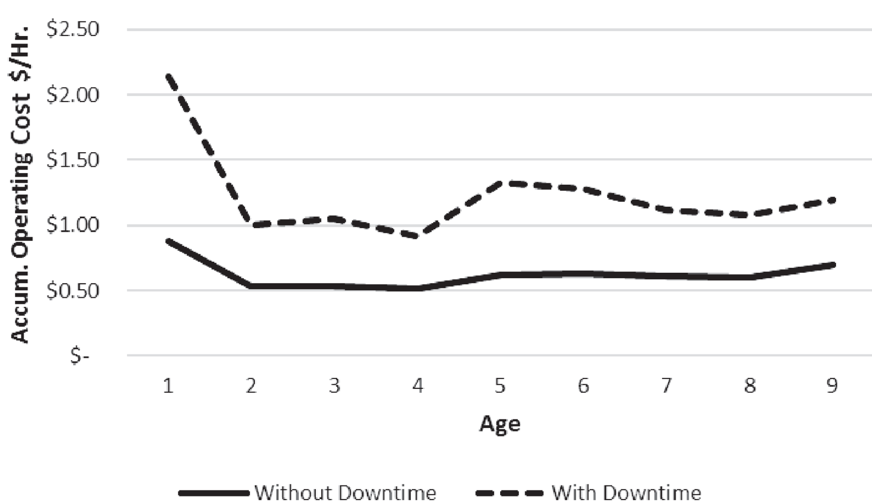

Figure 17. Operating cost comparison using downtime.

To ensure that downtime is effectively included as a replacement factor, the guide contains guidelines for tracking and reporting downtime. As a general rule, downtime is the time that a unit is out of service during normal working hours. Agencies are encouraged to review their downtime reporting procedures and initiate a reporting process consistent with the guidelines so that downtime can be appropriately considered in LCCA.

Downtime Cost Calculation in LCCA

The optimization tool uses the hourly rental rate method for calculating downtime cost. Including downtime is optional for the user agency, although it is highly recommended because of its relevance in the operating cost component. If an agency has reliable downtime data, the data can be uploaded to the tool as part of the data input routine. If no downtime is reported, the tool will ignore downtime cost when it performs LCCA.

The optimization tool contains default hourly downtime rates for the 40 equipment classes. The user agency should review and replace the default hourly rates with its own rates, if available. If an agency routinely rents or leases equipment, the hourly rate should be the equivalent hourly rent/lease value.

3.2.7 Physical Condition and Mission Criticality

Physical condition and mission criticality are not monetary factors used to perform LCCA. However, they are important factors to be considered in fleet replacement decisions.

The guide outlines an annual equipment replacement process, in which units are targeted for replacement based on their age, miles, and LTD cost. All targeted units should be assessed for their physical condition and be assigned a mission criticality level. The optimization tool provides an Excel spreadsheet for conducting the condition assessments, shown in Figure 18.

After the condition scores are logged onto the spreadsheet, the optimization tool calculates an overall condition score that factors in mission criticality. The optimization tool uses the overall condition score and LTD cost to determine replacement priorities.

3.2.8 Overhead Cost

To perform LCCA accurately, maintenance and repair costs must include both direct and indirect expenses. Reviewing and discussing cost data with the DOTs suggests that labor costs are understated in most cases because mechanic hourly rates are not fully loaded to account for overhead (although most agencies do include some amount of overhead). To provide a true measure of M&R costs, shop overhead costs must be factored into the mechanic hourly labor rate. Overhead costs occur as direct and indirect expenses and include the components shown in Table 7.

Direct Overhead

Direct overhead costs are associated with mechanic labor, including payroll additives and employee benefits such as FICA, worker's compensation, health insurance, and retirement benefits. They may also include tool and uniform allowances.

Another major component of direct overhead is nonchargeable time, that is, when a mechanic is not charging directly to a repair work order. This time is necessary and unavoidable and will always be present in a fleet maintenance environment. Leave time—annual, sick, and vacation—is the largest component of nonchargeable time. Other nonchargeable time includes mechanic time for training, shop cleanup, safety meetings, and other productive, but nonchargeable, hours.

Table 8 shows the analysis of nonchargeable hours for a selected DOT fleet organization. The analysis shows that 69% of a mechanic's total paid annual hours were charged to repair work orders. However, because the remaining 31% is an operational cost, it should be included when analyzing the cost of operating and maintaining the fleet. This is accomplished by allocating the nonchargeable time, as well as other mechanic direct overhead costs, as a percentage to be added to the base hourly mechanic pay rate.

Indirect Overhead

Indirect overhead costs consist of general and administrative costs at the fleet enterprise level, including nonmechanic personnel such as warehouse operations, procurement, disposal, and warranty management. Other indirect costs include general overhead expenses, facilities operating costs, and shop tools/operations that are not directly chargeable on a repair work order. Similar to direct overhead, indirect overhead expenses should be prorated to M&R costs on the basis of mechanic hours charged.

Example Overhead Cost Calculation

Table 9 shows an example for calculating direct and indirect overhead rates using real data from a DOT agency's fiscal year 2017 budget. The analysis shows that the direct and indirect overhead rates should be 115% and 93%, respectively. The agency's average mechanic hourly rate for all mechanic classifications is $17.62. The agency charges mechanic labor cost to work orders at the rate of $35 per hour. As shown in the example, the true cost for fully loaded labor should be $53.01 per hour. This means that the agency's equipment

Vehicle Condition Assessment				
Equipment Number			**Description:**	
Date:			**By:**	
Equipment Criticality	**Very Low**			
Body		Weight	**15**	
		○	Good	No rust, no body damage
		○	Fair	Very little rust, minor body damage
		○	Poor	Visible rust, some minor body repairs needed
		◉	Very Poor	Major rust or body damage. Requires major work within one year
	SCORE:	3.8		
Engine		Weight	**20**	
		○	Good	Good mechanical condition
		○	Fair	Some minor services needed
		○	Poor	Major repairs and more frequent maintenance needed
		◉	Very Poor	Major repairs needed within one year
	SCORE:	5.0		
Transmission		Weight	**20**	
		○	Good	Good mechanical condition
		○	Fair	Some minor services needed
		○	Poor	Major repairs and more frequent maintenance needed
		◉	Very Poor	Major repairs needed within one year
	SCORE:	5.0		
Steering/Suspension		Weight	**20**	
		◉	Good	Good mechanical condition
		○	Fair	Some minor services needed
		○	Poor	Major repairs and more frequent maintenance needed
		○	Very Poor	Major repairs needed within one year
	SCORE:	20.0		
Electrical		Weight	**10**	
		○	Good	Good mechanical condition
		○	Fair	Some minor services needed
		◉	Poor	Major repairs and more frequent maintenance needed
		○	Very Poor	Major repairs needed within one year
	SCORE:	7.0		
Frame		Weight	**15**	
		◉	Good	No rust or frame damage
		○	Fair	Some minor rust and/or frame damage
		○	Poor	Moderate rust and/or frame damage but safe to operate
		○	Very Poor	Major rust and/or frame damage; safety concerns
	SCORE:	15.0		
Overall Condition Score:		**55.8**		
Notes:				

Figure 18. Vehicle condition assessment form.

Table 7. Components of overhead costs.

Direct Overhead	Indirect Overhead
• Payroll Additive/Benefits • Training • Uniforms • Tool Allowance • Nonchargeable Time	• Shop Management • Warehouse Operations • Expendable Parts and Supplies • Facility Costs

M&R costs are being significantly understated and most likely will have a significant impact on determining optimal life cycles.

Accounting for Overhead in LCCA

The optimization tool is designed to allow agencies to account fully for shop overhead and to apply overhead factors to the mechanic labor cost. The templates shown in Tables 8 and 9 are included in the guide with instructions for determining agency-specific overhead rates.

The optimization tool contains default factors of 45% and 90%, respectively, for direct and indirect overhead rates, considering that some overhead has already been accounted for in the downloaded labor cost. The tool multiplies the downloaded labor cost by the overhead factors to arrive at a fully loaded cost for mechanic labor.

Table 8. Example of mechanic non-chargeable time.

Mechanic Chargeable Versus Non-Chargeable Time	
Component	**Hours**
Nominal Hours per Year	2,080
Overtime Hours at 6% Average per Year	125
Total Paid Hours per Year	2,205
Non-Chargeable Time	
Holidays, 12 Days per Year	96
Annual Leave, 15 Days per Year, Average	120
Sick Leave, 10 Days per Year, Average	80
Administrative Time*	382
Total Non-Chargeable Time	678
% Non-Chargeable Time	**31%**
% Chargeable Time	**61%**

*Includes safety meetings, training, shop cleanup, and other nonwork order time.

3.2.9 Obsolescence

Equipment obsolescence is a factor that considers equipment efficiency and dependability. Fuel efficiency, safety features, operator convenience, and reliability make newer model equipment more productive and cheaper to operate than older models. This is particularly true for heavy equipment items that can have replacement cycles of 12 to 15 years, during which time major equipment advances can occur.

Quantifying obsolescence related to productivity is difficult and is not practical in a highway operations environment. However, it is possible to determine how newer vehicles compare with older vehicles for fuel economy. Using U.S. Department of Transportation Corporate Average Fuel Economy (CAFÉ) data (*12*), Figure 19 shows the performance of passenger cars and light trucks, measured in miles per gallon (mpg) from 2000 to 2014. The data include all makes and models. In the 15-year period, fuel economy for passenger cars rose from 24.8 mpg to 31.5 mpg, a 27% improvement, or an average of 1.8% per year. For light trucks, the performance rose from 21.3 to 26.3 mpg, a 23.4% increase or an average of 1.6% per year. Jeannin et al. (*13*) reported that fuel efficiency for over-the-road trucks improved by 11% over the 6-year period from 2005 to 2010, or approximately 1.8% annually.

Accounting for Obsolescence in LCCA

To account for obsolescence, the optimization tool quantifies obsolescence on the basis of fuel utilization. The tool contains a preloaded default obsolescence rate of 2%, which is applied to the vehicle's fuel cost to calculate obsolescence cost.

Replacement Cost and Purchase Cost

Replacement cost is used by the optimization tool and in equipment replacement to

- Calculate depreciation when performing a class-level LCCA.
- Project long-range replacement budget needs.

Replacement cost is the original price paid for the unit plus the cost for outfitting the unit prior to field deployment. The optimization tool uses average replacement cost for all units in a class for determining depreciation in LCCA.

Purchase cost is not used by the optimization tool; however, it is needed to analyze salvage history and to customize the depreciation schedules during initial tool setup.

3.2.10 Cost of Money

The cost of money is used in economic analysis to develop discount factors when comparing the net present values of

Table 9. Example of calculation of mechanic direct and overhead rates.

Cost Item	Factors	Direct Salaries	Direct OH	Indirect OH
Salaries				
Charged to Work Orders		$ 562,815		
Mechanic Non-WO Time			$ 249,799	
Shop Management Pro-rated				$ 57,000
FICA	6.20%		$ 50,382	$ 3,534
Worker's Comp	7.24%		$ 58,833	$ 4,127
Retirement	12.20%		$ 96,706	$ 6,954
Health Insurance	19.00%		$ 150,608	$ 10,830
Parts				$ 23,142
Mechanic General				$ 70,800
Paint Shop - General				$ 24,000
Welding Shop - General				$ 24,000
Shop Tools				$ 35,150
IT - Software License				$ 13,000
IT - Computers, every 5 years				$ 1,500
Building Maintenance				$ 29,000
Hazardous Material Disposal				$ 15,000
Utilities				$ 25,600
Uniforms			$ 8,400	$ 800
Training			$ 29,500	$ -
Tool Allowance	$150		$ 3,000	$ 150
Supplies, Postage and Freight				$ 7,040
Telephone				$ 16,500
Office Furniture				$ 3,900
Fuel/Oil				$ 23,471
Small Equipment				$ 44,000
Shop Vehicles				$ 34,375
Warehouse Operations				$ 48,000
Totals		$ 562,815	$ 647,228	$ 521,873
Overhead as a % of Direct Salaries			**115%**	**93%**
Total Budget for Maintenance and Repair				$ 1,731,916
Total Shop Hours Charged to WO				32,674
Loaded Labor Rate for Mechanic				**$ 53.01**

Note: WO designates work order; OH designates overhead.

competing investment options. Using the cost of money in equipment LCCA assumes that the fleet agency has viable investment options for using the available funds. In government agencies, and specifically highway operations, investment alternatives do not exist in a practical sense. Additionally, the returns normally being garnered by agency investments are typically so small as to render alternative investments insignificant. Moreover, it is assumed that the agency needs each equipment unit in the fleet and that there is no viable alternative but to replace it (ignoring the lease-buy option). For these reasons, the optimization tool does not use the cost of money in the LCCA approach.

Inflation rates, on the other hand, are used by the optimization tool to change historical equipment costs into current dollars and project the replacement cost of equipment in future years. The optimization tool contains a default inflation value of 2.5% for inflation, which the user agency can override in the initial tool setup.

3.2.11 Soft Costs

Soft costs, such as image and operator morale, are nonmonetary factors that are not considered in LCCA. However, these factors can come into play in the decision-making pro-

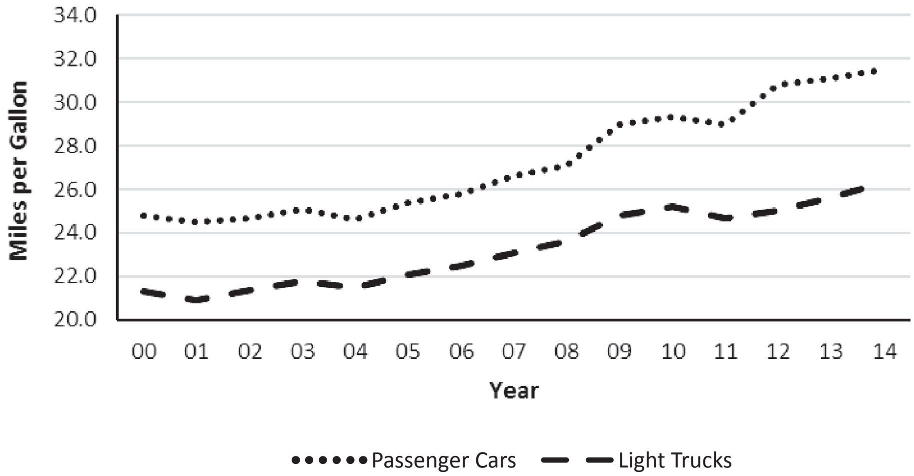

Figure 19. Fuel economy history (CAFÉ performance) for passenger cars and light trucks.

cess. Soft costs are discussed in the guide as part of the equipment replacement process.

3.3 Life Cycle Cost Analysis

LCCA is used in many asset management applications such as pavements, bridges, culverts, and buildings. While conceptually similar to other applications, LCCA for equipment uses a slightly different approach that depends on costs and other factors specific to equipment operations.

The LCCA approach for equipment is depicted in the graph shown in Figure 20 and can be summarized by the following:

- Equipment costs consist of two main components: ownership and operating.
  - *Ownership cost* is the capital investment in equipment, which is determined from depreciation. Depreciation is the original price paid for a unit less the amount that is realized from its resale. If a unit costs $20,000 new and is sold for $1,500, the ownership cost (depreciation) would be $18,500. Ownership costs per mile/hour decrease over the life of an equipment unit.
  - *Operating cost* is the cost to operate and maintain a unit. Operating cost consists of out-of-pocket expenditures for maintenance, repair, fuel, and overhead. It also includes downtime and obsolescence, which are not out-of-pocket expenditures but are nonetheless real costs that must be factored into LCCA. Operating costs per mile/hour increase over the life of an equipment unit.
- LCCA is performed by calculating the LTD cost per unit of utilization in miles or hours for both the ownership and operating cost components.
- The two cost components are plotted against age. The point at which the total cost—the sum of ownership and operating cost—is lowest is when a unit has reached its economic life.

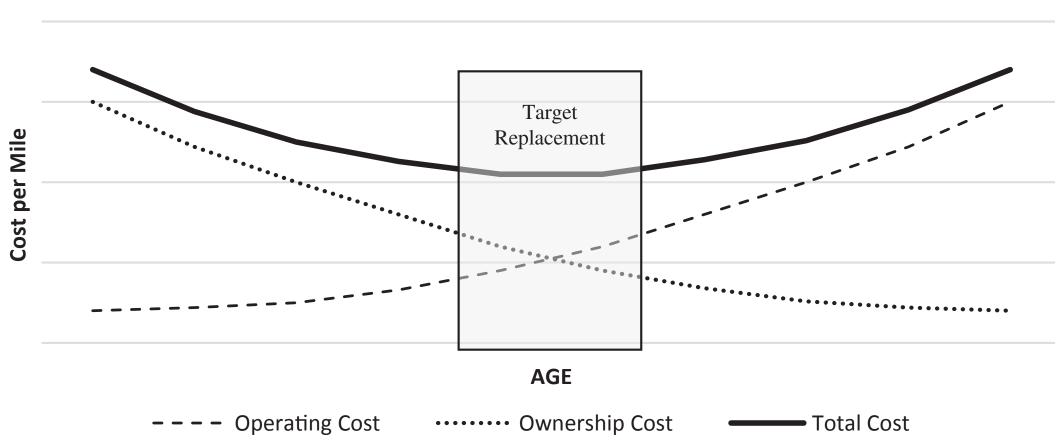

Figure 20. LCCA approach for equipment.

Two levels of LCCA were developed for the project, each with a specific purpose:

- A class-level LCCA to determine optimal life cycles and
- A unit-level LCCA to analyze the cost history of individual pieces of equipment.

3.3.1 Class-Level LCCA

The class-level LCCA determines optimal life cycles for the various equipment classes such as pickup, tandem dump truck, or end loader. It analyzes LTD cost by averaging the operating history of all units in the class. For example, if there are 657 units in the ½-Ton Pickup Class, the class-level LCCA looks at all 657 units to determine the optimal life cycle for the class. In essence, it attempts to model the life cycle costs of an average unit.

The following data are needed for class-level LCCA:

- Equipment number,
- Agency class code,
- Description,
- In-service year,
- LTD miles or hours,
- LTD maintenance and operating costs,
- LTD downtime hours, and
- Replacement cost.

Quality data are the keys to obtaining reliable LCCA results, and it is important that data downloaded from agency sources are reviewed and corrected for errors before performing the LCCA. The process for data cleanup is described in the guide.

Once the equipment data are downloaded from the agency's data sources, cleaned up, and input to the optimization tool, the tool produces a class-level LCCA report similar to that shown in Figure 21. The tool user manual provides step-by-step instructions for performing class-level LCCA.

The optimization tool shows the LCCA results in tabular form by year and provides a graph to the right of the tabulated results. (Note the erratic nature of the operating and total cost curves in the graph.) This type of variation naturally occurs because of the practical way in which maintenance is performed on equipment. In some years, only preventive maintenance or minor repairs are performed and maintenance costs are low. In other years, major maintenance such as brakes or transmission services is performed and the maintenance costs are high.

The erratic nature of the curves would make it difficult to determine when the LTD cost per mile is at its lowest point and therefore difficult to determine the optimal life cycle. To compensate for this, the tool develops a trend line to model the total cost curve. This trend line is used to project the optimal equipment life.

The class-level LCCA output report in Figure 21 shows the number of units by age and the average LTD cost per mile. The optimal replacement year and optimal replacement mileage are shown in the highlighted boxes at the top of the report. In this case, which used actual DOT data, the LCCA determined that the optimal life cycle is 11 years and 105,198 miles.

3.3.2 Unit-Level LCCA

Unit-level LCCA analyzes the cost performance of individual equipment units. It is similar in concept and approach to the class-level LCCA but uses annual instead of LTD costs. The following data are required for unit-level LCCA:

- Equipment number,
- Agency class code,
- Description,
- In-service year,
- Annual miles or hours,
- Annual maintenance and operating costs,
- Annual downtime hours, and
- Replacement cost.

In unit-level LCCA, the costs must be broken down by year for each year of the unit's life. If annual cost data are not available, the optimization tool will not produce reliable LCCA results.

Historical annual costs are sometimes problematic for agencies because the data are lost or compiled into a lump sum amount when an agency switches to a new equipment information system. If annual data are available, once they are loaded into the optimization tool, the tool produces a unit-level LCCA report as shown in Figure 22.

The unit-level LCCA report displays the unit's cost history. At the top of the report, the year with the lowest LTD cost per mile and the equivalent mileage are shown in highlighted boxes.

3.3.3 Interpreting and Applying LCCA Results

Class-level LCCA answers the question of optimal life cycles, but it does not tell the fleet manager if a specific unit should be replaced. Making replacement decisions is a process, and although optimal life cycles are key inputs to the process, there are a number of factors to be considered. Making sound replacement decisions can be art as much as it is science. In real life, equipment cost trends seldom follow the stylized graphic depicted in Figure 20. More often the cost curves are erratic, as illustrated in Figures 21 and 22. From a

LCCA Analysis: Single Axle Dump Trucks

Sample DOT — Class: DT-5001

Optimal Replacement Year: 11 — Optimal Replacement Mileage: 105,198

			LTD Cost Per Mile						
Age	# Of Units	Year	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs	Trend
1	59	2015	0.51	0.39	0.08	0.98	2.20	3.19	2.58
2	78	2014	0.62	0.40	0.10	1.13	1.25	2.38	2.54
3	20	2013	0.53	0.41	0.08	1.03	1.09	2.13	2.50
4	50	2012	0.46	0.43	0.07	0.96	1.05	2.01	2.47
5	42	2011	0.56	0.44	0.09	1.09	1.02	2.10	2.44
6	3	2010	1.30	0.45	0.24	1.99	0.98	2.97	2.42
7	45	2009	0.88	0.47	0.14	1.48	0.95	2.43	2.40
8	46	2008	0.89	0.48	0.14	1.52	0.92	2.44	2.38
9	0	2007	#N/A	#N/A	#N/A	#N/A	0.88	#N/A	2.37
10	77	2006	0.86	0.51	0.14	1.51	0.85	2.36	2.36
11	152	2005	0.92	0.53	0.14	1.58	0.82	2.40	2.36
12	0	2004	#N/A	#N/A	#N/A	#N/A	0.79	#N/A	2.36
13	46	2003	1.01	0.56	0.17	1.74	0.76	2.50	2.37
14	2	2002	0.78	0.58	0.12	1.48	0.73	2.21	2.38
15	27	2001	1.03	0.59	0.18	1.81	0.69	2.50	2.39
16	14	2000	1.09	0.61	0.19	1.89	0.66	2.56	2.41
17	0	1999	#N/A	#N/A	#N/A	#N/A	0.63	#N/A	2.43
18	7	1998	0.90	0.65	0.18	1.72	0.60	2.32	2.46
19	15	1997	0.92	0.67	0.18	1.77	0.58	2.35	2.49
20	1	1996	1.15	0.69	0.21	2.06	0.55	2.61	2.53
21	0	1995	#N/A	#N/A	#N/A	#N/A	0.52	#N/A	2.56
22	0	1994	#N/A	#N/A	#N/A	#N/A	0.50	#N/A	2.61
23	0	1993	#N/A	#N/A	#N/A	#N/A	0.48	#N/A	2.66
24	0	1992	#N/A	#N/A	#N/A	#N/A	0.46	#N/A	2.71
25	0	1991	#N/A	#N/A	#N/A	#N/A	0.44	#N/A	2.77

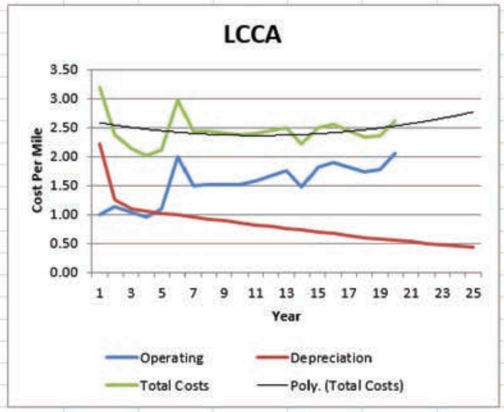

Figure 21. Example of class-level LCCA.

Agency Name Here — Equipment Number: 123 — Description: Tandem

Lowest Cost Year, To-Date: 13 — Mileage: 160,353

	Cost Per Mile					
Age	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs
1	0.16	0.13	0.02	0.31	0.56	0.87
2	0.09	0.13	0.02	0.24	0.33	0.57
3	0.07	0.13	0.01	0.21	0.32	0.53
4	0.08	0.13	0.01	0.22	0.26	0.47
5	0.09	0.12	0.01	0.22	0.26	0.48
6	0.10	0.12	0.02	0.24	0.25	0.49
7	0.12	0.12	0.02	0.26	0.23	0.50
8	0.12	0.12	0.02	0.27	0.21	0.48
9	0.12	0.12	0.02	0.26	0.21	0.47
10	0.11	0.12	0.03	0.26	0.20	0.46
11	0.12	0.12	0.04	0.27	0.18	0.45
12	0.11	0.11	0.04	0.26	0.17	0.43
13	0.12	0.11	0.04	0.27	0.16	0.43
14	0.13	0.11	0.05	0.29	0.15	0.44
15	0.14	0.11	0.05	0.31	0.14	0.45
16	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
17	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

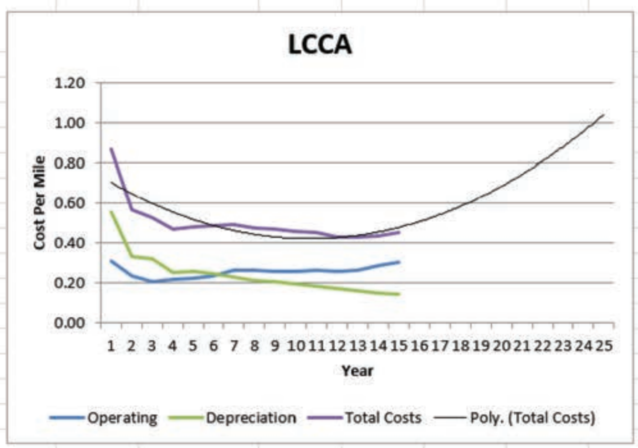

Figure 22. Example of unit-level LCCA.

practical viewpoint, optimal replacement times seldom occur at an exact point of age or utilization but rather over a window of time.

Unit-level LCCA is helpful in reviewing the cost history of individual units, but there are two practical limitations in interpreting and applying the results. First, the point at which the unit reaches its economic life cannot be known until after the fact. Second, if data are not available for annual costs in the unit's early years, which can often be the case, the analysis cannot be performed.

Determining optimal life cycles and making replacement decisions are two distinctly separate tasks. They can be time consuming and demand dedicated staff who can commit continuous effort. The guide outlines an annual equipment replacement process that incorporates LCCA, along with considerations of other realistic factors that affect replacement decisions.

3.4 Replacement Processes

The guide presents a systematic and methodical annual process for analyzing equipment replacement needs and making replacement decisions. Appendix B contains a flowchart of the process, which includes the following major activities:

- Download data from the agency's equipment information systems. Clean up the data by correcting errors and eliminating units that do not have sufficient cost history to represent a valid cost trend.
- Make sure that there are enough units in the class to provide a statistically valid sample of units for the class-level LCCA. Perform the class-level LCCA to determine optimal life cycles. If there are not enough units to perform a class-level LCCA, rely on the unit-level LCCA to analyze costs of individual units.
- Identify replacement candidates based on a unit's LTD miles/hours or cost.
- Perform condition assessments on the candidate units and prioritize units for replacement based on mission criticality, condition, and cost analysis.
- Make final replacement decisions based on available replacement funding and other agency-specific factors and considerations.
- Develop a 5-year plan and analyze the cost consequences of various replacement scenarios to provide the fleet manager with information to make a business case for future funding levels.

The replacement processes are further amplified in the next section describing how the optimization tool supports the processes.

3.5 Optimization Tool

The optimization tool is built in Microsoft Excel and contains the 45 separate spreadsheets, or files, noted in Figure 23.

The optimization tool has six main functions:

- Determine optimal life cycles for each equipment class.
- Perform LCCA on individual equipment units.
- Identify candidate replacement units based on utilization or life cycle cost.
- Prioritize equipment replacement units.
- Develop a 5-year replacement needs budget.
- Analyze the cost consequences of various replacement cycles.

The following sections provide a general overview of the optimization tool. The tool user manual provides detailed instructions for using the tool and describes how the tool supports the equipment replacement process.

3.5.1 Tool Setup and Configuration

Initial setup and configuration are required before using the optimization tool. This is done in the Configuration File, which allows the user agency to review the default values for the various replacement factors and customize the tool to fit the agency's operating environment and needs. The configuration steps include

- Cross reference agency class codes with the NAFA class codes for the 40 equipment classes preloaded in the tool.
- Enter the agency's average unit replacement cost for each equipment class.

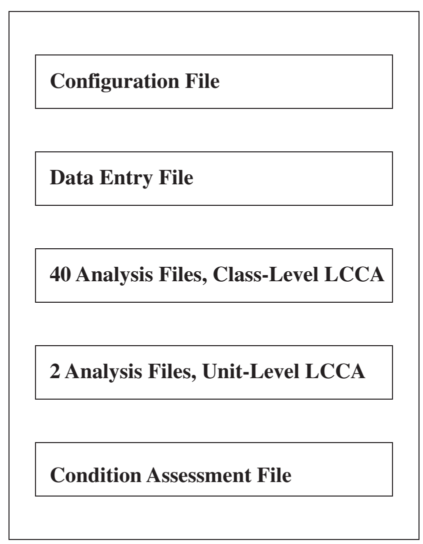

Figure 23. Optimization tool files.

	A	B	C	D	E	F	G	H	I	J	K
1	Equipment Number	Agency Class Code	Description	In-Service Year	Miles	Parts	Labor	Commercial	Fuel	Downtime Hours	Purchase Cost
2	008-01-0329	201	1/2 TON P-U	1998	196318	7,192.58	8,600.42	46.60	26175.73	1003	27,500
3	008-01-0339	201	1/2 TON P-U	1998	201293	7,192.23	5,696.16	32.28	26839.07	537	27,500
4	008-01-0340	201	1/2 TON P-U	1998	183370	14,328.31	10,384.03	6.52	24449.33	1673	27,500
5	008-01-0344	201	1/2 TON P-U	1998	162613	7,329.83	9,807.41	151.62	21681.73	1080	27,500
6	008-01-0380	201	1/2 TON P-U	2002	237124	17,563.90	16,801.64	6.42	31616.53	1816	27,500
7	008-01-0381	201	1/2 TON P-U	2002	199522	10,169.45	9,250.74	486.69	26602.93	1002	27,500
8	008-01-0383	201	1/2 TON P-U	2002	191747	10,114.84	11,389.78	31.57	25566.27	995	27,500
9	008-01-0384	201	1/2 TON P-U	2002	202465	10,830.88	8,322.28	112.80	26995.33	616	27,500
10	008-01-0386	201	1/2 TON P-U	2002	223851	12,323.49	10,094.06	38.45	29846.8	668	27,500
11	008-01-0388	201	1/2 TON P-U	2002	245586	10,141.32	10,913.30	253.77	32744.8	998	27,500
12	008-01-0389	201	1/2 TON P-U	2002	180391	14,684.60	11,714.46	293.29	24052.13	1202	27,500
13	008-01-0391	201	1/2 TON P-U	2002	222254	11,135.95	11,539.76	96.66	29633.87	1856	27,500
14	008-03-0555	201	1/2 TON P-U	2007	86949	7,009.59	7,387.14	55.40	11593.2	655	27,500
15	008-03-0556	201	1/2 TON P-U	2007	195313	9,991.31	11,076.12	40.44	26041.73	787	27,500
16	008-03-0557	201	1/2 TON P-U	2007	158433	4,975.81	7,018.44	81.67	21124.4	334	27,500
17	008-03-0558	201	1/2 TON P-U	2007	212641	8,605.28	9,221.85	134.17	28352.13	641	27,500
18	008-03-0559	201	1/2 TON P-U	2007	176493	10,086.53	9,545.29	75.60	23532.4	484	27,500
19	008-03-0560	201	1/2 TON P-U	2007	127563	9,743.67	12,395.55	323.41	17008.4	1595	27,500

Figure 24. Data entry format for class-level LCCA.

- Review the default values for the preloaded replacement factors and either adopt or override them with agency-specific values.

3.5.2 Importing Agency Data into the Tool

Because the optimization tool is built in Microsoft Excel, it cannot be interfaced with agency systems for automatic data loading. Equipment data must be downloaded from agency systems, formatted, and uploaded to the tool. Two types of data are required:

- LTD data for all units in a specified class, used to perform class-level LCCA and
- Annual cost data for each year of a unit's life, used to perform unit-level LCCA.

The data elements and format for data uploading are shown in Figures 24 and 25. Once in the specified format, the data can be copied and pasted into the optimization tool.

A thorough review of the data should be performed to eliminate errors or outlier data. The guide and tool user manual provide helpful tips for data cleanup.

10	Year	Miles	Parts	Labor	Commercial	Fuel	Downtime Hours
11	1	4,138	$ 7,920	$ 1,925		$ 405	137.5
12	2	9,675	$ 2,748	$ 1,045		$ 947	31.5
13	3	5,980	$ 5,608	$ 1,073		$ 585	101.5
14	4	11,086	$ 4,983	$ 2,008		$ 1,085	59.5
15	5	5,338	$ 18,663	$ 2,393		$ 522	350.5
16	6	7,543	$ 5,848	$ 2,090		$ 738	60.5
17	7	13,866	$ 5,534	$ 2,613		$ 1,357	33.5
18	8	5,639	$ 2,407	$ 825		$ 552	16.5
19	9	3,516	$ 10,827	$ 3,548		$ 344	88
20	10						

Figure 25. Data entry format for unit-level LCCA.

3.5.3 Performing Class-Level LCCA

Once setup and data entry are complete, the optimization tool performs LCCA automatically when one of the equipment analysis files is opened, using the replacement factors and values in the Configuration File and the data input to the system. Figure 26 shows an example report of the LCCA results for the dump truck class.

3.5.4 Performing Unit-Level LCCA

Using the replacement factors in the Configuration File and the uploaded cost data, the optimization tool performs the unit-level LCCA and develops a report as shown in Figure 27.

3.5.5 Identifying Units as Potential Replacement Candidates

The optimization tool identifies potential replacement candidates when one or both of two criteria are met:

- When a unit reaches the replacement planning target values in the Configuration File.
- When a unit's LTD cost per mile/hour exceeds the class average for similar-aged vehicles by 25%.

The equipment units that are flagged as potential replacements are displayed on the Replacement Candidate List report shown in Figure 28. The units are listed in order of their LTD cost, with the highest cost units at the top.

3.5.6 Performing Condition Assessment

The optimization tool provides an Excel spreadsheet for performing condition assessments (see Figure 18). The condition assessment spreadsheet is not linked to the other files in the tool.

All units flagged as replacement candidates should have a condition assessment performed. The assessments can be done on the electronic spreadsheet or on a paper copy. Once the assessments have been completed, the scores must be manually entered in the Assessment column of the Replacement Candidate List file.

3.5.7 Prioritizing Equipment Replacements

Only the equipment units that have condition scores will show up on the priority replacement list. Condition assessments are not required but are highly recommended. After the assessment scores have been entered, the tool will determine

Equipment Replacement Analysis Tool

LCCA Analysis: Dump Trucks

Sample DOT

Class: DT-5000

Optimal Replacement Year: **11**

Optimal Replacement Mileage: **105,507**

			LTD Cost Per Mile						
Age	# Of Units	Year	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs	Trend
1	59	2015	0.51	0.39	0.07	0.97	2.20	3.17	2.57
2	78	2014	0.62	0.40	0.09	1.11	1.25	2.36	2.52
3	20	2013	0.53	0.41	0.07	1.02	1.09	2.11	2.48
4	50	2012	0.46	0.43	0.06	0.95	1.05	2.00	2.45
5	42	2011	0.56	0.44	0.08	1.07	1.02	2.09	2.42
6	3	2010	1.30	0.45	0.21	1.96	0.98	2.94	2.39
7	45	2009	0.88	0.47	0.12	1.46	0.95	2.41	2.37
8	46	2008	0.89	0.48	0.13	1.50	0.91	2.42	2.35
9	0	2007	#N/A	#N/A	#N/A	#N/A	0.88	#N/A	2.34
10	77	2006	0.86	0.51	0.12	1.49	0.85	2.34	2.33
11	153	2005	0.87	0.53	0.12	1.51	0.82	2.33	2.33
12	0	2004	#N/A	#N/A	#N/A	#N/A	0.79	#N/A	2.33
13	46	2003	1.01	0.56	0.15	1.72	0.75	2.48	2.34
14	2	2002	0.78	0.58	0.11	1.46	0.72	2.19	2.35
15	27	2001	1.03	0.59	0.16	1.78	0.69	2.47	2.36
16	14	2000	1.09	0.61	0.17	1.87	0.66	2.53	2.38
17	0	1999	#N/A	#N/A	#N/A	#N/A	0.63	#N/A	2.40
18	7	1998	0.90	0.65	0.15	1.70	0.60	2.30	2.43
19	15	1997	0.92	0.67	0.16	1.75	0.57	2.32	2.46
20	1	1996	1.15	0.69	0.19	2.03	0.55	2.58	2.50
21	0	1995	#N/A	#N/A	#N/A	#N/A	0.52	#N/A	2.54
22	0	1994	#N/A	#N/A	#N/A	#N/A	0.50	#N/A	2.59
23	0	1993	#N/A	#N/A	#N/A	#N/A	0.48	#N/A	2.64
24	0	1992	#N/A	#N/A	#N/A	#N/A	0.46	#N/A	2.69
25	0	1991	#N/A	#N/A	#N/A	#N/A	0.44	#N/A	2.75

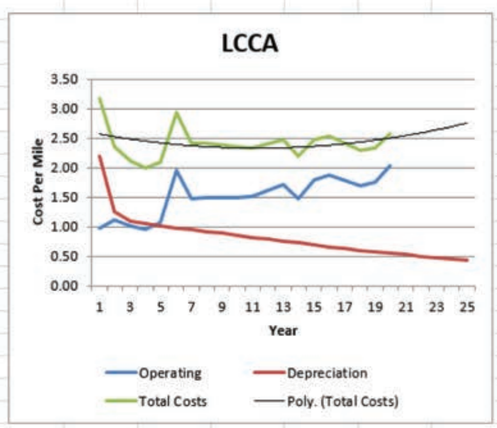

Figure 26. Example report of class-level LCCA.

Agency Name Here | Equipment Number: 123 | Description: Tandem

Lowest Cost Year, To-Date: 13 | Mileage: 160,353

Age	Cost Per Mile Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs
1	0.16	0.13	0.02	0.31	0.56	0.87
2	0.09	0.13	0.02	0.24	0.33	0.57
3	0.07	0.13	0.01	0.21	0.32	0.53
4	0.08	0.13	0.01	0.22	0.26	0.47
5	0.09	0.12	0.01	0.22	0.26	0.48
6	0.10	0.12	0.02	0.24	0.25	0.49
7	0.12	0.12	0.02	0.26	0.23	0.50
8	0.12	0.12	0.02	0.27	0.21	0.48
9	0.12	0.12	0.02	0.26	0.21	0.47
10	0.11	0.12	0.03	0.26	0.20	0.46
11	0.12	0.12	0.04	0.27	0.18	0.45
12	0.11	0.11	0.04	0.26	0.17	0.43
13	0.12	0.11	0.04	0.27	0.16	0.43
14	0.13	0.11	0.05	0.29	0.15	0.44
15	0.14	0.11	0.05	0.31	0.14	0.45
16	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

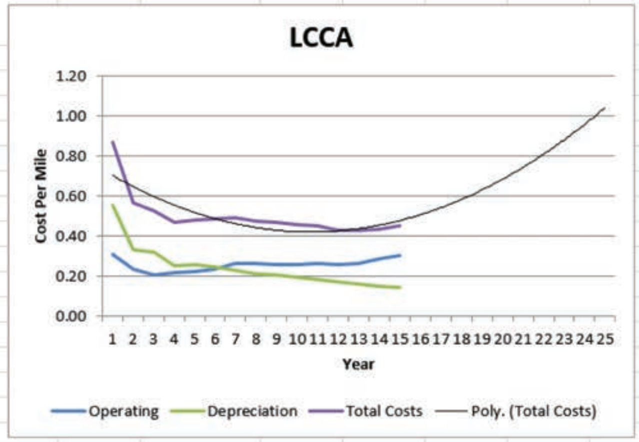

Figure 27. Example report of unit-level LCCA.

Equipment Number	Description	In-Service Year	Exceeds Cost	Exceeds Depreciation	Assessment
008-03-0702	1/2 TON P-UP EXTEND CAB FULL	2010	1.28		55
008-03-0678	1/2 TON P-UP EXTEND CAB FULL	2009	1.13		64
008-03-0658	1/2 TON P-UP EXTEND CAB FULL	2009	1.09		63
008-02-0834	1/2 TON P-UP STAND CAB FULL	1999	1.08	90%	77
008-01-0426	1/2 TON P-UP STAND CAB FULL	2003	1.06		49
008-01-0562	1/2 TON P-UP EXTEND CAB FULL	2006	1.03		97
008-02-0789	1/2 TON P-UP STAND CAB FULL	1999	1.02	90%	96
008-01-0596	1/2 TON P-UP EXTEND CAB FULL	2006	1.01	90%	57
008-03-0510	1/2 TON P-UP EXTEND CAB FULL	2007	0.99		45
008-01-0603	1/2 TON P-UP EXTEND CAB FULL	2006	0.99	90%	89
008-03-0629	1/2 TON P-UP 4WD EXTEND FULL	2008	0.97		69
008-03-0524	1/2 TON P-UP EXTEND CAB FULL	2007	0.96		73
008-02-0839	1/2 TON P-UP STAND CAB FULL	2001	0.95	90%	68
008-03-0560	1/2 TON P-UP STAND CAB FULL	2007	0.94	90%	73
008-03-0546	1/2 TON P-UP EXTEND CAB FULL	2007	0.94		57
008-03-0491	1/2 TON P-UP STAND CAB FULL	2007	0.92		81

Figure 28. Example of the replacement candidate list.

Equipment Replacement Analysis Tool				
Sample DOT		Class:		DT-5001
	Dump Truck Priority Replacement List			
Equipment Number	Description	Final Ra	Condition Assessment Score	
51457	Tandem Dump Truck		69	
51134	Tandem Dump Truck		59	
51333	Tandem Dump Truck		68	
51214	Tandem Dump Truck		65	
51439	Tandem Dump Truck		56	
51133	Tandem Dump Truck		44	
51197	Tandem Dump Truck		54	
51196	Tandem Dump Truck		52	
51226	Tandem Dump Truck		59	
51141	Tandem Dump Truck		68	
51586	Tandem Dump Truck		65	
51256	Tandem Dump Truck		52	
51364	Tandem Dump Truck		68	

Figure 29. Example of the priority replacement list.

the overall ranking and display the units in priority order, as illustrated in Figure 29. The optimization tool computes priority rankings using the weight factors from the Configuration File as follows:

$$\text{Priority Rank} = \text{Condition Rank} \times 60\% + \text{Cost Rank} \times 40\%$$

where

Condition Rank is computed by the tool based on the condition assessment;

60% is the default value for the condition weight factor in the Configuration File;

Cost Rank is computed by the tool based on the cost-per-mile analysis; and

40% is the default value for the cost-per-mile weight factor in the Configuration File.

The 60% and 40% weight factors are default values that the user may change.

3.5.8 Developing a 5-Year Plan

The optimization tool generates a 5-year plan based on the target replacement factors in the Configuration File and the LTD miles/hours from the downloaded data, as illustrated in Figure 30. The tool compares the unit's current age with the replacement target planning values in the Configuration File. Units that are past their target age are shown as backlog needs. Units that will become due for replacement in the next 5 years are shown in the year in which they will be due, with replacement costs based on the inflation rate in the Configuration File.

3.5.9 Analyzing Cost Consequences

Analyzing cost consequences is not needed to make replacement decisions; however, it does provide useful information for fleet managers to make a business case for funding levels. The optimization tool calculates the annual cost of various replacement cycle scenarios based on the class-level LCCA and displays the results as shown in Figure 31.

Equipment Replacement Analysis Tool

Sample DOT — Class: DT-5001

5-Year Replacement Schedule: Single Axle Dump Truck

Replacement Cost: $ 117,000
Inflation Rate: 2.0%

					5-Year Annual Replacement Needs				
				Backlog	2016	2017	2018	2019	2020
Equipment Number	Description	In- Service Year	Until Replac	$ 7,839,000	$ 5,382,000	$ -	$18,502,474	$ 9,560,423	$ -
			-2003	$ 117,000					
51101	Tandem Dump Truck	1996	-7	$ 117,000					
51104	Tandem Dump Truck	1997	-6	$ 117,000					
51103	Tandem Dump Truck	1997	-6	$ 117,000					
51102	Tandem Dump Truck	1997	-6	$ 117,000					
51105	Tandem Dump Truck	1997	-6	$ 117,000					
51106	Tandem Dump Truck	1997	-6	$ 117,000					
51107	Tandem Dump Truck	1997	-6	$ 117,000					
51108	Tandem Dump Truck	1997	-6	$ 117,000					
51111	Tandem Dump Truck	1997	-6	$ 117,000					
51112	Tandem Dump Truck	1997	-6	$ 117,000					
51113	Tandem Dump Truck	1997	-6	$ 117,000					

Figure 30. Example of a 5-year replacement plan.

Equipment Replacement Analysis Tool

Cost Consequences

Sample DOT — Class: DT-5000

Average Annual Mileage Per Unit: 12,220
No of Units in Class: 720

Replacement Cycle	LTD $ Per Mi/Hour	Annual Unit Total Cost	Annual Class Cost
1	2.57	$ 31,366	$22,583,242
2	2.52	$ 30,853	$22,214,436
3	2.49	$ 30,393	$21,883,248
4	2.45	$ 29,986	$21,589,679
5	2.42	$ 29,630	$21,333,728
6	2.40	$ 29,327	$21,115,395
7	2.38	$ 29,076	$20,934,680
8	2.36	$ 28,877	$20,791,584
9	2.35	$ 28,731	$20,686,105
10	2.34	$ 28,636	$20,618,246
11	2.34	$ 28,594	$20,588,004
12	2.34	$ 28,605	$20,595,381
13	2.35	$ 28,667	$20,640,376
14	2.36	$ 28,782	$20,722,989
15	2.37	$ 28,949	$20,843,221
16	2.39	$ 29,168	$21,001,070
17	2.41	$ 29,440	$21,196,539
18	2.44	$ 29,763	$21,429,625
19	2.47	$ 30,139	$21,700,330

Figure 31. Example of cost consequences report.

CHAPTER 4

Summary and Suggested Research

NCHRP 13-04 was accomplished in two phases. In Phase I, a large volume of literature pertaining to equipment replacement practices and tools was reviewed and examined to assess how commonly used replacement factors, practices, and tools could be adapted and applied in the highway operations environment. In Phase II, the project developed the

- Optimal Replacement Cycles of Highway Operations Equipment guide
- Excel-based Optimization Analysis Tool
- Tool User Manual

The guide was developed to incorporate promising practices identified in the literature search with adaptations to fit real-world operating conditions within a state DOT fleet agency. Actual equipment cost and history data were gathered from a number of state DOTs to use in developing the replacement factors and testing the optimization tool.

The optimization tool was built using Microsoft Excel because of its ready availability and general ease of use. The tool is designed to perform LCCA using replacement factors specific to highway operations equipment and to support a systematic equipment replacement process.

The guide and tool user manual are included in this report as Parts II and III, respectively. The optimization tool is available for download from TRB's website at www.trb.org by searching on *NCHRP Research Report 879*.

4.1 Summary of Findings

The literature search revealed that various approaches, methodologies, and factors are used for determining optimal life cycles and making replacement decisions.

- LCCA is considered the best approach for determining equipment life cycles because it is data driven and based on sound economic theory.
- LCCA is time consuming, requires good data, and demands continuous commitment of staff to obtain reliable results. The most time-consuming task may lie in the effort to download and clean up the data before the data are entered into the tool.
- There is a need to improve equipment information and data in the highway operations industry to ensure that LCCA results in reliable outputs for determining optimal life cycles.
- Making replacement decisions is a process that requires a systematic, methodical approach to attain optimal results.
- Although a detailed evaluation could not be made of proprietary software and tools, it appears that while most of them provide equipment cost analysis capabilities, few provide LCCA features and outputs for determining optimal life cycles.
- The factors used in the various cost analysis approaches were generally the same, but not always, and the methods for measuring and quantifying the factors varied.
- Equipment condition, a fundamentally important factor in asset management, was not found to be used systematically in any of the approaches.
- Mission criticality is not considered in most current practices but was mentioned in some literature as a soft cost to be considered indirectly.

4.2 Suggested Research

Four areas were identified for possible future research to augment and enhance the work completed in this project:

- **Data quality and consistency.** Data quality was identified in the project research as a major concern. An effort should be made to develop standards or guidelines for reporting and tracking equipment maintenance and repair cost. The guidelines should incorporate recommended data quality control procedures.

- **A more robust software application for the optimization tool.** Excel was chosen for the development of the optimization tool because of its ready availability. The Excel-based tool accomplishes the project objectives by providing the appropriate features to support equipment replacement. However, the tool's functionality could be enhanced with more robust software.
- **Equipment maintenance cost reporting and tracking.** Guidelines should be developed for determining the true cost of mechanic labor rates. Prevailing practices fail to account fully for direct and indirect overhead expenses, and equipment operating costs are being understated.
- **Downtime reporting and tracking.** Guidelines should be developed for measuring, reporting, and tracking equipment downtime. It appears that most agencies do not currently track downtime, resulting in the true cost of equipment operations being understated.

The developed guide addresses all of these concerns and provides guidelines and recommended procedures for cleaning up data, reporting maintenance costs, accounting for overhead expenses, and tracking downtime. The guidelines contained in the guide should be considered as starting points for future refinement, with the goal of achieving more standardized practices.

4.3 Need for System Training and Ongoing Support

User training is necessary when any new software system is implemented in an agency. Such is the case with the equipment replacement processes and optimization tool contained in Parts II and III. Agencies that wish to implement the tool will require training to understand the recommended processes supported by the tool and how to apply the tool in performing LCCA and making effective replacement decisions. System training is a normal and important step for successful system implementation.

Also, ongoing system support will be required. This too is a natural step in the implementation and ongoing use of the tool. An industry organization such as AASHTO is most likely the best organization to provide the ongoing support.

4.4 Need for Trained Dedicated Staff

Implementing an effective equipment replacement program can be time consuming and requires dedicated staff who can commit the time to ensure quality data, perform analysis, interpret results, and consider other factors in replacement decision making. The benefit in reduced overall cost of equipment ownership outweighs the cost of resources.

Fleet agencies need to exert the level of effort required to effectively manage their replacement programs. The literature noted that LCCA is time consuming and difficult for many fleet management agencies and that establishing replacement cycles is both an art and a science, involving data analysis on one hand and judgment, prediction, forecasts, and assumptions on the other (*14*).

The art of performing LCCA and making replacement decisions can only be learned through performing the tasks over time. There is nuance in the analysis and the process is intricate. A dedicated and sufficiently trained staff is needed to fully realize the benefits of the products developed in this project.

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APPENDIX A

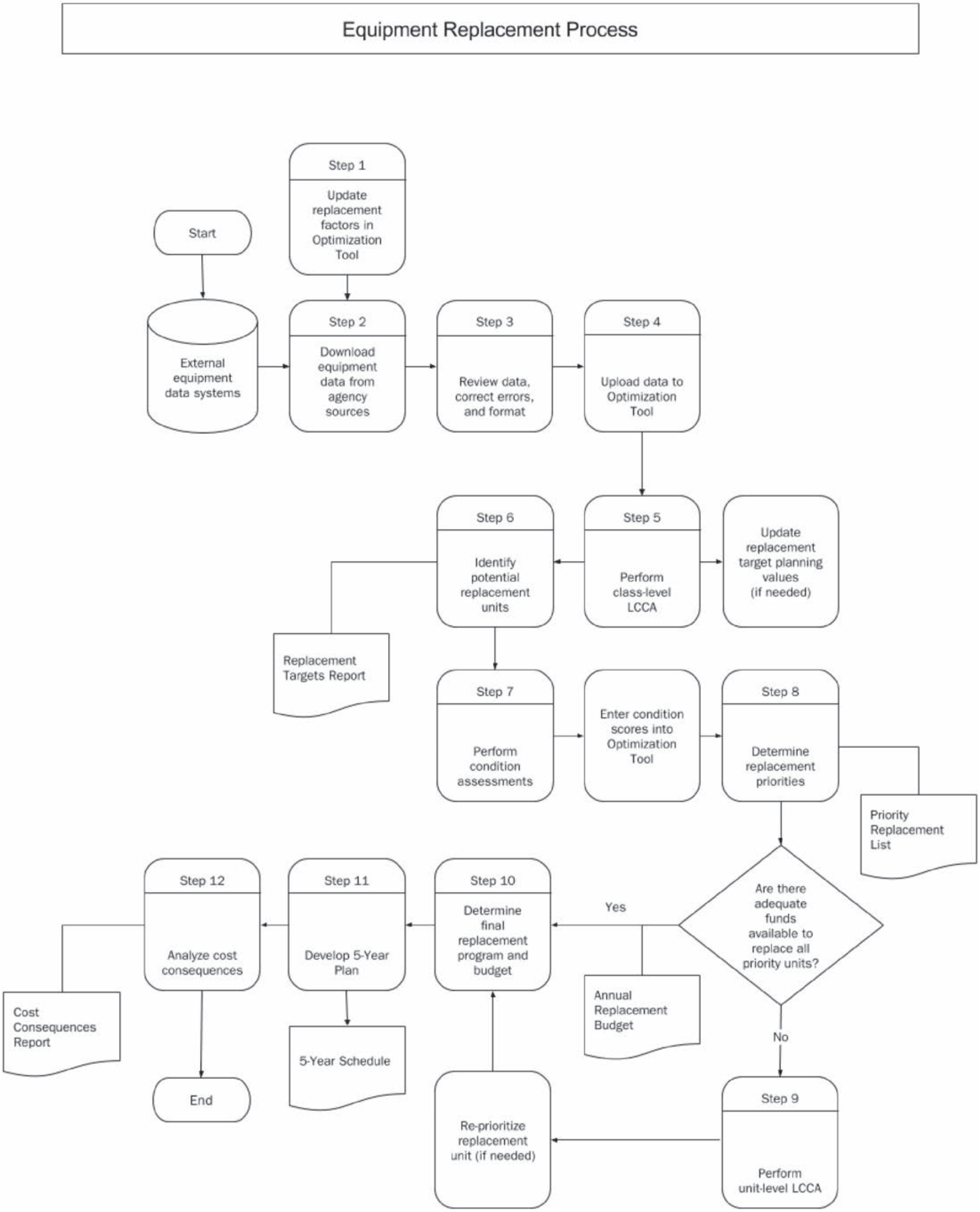
Default Depreciation Tables

Class Code	Description	Accumulated Depreciation at Miles or Hours											
	Utilization, 1,000 Miles →	10	20	30	40	50	60	70	80	90	100	110	120
	Utilization, Hours →	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
1300	Sedan	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%
1600	SUV	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%
1348	Police Cruiser	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%
1521	1/2 Ton Pickup	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1531	3/4 Ton Pickup	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1523	1/2 Ton Crew Cab	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1533	3/4 Ton Crew Cab	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
1424	Vans	20%	31%	42%	51%	59%	67%	73%	78%	83%	86%	88%	90%
3514	Mechanic Shop Truck	16%	22%	30%	36%	43%	49%	54%	60%	64%	69%	73%	76%
2513	1 Ton Crew Cab	15%	24%	32%	40%	47%	53%	59%	65%	70%	74%	77%	80%
3711	Flat Bed Truck	15%	22%	30%	36%	43%	49%	54%	60%	64%	69%	73%	76%
3744	Scissor Bed Truck	15%	22%	30%	36%	43%	49%	54%	60%	64%	69%	73%	76%
6712	Single-Axle Dump	18%	23%	31%	38%	45%	51%	57%	63%	68%	72%	76%	79%
8712	Tandem Dump	15%	23%	31%	38%	45%	51%	57%	63%	68%	72%	76%	79%
8785	Tri-Axle Dump	15%	23%	31%	38%	45%	52%	57%	63%	68%	72%	76%	79%
8786	Bottom Dump	15%	23%	31%	38%	45%	52%	57%	63%	68%	72%	76%	79%
8810	Tractor/Trailer	15%	23%	31%	38%	45%	52%	57%	63%	68%	72%	76%	79%
8743	Bucket Truck	18%	30%	40%	50%	58%	66%	72%	77%	81%	85%	86%	87%
8744	Bridge Snooper Truck	11%	17%	23%	28%	33%	38%	43%	48%	52%	56%	60%	63%
8771	Roadway Sweeper Truck	18%	30%	41%	51%	59%	66%	73%	78%	82%	85%	87%	88%
8741	Mobile Crane	18%	30%	40%	50%	58%	66%	72%	77%	81%	85%	86%	87%
8773	Culvert Cleaner/Vacuum Truck	18%	30%	41%	51%	59%	66%	73%	78%	82%	85%	87%	88%
8778	Asphalt Distributor	18%	30%	41%	51%	59%	66%	73%	78%	82%	85%	87%	88%
8731	Wrecker Truck	11%	17%	23%	28%	33%	38%	43%	48%	52%	56%	60%	63%
9452	Striping/Paint Truck	11%	17%	23%	28%	33%	38%	43%	48%	52%	56%	60%	63%
9132	End Loader, Wheeled	14%	23%	31%	39%	46%	52%	58%	64%	68%	72%	76%	79%
9220	End Loader, Track	14%	23%	31%	39%	46%	52%	58%	64%	68%	72%	76%	79%
9110	Loader, Skid Steer	14%	23%	31%	39%	46%	52%	58%	64%	68%	72%	76%	79%
9160	Motor Grader	15%	25%	34%	42%	49%	56%	62%	67%	72%	76%	79%	81%
9440	Roller, Pneumatic	15%	25%	34%	42%	49%	56%	62%	67%	72%	76%	79%	81%
9441	Roller, Steel Wheel	15%	25%	34%	42%	49%	56%	62%	67%	72%	76%	79%	81%
9150	Excavator, Wheeled	15%	25%	34%	42%	49%	56%	62%	67%	72%	76%	79%	81%
9250	Excavator, Track	15%	25%	34%	42%	49%	56%	62%	67%	72%	76%	79%	81%
9230	Dozer	15%	25%	34%	42%	49%	56%	62%	67%	72%	76%	79%	81%
9290	Dragline	15%	25%	34%	42%	49%	56%	62%	67%	72%	76%	79%	81%
9142	Backhoe	17%	28%	39%	48%	56%	63%	70%	75%	79%	82%	85%	86%
9431	Asphalt Paver	15%	24%	32%	40%	48%	54%	60%	66%	71%	75%	79%	81%
9426	Pavement Profiler	15%	24%	32%	40%	48%	54%	60%	66%	71%	75%	79%	81%
9623	Tractor, Mower	21%	35%	47%	57%	66%	74%	80%	84%	86%	88%	89%	90%
0110	Salt Spreader	15%	26%	36%	45%	53%	60%	66%	71%	75%	77%	79%	81%

Class Code	Description	Accumulated Depreciation at Miles or Hours												
	Utilization, 1,000 Miles →	130	140	150	160	170	180	190	200	210	220	230	240	250
	Utilization, Hours →	6,500	7,000	7,500	8,000	8,500	9,000	9,500	10,000	10,500	11,000	11,500	12,000	12,500
1300	Sedan	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
1600	SUV	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
1348	Police Cruiser	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
1521	1/2 Ton Pickup	83%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%
1531	3/4 Ton Pickup	83%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%
1523	1/2 Ton Crew Cab	83%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%
1533	3/4 Ton Crew Cab	83%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%
1424	Vans	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
3514	Mechanic Shop Truck	79%	82%	84%	86%	87%	88%	89%	90%	90%	90%	90%	90%	90%
2513	1 Ton Crew Cab	83%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%
3711	Flat Bed Truck	79%	82%	84%	86%	87%	88%	89%	90%	90%	90%	90%	90%	90%
3744	Scissor Bed Truck	79%	82%	84%	86%	87%	88%	89%	90%	90%	90%	90%	90%	90%
6712	Single-Axle Dump	82%	84%	86%	87%	88%	89%	90%	90%	90%	90%	90%	90%	90%
8712	Tandem Dump	82%	84%	86%	87%	88%	89%	90%	90%	90%	90%	90%	90%	90%
8785	Tri-Axle Dump	82%	84%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%
8786	Bottom Dump	82%	84%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%
8810	Tractor/Trailer	82%	84%	86%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%
8743	Bucket Truck	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
8744	Bridge Snooper Truck	66%	69%	72%	75%	77%	79%	81%	82%	83%	84%	85%	86%	87%
8771	Roadway Sweeper Truck	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
8741	Mobile Crane	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
8773	Culvert Cleaner/Vacuum Truck	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
8778	Asphalt Distributor	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
8731	Wrecker Truck	66%	69%	72%	75%	77%	79%	81%	82%	83%	84%	85%	86%	87%
9452	Striping/Paint Truck	66%	69%	72%	75%	77%	79%	81%	82%	83%	84%	85%	86%	87%
9132	End Loader, Wheeled	81%	83%	84%	85%	86%	87%	88%	89%	90%	90%	90%	90%	90%
9220	End Loader, Track	81%	83%	84%	85%	86%	87%	88%	89%	90%	90%	90%	90%	90%
9110	Loader, Skid Steer	81%	83%	84%	85%	86%	87%	88%	89%	90%	90%	90%	90%	90%
9160	Motor Grader	83%	84%	85%	86%	87%	88%	90%	90%	90%	90%	90%	90%	90%
9440	Roller, Pneumatic	83%	84%	85%	86%	87%	88%	90%	90%	90%	90%	90%	90%	90%
9441	Roller, Steel Wheel	83%	84%	85%	86%	87%	88%	90%	90%	90%	90%	90%	90%	90%
9150	Excavator, Wheeled	83%	84%	85%	86%	87%	88%	90%	90%	90%	90%	90%	90%	90%
9250	Excavator, Track	83%	84%	85%	86%	87%	88%	90%	90%	90%	90%	90%	90%	90%
9230	Dozer	83%	84%	85%	86%	87%	88%	90%	90%	90%	90%	90%	90%	90%
9290	Dragline	83%	84%	85%	86%	87%	88%	90%	90%	90%	90%	90%	90%	90%
9142	Backhoe	87%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
9431	Asphalt Paver	84%	86%	87%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%
9426	Pavement Profiler	84%	86%	87%	88%	89%	90%	90%	90%	90%	90%	90%	90%	90%
9623	Tractor, Mower	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
0110	Salt Spreader	83%	85%	87%	88%	90%	90%	90%	90%	90%	90%	90%	90%	90%

APPENDIX B

Equipment Replacement Process


Equipment Replacement Process
Start
Step 1
Update replacement factors in Optimization Tool
External equipment data systems
Step 2
Download equipment data from agency sources
Step 3
Review data, correct errors, and format
Step 4
Upload data to Optimization Tool
Step 6
Identify potential replacement units
Step 5
Perform class-level LCCA
Update replacement target planning values (if needed)
Replacement Targets Report
Step 7
Perform condition assessments
Enter condition scores into Optimization Tool
Step 8
Determine replacement priorities
Priority Replacement List
Step 12
Analyze cost consequences
Step 11
Develop 5-Year Plan
Step 10
Determine final replacement program and budget
Yes
Are there adequate funds available to replace all priority units?
Annual Replacement Budget
Cost Consequences Report
5-Year Schedule
No
End
Re-prioritize replacement unit (if needed)
Step 9
Perform unit-level LCCA

PART II

Guide for Optimal Replacement Cycles of Highway Operations Equipment

CONTENTS

CHAPTER 1

Introduction and Purpose

The *Guide for Optimal Replacement Cycles of Highway Operations Equipment* was developed as part of NCHRP Project 13-04, which had two primary objectives:

- Develop rational processes that will provide a realistic means of determining optimal replacement cycles.
- Include processes and tools for consideration in making decisions regarding optimal replacement cycles.

The guide presents a realistic cost analysis approach and outlines replacement decision-making processes adapted to highway operations equipment.

An Excel-based replacement optimization analysis tool was also developed to support the equipment replacement processes. A user manual in Part III provides instructions for using the optimization tool in combination with the guide. The tool is available for download from TRB's website at www.trb.org by searching on *NCHRP Research Report 879*.

The guide is both a handbook on equipment replacement concepts and an instruction manual for making cost-effective replacement decisions. The guide will help fleet managers determine optimal life cycles and implement systematic replacement processes supported by sound data-driven analysis. Ultimately, the guide should help fleet managers determine replacement needs and develop justifiable replacement budgets necessary for ensuring that the highway operations program is provided with a high-quality, dependable fleet to support the agency's mission.

1.1 Importance of Fleet Planning and Replacement

A quality fleet is vital for an efficient and effective highway operations program. Having a high-quality fleet requires good maintenance and sound replacement decisions. The guide provides the framework for making sound replacement decisions.

When faced with budget restrictions, the task of making fleet replacement decisions becomes more difficult. Keeping equipment too long costs more in the long run, and replacement budget cuts may save dollars in the near term but result in higher future expenditures. Also, as downtime increases with older fleets and sufficient equipment becomes unavailable, vital services are underperformed or performed inefficiently.

Without an effective fleet planning and replacement program, equipment-operating costs go up, downtime goes up, the cost of highway operations goes up, and service levels go down. High-quality fleets are important to an agency's mission and service delivery goals.

1.2 Benefits of an Effective Equipment Replacement Program

Good equipment replacement practices provide significant economic benefits for highway operations. Benefits can be measured in real dollars associated with reduced cost of equipment ownership and operation. Nontangible benefits also accrue. Newer, more dependable fleets reduce equipment downtime with a resulting outcome of more effective service delivery. Employee morale, safety, and public image are other real nontangible benefits that result with newer, well-maintained fleets.

If equipment is not replaced at optimal cycles, the total cost of owning and operating the equipment is higher. Replacing equipment too soon or too late has the same negative cost impacts. Table 1 illustrates potential cost savings based on actual highway agency cost data for a fleet of 266 wheeled end loaders. The replacement optimization tool analyzed the agency's cost data and determined the optimal replacement year for the loaders to be 16 years.

If the end loaders were replaced on 16-year cycles (optimal cycle), the total annual cost to own and operate the 266 wheeled end loaders would be $3,580,103 annually. If the units were replaced before they reached their optimal life, for example, at 14 years, the total annual cost would be $3,667,820, or $88,717 more. If the units were replaced on a 20-year cycle, the additional total cost of ownership would approach $400,000 per year.

Applying this example of savings for the end loaders to an entire equipment fleet consisting of thousands of units

Table 1. Example of potential cost savings.

Potential Cost Savings	
Equipment Class: End Loaders **No. of Units:** 266 **Optimal Replacement Cycle:** 16 Years	
If the replacement cycle is:	The total annual cost of ownership and operation will be:
12 Years	$3,942,200
14 Years	$3,667,820
16 Years	$3,580,103 Optimal
18 Years	$3,679,049
20 Years	$3,964,659

would demonstrate the magnitude of potential savings that can accrue when equipment is replaced at optimal cycles.

Implementing the equipment replacement processes outlined in this guide will help the fleet manager provide a reliable fleet for highway operations. The guide and the accompanying replacement optimization tool are designed to help fleet managers and improve fleet performance in three ways:

1. Provide a realistic and rational approach for determining optimal equipment replacement cycles that, if followed, will reduce the cost of owning the fleet and performing highway operations.
2. Lay out step-by-step procedures for making replacement decisions so units are replaced at the optimal time and achieve maximum benefits within available budgets.
3. Provide easily understood estimates of replacement needs and the cost consequences if equipment is kept beyond its optimal life cycle. These estimates can help fleet managers make a business case for replacement budgets.

CHAPTER 2

How to Use This Guide

This guide, the replacement optimization tool, and the tool's user manual should be used together to implement the recommended replacement processes. The guide applies to all major types and classes of highway operations equipment, both on-road and off-road.

Fleet replacement is both art and science. On one hand, sound analysis based on quality data provides the information that fleet managers need to make sensible replacement decisions. On the other hand, the results produced by the optimization analysis sometimes require review and interpretation beyond that obtained solely from analytics.

A general understanding of equipment cost analysis can provide a foundation for applying the processes and resources outlined in this guide. Chapter 3 describes the approach for determining optimal life cycles using life cycle cost analysis (LCCA) for highway operations equipment. Chapter 4 outlines the equipment classification structure, and Chapter 5 describes the factors used in cost and replacement analysis.

Chapter 6 describes rational and practical equipment replacement processes that consider the real-world environment of highway operations. These processes are used for identifying replacement needs, determining budget requirements, and making replacement decisions. The concepts outlined in this chapter can be used to help implement an agency's systematic replacement program.

Chapter 7 provides a case example to demonstrate the use of the tool and the replacement processes, using actual data from a fleet agency source.

The processes recommended in this guide and the factors built into the tool are based on industry best practices and norms. The optimization tool and the replacement processes can be used to

- Determine optimal equipment life cycles.
- Determine when an individual equipment unit has reached, or the equipment unit is projected to reach, its economic life.
- Establish current replacement needs.
- Prioritize the replacement of individual equipment units.
- Estimate future equipment replacement needs and budgets.
- Evaluate the consequences of not replacing equipment at optimal cycles.

CHAPTER 3

Life Cycle Cost Analysis

LCCA is used in many asset management applications, including pavements, bridges, culverts, buildings, and other assets. For highway operations equipment, LCCA is used to determine optimal life cycles and to analyze the cost history of individual equipment units. While conceptually similar to other applications, LCCA for equipment uses a slightly different approach that considers cost and other replacement factors specific to equipment operations.

The LCCA approach for equipment is illustrated in Figure 1. The approach is summarized as follows:

- Equipment costs consist of two main components: ownership and operating.
  - *Ownership cost* is the capital investment in equipment, which is determined from depreciation. Depreciation is the original price paid for a unit less the amount that is realized from its resale. For example, if the cost of a unit is $20,000 but sells for $1,500, then the ownership cost (depreciation) would be $18,500. Ownership costs per mile/hour go down over the life of an equipment unit.
  - *Operating cost* is the cost to operate and maintain a unit. Operating cost consists of out-of-pocket expenditures for maintenance, repair, and fuel. Operating cost also includes downtime and obsolescence, which are not out-of-pocket expenditures, but are nonetheless real costs that must be factored into LCCA. Operating costs per mile/hour go up over the life of an equipment unit.
- LCCA is performed by calculating the life-to-date cost (the LTD) per unit of utilization either in miles or in hours for both the ownership and operating cost components.
- The two main cost components are plotted against age. The point at which the total cost (the sum of ownership cost and operating cost) is lowest is when a unit has reached its economic life.

When LCCA is used to determine optimal equipment life cycles, the analyst should consider some key aspects of the methodology and its outcomes:

- Optimal replacement is seldom a single point in time, but rather a window of time. A number of real-world considerations come into play when making replacement decisions and the point at which a vehicle reaches its lowest LTD cost may not necessarily be the optimal time for replacing the equipment. This guide presents a systematic process for making equipment replacement decisions.
- The smooth curves depicted in Figure 1 rarely occur. Equipment maintenance and repair costs often fluctuate considerably from year to year as does utilization.
- The life cycle costs of similar equipment units can be very different depending on where and how they are used in highway operations, the effectiveness of the equipment maintenance program, and operator training and skill.
- Good equipment data are essential for obtaining reliable LCCA results. The research reported in Part I of this report found that agency equipment data are not always complete, consistent, and accurate. A considerable effort is required before beginning the cost analysis, to ensure that good, clean data are used for performing LCCA. Chapter 7 discusses the types of data errors commonly found and provides guidance on correcting the data before using to perform LCCA.

The guide presents two levels of LCCA: *class-level LCCA* and *unit-level LCCA*. The class-level LCCA determines optimal life cycles by using average LTD cost for all vehicles in a specific equipment class. This method will be the one most often used by highway agencies because it does not require annual cost data for each year of a unit's life; many highway

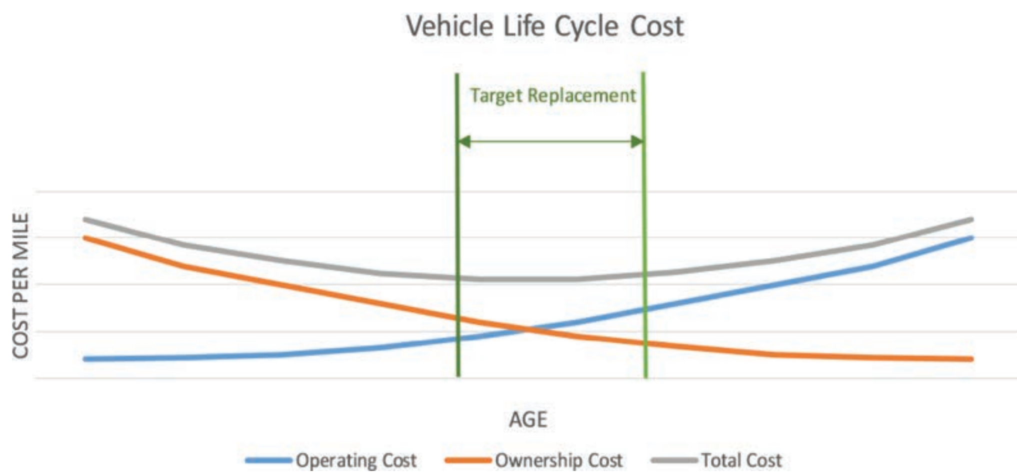


Figure 1. Stylized LCCA approach.

agencies do not have complete annual cost data for all equipment units.

The unit-level LCCA looks at a single piece of equipment and analyzes life cycle cost based on annual cost and utilization data. This method is a very good approach for analyzing life cycle cost but the optimal life cycle of an equipment unit cannot be known until after the unit has passed its lowest LTD cost. Only when the total cost curve has bottomed out and begins to rise has the unit reached its optimal life. The replacement process discussed in Chapter 6 uses unit-level LCCA to analyze cost of individual units as one input to the decision-making process.

3.1 Class-Level LCCA for Determining Optimal Life Cycles

The class-level LCCA determines optimal life cycles for the various equipment classes such as ½-ton pickups, tandem dump trucks, or end loaders. The class-level LCCA analyzes LTD cost by averaging the operating history of all units in the class. For example, if there are 657 units in the ½-ton pickup class, the class-level LCCA looks at all 657 units to determine the average operating cost for the class.

Table 2 lists the data elements needed for class-level LCCA. Quality data are key to obtaining reliable LCCA results, and it is important to ensure adequacy of the equipment data before inputting data into the optimization tool.

After the equipment data are downloaded from an agency's data sources, verified, and input into the optimization tool, the tool will produce LCCA results like that shown in Figure 2. The optimization tool's user manual provides step-by-step instructions for performing class-level LCCA.

In this example, the optimization tool computed the optimal life cycle for the ½-ton pickup class to be 7 years and approximately 95,000 miles. The LCCA estimates the LTD total cost per mile based on the averages of all units of the same age. For example, the average LTD cost per mile for the 64 pickups at 7 years of age is $0.71.

The optimization tool shows the results in tabular form by year and provides a graph to the right of the tabulated results. Note the erratic nature of the operating and total cost curves in the graph. This type of variation going up and down from year to year naturally occurs over the equipment life cycle. This variation occurs because of the practical way in which maintenance is performed on equipment. In some years, only preventive maintenance or minor repairs are performed and, in other years, major maintenance such as brakes or transmission services are performed at a high cost.

Left as they are, the erratic nature of the curves would make it difficult to determine when the LTD cost per mile is at its lowest point and to determine the optimal life cycle. The

Table 2. Class-level LCCA data elements.

Data Elements for Class-Level LCCA
• Equipment Number
• Agency Class Code
• Description
• In-Service Year
• LTD Miles or Hours
• LTD Maintenance and Operating Costs
• LTD Downtime Hours
• Replacement Cost

Equipment Replacement Analysis Tool

LCCA Analysis: 1/2 Ton Pickups

Agency Name Here   Class: 2001

Optimal Replacement Year: 7   Optimal Replacement Mileage: 95,377

			LTD Cost Per Mile						
Age	# Of Units	Year	Maintenance	Fuel	Downtime	Operating	Depreciation	Total	Trend
1	16	2015	0.33	0.14	0.13	0.60	0.39	0.99	0.82
2	3	2014	0.09	0.14	0.08	0.32	0.28	0.60	0.79
3	11	2013	0.18	0.14	0.15	0.48	0.29	0.77	0.77
4	0	2012	#N/A	#N/A	#N/A	#N/A	0.25	#N/A	0.75
5	13	2011	0.18	0.15	0.13	0.47	0.23	0.69	0.74
6	7	2010	0.20	0.16	0.25	0.61	0.23	0.83	0.73
7	64	2009	0.19	0.16	0.15	0.51	0.21	0.71	0.73
8	77	2008	0.19	0.17	0.15	0.50	0.19	0.70	0.73
9	76	2007	0.21	0.18	0.20	0.59	0.18	0.77	0.74
10	108	2006	0.20	0.18	0.18	0.56	0.17	0.73	0.75
11	46	2005	0.21	0.19	0.18	0.57	0.16	0.73	0.77
12	47	2004	0.24	0.19	0.25	0.68	0.15	0.83	0.79
13	26	2003	0.22	0.20	0.25	0.67	0.14	0.81	0.81
14	12	2002	0.21	0.21	0.20	0.61	0.13	0.74	0.85
15	4	2001	0.24	0.21	0.37	0.82	0.12	0.94	0.88
16	0	2000	#N/A	#N/A	#N/A	#N/A	0.11	#N/A	0.92
17	7	1999	0.31	0.23	0.56	1.10	0.11	1.20	0.97
18	4	1998	0.20	0.24	0.25	0.69	0.10	0.79	1.02
19	1	1997	0.25	0.24	0.66	1.15	0.10	1.25	1.08
20	2	1996	0.36	0.25	0.32	0.93	0.09	1.02	1.14

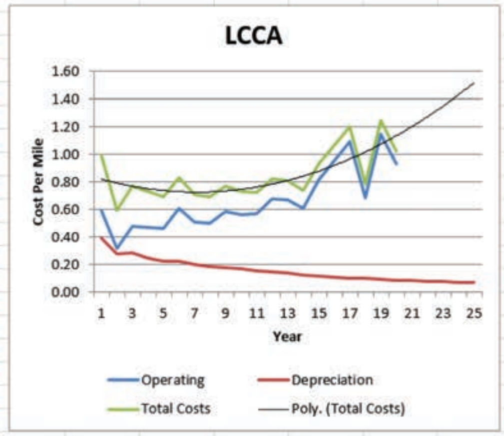


Figure 2. Example of class-level LCCA.

optimization tool is designed to develop a trend line to model the total cost curve that is used to determine the optimal life cycle (7 years in this case). The trend line costs are displayed in the last column of the LCCA page.

It is important to recognize that class-level LCCA determines optimal life cycles at the class level based on averages of all units in the class. Unit-level LCCA is used to analyze cost for individual equipment units.

3.2 Unit-Level LCCA

Class-level LCCA answers the question of optimal life cycles but does not identify if a specific unit should be replaced. Making replacement decisions is a process, and although optimal life cycles are key inputs to the process, there are a number of factors to be considered.

Unit-level LCCA analyzes the cost performance of individual equipment units. It is similar to the class-level LCCA, but requires different data. In the unit-level analysis, the costs must be broken down year by year.

Unit-level LCCA must have cost history for each year of the unit's life. If annual cost data are not available for all years, the optimization tool will not produce reliable LCCA results. Data requirements for unit-level LCCAs are shown in Table 3.

The annual costs and not the LTD costs are required for the unit-level LCCA. Historical annual costs are sometimes problematic because the data are not available or compiled into a lump sum amount when an agency switches to a new equipment information system. If annual data are available and loaded into the optimization tool, the tool will produce the unit-level analysis results in a form similar to the one shown in Figure 3.

The output from the optimization tool is similar to a class-level LCCA, with a tabular report and graph. The unit-level

Table 3. Unit-level LCCA data elements.

Data Elements for Unit-Level LCCA
• Equipment Number
• Agency Class Code
• Description
• In-Service Year
• Annual Miles or Hours
• Annual Maintenance and Operating Costs
• Annual Downtime Hours
• Replacement Cost

Equipment Replacement Analysis Tool

Unit Level LCCA Analysis

Sample DOT — Equipment Number: 123 — Description: Tandem Dump Truck

Lowest Cost Year, To-Date: 13 — Mileage: 160,353

	Cost Per Mile					
Age	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs
1	0.16	0.13	0.03	0.32	1.77	2.09
2	0.09	0.13	0.02	0.24	1.08	1.33
3	0.07	0.13	0.02	0.21	1.06	1.27
4	0.08	0.13	0.02	0.22	0.84	1.06
5	0.09	0.12	0.02	0.23	0.85	1.08
6	0.10	0.12	0.02	0.25	0.81	1.06
7	0.11	0.12	0.03	0.27	0.76	1.03
8	0.12	0.12	0.03	0.27	0.69	0.96
9	0.11	0.12	0.04	0.27	0.68	0.95
10	0.11	0.12	0.04	0.27	0.65	0.92
11	0.11	0.12	0.05	0.28	0.60	0.88
12	0.11	0.11	0.05	0.28	0.57	0.84
13	0.12	0.11	0.06	0.29	0.54	0.83
14	0.15	0.11	0.06	0.33	0.51	0.83
15	0.17	0.11	0.08	0.35	0.48	0.84
16	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

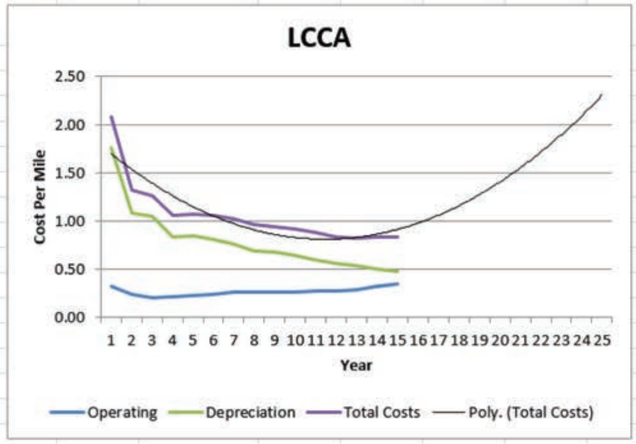


Figure 3. Example of unit-level LCCA.

LCCA is preset to predict a 25-year cost trend regardless of the age of the equipment. In this example, only 15 years of data are available; the trend for the entire 25 years is projected.

The unit-level LCCA results are displayed a little differently from the class-level LCCA results. In the example in Figure 3 for a tandem dump truck that is 15 years old, the optimization tool calculates the "Lowest Cost Year, To-Date" as Year 13. That might not be the optimal life cycle. However, the trend line in the graph suggests that the unit may be on an upward cost trend and that it may be past its economic life. On the other hand, the actual total cost curve has leveled out and the future trajectory cannot be known with certainty, as maintenance costs are not always predictable. The replacement process outlined in Chapter 6 proposes a condition assessment process that considers mission criticality to help predict future maintenance costs and make informed replacement decisions.

3.3 Using LCCA in Replacement Decisions

Making sound replacement decisions can be an art as much as a science. In real life, equipment cost trends seldom follow the graphic depicted previously in Figure 1. The cost curves are more often erratic and not smooth as shown in Figures 2 and 3. From a practical viewpoint, optimal replacement times seldom occur at an exact point of age or utilization, but rather over a window of time.

Performing equipment cost analysis and making replacement decisions are intricate tasks. They can be time consuming and demand dedicated resources. The following guidelines will help an agency gain maximum benefits and ensure the analysis yields the best and most reliable results:

- *Start with good quality data.* In nearly all cases, the equipment data downloaded from agency systems will contain some errors. Research shows that the error rate can be as high as 10%; thus the data for a number of equipment units should be errors corrected or be eliminated from the cost analysis.
- *Determine if there are outliers.* Invariably, maintenance costs for some equipment units fall outside the norm. These cost data do not represent typical cost trends, and should not be used to compute optimal life cycles.
- *Assess the number of units.* Make sure that there are enough units in the class to provide a statistically valid sample of units for the class-level LCCA. If the number of units in a specific class is too small, with wide variations in age and miles/hours, determining a class average optimal life cycle is not realistic. In this case, analyze each unit separately by using the unit-level LCCA if the data are available. An

example would be a bridge snooper truck; an agency might only have one or two units in the fleet: one may be 2 years old and the other 12 years old. A meaningful class-level LCCA cannot be performed with such a low number of units with disparate ages.

- *Analyze similar units together.* Carefully consider the makeup of each equipment class so that similar units are analyzed together. The optimization tool contains 40 equipment classes representing the majority of equipment types in a typical highway operations fleet. For example, the tool has a class for ½-ton pickups, which includes all types of vehicle configurations such as 2WD, 4WD, regular cab, and extended cab. It is unnecessary to break the ½-ton pickup class into these more specific types to perform LCCA. However, the analysis may be performed on separate equipment classes if a user determines that the cost model for the preset classes should be broken into a finer set of class descriptions.

CHAPTER 4

Equipment Classification Structure

For the optimization tool to be universally applicable, it is necessary to adopt a standardized equipment classification numbering scheme. Table 4 shows the 40 major equipment classes that are preloaded in the optimization tool, each of which has class-specific default replacement factors built into the tool. The numbering scheme follows closely the equipment classification codes adopted by the National Association of Fleet Administrators (NAFA). Most of these class code descriptions are self-explanatory; however, two may need further clarification:

- Class 8786, Bottom Dump, is used to describe the full bottom dump truck unit, including the tractor and bottom dump trailer. Although few agencies have these units in their fleet, this class is included as one of the major equipment classes.
- Class 0110, Salt Spreader, uses the same number as the general NAFA class for "Snow Removal" units. For the purposes of analyzing life cycle cost in the optimization tool, this class code represents a generic type class description for salt spreaders, regardless of the configuration or type of salt spreader used by the agency. This class code may be used for tailgate spreaders, drop-in spreaders, or any other configuration that is most prevalent within the agency. Because these units typically do not have hour meters, their utilization is measured by hours of usage reported by maintenance crew daily reports.

These class codes are used by the optimization tool and are not intended to replace an agency's class codes.

The agency's internal equipment classification and numbering scheme are likely unique, developed specifically to fit the agency's needs. Some agencies have very detailed schemes with many class codes, while other agencies have more generalized class schemes. The optimization tool adopts a more generalized scheme. A cross-reference table between the tool class codes and the agency's class codes will be needed. Table 5 provides an example of cross-referencing for the ½-ton pickup class.

In this example, five different pickup types are included in the universal ½-ton pickup class under Code 1521. In this way, the optimization tool analyzes all of the agency classes using the replacement factors for tool Code 1521.

When performing LCCA for the ½-ton pickup class, the user has the option of analyzing all five classes under Code 1521, or any one, or a combination of the five classes. Likewise, the user may analyze subgroups within a class such as equipment manufacturer (e.g., GMC versus Ford). However, there should be enough units in the class to provide a valid sample for performing a class-level LCCA.

It should be noted that categorizing equipment class codes at a level too low could affect the quality of results when performing class-level LCCA. Having too few equipment units in a class may lend an unrealistic class average cost analysis.

When performing replacement analysis in the optimization tool, the agency's class codes that correspond to equipment class codes preloaded in the tool can be used as inputs.

Table 4. Equipment groups, tool codes, and equipment classes.

Equipment Group	Equipment Class	
	Tool Code	Description
Passenger Vehicles	1300	Sedan
	1600	SUV
	1348	Police Cruiser
Light Trucks	1521	½-Ton Pickup
	1531	¾-Ton Pickup
	1523	½-Ton Crew Cab
	1533	¾-Ton Crew Cab
	1424	Vans
Medium Duty Trucks	3514	Mechanic Shop Truck
	2513	1-Ton Crew Cab
	3711	Flat Bed Truck
	3744	Scissor-Bed Truck
Large Trucks	6712	Single-Axle Dump
	8712	Tandem Dump
	8785	Tri-axle Dump
	8786	Bottom Dump
	8810	Tractor/Trailer
	8743	Bucket Truck
Specialty Trucks	8744	Bridge Snooper Truck
	8771	Roadway Sweeper Truck
	8741	Mobile Crane
	8773	Culvert Cleaner/Vacuum Truck
	8778	Asphalt Distributor
	8731	Wrecker Truck
	9452	Striping/Paint Truck
Heavy/Off-Road Equipment	9132	End Loader, Wheeled
	9220	End Loader, Track
	9110	Loader, Skid Steer
	9160	Motor Grader
	9440	Roller, Pneumatic
	9441	Roller, Steel Wheel
	9150	Excavator, Wheeled
	9250	Excavator, Track
	9230	Dozer
	9290	Dragline
	9142	Backhoe
Maintenance Equipment	9431	Asphalt Paver
	9426	Pavement Profiler
	9623	Tractor, Mower
	0110	Salt Spreader

Table 5. Example of class cross-referencing for ½-ton pickups.

Tool Class		Agency Class	
Code	Description	Code	Description
1521	½-Ton Pickup	P2131	2WD Regular Cab, Gas
		P2132	2WD Regular Cab, Diesel
		P4131	4WD Regular Cab, Gas
		P4132	4WD Regular Cab, Diesel
		P4252	4WD Extended Cab, Diesel

CHAPTER 5

Equipment Replacement Factors

Several factors are used to perform LCCA and as inputs in the fleet replacement processes. Table 6 provides a summary of these factors. The table shows how the factors are used and displays the data sources for developing factors specific to an agency.

The replacement factors have two purposes: (1) as cost factors used in calculating costs in LCCA and (2) as planning values in the replacement process to identify potential replacement targets and establish replacement priorities. The following sections describe these factors.

5.1 Age

Equipment replacement decisions should not be made solely based on age. However, equipment age is a primary factor in the replacement process and is used (1) to express optimal replacement cycles in years and (2) in long-range planning to project when a unit potentially will be due for replacement.

A specific equipment unit may be evaluated at any time in its life but should be analyzed for replacement when it approaches its target age. The optimization tool has default values for the replacement planning targets, as shown in Table 7. During initial tool setup, the preloaded default values should be reviewed and replaced as needed with agency specific values.

After the optimization tool has determined the optimal life cycles, the user can update and fine-tune the replacement planning values. It may be best to use the tool over two or three planning cycles before deciding to change the existing replacement planning targets.

5.2 Utilization

Utilization normally goes hand in hand with age, that is, the older the equipment, the higher its LTD utilization. However, this is not always the case. Utilization can vary significantly between equipment classes and from year to year for individual units. Older units tend to be used less on an annual basis, as operators prefer to operate new equipment if it is available. Annual utilization also decreases with age because of higher downtime.

Utilization is used in three ways in equipment replacement: (1) in LCCA to calculate LTD cost per mile/hour, (2) as a planning value to identify potential replacement candidates, and (3) to express optimal replacement cycles by miles/hours.

The optimization tool contains default replacement planning targets for miles or hours for each equipment class (see Table 7). For example, Equipment Class 2513, 1-Ton Crew Cab, has default targets of 10 years and 120,000 miles. Any unit exceeding 120,000 miles is identified as a potential replacement candidate.

5.3 Depreciation

Depreciation is a very important factor in equipment LCCA. It generally comprises 30% to 40% of the total cost to own and operate equipment over its lifetime. Depreciation is defined in accounting terms and is used to determine an asset's book value based on age. The LCCA approach in this guide calculates depreciation as the true cost of ownership, which is not necessarily the same as the depreciation amount computed by accounting methods.

The optimization tool computes the ownership cost component of LCCA based on a unit's utilization, which is a better indication of a unit's true depreciation than age. As an example, consider two units of the same age, 6 years, one with 70,000 miles and one with 110,000 miles. Although they have the same age, the unit with 110,000 miles will likely have a significantly lower salvage value, meaning that it has depreciated more.

The optimization tool contains a default depreciation schedule for each equipment class. Table 8 shows an example for

Table 6. Equipment replacement factors.

Replacement Factor	How It Is Used	Source
Age	Project future replacement needs. Express optimal replacement cycle in years.	Downloaded from the agency's equipment data source.
Utilization	Identify potential replacement targets. Express optimal replacement cycle in miles/hours. Compute LTD cost per mile or hour.	Downloaded from the agency's equipment data source.
Depreciation	Calculate ownership cost component in LCCA.	Replacement cost input by user. Depreciation schedules in the optimization tool.
Maintenance and Repair Cost	Calculate operating cost component in LCCA.	Downloaded from the agency's equipment data source.
Fuel Cost	Calculate operating cost component in LCCA.	Downloaded from the agency's equipment data source.
Downtime Cost	Calculate operating cost component in LCCA.	Downtime hours downloaded from the agency's equipment data source. Downtime hourly rate input by user.
Condition and Mission Criticality	Develop priority ranking of equipment replacements.	From physical condition assessment of equipment unit.
Overhead Cost	Calculate operating cost component in LCCA.	Overhead cost factors in the optimization tool.
Obsolescence Cost	Calculate operating cost component in LCCA.	Obsolescence cost factor in the optimization tool.
Replacement Cost	Calculate depreciation. Project future replacement budget needs.	From the agency's equipment data source, or input a value specific to each unit.

the ½-Ton Pickup class. The default factors were determined based on salvage value data obtained from several highway agency information sources (see Part I in this report). When needed, the optimization tool approximates depreciation between mileage intervals using the midpoint of the two values.

The following example shows how the ownership cost component (depreciation) of LCCA is developed.

Equipment type: ½-Ton Pickup
LTD utilization: 45,500 miles
Replacement cost: $25,000

$$\text{accumulated depreciation} = (\text{accumulated depreciation \%}) * \text{replacement value} = 43.5\% * \$25{,}000 = \$10{,}875$$

The LCCA ownership cost component is based on LTD cost per mile:

$$\text{LTD cost per mile} = \$10{,}875/45{,}500 \text{ miles} = \$0.24/\text{mile}$$

When setting up the optimization tool for the first time, the default depreciation values can be used or customized to an agency's needs.

5.3.1 Depreciation for Agencies Receiving no Proceeds from Equipment Sales

Some fleet agencies receive no returns on equipment sales because the sale proceeds are not returned to the fleet agency. The optimization tool accounts for this by allowing the user to override the default values and to set salvage values at zero at a selected age or utilization level.

5.4 Maintenance and Repair Cost

Maintenance and repair (M&R) cost is a major component of the total cost to own and operate equipment, typically making up to 40% to 50% of a unit's total cost over its life; it is a necessary factor required for performing LCCA. When used in LCCA, M&R costs are included in the operating cost component of the total life cycle cost.

To provide reliable outcomes from LCCA, it is important to accurately and fully define M&R costs. M&R cost can fluctuate widely from year to year, as illustrated in Figure 4.

The annual fluctuations of M&R costs naturally occur over a unit's life. Units may go a year or two with only preventive maintenance and minor repairs, followed by a year with a sharp rise in cost due to a major repair or service such as tire or brake replacement and then experience low M&R costs in

Table 7. Replacement planning targets for age and utilization.

Equipment Group	Equipment Class		Replacement Planning Targets		
	Code	Description	Year	Miles	Hours
Passenger Vehicles	1300	Sedan	6	90,000	
	1600	SUV	6	90,000	
	1348	Police Cruiser	5	80,000	
Light Trucks	1521	½-Ton Pickup	8	110,000	
	1531	¾-Ton Pickup	8	110,000	
	1523	½-Ton Crew Cab	8	110,000	
	1533	¾-Ton Crew Cab	8	110,000	
	1424	Vans	8	110,000	
Medium Duty Trucks	3514	Mechanic Shop Truck	10	120,000	
	2513	1-Ton Crew Cab	10	120,000	
	3711	Flat Bed Truck	10	120,000	
	3744	Scissor-Bed Truck	10	120,000	
Large Trucks	6712	Single-Axle Dump	12	120,000	
	8712	Tandem Dump	12	120,000	
	8785	Tri-axle Dump	12	120,000	
	8786	Bottom Dump	12	120,000	
	8810	Tractor/Trailer	12	120,000	
	8743	Bucket Truck	15	120,000	
Specialty Trucks	8744	Bridge Snooper Truck	20	250,000	
	8771	Roadway Sweeper Truck	12	120,000	
	8741	Mobile Crane	15	120,000	
	8773	Culvert Cleaner/Vacuum Truck	12	120,000	
	8778	Asphalt Distributor	12	120,000	
	8731	Wrecker Truck	12	250,000	
	9452	Striping/Paint Truck	12	250,000	
Heavy/Off-Road Equipment	9132	End Loader, Wheeled	12		5,000
	9220	End Loader, Track	12		3,000
	9110	Loader, Skid Steer	12		3,000
	9160	Motor Grader	15		5,000
	9440	Roller, Pneumatic	12		5,000
	9441	Roller, Steel Wheel	12		5,000
	9150	Excavator, Wheeled	12		8,000
	9250	Excavator, Track	12		8,000
	9230	Dozer	12		5,000
	9290	Dragline	15		5,000
	9142	Backhoe	12		8,000
Maintenance Equipment	9431	Asphalt Paver	15		8,000
	9426	Pavement Profiler	15		8,000
	9623	Tractor, Mower	12		5,000
	0110	Salt Spreader	8		5,000

the following years. Although these annual cost fluctuations occur, Figure 4 shows that M&R costs progress on an upward trajectory over a unit's life.

High costs in the first year are common with highway operations equipment because most units require some degree of preparation and outfitting when they are received. Additionally, average utilization in the first year is low because many units are received in the middle of the year. This presents a potential problem when performing LCCA. As illustrated in Figure 5, using the same M&R cost for the unit in Figure 4 the LTD cost/mile in the first year is very high because maintenance costs are high and the utilization is low. In this example, the accumulated M&R cost in Year 1 is $0.65/mile and drops to $0.30/mile in Year 2.

Table 8. Example of a depreciation schedule, ½-ton pickups.

Depreciation Schedule							
Miles	10,000	20,000	30,000	40,000	50,000	60,000	80,000
Accumulated Depreciation	15%	24%	32%	40%	47%	53%	59%

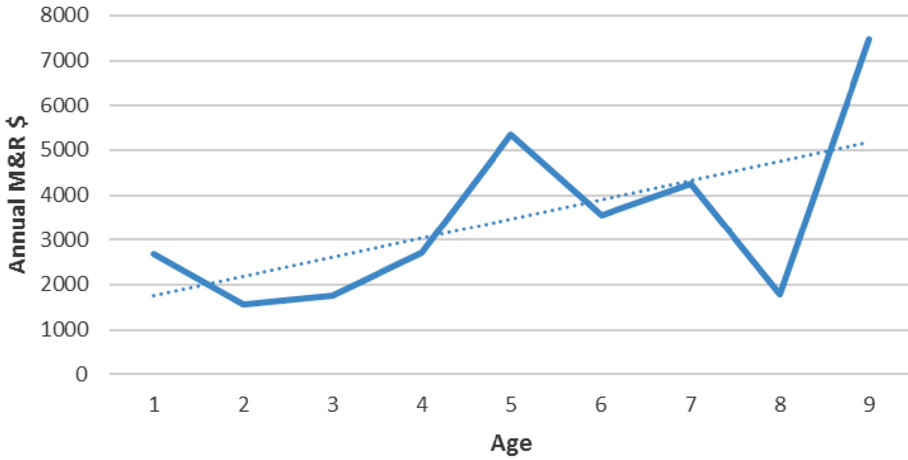


Figure 4. Illustration of yearly M&R cost fluctuations for a dump truck.

5.4.1 Maintenance and Repair Cost Data Consistency

To ensure that consistent and complete maintenance data are used to compute optimal life cycles, the following rules should be adopted for tracking and allocating M&R costs.

- *Include all repair types.* All types of maintenance and repairs performed on a vehicle should be included in the unit's operating cost. These include preventive maintenance, scheduled and unscheduled repairs, accident repairs and body work, and rebuilds and overhauls.
- *Assign initial outfitting cost to capital.* When new vehicles are received, most agencies perform some degree of setup on the units before deploying them to the field. The setup may include decals, safety striping, light bars, and radios. If the agency purchases a chassis only, the setup may also include installation of truck beds.

  These initial preparation and outfitting costs should not be charged as M&R; rather the costs should be accounted for in the equipment's replacement cost and depreciation. An exception would be for separate beds installed on a chassis. If the agency intends to remove the bed at resale and use it again, the bed is considered a separate asset and should not be included in the life cycle cost of the unit.
- *Use a shop work order system.* An effective system for reporting M&R cost to specific equipment units is needed to ensure that M&R costs are properly accounted for in LCCA. A shop work order system is the best practice to capture equipment maintenance costs.

  The shop work order should capture all labor and parts costs for all work performed on an equipment unit. To capture all M&R costs, a shop work order should be used no matter how small the repair job and all types of M&R activities should be reported. The shop work order should categorize costs by labor, parts, and commercial repairs.

  Most fleet agencies already have these procedures in place; however, a review of existing practices would be beneficial as part of implementing the replacement processes outlined in the guide.
- *Report only actual mechanic time worked.* Only actual mechanic work hours involved in completing an M&R job

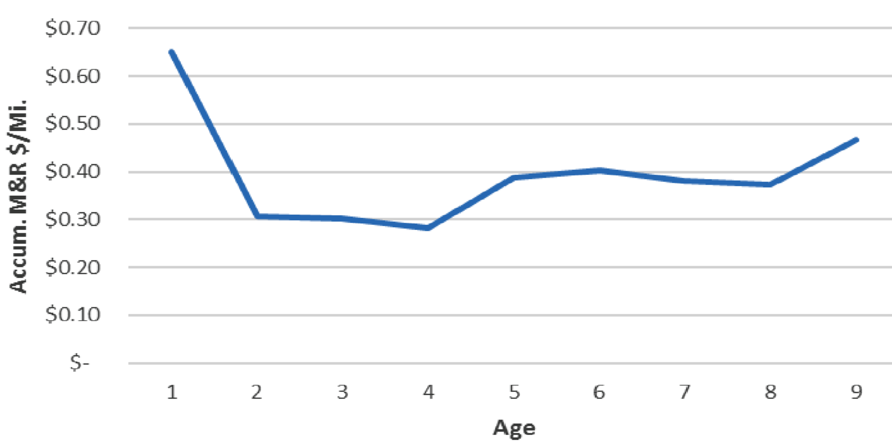


Figure 5. Accumulated M&R costs for a dump truck.

should be charged to a shop work order. For nonrepair activities, such as shop cleanup, training, or safety meetings, a nonmaintenance activity code should be used to report mechanic time. These types of activities are necessary and important and are part of the overall cost of equipment operations. However, if a repair work order incorporates the hours, M&R cost can be overstated for a specific repair. The mechanic's nonrepair hours are treated as a direct overhead expense and are allocated proportionately across all equipment classes, as discussed in Section 5.8, Overhead Cost.

- *Report all parts costs.* All parts and fluids used to perform M&R on a specific equipment unit should be captured on the shop work order. Expendable items—such as nuts, bolts, and washers whose costs are too small to allocate by work order—should be treated as part of the shop overhead costs. Lubricants, grease, and other fluids may be reported on the work order if the agency can accurately measure quantities, but when dispensed in small quantities, they may just as effectively be treated as a shop overhead expense.

5.5 Fuel Cost

Fuel cost generally comprises 20% to 40% of total equipment cost. In a unit's early years, fuel costs often exceed M&R costs. Fuel prices are volatile and vary from year to year based on market conditions. Market cost must be considered when calculating costs in LCCA. The optimization tool performs LCCA using average annual fuel cost per mile for all equipment units in a class.

5.6 Downtime Cost

Downtime is an important and significant cost factor. Downtime does not result in additional cash outlays from the fleet budget but does have a direct and significant cost impact on highway operations. If equipment is not available due to downtime, vital services suffer, and ultimately the cost of highway operations increases.

Equipment downtime is an often-overlooked cost factor. If it is not captured and reported, the true cost of equipment operating cost will be understated. Factoring in downtime could add as much as 50% to equipment operating costs (see Part I in this report).

The optimization tool includes downtime in the operating cost component of LCCA. It is not necessary to include downtime to perform LCCA; however, it is highly recommended. If an agency does not track downtime, the optimization tool will ignore this factor and the resulting operating cost component of the LCCA will be lower than it would be if downtime had been included.

5.6.1 Tracking Downtime Hours

While downtime costs can be significant, tracking downtime hours can be challenging in a highway operations environment. As a rule, downtime is the time that a unit is out of service during normal working hours. To ensure accurate and complete downtime tracking, the following rules should be adopted:

- For preventive maintenance and scheduled repairs, downtime should account for the total hours the unit is not available for use. If, for example, the unit were out of service for an entire day during normal working hours, downtime would be 8 hours. If preventive maintenance were performed at night, on weekends, or during other nonworking hours, there would be no downtime.
- If scheduled maintenance were performed in the off season, when the unit is not normally needed, there would be no downtime hours reported. Examples include refurbishing salt spreaders during the summer or refurbishing mowers during winter.
- For breakdowns and unscheduled repairs, downtime begins when a unit initially goes out of service, regardless of when it is repaired by field mechanics or brought into the shop. For example, if a vehicle breaks down while in the field, downtime would begin at the time of the breakdown. Even though the field mechanic might not arrive to make repairs or the unit might not be transported to the shop until later, downtime should be tracked from the time the unit goes out of service.
- Downtime ends when a unit is ready to go back into service.

As part of implementing the replacement processes outlined in this guide, review of the agency's downtime reporting procedures and initiating a reporting process that is consistent with these rules is required.

5.6.2 Determining Downtime Costs for LCCA

To determine the downtime costs for LCCA, the optimization tool uses downtime hours downloaded from the agency's data source. Multiply the downtime hours by the hourly downtime rate for each equipment class. If the agency has established equipment rental rates, the hourly downtime rate is the same as the hourly rental rate.

The optimization tool contains default values for downtime rates for each of the 40 equipment classes. The default downtime rates were developed from industry data. During tool setup, the user can either adopt the default rates or replace them with hourly rates specific to the agency.

5.7 Physical Condition and Mission Criticality

Physical condition and mission criticality are not monetary factors used in performing LCCA. However, they are important factors to be considered in replacement decisions.

Condition assessments for equipment are similar to condition assessments used in other asset management processes. The optimization tool uses the condition score and LTD cost to determine replacement priorities; mission criticality is factored into the condition score.

Condition assessments are completed by using the vehicle condition assessment form shown in Figure 6. The form is an Excel spreadsheet in the optimization tool; it can be used either as a paper document or by working in the spreadsheet and is highly customizable by the user.

The following instructions describe how to complete the form.

1. **Equipment Number and Description**

   Use these fields to identify the specific piece of equipment, identify the date of the inspection, and identify who is performing the assessment. These are free-form fields and any combination of text may be entered (Figure 7).

2. **Equipment Criticality**

   This drop-down box allows the user to select a level of mission criticality for the unit under assessment (Figure 8). Five levels of criticality are defined and assigned weight values:

   – Very High
   – High
   – Moderate
   – Low
   – Very Low

   Select the criticality level that best fits the unit under evaluation. The mission criticality level is discretionary; however, guidelines specific to the agency should be adopted to ensure consistency among evaluators.

   The selected criticality level affects the condition score of each vehicle component and ultimately affects the overall condition score for the unit. For example, if a Very High mission criticality level is selected, the overall condition score is lowered and the unit is given a higher priority for replacement in the replacement process.

3. **Equipment Components**

   When the optimization tool is opened, the form is broken into six major vehicle components (Figure 9):

   – Body
   – Engine
   – Transmission
   – Steering/Suspension
   – Electrical
   – Frame

   These components can be changed to fit the agency's preferred description. They can also be tailored to the specific equipment classes. For example, the components for front end loaders will likely be different from those for sedans or pickups.

4. **Component Weight Values**

   Each of the six components has an assigned weight value based on the relative importance of each component. In the example shown in Figure 10, the Body and Engine components have weight values of 15 and 20, respectively, indicating that the condition of the engine is more important than the condition of the body.

   The weight values are preloaded in the tool and can be changed to fit the agency's needs by simply changing the electronic form. Any weight value can be assigned, but once the weight is assigned, it should not be altered by individual evaluators.

5. **Condition Ratings**

   A rating of Good, Fair, Poor, or Very Poor is assigned to each component by the mechanic or technician who is performing the evaluation, based on the rating descriptions in the right column (see Figure 11).

   – **If using the electronic version of the form**, click on the appropriate condition level. The score will automatically populate for each component. In the example in Figure 11, a Fair rating was assigned to the body component, which resulted in a component score of 12.8, and a Very Poor rating was assigned to the engine, which resulted in a component score of 5.0.

     The spreadsheet automatically calculates the component score based on three inputs:

     1. The rating selected by the evaluator;
     2. The criticality level selected at the top of the form; and
     3. The weight values assigned to each component.

   – **If using a paper copy of the form**, mark the appropriate condition for each component. The scores from the paper forms must then be input into the spreadsheet in the tool to calculate an overall condition score for the unit.

6. **Overall Condition Score**

   The overall condition score is derived by adding the individual component scores (Figure 12). The lower the score, the worse the condition of the unit. The mission criticality is factored into the overall condition score.

7. **Notes**

   The bottom of the form provides space to make appropriate notes about the unit under assessment. Notes may be written in any free-form style.

Vehicle Condition Assessment				
Equipment Number			**Description:**	
Date:			**By:**	
Equipment Criticality	**Very Low**			
		Weight	**15**	
Body		○	Good	No rust, no body damage
		○	Fair	Very little rust, minor body damage
		○	Poor	Visible rust, some minor body repairs needed
		◉	Very Poor	Major rust or body damage. Requires major work within one year
	SCORE:	3.8		
		Weight	**20**	
Engine		○	Good	Good mechanical condition
		○	Fair	Some minor services needed
		○	Poor	Major repairs and more frequent maintenance needed
		◉	Very Poor	Major repairs needed within one year
	SCORE:	5.0		
		Weight	**20**	
Transmission		○	Good	Good mechanical condition
		○	Fair	Some minor services needed
		○	Poor	Major repairs and more frequent maintenance needed
		◉	Very Poor	Major repairs needed within one year
	SCORE:	5.0		
		Weight	**20**	
Steering/Suspension		◉	Good	Good mechanical condition
		○	Fair	Some minor services needed
		○	Poor	Major repairs and more frequent maintenance needed
		○	Very Poor	Major repairs needed within one year
	SCORE:	20.0		
		Weight	**10**	
Electrical		○	Good	Good mechanical condition
		○	Fair	Some minor services needed
		◉	Poor	Major repairs and more frequent maintenance needed
		○	Very Poor	Major repairs needed within one year
	SCORE:	7.0		
		Weight	**15**	
Frame		◉	Good	No rust or frame damage
		○	Fair	Some minor rust and/or frame damage
		○	Poor	Moderate rust and/or frame damage but safe to operate
		○	Very Poor	Major rust and/or frame damage; safety concerns
	SCORE:	15.0		
Overall Condition Score:		**55.8**		
Notes:				

Figure 6. Vehicle condition assessment form.

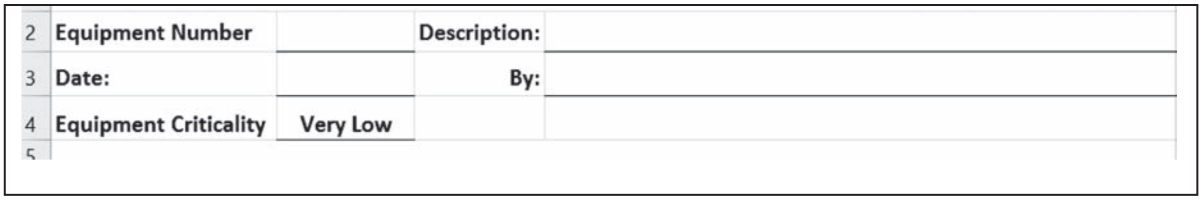


Figure 7. Vehicle condition assessment form headings.

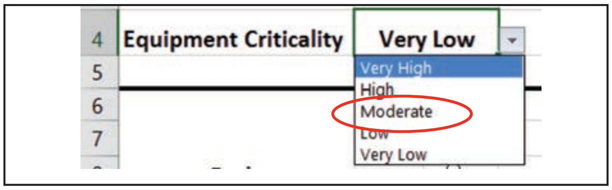


Figure 8. Criticality selection.

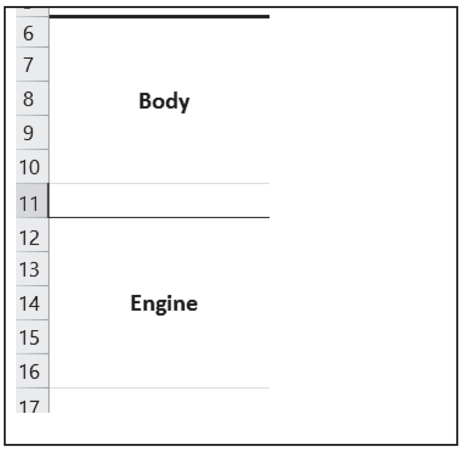


Figure 9. Equipment components.

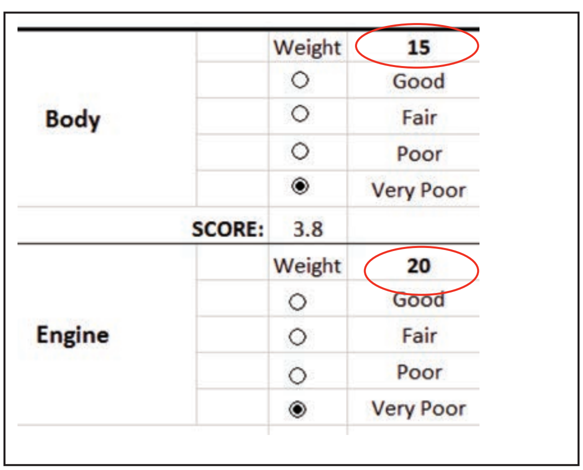


Figure 10. Component weight values.

5.7.1 Recording and Tracking Condition Scores

Condition assessments may be completed by using either a paper copy of the vehicle condition assessment form or the electronic spreadsheet in the optimization tool. If a paper form is used, the condition ratings must be entered into the electronic form so that the spreadsheet can compute an overall condition score.

The electronic vehicle condition assessment form is not linked to any other files or spreadsheets in the optimization tool. This requires the implementation of a systematic process for recording and tracking the scores so the scores can be manually entered into the optimization tool during the annual replacement planning process. An agency may develop a recording and tracking process that is best for its needs; recommended processes are described as follows.

Using an Electronic Form

Laptops or mobile devices with Microsoft Excel are best for completing forms, so evaluators (mechanics or technicians) would need access to these devices in the field.

1. Copy the original blank form from the optimization tool into a new folder on the computer.
2. Make any necessary adjustments to the form for the agency's fleet, such as component names and weight values.
3. Make separate master forms for each major equipment category. Example categories include transportation equipment, heavy trucks, maintenance equipment, and off-road equipment. Save the original master forms so they cannot be changed.
4. Load the original master forms onto laptops or mobile devices for use in the field by evaluators who will perform the assessments.
5. Using the forms in the laptops and mobile devices, open a blank master form and complete the condition assessment for the unit under evaluation.
6. As each unit is completed, save the completed assessment as a separate Excel file or tab within a spreadsheet.

Body		Weight	15	
		○	Good	No rust, no body damage
		◉	Fair	Very little rust, minor body damage
		○	Poor	Visible rust, some minor body repairs needed
		○	Very Poor	Major rust or body damage. Requires major work within one year
	SCORE:	12.8		
Engine		Weight	20	
		○	Good	Good mechanical condition
		○	Fair	Some minor services needed
		○	Poor	Major repairs and more frequent maintenance needed
		◉	Very Poor	Major repairs needed within one year
	SCORE:	5.0		

Figure 11. Selecting a condition rating.

7. Compile all saved condition assessments onto a central computer for ready access by the fleet manager or equipment replacement coordinator for later input into the optimization tool.

Using a Paper Form

If laptops or mobile devices are not available, complete forms on paper.

1. Perform Steps 1 through 3 in the same manner for electronic forms.
2. Make sufficient paper copies of each form to distribute to the evaluators who will perform the assessments.
3. Fill out the top of the form with the necessary information identifying the unit.
4. Manually mark the appropriate condition score for each component.
5. Make appropriate notes at the bottom of the form as needed.
6. Collect the completed paper forms and enter the information into the electronic format using the steps outlined above.

Enter the paper forms into the optimization tool to compute an overall condition score.

40			○
41		SCORE:	10.5
42	Overall Condition Score:		60.3
43			

Figure 12. Overall condition score.

During the annual fleet planning process (Chapter 6), the condition assessment scores will be input into the optimization tool to help determine replacement priorities.

5.8 Overhead Cost

The M&R costs downloaded from the agency's system might not have fully loaded mechanic labor rates. Research has shown that M&R costs are often understated because mechanic hourly rates do not fully account for overhead costs.

There are two types of overhead associated with equipment repairs: direct and indirect. Table 9 shows examples of cost components associated with each type of overhead.

The optimization tool is designed to allow the user to add overhead to the labor costs downloaded from the agency's equipment cost tracking system. The tool has preloaded default factors for both direct and indirect overhead; review and modify these default factors as needed during initial tool setup.

The agency may have some overhead costs already built into labor costs. For example, employee benefits but not many other

Table 9. Overhead cost components.

Direct Overhead	Indirect Overhead
Payroll Additive/Benefits	Shop Management
Training	Warehouse Operations
Uniforms	Expendable Parts and Supplies
Tool Allowance	Facility Costs
Non-direct Time	Computers/Software

overhead expenses may have been added into direct wages. To help establish the correct values, it may be appropriate to consult the agency's accounting department.

5.8.1 Direct Overhead

Direct overhead costs are directly associated with mechanic labor. The cost elements included as direct overhead follow.

Payroll Additive and Employee Benefits

Payroll additives and employee benefits include items such as FICA, worker's compensation, health insurance, and retirement benefits. These costs are directly associated with mechanic labor costs and can typically amount to 45% to 55% of a mechanic's hourly wage.

Training, Uniforms, and Tool Allowance

Training is a major expense in fleet operations because of constant and fast-changing equipment technology. It is a necessary overhead expense to be factored into the cost of M&R. Training costs are those paid for training courses and associated expenses for mechanics to attend training. Training costs do not include the mechanic's time for attending the training, which is nondirect time, discussed below.

Many fleet agencies provide mechanic uniforms and tool allowances. If the agency provides these benefits to mechanics, factor them in as direct overhead.

Nondirect Time

Nondirect time may constitute a significant portion of a mechanic's total paid hours in a year. Nondirect time is a major cost component in fleet operations that is often overlooked. Nondirect time is the time when a mechanic is not charging directly to a repair work order. This time is necessary and unavoidable and will always be present in a fleet maintenance environment.

Examples of nondirect time include

- Leave time—annual, sick, and vacation—the largest component of nondirect time;
- Mechanic training hours;
- Shop cleanup; and
- Safety meetings.

Table 10 shows an example of how to determine nondirect time, using actual data from a DOT fleet organization. Use the example as a template to compute chargeable time for the agency.

Table 10. Example of mechanic nondirect time.

Mechanic Nondirect Time	
Component	Hours
Nominal Hours per Year	2,080
Overtime Hours at 6% per Average Year	125
Total Paid Hours per Year	2,205
Holidays, 12 Days per Year	96
Annual Leave, 15 Days per Year, Average	120
Sick Leave, 10 Days per Year, Average	80
Annual Hours Available for Work Orders	1,909
% Time Charged to Repair Work Orders—80%	1,527
Total Chargeable Time	69%

The example shows that 69% of a mechanic's total paid annual hours are typically chargeable to repair work orders. The remaining 31% is nondirect time and is an operational expense for the fleet agency; it should be included as an overhead factor in the M&R cost.

5.8.2 Indirect Overhead Costs

Indirect overhead costs consist of general and administrative costs at the fleet enterprise level, including nonmechanic personnel such as warehouse operations, procurement, disposal, or warranty management. Other indirect overhead costs include general overhead expenses, facilities operating cost, and shop tools/operations that are not directly chargeable on a repair work order.

Not all indirect costs should be allocated to M&R. Some costs, such as procurement, do not affect maintenance costs. Similar to direct overhead expenses, indirect overhead expenses should be prorated to M&R costs based on mechanic hours charged.

5.8.3 Case Example of Overhead Cost Calculation

Table 11 shows an example of calculating direct and indirect overhead factors for use in performing LCCA, using data from a DOT agency. The fleet budget data were taken from the agency's fiscal year 2017 budget. The example shows budgeted expenses specific to the agency but can be used as a template to arrive at overhead cost factors for another agency.

The example shows that the direct and indirect overhead rates for this agency are 115% and 93%, respectively. The agency's average mechanic hourly rate for all mechanic classifications is $17.62. The agency charges mechanic labor cost to work orders at the rate of $35.00 per hour. In real-

Table 11. Case example for calculating overhead rates.

Cost Item	Factors	Direct Salaries ($)	Direct OH ($)	Indirect OH ($)
Salaries				
Charged to Work Orders		562,815		
Mechanic Non-WO Time			249,799	
Shop Management Pro-rated				57,000
FICA	6.20%		50,382	3,534
Worker's Comp	7.24%		58,833	4,127
Retirement	12.20%		96,706	6,954
Health Insurance	19.00%		150,608	10,830
Parts				23,142
Mechanic General				70,800
Paint Shop - General				24,000
Welding Shop - General				24,000
Shop Tools				35,150
IT - Software License				13,000
IT - Computers, every 5 years				1,500
Building Maintenance				29,000
Hazardous Material Disposal				15,000
Utilities				25,600
Uniforms			8,400	800
Training			29,500	-
Tool Allowance	$150		3,000	150
Supplies, Postage and Freight				7,040
Telephone				16,500
Office Furniture				3,900
Fuel/Oil				23,471
Small Equipment				44,000
Shop Vehicles				34,375
Warehouse Operations				48,000
Totals		562,815	647,228	521,873
Overhead as a % of Direct Salaries			**115%**	**93%**
Total Budget for Maintenance and Repair				$1,731,916
Total Shop Hours Charged to WO				32,674
Loaded Labor Rate for Mechanic				**$ 53.01**

Note: WO designates work order; OH designates overhead.

ity, as shown in the example, the true cost for fully loaded mechanic labor should be $53.01 per hour. This means that the agency's equipment M&R costs are being significantly underestimated and most likely will have a significant impact on determining optimal life cycles.

To perform LCCA accurately, it is important that a true hourly rate be established for mechanic labor based on the overhead factors specific to each agency. The optimization tool provides default values for direct and indirect overhead of 45% and 90%, respectively.

For LCCA operating cost calculations, these overhead factors are applied to the M&R costs downloaded from the agency's equipment system. If the agency's M&R costs already include some overhead in the labor cost, that amount should be considered when setting up the overhead factors in the optimization tool's configuration file.

5.9 Obsolescence

Equipment obsolescence is a factor that considers equipment safety, efficiency, and dependability. While it is difficult to quantify obsolescence cost for vehicle safety and productivity, it is possible to determine how newer vehicles compare with older vehicles for fuel economy.

To account for obsolescence, the LCCA measures obsolescence based on fuel utilization. Based on the corporate average fuel economy data, fuel economy for passenger vehicles and light trucks has been 1.6% and 1.8%, respectively, over the recent 15-year period. The optimization tool has a default obsolescence rate of 2.0%, which is applied to the vehicle's fuel cost to calculate obsolescence cost.

5.10 Replacement Cost

Replacement cost is used in two ways for equipment replacement: to calculate depreciation in LCCA and to project long-range replacement budget needs.

Replacement cost is the original price paid for the unit plus the cost of outfitting the unit before deploying it to the field. Update the replacement costs in the optimization tool annually before beginning the equipment replacement process.

Use the average replacement cost for all units in a class. For example, Class Code 1521, ½-Ton Pickup, includes 2WD Regular Cab gas pickups, 4WD Extended Cab diesel pickups, and other pickup truck configurations. Use the average replacement cost for all ½-Ton Pickup types in the 1521 class. If analyzing a subgroup within a general class, for example, 2WD Regular Cab gas pickups, then use the replacement cost only for that subgroup.

The agency may choose the replacement cost that represents the majority of unit types within the class.

CHAPTER 6

Equipment Replacement Processes

Making equipment replacement decisions is a process. The LCCA approach, discussed in Chapter 3, determines optimal equipment life cycles. However, determining when to replace equipment and actually making replacement decisions are two different exercises. This guide recommends an annual equipment process to

- Identify potential replacement candidates.
- Determine replacement needs.
- Determine equipment replacement priorities.
- Develop an equipment replacement program consistent with available funding.
- Project future replacement needs for long-range budget planning.

It is important to understand how to interpret and use optimal life cycles in the equipment replacement process. Knowing that ½-ton pickups, for example, have an optimal life cycle of 6 years does not mean that every pickup must be replaced when it reaches 6 years of age. Over the long term, pickups should be replaced an average of every 6 years, but individual pickups may have shorter or longer economic life cycles.

Replacement decisions consider optimal life cycles along with other factors in the decision-making process. Consider major factors such as physical condition and mission criticality. Budget limitations affect replacement decisions. When funds are not sufficient to meet total replacement needs, establish replacement priorities. Replacement timing can be affected by dealer incentives and model year closeouts. Bulk purchases of similar units can influence which specific units should be replaced.

A systematic equipment replacement process is required that recognizes the real-world conditions and the operating environment within which fleet managers must operate. The annual capital investment in equipment is a large part of the overall fleet budget. Making good replacement decisions will ensure that available budget dollars are optimized and, just as importantly, that highway operations crews have a dependable, high-quality fleet for delivering cost-effective services.

6.1 Organizational Considerations

As discussed in Chapter 1, an effective equipment replacement program provides significant cost savings for fleet agencies. Because equipment replacement is both an art and a science, it merits the attention of trained and dedicated resources within the fleet management organization. Effective equipment replacement requires more than simply uploading data and generating outputs from the optimization tool. LCCA results must be interpreted, condition assessments must be performed, priorities must be established, and statewide coordination with field operating divisions is required.

The equipment replacement process requires continual effort. Someone in the fleet organization should be available throughout the year to perform quality control and ensure that equipment cost data are accurately reported and maintained. Condition assessments are important and time-consuming tasks in the replacement process. Assessments can be performed by field shops, but someone in the central fleet agency should be assigned to coordinate the assessments and compile the assessment results. Analyzing equipment costs is not a simple task. LCCA requires interpretation and examination of the results. Implementation of the replacement processes will yield the best results if consistent and coordinated efforts are applied in the replacement process.

Because fleet replacement decisions are so important and require year-round administration functions, a fleet replacement coordinator or fleet asset manager position should be established and be responsible for implementing the replacement program. For large organizations, this may be a

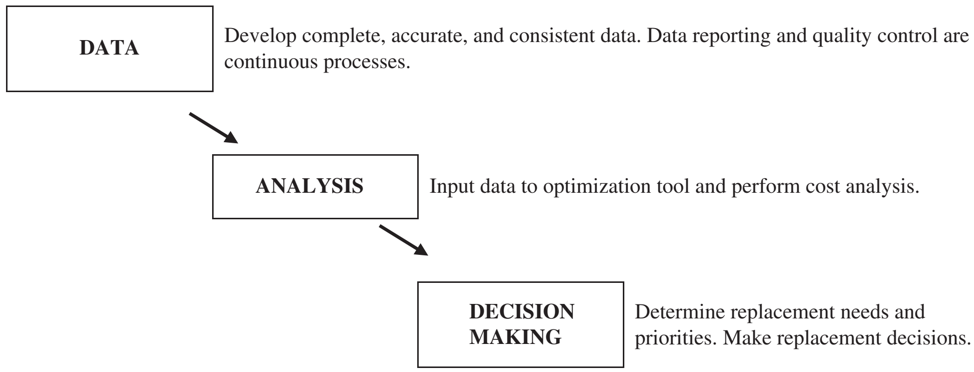


Figure 13. Replacement process overview.

stand-alone position but some agencies may incorporate this function into an existing staff position. Each agency should consider creating such a position if it does not already exist.

6.2 Overview of Replacement Processes

LCCA can be performed and equipment can be evaluated at any time during the year. However, because most highway agencies evaluate needs and prepare replacement budgets as part of the agency-wide annual budgeting cycle, the following chapter outlines an annual process for equipment replacement. Adopting an annual process provides a systematic approach for evaluating equipment replacement needs, determining replacement priorities, and developing an annual replacement program that optimizes the use of available replacement funding.

The equipment replacement process comprises three general phases, as shown in Figure 13.

Figure 14 shows a more detailed flowchart with the individual steps of the process. Review the process and adapt it to the agency's operating environment and organization as needed. Establish calendar timelines and due dates so the process can be synchronized with the agency's budget development schedule. Some activities, such as data quality control, are continuous. Other processes could take several months and require the user to begin well in advance to ensure the replacement budget request is completed on time.

The optimization tool must be set up and configured for the agency in accordance with the instructions in the tool's user manual before beginning the replacement process. The tool supports the processes outlined in Figure 14 and described in the case example in Chapter 7.

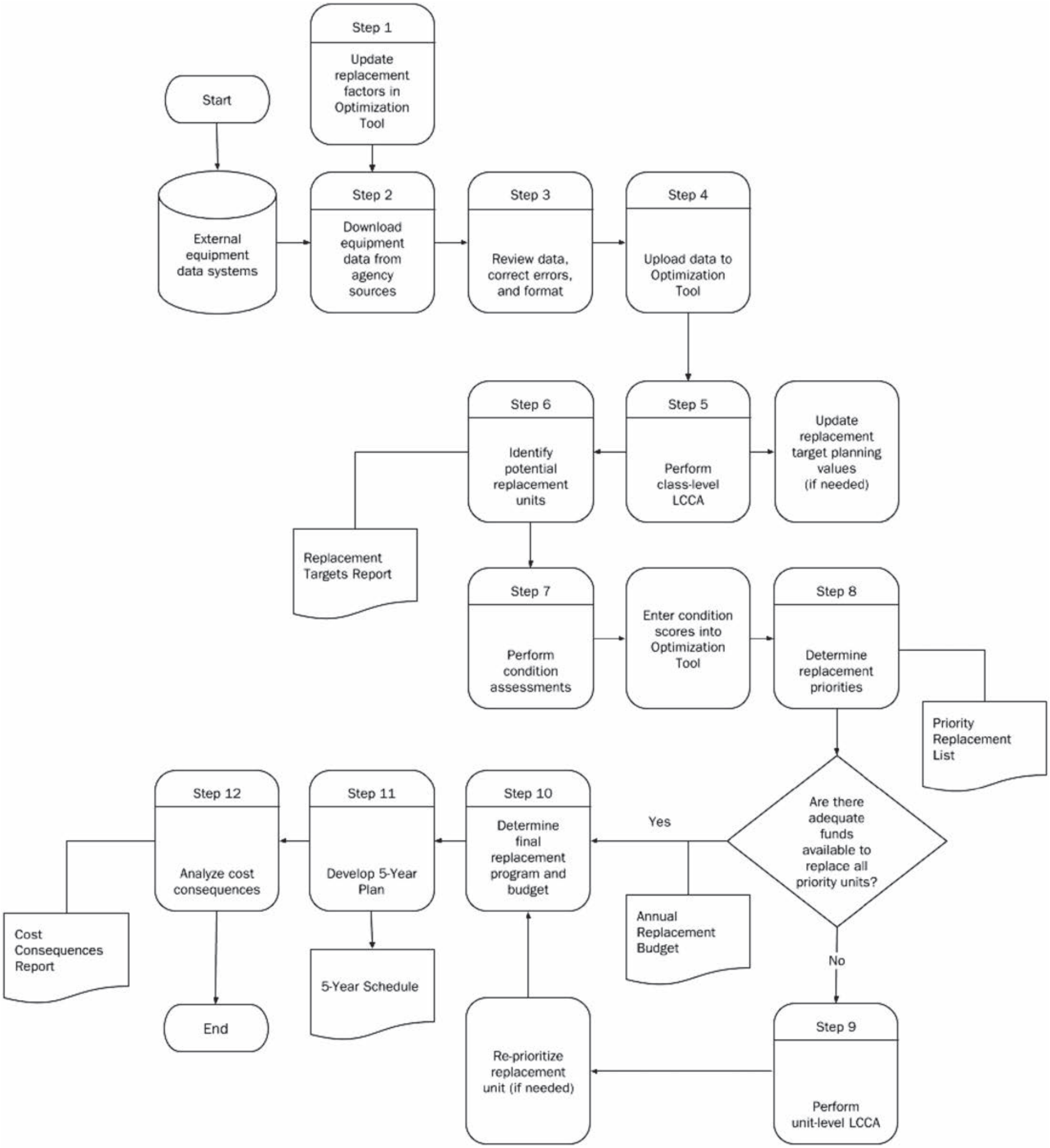


Figure 14. Equipment replacement process.

CHAPTER 7

Case Example Illustrating Use of the Optimization Tool and Replacement Processes

Review the tool's user manual before walking through the following example.

To illustrate the replacement process and demonstrate how to use the tool to support the process, consider the example scenario described in Table 12 for the class of tandem dump trucks. Most of the data used in this example were provided by a fleet agency. Where data were not available from the agency, hypothetical data were used.

The following steps illustrate the equipment replacement process.

Step 1. Review and Update Replacement Factors

Before using the optimization tool for the first time, configure the tool and tailor the replacement factors to the agency's specific needs. At the beginning of each new year's planning cycle, review and update the factors as needed (not all factors require updating each year). Factors that typically change from year to year include

- Unit replacement costs for each equipment class;
- Inflation rate;
- Overhead factors; and
- Replacement planning target values—age and utilization.

Updating the replacement factors annually will result in accurate and reliable cost analysis results. Update the replacement factors in the tool's configuration file, as shown in Figure 15.

Step 2. Download Equipment Data from Agency Data Source

After updating the replacement factors, download the required equipment data from the agency's equipment information data source. The source may be a fleet management system, accounting system, or other repository of equipment information. Two types of data are required:

- LTD data for completing the class-level LCCA and
- Annual data for completing the unit-level LCCA.

For this example, LTD data were downloaded for 720 tandem dump trucks. Figure 16 shows an example of the class-level LCCA data. In the example, Unit 51129 is a 17-year-old vehicle with 159,330 LTD miles. The downloaded data include LTD M&R cost (parts, labor, and commercial), LTD fuel cost, LTD downtime hours, and the original purchase cost of the unit. The original purchase cost is optional as the tool uses current replacement cost to perform LCCA. The year format used is a four-digit general number and not the Excel date format.

To perform unit-level LCCA, the tool requires annual data for each equipment unit, shown in Figure 17.

Step 3. Review Downloaded Data for Errors

Note: The downloaded data require close examination and cleanup to ensure reliable cost analysis.

Even with the best of information systems, data input errors can occur, and it is likely that there will be errors in the equipment data downloaded in Step 2. Delete equipment units with obvious data errors before entering them into the optimization tool and correct suspicious or questionable data if possible.

Erroneous or unreliable data can occur for several reasons. Sometimes odometers or hour meters are changed during a unit's life, meaning that true LTD miles or hours are not available. Errors may also occur at the source reporting level, such as the shop work order. Some equipment units may have unusable data because they are new and have limited utilization and cost history to be representative of future cost trends.

There is no specific methodology for correcting the data; use any techniques that are preferred. The optimization tool

Table 12. Case scenario.

Example Scenario
Equipment Class: DT-5000, Tandem Dump Trucks
Number of Units in Class: 720
Available Replacement Budget: $8,000,000
Unit Replacement Cost: $117,000

automatically disregards units that are less than 1 year old but does not edit data errors. It is best to perform a rigorous edit routine externally to the tool. The most appropriate method is to download the data from the internal systems into an Excel file and then run some basic checks to examine the data for accuracy. After running the data through the external editing process, it is ready to input to the tool.

Some basic guidance for data editing and cleanup follows.

Equipment Replacement Optimization Tool

Configuration Input Tables

Agency Name: Agency Name Here

Planning Year: 2017 *Update before yearly data entry

	Class Codes						Replacement Planning Targets		
								Utilization	
	Agency	Tool	Description	Current Replacement Cost	Hourly Downtime Rate	Age Years	Miles	Hours
10	S1001	1300	Sedan	$ 25,000	$ 25	6	90,000	
11	S1002	1600	SUV	$ 25,000	$ 25	6	90,000	
12	S1003	1348	Police Cruiser	$ 25,000	$ 25	5	80,000	
13								
25	DT-4000	6712	Single-Axle Dump	$ 80,000	$ 60	12	120,000	
26	DT-5000	8712	Tandem Dump	$ 117,000	$ 60	12	120,000	
27	DT-6000	8785	Tri-Axle Dump	$ 130,000	$ 60	12	120,000	
28	DT-7000	8786	Bottom Dump	$ 145,000	$ 60	12	120,000	

Figure 15. Configuration file.

Equipment Number	Agency Class Code	Description	In Service Year	Miles or Hours	Parts	Labor	Commercial	Fuel	Downtime Hours	Purchase Cost
51126	DT-5000	Tandem Dump Truc	2000	109,857	22,250.51	20,883.34	5,255.99	31710.56	348	49,954
51127	DT-5000	Tandem Dump Truc	2000	106,783	21,996.32	20,621.48	7,597.91	31233.27	344	49,954
51128	DT-5000	Tandem Dump Truc	2000	62,099	22,215.67	29,976.16	11,306.12	20786.29	500	49,954
51129	DT-5000	Tandem Dump Truc	2000	159,330	30,082.31	24,894.24	18,973.96	48201.21	415	49,954
51130	DT-5000	Tandem Dump Truc	2000	171,230	10,772.21	27,021.68	10,588.48	43020.19	450	49,954
51131	DT-5000	Tandem Dump Truc	2000	52,018	44,474.41	48,660.75	19,574.53	48604.03	811	49,954
51132	DT-5000	Tandem Dump Truc	2000	183,347	42,196.50	43,026.39	21,498.24	48731.93	717	49,954
51133	DT-5000	Tandem Dump Truc	2000	147,143	40,060.95	37,649.80	15,778.95	43691.99	627	49,954
51134	DT-5000	Tandem Dump Truc	2000	154,463	49,067.21	35,645.03	21,752.93	45414.31	594	49,954
51135	DT-5000	Tandem Dump Truc	2000	151,417	16,603.55	12,709.97	11,458.83	48738.36	212	49,954
51136	DT-5000	Tandem Dump Truc	2000	125,899	16,093.72	30,301.81	36,139.11	43577.88	505	49,954
51137	DT-5000	Tandem Dump Truc	2000	129,226	43,386.62	39,080.06	22,965.26	43834.4	651	49,954
51138	DT-5000	Tandem Dump Truc	2000	134,438	18,021.27	25,078.55	11,595.15	46857.95	418	49,954

Figure 16. Sample data for class-level LCCA, tandem dump trucks.

Year	Annual Miles	Parts	Labor	Commercial	Fuel	Annual Downtime Hours
1	5529	$1,462.40	$705.83	$0.00	$1,193.36	12
2	8717	$1,693.36	$1,453.12	$0.00	$2,704.90	24
3	16274	$695.22	$781.02	$345.00	$6,849.19	13
4	11120	$1,797.64	$310.70	$301.49	$5,800.15	5
5	14554	$5,157.75	$571.95	$644.00	$7,992.88	10
6	14298	$4,806.90	$3,019.05	$940.00	$8,744.39	50
7	9324	$10,527.35	$2,945.00	$2,448.00	$4,525.34	49
8	14890	$6,189.56	$860.10	$1,428.00	$4,674.66	14
9	12642	$7,450.46	$1,127.49	$0.00	$774.77	19

Figure 17. Sample data for unit-level LCCA, tandem dump truck.

Eliminate Low Utilization Units

Figure 18 is an example of two low utilization units with 1,125 and 733 miles, respectively. These units are deleted from the analysis because their utilization is too low to provide representative cost history. In the case example, all units with less than 3,000 miles were eliminated. The 3,000-miles is an arbitrary threshold; the agency may select a threshold suited to the agency.

One technique for reviewing the utilization data is to sort it, either by age or miles, from lowest to highest. This technique allows for easy identification of low utilization units.

Identify Obvious Errors or Questionable Data

Figures 19, 20, and 21 are examples of what appear to be obvious errors or questionable data. Figure 19 shows four units that have an "In Service Year" of 1900. If the true in-service year cannot be identified, the units should be deleted.

Figure 20 shows three units with negative expenditures noted in red in the "Commercial" cost column. Any negative numbers in the cost columns for labor, parts, commercial, or fuel are a red flag for possible errors.

Eliminate Extreme Outliers

The equipment cost and utilization history of some units may not be representative of typical units in a class. If there are extreme outliers where mileage, hours, or LTD costs are far outside the norm, it may be appropriate to eliminate those units from the class-level LCCA so they do not skew the results. Figure 21 provides some examples. Unit 51107 shows negative miles; Unit 51184 is a 14-year-old truck with only 36,862 miles, which is far outside the norm for other similar-aged units; and Unit 51333 is a 12-year-old truck with 901,206 miles. These types of outliers should be identified, examined, and either corrected or eliminated from the cost analysis.

Step 4. Upload Data into the Optimization Tool

After cleaning up the data, the data are ready for input into the optimization tool. In this example, 720 units were downloaded from the agency's data source. As part of the cleanup process in Step 3, 35 units were purged due to data errors,

Equipment Number	Agency Class Code	Description	In-Service Year	Miles or Hours	Parts	Labor	Commercial	Fuel	Downtime Hours	Purchase Cost
52017	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2015	24,582	$3,666.25	$4,097.57	$5,895.23	$6,424.98	15.6	$120,300.98
52018	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	13,777	$2,391.65	$2,017.35	$0.00	$2,120.23	12.0	$121,970.22
52019	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	14,550	$524.56	$838.50	$0.00	$2,056.86	12.5	$122,295.28
52020	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	1,125	$2,465.25	$805.50	$0.00	$78.41	5.5	$76,679.76
52026	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	2,750	$1,710.95	$1,154.85	$0.00	$67.32	11.0	$122,295.28
52027	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	2,226	$1,707.22	$987.00	$0.00	$83.38	8.0	$122,295.28
52028	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	2,927	$2,736.03	$3,809.94	$0.00	$99.89	8.5	$123,062.08
52029	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	733	$1,913.30	$1,882.65	$795.00	$0.00	9.0	$121,386.21
52030	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	1,730	$1,947.32	$2,070.48	$0.00	$242.92	5.0	$121,386.21
52031	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	1,321	$1,641.74	$846.25	$0.00	$70.68	7.5	$121,386.21
52032	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	2,371	$1,996.66	$1,742.70	$0.00	$283.35	7.0	$121,386.21
52033	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	1,227	$1,120.08	$818.14	$417.50	$85.93	6.6	$121,386.21
52034	DT-5000	TRUCK - DUMP - 36000 GVW C/C A/T	2016	10,272	$882.96	$1,508.80	$0.00	$9.30	8.0	$121,386.21

Figure 18. Example of low utilization units, tandem dump trucks.

Equipment Number	Agency Class Code	Description	In-Service Year	Miles or Hours	Parts	Labor	Commercial	Fuel	Downtime Hours	Purchase Cost
51897	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	2,806	$1,622.84	$727.72	$0.00	$267.24	6.0	$116,050.88
51898	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	10,299	$1,443.00	$514.85	$0.00	$158.40	9.0	$116,050.88
51899	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1900	710	$855.46	$774.25	$0.00	$0.00	928.0	$116,050.88
51900	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	4,110	$849.35	$869.19	$0.00	$9.30	7.0	$116,050.88
51901	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	3,741	$835.55	$988.04	$0.00	$175.81	4.5	$116,050.88
51902	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	1,656	$905.89	$881.47	$0.00	$9.30	8.0	$116,050.88
51903	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	1,709	$924.60	$1,193.10	$0.00	$68.89	6.0	$116,050.88
51904	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	3,327	$905.22	$1,299.67	$0.00	$71.87	7.0	$116,050.88
51905	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1900	629	$397.95	$1,256.00	$5,606.00	$74.25	928.0	$116,050.88
51906	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1900	2,387	$380.59	$588.75	$900.00	$51.68	928.0	$116,050.88
51907	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	1,943	$2,562.01	$1,464.03	$14,898.68	$247.90	3.0	$116,050.88
51908	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2016	1,589	$1,721.46	$1,958.25	$0.00	$20.46	8.0	$117,726.75
51909	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1900	0	$1,707.76	$2,630.25	$0.00	$0.00	928.0	$117,726.75
51910	DT-5000	TRUCK - DUMP - 36000 GVW M/T SSD	1996	116,798	$43,383.10	$36,326.65	$61,675.57	$41,565.24	175.0	$54,567.00
51911	DT-5000	TRUCK - DUMP - 36000 GVW M/T SSD	1996	198,630	$56,313.91	$43,120.58	$42,054.13	$48,500.54	180.0	$54,567.00

Figure 19. Example of obvious data errors.

Equipment Number	Agency Class Code	Description	In-Service Year	Miles or Hours	Parts	Labor	Commercial	Fuel	Downtime Hours	Purchase Cost
51499	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	117,577	$48,051.39	$20,402.82	$9,332.28	$47,511.90	57.0	$74,427.07
51500	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	94,764	$41,453.73	$17,546.79	$4,513.32	$46,053.63	51.5	$74,427.07
51501	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	118,554	$38,600.97	$14,409.26	$10,728.12	$55,474.19	56.0	$74,427.07
51502	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	111,343	$38,047.59	$15,347.68	$17,340.70	$51,435.58	70.0	$74,427.07
51503	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	67,017	$22,064.74	$20,738.24	$993.23	$24,402.71	54.0	$52,543.80
51504	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	39,336	$25,579.45	$28,809.38	($369.86)	$19,085.75	48.0	$52,543.80
51528	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	77,463	$11,085.90	$9,056.69	$4,862.89	$35,079.96	48.0	$76,031.96
51529	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	28,677	$6,633.06	$8,720.08	$0.00	$10,862.30	61.0	$76,111.83
51530	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2010	38,643	$14,966.67	$8,731.86	$462.82	$20,473.17	48.0	$76,111.83
51531	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2010	17,475	$11,023.99	$11,259.87	$812.13	$8,623.72	54.0	$76,111.83
51532	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2010	31,864	$12,532.17	$9,446.74	($1,360.43)	$20,574.99	50.5	$76,111.83
51533	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	38,569	$13,472.78	$14,763.72	($306.14)	$14,916.05	52.5	$75,200.47
51534	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	71,751	$15,619.30	$14,798.30	$1,776.72	$33,971.48	56.0	$75,200.47
51535	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2009	62,887	$30,308.19	$20,337.34	$140.00	$13,481.10	48.0	$75,200.47

Figure 20. Example of questionable commercial cost data.

Equipment Number	Agency Class Code	Description	In-Service Year	Miles or Hours	Parts	Labor	Commercial	Fuel	Downtime Hours	Purchase Cost
51104	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1997	207,597	$19,712.96	$30,654.40	$15,091.84	$55,349.24	195.0	$41,372.75
51105	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1997	77,224	$25,242.93	$23,360.82	$5,475.63	$32,487.99	90.5	$41,372.75
51106	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1997	111,028	$20,254.80	$47,981.80	$11,575.92	$31,666.38	115.5	$41,872.08
51107	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1997	-400,476	$12,450.09	$20,306.26	$6,164.94	$12,803.28	200.0	$41,872.08
51108	DT-5000	TRUCK - DUMP - 36000 GVW A/T	1997	163,562	$14,136.55	$25,282.49	$18,735.56	$44,653.28	180.5	$41,872.08
51183	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2003	89,352	$15,783.31	$15,873.00	$6,147.62	$26,178.02	110.5	$61,304.00
51184	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2003	36,862	$73,857.68	$46,434.22	$6,974.64	$13,251.94	98.0	$61,304.00
51185	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2003	92,426	$12,100.24	$15,902.40	$15,204.38	$30,545.75	94.0	$61,304.00
51186	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2003	151,063	$17,488.81	$23,435.41	$12,026.91	$47,171.26	118.5	$61,304.00
51332	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2005	147,214	$17,516.82	$12,849.01	$2,221.00	$56,730.33	94.5	$60,725.04
51333	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2005	901,206	$47,545.89	$20,568.84	$19,979.55	$64,820.55	88.0	$60,725.04
51334	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2005	163,691	$26,069.73	$17,840.43	$5,364.89	$51,080.25	92.0	$60,725.04
51335	DT-5000	TRUCK - DUMP - 36000 GVW A/T	2005	54,412	$16,417.29	$18,382.24	$7,875.87	$20,415.45	71.0	$60,725.04

Figure 21. Example of outlier data.

leaving 685 units to be analyzed by the optimization tool. The data were then input into the optimization tool in the formats shown in Figures 18 and 19.

Step 5. Perform Class-Level LCCA

After the cleanup data are entered into the optimization tool, the LCCA is performed automatically. Figure 22 shows the printout for class-level LCCA (for the 685 tandem dump trucks included in the example). The optimal replacement cycle is calculated to be 11 years and approximately 105,000 miles.

At this point, the results of the LCCA can be used to update the replacement planning target values if desired. Before updating the values, be sure that the results are based on valid data. Updated planning values can be entered into the tool's configuration file as appropriate.

The LCCA computes the average LTD cost for all units by age. In the example in Figure 22, 45 units are 7 years old with an average LTD cost of $2.41 per mile.

Step 6. Identify Units Flagged for Potential Replacement

The optimization tool identified 104 tandem dump trucks as potential replacements because they were either past their replacement target of 120,000 miles set in the configuration file, or they had excessively high costs in comparison with the average cost for units of the same age in the class. The optimization tool displays the replacement candidates report, as shown in Figure 23. The replacement candidates are listed in descending order based on the unit's LTD cost per mile compared with the class average. In this case example, Unit 51256 is 121% higher than the average and has been placed at the top. The report also shows the LTD miles for units that have exceeded the 120,000-mile utilization target. Column J, Condition Assessment Score, is blank because no condition assessment scores have been entered at this step in the process.

The units listed in the replacement candidates report are only candidates for replacement at this point. Not all the units should be replaced solely because they have exceeded their replacement planning targets. Each unit should be evaluated individually to determine if it should be replaced.

Step 7. Perform Condition Assessments

The next step in the process is to conduct condition assessments. Condition assessments are very important as they provide insight on individual equipment units, and the condition score is a key factor in determining replacement priority ranking. Condition assessments allow factoring in mission criticality into replacement decisions.

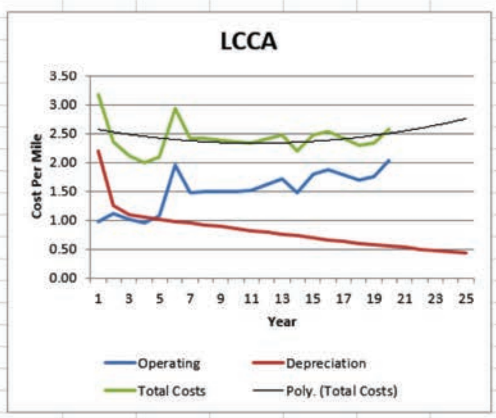
Equipment Replacement Analysis Tool

LCCA Analysis: Dump Trucks

Sample DOT — Class: DT-5000

Optimal Replacement Year: **11** — Optimal Replacement Mileage: **105,507**

			LTD Cost Per Mile						
Age	# Of Units	Year	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs	Trend
1	59	2015	0.51	0.39	0.07	0.97	2.20	3.17	2.57
2	78	2014	0.62	0.40	0.09	1.11	1.25	2.36	2.52
3	20	2013	0.53	0.41	0.07	1.02	1.09	2.11	2.48
4	50	2012	0.46	0.43	0.06	0.95	1.05	2.00	2.45
5	42	2011	0.56	0.44	0.08	1.07	1.02	2.09	2.42
6	3	2010	1.30	0.45	0.21	1.96	0.98	2.94	2.39
7	45	2009	0.88	0.47	0.12	1.46	0.95	2.41	2.37
8	46	2008	0.89	0.48	0.13	1.50	0.91	2.42	2.35
9	0	2007	#N/A	#N/A	#N/A	#N/A	0.88	#N/A	2.34
10	77	2006	0.86	0.51	0.12	1.49	0.85	2.34	2.33
11	153	2005	0.87	0.53	0.12	1.51	0.82	2.33	2.33
12	0	2004	#N/A	#N/A	#N/A	#N/A	0.79	#N/A	2.33
13	46	2003	1.01	0.56	0.15	1.72	0.75	2.48	2.34
14	2	2002	0.78	0.58	0.11	1.46	0.72	2.19	2.35
15	27	2001	1.03	0.59	0.16	1.78	0.69	2.47	2.36
16	14	2000	1.09	0.61	0.17	1.87	0.66	2.53	2.38
17	0	1999	#N/A	#N/A	#N/A	#N/A	0.63	#N/A	2.40
18	7	1998	0.90	0.65	0.15	1.70	0.60	2.30	2.43
19	15	1997	0.92	0.67	0.16	1.75	0.57	2.32	2.46
20	1	1996	1.15	0.69	0.19	2.03	0.55	2.58	2.50
21	0	1995	#N/A	#N/A	#N/A	#N/A	0.52	#N/A	2.54
22	0	1994	#N/A	#N/A	#N/A	#N/A	0.50	#N/A	2.59
23	0	1993	#N/A	#N/A	#N/A	#N/A	0.48	#N/A	2.64
24	0	1992	#N/A	#N/A	#N/A	#N/A	0.46	#N/A	2.69
25	0	1991	#N/A	#N/A	#N/A	#N/A	0.44	#N/A	2.75



#N/A designates no data available.

Figure 22. Example of class-level LCCA, tandem dump trucks.

	A	B	G	H	I	J
1	Equipment Number	Description	% Over Class AVG Cost	LTD Miles or Hours	Exceeds Replacement Target?	Condition Assessment Score
2	51256	Tandem Dump Truck	121%			
3	51170	Tandem Dump Truck	119%			
4	51131	Tandem Dump Truck	73%			
5	51465	Tandem Dump Truck	53%			
6	51451	Tandem Dump Truck	32%			
7	51450	Tandem Dump Truck	28%			
8	51353	Tandem Dump Truck	-21%	124,463	X	
9	51285	Tandem Dump Truck	-22%	145,895	X	
10	51500	Tandem Dump Truck	-26%	122,999	X	
11	51328	Tandem Dump Truck	-27%	159,292	X	
12	51195	Tandem Dump Truck	-28%	122,950	X	
13	51323	Tandem Dump Truck	-30%	143,158	X	
14	51137	Tandem Dump Truck	-31%	129,226	X	

Figure 23. Replacement candidates report.

Figure 24 shows an example condition assessment for Unit 51131, which is listed third on the replacement candidates report because of its excessively high cost. The mission criticality for the unit is rated as "Very High" because of its assigned function. A tandem dump truck assigned to a high-priority snow route would be a good example of a unit that would be given a Very High mission criticality rating.

In the example for Unit 51131 in Figure 24, the Body component has been rated Very Poor and will require major work within the next year. After rating all of the equipment components, the spreadsheet computed the overall condition score for this unit to be 36, which is low.

All flagged equipment units should be assessed. If a large number of units will be assessed, the task can be delegated to the field shops. Some training would be required to ensure consistent results between shops. Performing condition assessments is a time-consuming task that could be performed as part of the annual inspection or service. In this way, condition scores will be readily available to input into the optimization tool.

After the units have been assessed, enter the condition assessment scores in Column J of the replacement candidates report, as shown in Figure 25 (hypothetical condition scores are used in this example).

Step 8. Determine Replacement Priorities

After the condition scores are entered, the optimization tool determines a priority ranking based on a unit's LTD cost and condition score. Only equipment units that have been assessed and whose condition scores have been entered into the tool are shown on the priority ranking list. In this case example, condition scores were entered for all 104 tandem replacement candidates.

The optimization tool uses the weight factors from the configuration file to calculate priorities. In this example, weight values of 40% and 60% have been assigned to cost and condition, respectively, as shown in Figure 26. During tool setup, input the weight factors that fit the agency's needs, as long as they add up to 100%.

The optimization tool displays the priority ranking, as shown in Figure 27. The priority ranking shows that Unit 51131 is now the highest priority unit for replacement, primarily because of its low condition score, which includes mission criticality.

Step 9. Perform Unit-Level LCCA

A unit-level analysis of individual equipment units can help make replacement decisions. To perform this analysis, enter the annual cost and utilization data as shown previously in Figure 17.

For this example, choose a 15-year-old unit, Unit 51111. The unit was not in the priority ranking list but was selected to see how its life cycle cost was trending. The agency had annual dump truck data for only the first 9 years. To demonstrate the unit-level functionality, hypothetical data were entered for the remaining 6 years. Figure 28 presents the analysis results and shows that this unit may have passed its economic life.

Step 10. Determine Replacement Program and Budget

In this case example, the optimization tool identified 104 tandem dump trucks as possible replacement candidates and ranked them in priority replacement order. At this point, the replacement process could be considered complete if sufficient funds are available to replace all the candidate units. At a replacement cost of $117,000 each, $12.2 million would

Vehicle Condition Assessment

Equipment Number 51131 **Description:** Tandem Dump Truck

Date: 9/15/17 **By:** Joe Mechanic

Equipment Criticality Very High

Body	Weight	**15**	
	○	Good	No rust, no body damage
	○	Fair	Very little rust, minor body damage
	○	Poor	Visible rust, some minor body repairs needed
	◉	Very Poor	Major rust or body damage. Requires major work within one year
	SCORE: 0.8		
Engine	Weight	**20**	
	○	Good	Good mechanical condition
	◉	Fair	Some minor services needed
	○	Poor	Major repairs and more frequent maintenance needed
	○	Very Poor	Major repairs needed within one year
	SCORE: 13.0		
Transmission	Weight	**20**	
	○	Good	Good mechanical condition
	○	Fair	Some minor services needed
	◉	Poor	Major repairs and more frequent maintenance needed
	○	Very Poor	Major repairs needed within one year
	SCORE: 4.0		
Steering/Suspension	Weight	**20**	
	○	Good	Good mechanical condition
	◉	Fair	Some minor services needed
	○	Poor	Major repairs and more frequent maintenance needed
	○	Very Poor	Major repairs needed within one year
	SCORE: 13.0		
Electrical	Weight	**10**	
	○	Good	Good mechanical condition
	○	Fair	Some minor services needed
	◉	Poor	Major repairs and more frequent maintenance needed
	○	Very Poor	Major repairs needed within one year
	SCORE: 2.0		
Frame	Weight	**15**	
	○	Good	No rust or frame damage
	○	Fair	Some minor rust and/or frame damage
	◉	Poor	Moderate rust and/or frame damage but safe to operate
	○	Very Poor	Major rust and/or frame damage; safety concerns
	SCORE: 3.0		

Overal Condition Score: **36**

Notes: Lots of body work needed. Transmission is in poor shape, may need major work soon.

Figure 24. Example of vehicle condition assessment.

	A	B	G	H	I	J
1	Equipment Number	Description	% Over Class AVG Cost	LTD Miles or Hours	Exceeds Replacement Target?	Condition Assessment Score
2	51256	Tandem Dump Truck	121%			52
3	51170	Tandem Dump Truck	119%			48
4	51131	Tandem Dump Truck	73%			36
5	51465	Tandem Dump Truck	53%			57
6	51451	Tandem Dump Truck	32%			65
7	51450	Tandem Dump Truck	28%			62
8	51353	Tandem Dump Truck	-21%	124,463	X	52
9	51285	Tandem Dump Truck	-22%	145,895	X	70
10	51500	Tandem Dump Truck	-26%	122,999	X	73
11	51328	Tandem Dump Truck	-27%	159,292	X	65
12	51195	Tandem Dump Truck	-28%	122,950	X	68
13	51323	Tandem Dump Truck	-30%	143,158	X	54
14	51137	Tandem Dump Truck	-31%	129,226	X	59

Figure 25. Condition assessment scores.

be needed to replace all units. However, this case scenario assumes only $8 million are available, which is enough to replace 68 units. The next step is to decide which specific units to replace.

There is no defined process for making the final decision. The tool provides information to identify needs and analyze costs but it does not make the final replacement decisions. These decisions must also consider factors such as seasonal timing, bulk discounts, and other practical considerations that might not be easily quantified.

The following general guidelines can be used in the decision-making process:

- Use the priority ranking displayed in Figure 27 as the initial starting point.
- Using the condition assessments, identify units that are in the best condition and that are not likely to incur high maintenance and repair costs in the next year.
- Using the unit-level LCCA, identify the cost trends of individual units.
- Consider cost, condition, and other objective factors to select the 68 units that will provide the optimal replacement program for tandem dump trucks.

Universal Cost Factors	
Direct Overhead	45%
Indirect Overhead	90%
Inflation Rate	2.0%
Obsolescence Rate	2.0%
Equipment Replacement Priority Factors	
Cost Per Mile Weight	40.0%
Condition Score Weight	60.0%

Figure 26. Priority weight factors.

Step 11. Develop a 5-Year Plan

This step is not needed to prepare the annual replacement program but it provides the fleet manager with information to quantify future funding needs and develop a long-range plan for replacement needs. The 5-Year Plan is a planning tool that is used to communicate future budget needs to upper management and budget decision makers. The optimization tool generated the 5-Year Plan, as shown in Figure 29, for this case scenario.

The projected replacement needs for each year are determined by comparing each unit's current age with the target replacement age in the tool's configuration file. The 5-Year Plan shows the projected year for replacement and the total budget needs for the year. Future costs are inflated based on the annual inflation rate from the configuration file.

In this case scenario, the 5-Year Plan shows a $4.3 million backlog of replacement needs, and in 2020, for example, $19.2 million will be needed for replacement.

To put the backlog and future annual funding needs in perspective, consider that the case scenario has 720 tandem dump trucks in the fleet. At a replacement cost of $117,000 each, the replacement value for the tandem fleet is approximately $87.8 million dollars. If the target replacement for tandem dump trucks is 12 years, then the average annual replacement needs over the long term is $7.3 million.

Equipment Replacement Analysis Tool

Sample DOT | Class: | DT-5000

Single Axle Dump Truck Priority Replacement List

Equipment Number	Description	Final Rank	Condition Assessment Score
51131	Tandem Dump Truck	1	36
51170	Tandem Dump Truck	2	48
51256	Tandem Dump Truck	3	52
51353	Tandem Dump Truck	4	52
51361	Tandem Dump Truck	5	52
51214	Tandem Dump Truck	6	44
51263	Tandem Dump Truck	7	52
51323	Tandem Dump Truck	8	54
51439	Tandem Dump Truck	9	52
51228	Tandem Dump Truck	10	54
51457	Tandem Dump Truck	11	52

Figure 27. Priority ranking list.

Equipment Replacement Analysis Tool

Unit Level LCCA Analysis

Sample DOT | Equipment Number: 51111 | Description: Tandem Dump Truck

Lowest Cost Year, To-Date: 13 | Mileage: 160,353

	Cost Per Mile					
Age	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs
1	0.16	0.13	0.03	0.32	2.52	2.85
2	0.09	0.13	0.02	0.24	1.26	1.50
3	0.07	0.13	0.02	0.21	1.06	1.27
4	0.08	0.13	0.02	0.22	0.84	1.06
5	0.09	0.12	0.02	0.23	0.85	1.08
6	0.10	0.12	0.02	0.25	0.81	1.06
7	0.11	0.12	0.03	0.27	0.76	1.03
8	0.12	0.12	0.03	0.27	0.69	0.96
9	0.11	0.12	0.04	0.27	0.68	0.95
10	0.11	0.12	0.04	0.27	0.65	0.92
11	0.11	0.12	0.05	0.28	0.60	0.88
12	0.11	0.11	0.05	0.28	0.57	0.84
13	0.12	0.11	0.06	0.29	0.54	0.83
14	0.15	0.11	0.06	0.33	0.51	0.83
15	0.17	0.11	0.08	0.35	0.48	0.84
16	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

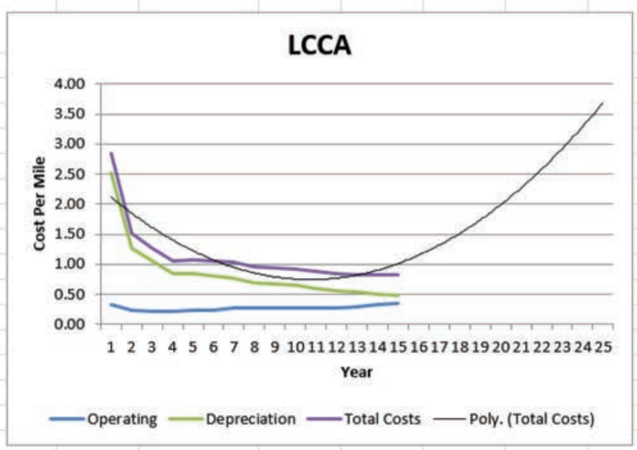


Figure 28. Example of unit-level LCCA for Tandem 51111.

Equipment Replacement Analysis Tool

Sample DOT   Class: DT-5000

5-Year Replacement Schedule: _ Dump Truck

Replacement Cost: $ 117,000
Inflation Rate: 2.0%

Equipment Number	Description	In- Service Year	Until Replac	Backlog	5-Year Annual Replacement Needs 2016	2017	2018	2019	2020
				$ 4,329,000	$ 3,159,000	$ 238,680	$ 5,599,433	$ -	$ 19,249,974
51101	Tandem Dump Truck	1996	-5	$ 117,000					
51103	Tandem Dump Truck	1997	-4	$ 117,000					
51109	Tandem Dump Truck	1997	-4	$ 117,000					
51102	Tandem Dump Truck	1997	-4	$ 117,000					
51104	Tandem Dump Truck	1997	-4	$ 117,000					
51105	Tandem Dump Truck	1997	-4	$ 117,000					
51106	Tandem Dump Truck	1997	-4	$ 117,000					
51107	Tandem Dump Truck	1997	-4	$ 117,000					
51110	Tandem Dump Truck	1997	-4	$ 117,000					
51111	Tandem Dump Truck	1997	-4	$ 117,000					
51112	Tandem Dump Truck	1997	-4	$ 117,000					

- in 2019 column designates years past due.

Figure 29. Example of 5-year replacement needs.

This case scenario uses only the class of tandem dump trucks. If all equipment classes are included with data uploaded to the optimization tool, the 5-Year Plan will show total replacement needs for the entire fleet. The 5-Year Plan provides fleet managers with valuable information on future funding needs.

Step 12. Analyze Cost Consequences

An optional step in the annual fleet replacement process is to analyze the cost consequences if equipment is not replaced at their optimal life cycles. This step is not needed in the replacement decision-making process but it provides information that fleet managers can use to support the business case for funding levels.

The optimization tool analyzes the annual cost of various replacement cycle scenarios. Figure 30 shows the analysis for the class of tandem dump truck case scenario. The optimization tool determined the optimal life cycle for tandem dump trucks to be 11 years. If the tandems are replaced on an average of every 17 years, for example, the analysis shows that the cost would be about $608,000 more per year to own and operate the dump truck fleet.

Equipment Replacement Analysis Tool

Cost Consequences

Sample DOT   Class: DT-5000

Average Annual Mileage Per Unit: 12,220
No of Units in Class: 720

Replacement Cycle	LTD $ Per Mi/Hour	Annual Unit Total Cost	Annual Class Cost
1	2.57	$ 31,366	$ 22,583,242
2	2.52	$ 30,853	$ 22,214,436
3	2.49	$ 30,393	$ 21,883,248
4	2.45	$ 29,986	$ 21,589,679
5	2.42	$ 29,630	$ 21,333,728
6	2.40	$ 29,327	$ 21,115,395
7	2.38	$ 29,076	$ 20,934,680
8	2.36	$ 28,877	$ 20,791,584
9	2.35	$ 28,731	$ 20,686,105
10	2.34	$ 28,636	$ 20,618,246
11	2.34	$ 28,594	$ 20,588,004
12	2.34	$ 28,605	$ 20,595,381
13	2.35	$ 28,667	$ 20,640,376
14	2.36	$ 28,782	$ 20,722,989
15	2.37	$ 28,949	$ 20,843,221
16	2.39	$ 29,168	$ 21,001,070
17	2.41	$ 29,440	$ 21,196,539
18	2.44	$ 29,763	$ 21,429,625
19	2.47	$ 30,139	$ 21,700,330

Figure 30. Cost consequences.

Glossary

Condition score—The score assigned to a vehicle component as part of the condition assessment process.

Depreciation—An equipment unit's loss in capital value measured as the original purchase price less the salvage value.

Downtime—The hours that an equipment unit is out of service during normal working hours.

Equipment age—The age of an equipment unit, measured in years from the current date to the in-service year.

Equipment class—A grouping of equipment units of similar size and functionality, normally accompanied by a unique class code.

Equipment utilization—The hours or miles that an equipment unit is operated, typically measured by annual utilization or life-to-date utilization.

Inflation rate—The annual inflation rate used to normalize equipment costs to constant dollars and to project future equipment replacement costs.

Life Cycle Cost Analysis (LCCA)—An economic model for analyzing equipment costs.

Class-level LCCA—Used for determining optimal life cycles; applied to all equipment units with a specific class.

Unit-level LCCA—Used for analyzing individual equipment units.

Maintenance and repair cost (M&R)—The cost for maintaining, servicing, and repairing equipment units includes all types of repairs.

Mission criticality—A rating assigned to equipment units to recognize the relative importance of individual units and used to help rank replacement priorities.

Obsolescence cost—The cost associated with the reduced performance and efficiency of equipment over time.

Operating cost—The cost of maintenance, repairs, and fuel of an equipment unit and expressed in cost per mile/hour for LCCA.

Optimization tool—The Excel-based tool for performing LCCA and providing analysis to support the replacement process.

Ownership cost—The capital investment cost of equipment; expressed in cost per mile/hour for LCCA.

Overhead rate—A percentage factor applied to mechanic labor to account for mechanic and shop overhead costs.

Direct overhead—Overhead associated directly with mechanic labor.

Indirect overhead—Overhead associated with shop operations for maintenance and repairs.

Replacement cost—The current cost to replace an equipment unit with a like unit.

Replacement planning values—Target values for age and utilization, used to identify potential replacement candidates.

Salvage value—The resale value of a unit that can be expressed as a percent of the original purchase price.

Shop work order—A paper or computerized form for capturing labor hours, costs, and other pertinent information for a single equipment repair event.

Unit—An individual piece of equipment.

PART III

Replacement Optimization Analysis Tool User Manual

CONTENTS

PART III Replacement Optimization Analysis Tool User Manual

CHAPTER 1

Introduction

1.1 Background

The National Cooperative Highway Research Program Project 13-04 has developed a guide for optimal replacement cycles of highway operations equipment and an Excel-based replacement optimization analysis tool to support equipment replacement processes. The guide describes the equipment replacement processes, replacement factors, and LCCA methods. This user manual describes how to use the Excel-based tool.

1.2 About This User Manual

The user manual is a companion document to the analysis tool. It is best to review the guide first to understand how the optimization tool supports the equipment replacement processes. The user manual provides instructions for

- Installing the optimization tool;
- Customizing the tool to meet an agency's needs;
- Importing equipment data from the agency's equipment information systems; and
- Using the tool's six main functions to analyze equipment life cycle cost and support equipment replacement.

1.3 Overview of the Optimization Analysis Tool

The tool has the following six functions:

1. Determining optimal life cycles for each equipment class;
2. Performing LCCA on individual equipment units;
3. Identifying candidate replacement units based on utilization or life cycle cost;
4. Prioritizing equipment replacement units;
5. Developing a 5-year replacement needs budget; and
6. Analyzing the cost consequences of various replacement cycles.

CHAPTER 2

Tool Installation

Note: Microsoft Office 2010 or newer is required on each computer that uses the tool.

The tool uses Microsoft Excel and contains 45 files, including separate linked spreadsheets for the 40 equipment classes listed in the guide.

Follow the steps below and reference the accompanying screenshots to ensure maintaining the links between the spreadsheets when installing the tool. These links are critical for the tool to function correctly.

Step 1. Locate the File

The tool may be available as a download or on a storage device such as a CD or thumb drive. Locate the file named "**Equipment Optimization Tool Installation.exe**" on the computer's desktop, default download folder, or storage device, as shown in Figure 1. Double-click on the file.

Step 2. Begin the Installation

If a Windows User Account Control message asking if you want to allow the program to make changes to the computer appears on the screen (Figure 2), click on Yes.

Step 3. Complete the Installation

When the installation window appears (Figure 3), click on Install to install the tool onto the computer.

Step 4. Extract the Files

After clicking on Install, the tool's installer will begin extracting all of the necessary spreadsheets onto the correct location on the computer. The tool is automatically installed to **C:\Equipment Replacement Optimization Tool/**. **Note:** This exact file location is required for the tool to work correctly. No user interaction is needed during this step.

Once file extraction is complete, the installer will indicate that setup has finished installing the Equipment Replacement Optimization Tool on the computer. Click on Finish to complete the installation (Figure 4).

Step 5. Verify the Files Were Copied to the Correct Location

Double-click on the C: drive and find the folder named "**Equipment Replacement Optimization Tool.**" Double-click on the folder to see the list of linked Excel files inside it, as shown in Figure 5.

Note: Do not change the spreadsheet names, as this will break the links between them.

The tool is now loaded onto the computer and is ready for setup.

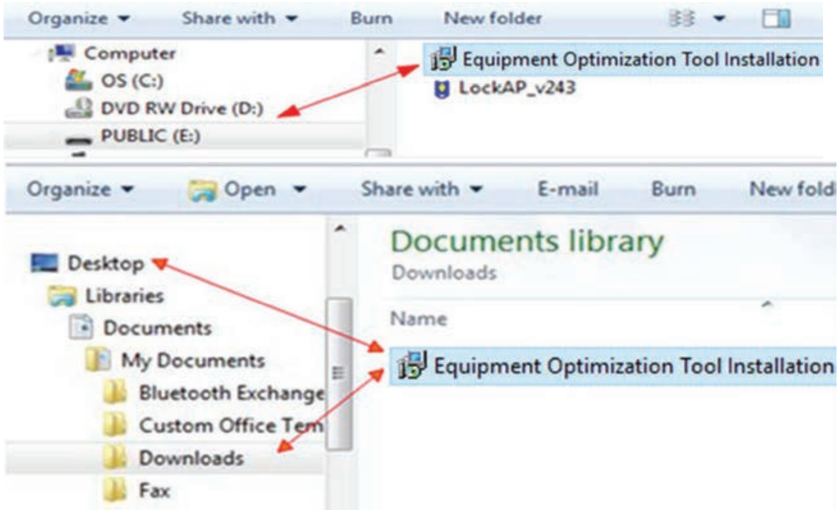


Figure 1. File location.

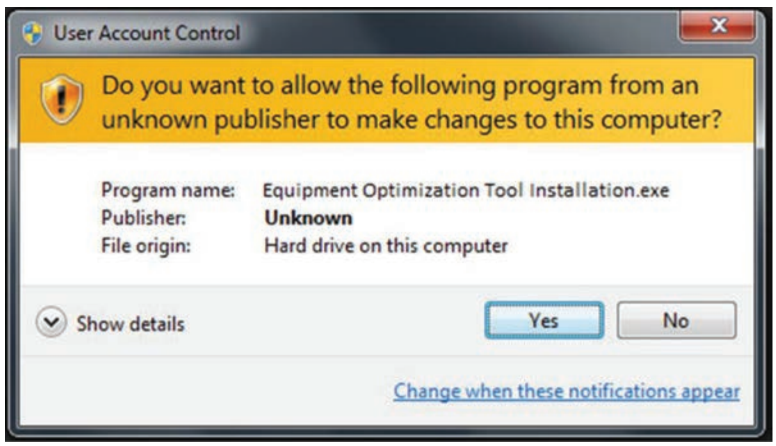


Figure 2. User account control message.

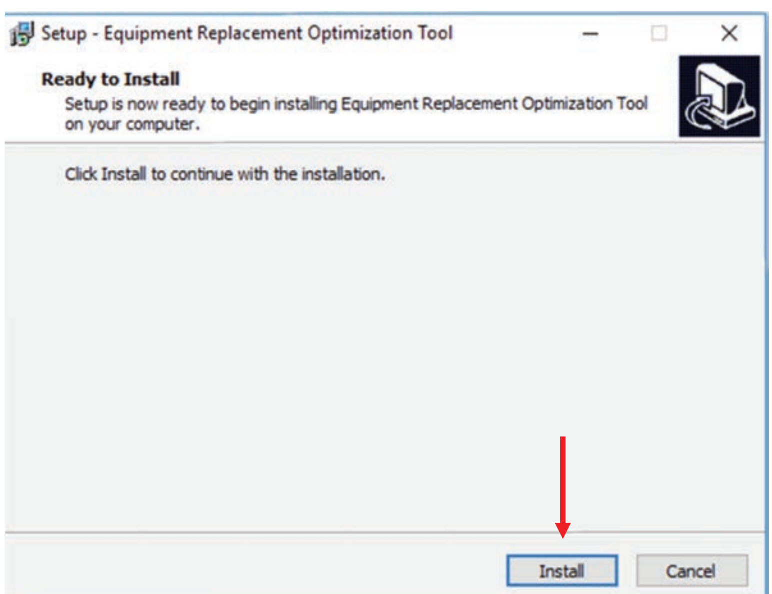


Figure 3. Installation.

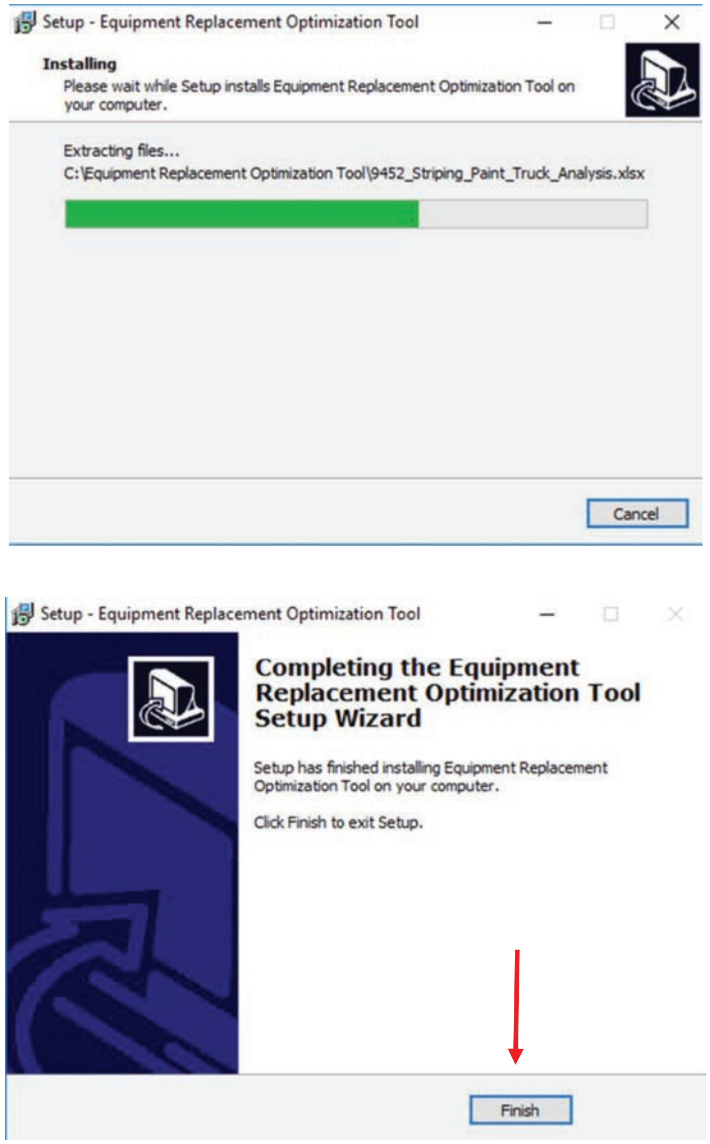


Figure 4. Extract files.

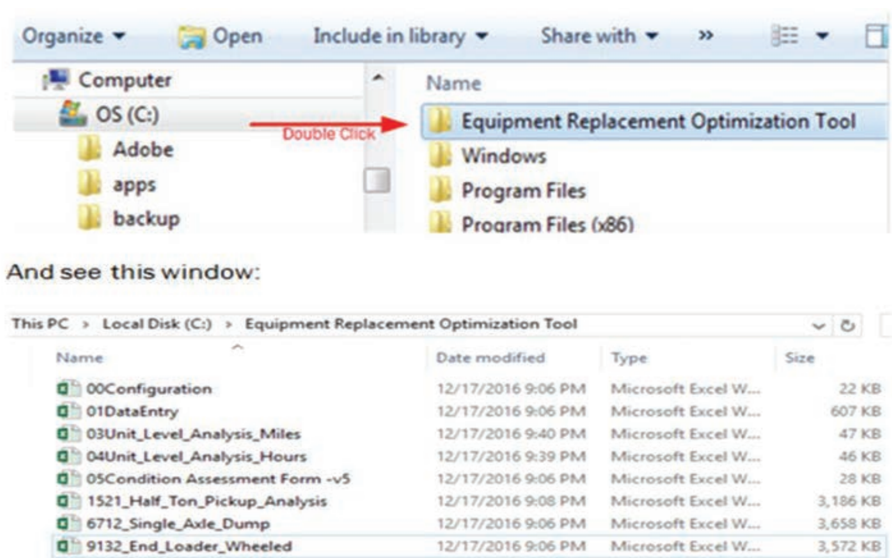


Figure 5. Verify file copy.

CHAPTER 3

Tool Setup and Configuration

Once the tool has been installed, initial setup and configuration are required to customize the replacement factors to your agency's specifications. The guide describes the replacement factors in detail and explains how they are used. Many of the replacement factors have default values preloaded in the optimization tool. Each of the preloaded factors can be adopted as is or changed to fit the agency's needs.

3.1 Tool Setup

Go to the tool folder **C:/Equipment Replacement Optimization Tool** on the computer and open the Configuration File, which is named "**00Configuration.xlsx.**" See Figure 6.

Note: In some versions of Microsoft Windows and Excel, an error message will appear when opening the tool directly from Windows without already having the Excel program open. This can be remedied by opening Excel before opening the tool's spreadsheets.

Formatting in the configuration file is as follows:

- *Blank white cells* require your input to set up the tool.
- *White cells with preloaded data* contain the default values for replacement factors that can be adopted as is or can be changed to meet the agency's needs.
- *Blue cells* are locked and cannot be modified.

Note: Rows or columns cannot be added to the configuration file because many of the tool's calculations are linked to specific cells in the tables. All of the tool's spreadsheets are password protected to prevent accidental changes.

3.2 Tool Configuration

Follow the steps below to review the default values and enter the values that meet the agency's needs. This process can occur in any order.

Agency Name

In Cell B3, input the organization's name (Figure 6). It will appear on most of the files within the tool.

Planning Year

In Cell B5 in Figure 6, use the drop-down box to select the year in which to begin the equipment analysis. Normally, this should be the current year; however, the tool is preset to go back to 2015.

Note: This cell must be updated annually at the beginning of the fleet planning process.

Agency Class Codes

When opening the tool (Figure 7), the white cells in the first column will be blank. In these cells, input the agency's existing class codes corresponding to the universal class codes and descriptions shown in the second and third columns.

Any alphanumeric numbering scheme can be used as long as the codes match the equipment history data that will be later uploaded or input to the tool, as discussed hereafter.

Note: The codes in the first column must match exactly the codes used in the data entry sheet (see Chapter 4).

Only one class code at a time may be entered into the class code cells. If the agency has more than one class code corresponding to the default class codes, the user can either analyze all of the units at one time or separate them into individual classes. The following example illustrates how to do this.

Assume that an agency has four classes of ½-ton pickup, as follows:

Class 1234—Regular Cab, Gas	90 units
Class 1235—Extended Cab, Gas	34
Class 1236—Regular Cab, Diesel	7
Class 1237—Extended Cab, Diesel	157
Total	**288 units**

Equipment Replacement Optimization Tool

Configuration Input Tables

Agency Name: Agency Name Here

Planning Year: 2017 *Update before yearly data entry

Class Codes					Replacement Planning Targets			
						Utilization		
			Current Replacement	Hourly Downtime	Age	Miles		10,000
Agency	Tool	Description	Cost	Rate	Years		Hours	500
	1300	Sedan		$ 25	6	90,000		20%
	1600	SUV		$ 25	6	90,000		20%
	1348	Police Cruiser		$ 25	5	80,000		20%
	1521	1/2 Ton Pickup		$ 35	8	110,000		15%
	1531	3/4 Ton Pickup		$ 35	8	110,000		15%
	1523	1/2 Ton Crew Cab		$ 35	8	110,000		15%
	1533	3/4 Ton Crew Cab		$ 35	8	110,000		15%
	1424	Vans		$ 35	8	110,000		20%
	3514	Mechanic Shop Truck		$ 45	10	120,000		15%
	2513	1 Ton Crew Cab		$ 45	10	120,000		15%
	3711	Flat Bed Truck		$ 45	10	120,000		15%
	3744	Scissor Bed Truck		$ 45	10	120,000		15%

Figure 6. Configuration file.

All 288 units can be analyzed together or each class can be analyzed separately. To analyze only Class 1234, for example, enter the number "1234" into the configuration file as the agency class code. To analyze all of the units together, enter all of the units into the data entry file under the same code.

8	Class Codes		
9	Agency	Tool	Description
10		1300	Sedan
11		1600	SUV
12		1348	Police Cruiser
13			
14		1521	1/2 Ton Pickup
15		1531	3/4 Ton Pickup
16		1523	1/2 Ton Crew Cab
17		1533	3/4 Ton Crew Cab
18		1424	Vans
19			
20		3514	Mechanic Shop Truck
21		2513	1 Ton Crew Cab
22		3711	Flat Bed Truck
23		3744	Scissor Bed Truck

Figure 7. Equipment class code in data entry.

Current Replacement Cost

When opening the optimization tool (Figure 8), the white cells in Column F will be blank. Input the average replacement cost for vehicles in the specific class. Replacement cost is the current cost to replace that class of equipment, including the cost to outfit it with lights or radios, if applicable.

Equipment replacement costs may vary for individual equipment types within a class. For example, pickups may be 2-wheel drive or 4-wheel drive, and may or may not have extended cabs. Enter the average replacement cost for vehicles within a class, or enter a replacement cost that represents the majority of the equipment types within a class.

Note: The replacement costs should be updated each year.

Hourly Downtime Rate

The hourly downtime rate in Column G in Figure 8 is the agency's internal hourly rental rate for each equipment class. The default values preloaded into the tool are based on industry norms. Use the default values or input values specific to the agency.

Replacement Planning Targets

Columns H, I, and J in Figure 9 contain default replacement planning target values for each equipment class based on

	A	B	C	D	E	F	G
7						Current	Hourly
8	Class Codes					Replacement	Downtime
9	Agency	Tool		Description		Cost	Rate
10		1300		Sedan			$ 14
11		1600		SUV			$ 16
12		1348		Police Cruiser			$ 19
13							
14		1521		1/2 Ton Pickup			$ 19
15		1531		3/4 Ton Pickup			$ 20
16		1523		1/2 Ton Crew Cab			$ 19
17		1533		3/4 Ton Crew Cab			$ 20
18		1424		Vans			$ 22
19							
20		3514		Mechanic Shop Truck			$ 22
21		2513		1 Ton Crew Cab			$ 22
22		3711		Flat Bed Truck			$ 25
23		3744		Scissor Bed Truck			$ 25

Figure 8. Replacement cost and hourly downtime rate entry.

age, miles, and hours. These values are used only to identify potential replacement candidates; these values are not hard-and-fast replacement standards. Use the default values or input values specific to the agency.

Accumulated Depreciation

Columns K through AI in Figure 10 (Columns E through J are not shown) contain the default accumulated depreciation percentages for each equipment class by miles or hours. These depreciation rates were developed from research conducted in this NCHRP project and represent industry norms. For example, a sedan with 30,000 LTD miles has accumulated depreciation of 42%, and a sedan with 40,000 miles has accumulated depreciation of 51%. The tool interpolates to compute depreciation between these two mileage values. Use the default values or input values specific to the agency.

Universal Cost Factors

The tool uses several universal factors for cost and replacement analyses (Figure 11). These factors, which begin on Row 64, are described. Use the default values or input values specific to the agency.

	A	B	C	D	H	I	J
6					Replacement Planning Targets		
7						Utilization	
8	Class Codes				Age	Miles	
9	Agency	Tool		Description	Years		Hours
10		1300		Sedan	6	90,000	
11		1600		SUV	6	90,000	
12		1348		Police Cruiser	5	80,000	
13							
14		1521		1/2 Ton Pickup	8	110,000	
15		1531		3/4 Ton Pickup	8	110,000	
16		1523		1/2 Ton Crew Cab	8	110,000	
17		1533		3/4 Ton Crew Cab	8	110,000	
18		1424		Vans	8	110,000	
19							

Figure 9. Replacement planning targets.

	A	B	C	D	K	L	M	N	O	P	Q	R
7					Accumulated Depreciation at Miles or Hours							
8	Class Codes				10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000
9	Agency	Tool		Description	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000
10		1300		Sedan	20%	31%	42%	51%	59%	67%	73%	78%
11		1600		SUV	20%	31%	42%	51%	59%	67%	73%	78%
12		1348		Police Cruiser	20%	31%	42%	51%	59%	67%	73%	78%
13												
14		1521		1/2 Ton Pickup	15%	24%	32%	40%	47%	53%	59%	65%
15		1531		3/4 Ton Pickup	15%	24%	32%	40%	47%	53%	59%	65%
16		1523		1/2 Ton Crew Cab	15%	24%	32%	40%	47%	53%	59%	65%
17		1533		3/4 Ton Crew Cab	15%	24%	32%	40%	47%	53%	59%	65%
18		1424		Vans	20%	31%	42%	51%	59%	67%	73%	78%

Figure 10. Accumulated depreciation.

- *Direct Overhead* (Cell E64) is applied to the labor cost downloaded from the agency's equipment information systems to arrive at a loaded labor cost for equipment maintenance. The tool contains a default value of 45%. The guide describes how the default value was derived and provides a template for developing a direct overhead factor for the agency. Review this factor carefully to make sure it is the correct value for the agency.
- *Indirect Overhead* (Cell E65) is applied to the labor cost in the same manner as the direct overhead factor. The tool contains a default value of 90%. Refer to the guide to develop a value specific to the agency.
- *Inflation Rate* (Cell E66) is the default annual inflation value of 2.5%, which can be changed if needed.
- *Obsolescence Rate* (Cell E67) is applied to fuel costs over the life of the equipment. The tool contains a default value of 2.0%, which can be changed if needed.
- *Equipment Replacement Priority Factors* (Cells E70 and E71) are used by the tool to compute a replacement priority ranking for each equipment unit based on its LTD cost and condition. These cells contain default values of 40% for cost and 60% for condition. Refer to the guide for an explanation of how the priority weighting factors are used.

62		
63	Universal Cost Factors	
64	Direct Overhead	45%
65	Indirect Overhead	90%
66	Inflation Rate	2.5%
67	Obsolescence Rate	2.0%
68		
69	Equipment Replacement Priority Factors	
70	Cost Per Mile Weight	40.0%
71	Condition Score Weight	60.0%
72		

Figure 11. Universal cost factors.

The tool setup and configuration process is now complete and importing the agency's equipment data can begin.

CHAPTER 4

Importing Agency Equipment Data into the Tool

Historical cost data and other equipment information are needed to determine optimal life cycles and make replacement decisions. This chapter describes how to import agency data into the tool for performing cost and replacement analysis.

4.1 Quick Tips

The tool will operate most effectively if maintenance costs are broken into separate cost categories for parts, labor, and commercial. If the agency does not separate cost by these categories, then combine all maintenance costs under the parts category.

VERY IMPORTANT: Always review the data downloaded from the agency's systems for errors and questionable data before entering it into the tool. Scrub the data so that any errors are corrected. If errors cannot be corrected, the unit in question should be eliminated from the cost analysis.

Determine if there are enough units in a particular class to perform a class-level LCCA. If there is a small number of units in a class, it is unlikely that an optimal life cycle can be calculated reliably. The tool needs multiple pieces of equipment with ages spread across the expected life of the equipment to produce acceptable results.

- One example is that a state may have two bridge snooper trucks, one that is 3 years old and one that is 15 years old. Calculating a class-average optimal life cycle with these two units would not be meaningful.
- Another example is that of the class of ½-ton pickup previously described in Chapter 3. There are only seven units in Class 1236. Again, it is not likely that this small sample size can generate a reliable class average LCCA.

4.2 Extracting Data from Agency Systems

The first step for entering the agency's historical data into the tool is to extract the required equipment data from the agency's existing systems and download it into an Excel file, external to the optimization tool. Two types of data are required:

1. LTD data to perform class-level LCCA, in which all units in a class are analyzed to determine a class average optimal life.
2. Annual cost data for each year of a unit's life to perform unit-level LCCA for individual units of equipment.

Highway agencies have different formats and systems for tracking equipment data. To make the tool universally applicable to all agencies, the user can do the data extraction externally from the optimization tool. Because this process depends on the agency's specific information systems, assistance may be required from the system administrator for each of the systems from which data were obtained. These individuals may be in the information technology or finance sections of the agency.

Once the extracted data have been downloaded into an Excel file, the data must be formatted, as discussed in Section 4.3.

Before entering the data into the tool, validate that the downloaded data is error free. The data should be complete, correct, and consistent in format. Erroneous data and extreme outliers should be corrected or eliminated. The replacement guide provides several examples of common data errors and illustrates various tests for determining data accuracy.

4.3 Uploading Data to the Tool

After downloading the data into an Excel file and reviewing for accuracy, use the following process to upload the data to the tool.

1. In Excel, go to the tool folder, **C:/Equipment Replacement Optimization Tool,** and open the data entry sheet, which is named "**01DataEntry.xlsx.**" See Figure 12.

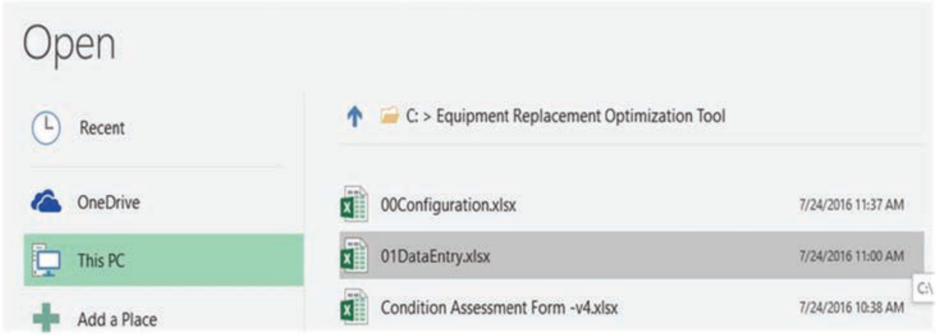


Figure 12. Tool folder selection.

2. When opening the data entry sheet, all cells will be empty. Row 1, Columns A through K (see Figure 13), are locked and cannot be changed.

   Enter the data in the exact format shown in Figure 13, which shows sample data for tandem dump trucks. Include all equipment units in the classes for which optimal life cycles will be determined.

   Note: Before uploading the data to the tool, the equipment data must be downloaded from the agency's existing systems or sources and must be formatted in an Excel file as shown in Figure 13.

3. The data format requirements for the data entry sheet are as follows:

   Equipment Number (Column A)—Required. The agency's existing equipment ID number; must be unique for each unit. Any alphanumeric form can be used.

   Agency Class Code (Column B)—Required. The agency class for each type of equipment; must exactly match the agency class information in the configuration file.

   Description (Column C)—Optional. A free-form description of the equipment class; use the agency's existing class description titles.

   In-Service Year (Column D)—Required. The four-digit year when the unit was first placed into service. The data type for this column must be number or general format and not a date format.

   Miles or Hours (Column E)—Required. The current LTD miles or hours on the unit.

   Parts, Labor, and Commercial Costs (Columns F through H)—Required. LTD costs for each cost component. The tool applies the direct and indirect overhead factors from the configuration file to the labor cost. If the agency does not separate maintenance and repair cost by labor, parts, and commercial, enter the combined cost into Parts.

   Fuel (Column I)—Optional. The LTD fuel costs in dollars. If the agency tracks fuel in gallons, convert gallons into dollars by using an average or current fuel price. If the agency does not have fuel costs, leave this column blank and the tool will ignore it. However, fuel costs are required for the tool to compute the full cost of equipment operations.

   Downtime Hours (Column J)—Optional. The tool provides for entering downtime hours if the data are

	A	B	C	D	E	F	G	H	I	J	K
1	Equipment Number	Agency Class Code	Description	In-Service Year	Miles or Hours	Parts	Labor	Commercial	Fuel	Downtime Hours	Purchase Cost
2	DT1234	8712	Tandem Dur	1996	172,525	34,750.22	44,711.11	22,250.55	45307.42	1413	41,373
3	DT1235	8712	Tandem Dur	1997	201,166	22,378.75	26,124.56	11,110.89	46133	973	41,373
4	DT1236	8712	Tandem Dur	1997	110,933	29,216.75	43,967.01	12,878.17	28809.88	1527	41,373
5	DT1237	8712	Tandem Dur	1997	206,531	18,008.68	26,561.54	16,386.72	62485.92	1328	41,373
6	DT1238	8712	Tandem Dur	1997	207,597	19,712.96	30,654.40	15,091.84	55349.24	1244	41,373
7	DT1239	8712	Tandem Dur	1997	77,224	25,242.93	23,360.82	5,475.63	32487.99	932	41,373
8	DT1240	8712	Tandem Dur	1997	169,084	32,227.93	30,396.50	21,184.12	38355.16	892	41,872
9	DT1241	8712	Tandem Dur	1997	111,028	20,254.80	47,981.80	11,575.92	31666.38	1041	41,872

Figure 13. Sample data entry.

available. If the agency does not have reliable downtime data, leave this column blank and the tool will ignore it. However, downtime data are required for the tool to compute the full cost of equipment operations.

Purchase Cost (Column K)—Optional. The original purchase cost of the unit, which may include the cost for equipment preparation and outfitting.

Subgroups within a class may be analyzed separately if desired. For instance, to analyze one manufacturer at a time, input only the vehicle of that make. When doing this type of analysis, always ensure there are enough units within the subgroup to provide a valid sample. Ensure also that the class codes in the configuration file are exactly the same as the class codes in the data entry sheet.

CHAPTER 5

Performing Life Cycle Cost Analysis

The optimization tool performs LCCA at two levels: class level and unit level, each with a specific purpose. Use a class-level LCCA to determine optimal life cycles when complete annual data are not available for LCCA of individual units. It looks at all units in a specific class and bases the cost analysis on average LTD cost for each unit within that class. Use a unit-level LCCA to analyze the life cycle costs of individual units, using annual cost data for each year of the unit's life.

5.1 Class-Level LCCA

The class-level LCCA uses LTD data uploaded in the format shown in Figure 13. The tool performs the LCCA in the following manner:

- All equipment units are grouped by age. The tool is preset for 25 years of analysis. Vehicles older than 25 years are not shown.
- The LTD cost per mile or hour is calculated for each of the cost components. Maintenance includes labor, parts, and commercial costs. Depreciation cost is calculated from the replacement cost and depreciation schedule in the configuration file for the particular class.
- The total cost per mile is obtained by totaling maintenance, fuel, downtime, operating, and depreciation costs.

Use the following process to perform class-level LCCA.

1. Open the tool folder, **C:/Equipment Replacement Optimization Tool,** and click on the spreadsheet for the desired class. The folder contains a separate spreadsheet for each of the 40 equipment classes. The following example uses the "**1521_Half_Ton_Pickup_Analysis.xlsx**" file as shown in Figure 14. To complete the cost calculations and view the results of other equipment classes, open each class spreadsheet separately.

   When opening a class spreadsheet, the tool automatically performs the cost calculations for that equipment class, using data that was loaded to the tool by the process detailed in Chapter 4. Although it is not always necessary, it is recommended that the data in each spreadsheet be refreshed by clicking on "**Data**" on the Excel toolbar and then clicking on "Refresh All," as shown in Figure 15.

   Note: In some versions of Microsoft Windows and Excel, an error message will appear when opening the tool directly from Windows without already having the Excel program open. Therefore, it is recommended to open Excel before opening the tool's spreadsheets.
2. Once selected, each class analysis spreadsheet displays five tabs as shown in Figure 16. Click on the LCCA tab at the bottom of the sheet to display the results of the class-level LCCA.
3. View the results in both table and graph form. Figure 17 shows the results for the example using the class of ½-ton pickup.
4. The following text explains the results shown in Figure 17.
   - Cell E6 displays the calculated optimal replacement year, which is 7 for this example. Cell J6 displays the calculated optimal replacement mileage, which is 95,377 for this example.
   - Column A displays the age of all equipment units for that row.
   - Column B shows the number of equipment units in that age category. For example, 16 ½-ton pickups are 1 year old.
   - Column C shows the year in which the units were placed in service.
   - Columns D through H show the calculated average LTD cost per mile for each of the cost components.
   - Column I is the average total cost per mile for all units of that age.
   - Column J displays the calculated values on the trend curve for each year. Use the trend values to determine the optimal replacement year shown in Cell E6.

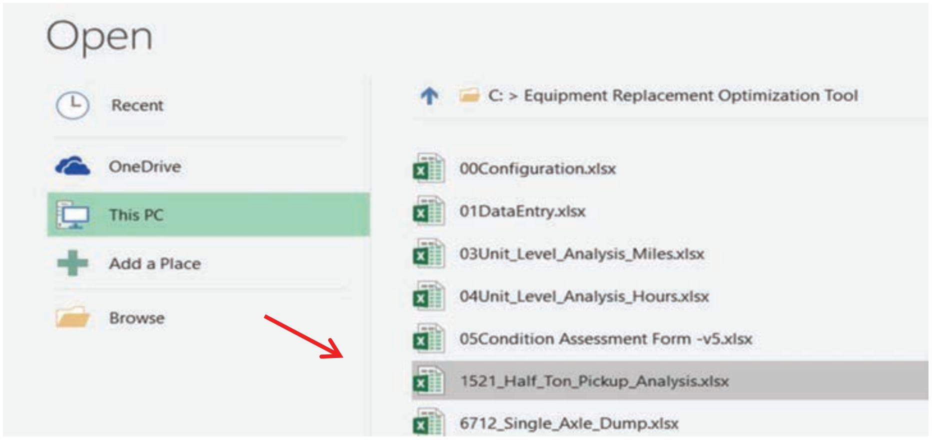


Figure 14. File selection for class-level LCCA.

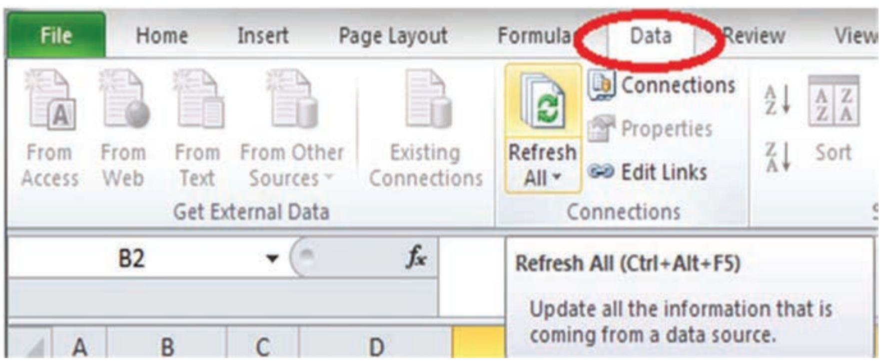
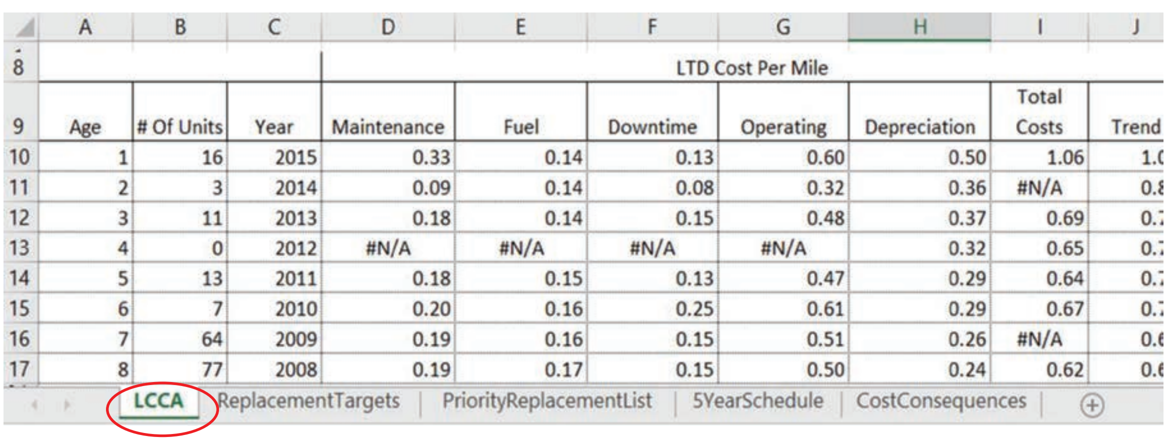


Figure 15. Data refresh.



	A	B	C	D	E	F	G	H	I	J
8				LTD Cost Per Mile						
9	Age	# Of Units	Year	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs	Trend
10	1	16	2015	0.33	0.14	0.13	0.60	0.50	1.06	1.0
11	2	3	2014	0.09	0.14	0.08	0.32	0.36	#N/A	0.8
12	3	11	2013	0.18	0.14	0.15	0.48	0.37	0.69	0.7
13	4	0	2012	#N/A	#N/A	#N/A	#N/A	0.32	0.65	0.7
14	5	13	2011	0.18	0.15	0.13	0.47	0.29	0.64	0.7
15	6	7	2010	0.20	0.16	0.25	0.61	0.29	0.67	0.7
16	7	64	2009	0.19	0.16	0.15	0.51	0.26	#N/A	0.6
17	8	77	2008	0.19	0.17	0.15	0.50	0.24	0.62	0.6

#N/A designates no data available.

Figure 16. Equipment analysis file tabs.

Equipment Replacement Analysis Tool

LCCA Analysis: 1/2 Ton Pickups

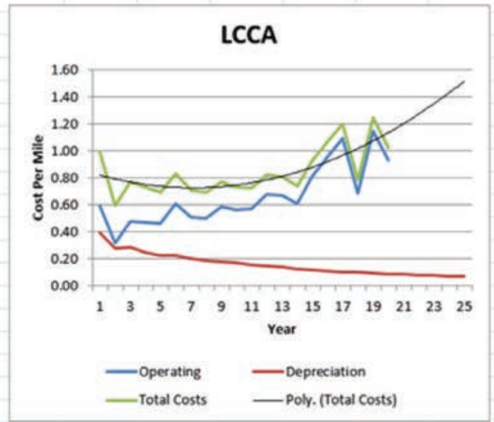
Agency Name Here

Class: 2001

Optimal Replacement Year: 7

Optimal Replacement Mileage: 95,377

			LTD Cost Per Mile						
Age	# Of Units	Year	Maintenance	Fuel	Downtime	Operating	Depreciation	Total	Trend
1	16	2015	0.33	0.14	0.13	0.60	0.39	0.99	0.82
2	3	2014	0.09	0.14	0.08	0.32	0.28	0.60	0.79
3	11	2013	0.18	0.14	0.15	0.48	0.29	0.77	0.77
4	0	2012	#N/A	#N/A	#N/A	#N/A	0.25	#N/A	0.75
5	13	2011	0.18	0.15	0.13	0.47	0.23	0.69	0.74
6	7	2010	0.20	0.16	0.25	0.61	0.23	0.83	0.73
7	64	2009	0.19	0.16	0.15	0.51	0.21	0.71	0.73
8	77	2008	0.19	0.17	0.15	0.50	0.19	0.70	0.73
9	76	2007	0.21	0.18	0.20	0.59	0.18	0.77	0.74
10	108	2006	0.20	0.18	0.18	0.56	0.17	0.73	0.75
11	46	2005	0.21	0.19	0.18	0.57	0.16	0.73	0.77
12	47	2004	0.24	0.19	0.25	0.68	0.15	0.83	0.79
13	26	2003	0.22	0.20	0.25	0.67	0.14	0.81	0.81
14	12	2002	0.21	0.21	0.20	0.61	0.13	0.74	0.85
15	4	2001	0.24	0.21	0.37	0.82	0.12	0.94	0.88
16	0	2000	#N/A	#N/A	#N/A	#N/A	0.11	#N/A	0.92
17	7	1999	0.31	0.23	0.56	1.10	0.11	1.20	0.97
18	4	1998	0.20	0.24	0.25	0.69	0.10	0.79	1.02
19	1	1997	0.25	0.24	0.66	1.15	0.10	1.25	1.08
20	2	1996	0.36	0.25	0.32	0.93	0.09	1.02	1.14



#N/A designates no data available.

Figure 17. Sample class-level LCCA results.

Figure 18 shows a close-up of the graph that displayed the results in Figure 17. The graph depicts the LCCA components for ownership cost (depreciation), operating cost, and total cost. For the purpose of the analysis, the tool projects a smooth trend line for the total cost curve.

5.2 Unit-Level LCCA

The tool also provides the ability to perform LCCA of individual equipment units. Unit-level LCCA is especially helpful if there are not enough equipment units in a particular class to perform the class-level LCCA or to examine the details of an individual unit's life cycle cost. For performing unit-level LCCA, note the following:

1. Unit-level LCCA can only be performed on equipment classes listed in the configuration file, because links to the replacement factors in the configuration file are used in the LCCA calculations.
2. Annual cost and utilization data for each year of the unit's life are required. There are two separate spreadsheets used for unit-level LCCA: one for equipment utilization measured by miles and one for equipment utilization measured by hours.

Use the following process to perform unit-level LCCA.

1. Open the tool folder, **C:/Equipment Replacement Optimization Tool,** and click on the unit-level analysis file with the correct utilization type: "**03Unit_Level_Analysis_Miles.xlsx**" for equipment tracked by mileage or "**04Unit_Level_Analysis_Hours.xlsx**" for equipment tracked by hours (see Figure 19).
2. When selected, the unit-level analysis displays the form shown in Figure 20 in the green DataEntry tab. All white cells on this sheet will be empty when first opened.

   The top section of the sheet is used to enter general information about the unit being analyzed, as shown in the example in Figure 21 for a tandem dump truck. Enter the information for the specific unit being analyzed.
3. Download the unit's annual cost data from the agency's system(s) and enter it into the spreadsheet. Enter the annual cost data for each year of the unit's life. This process happens external to the tool. Enter the required utilization, cost, and downtime data in the exact cells beginning on Row 12, as shown in Figure 22.
4. Once the data entry is complete, click on the LCCA tab at the bottom of the spreadsheet, as shown in Figure 23, to view the analysis.

Figure 24 shows the results for Unit 123, a tandem dump truck. Results of the analysis will show the equipment number, description of the unit, and the results in both table and graph form.

The output from the unit-level LCCA is similar to the output of the class-level LCCA but describes the results somewhat

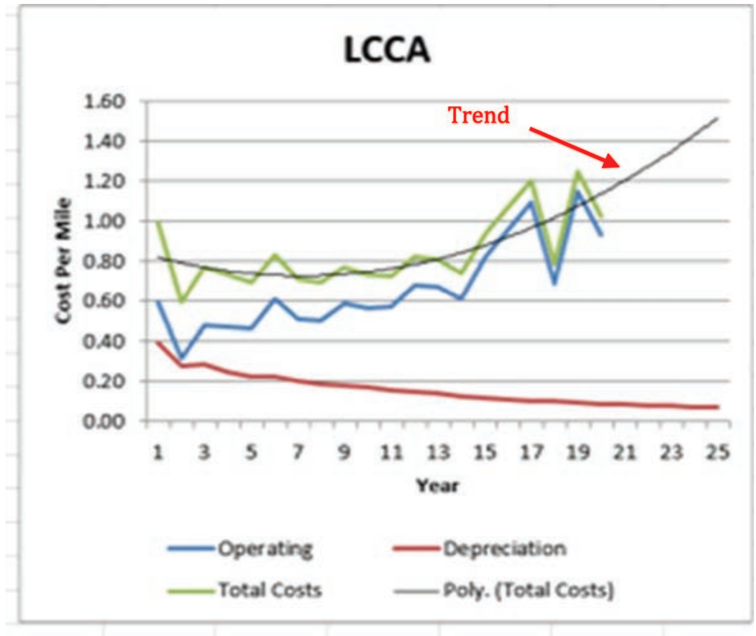


Figure 18. LCCA graph.

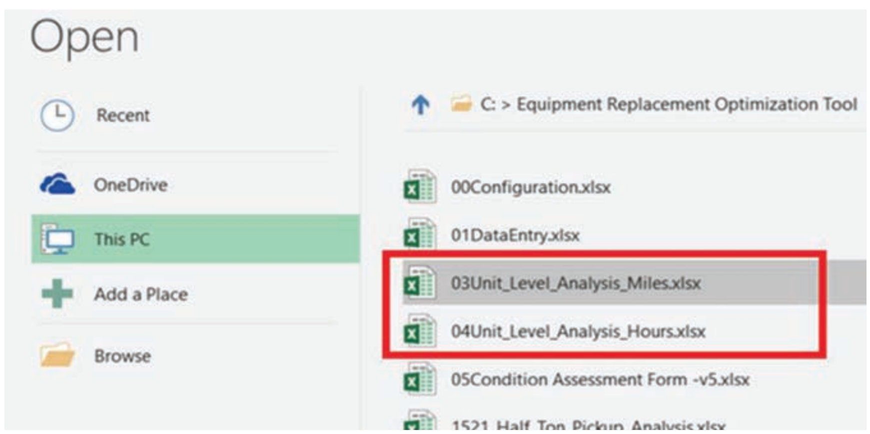


Figure 19. File selection for unit-level LCCA.

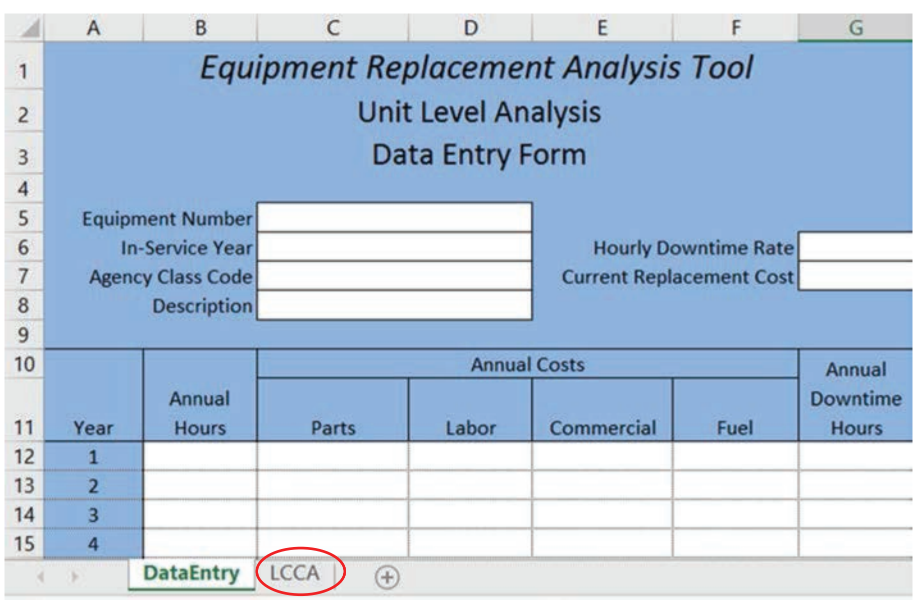


Figure 20. DataEntry tab selection.

	A	B	C	D	E	F	G
1			*Equipment Replacement Analysis Tool*				
2			Unit Level Analysis				
3			Data Entry Form				
4							
5		Equipment Number	123				
6		In-Service Year	2001			Hourly Downtime Rate	$ 60.00
7		Agency Class Code	4002			Current Replacement Cost	$ 98,500
8		Description	Tandem				

Figure 21. General equipment data.

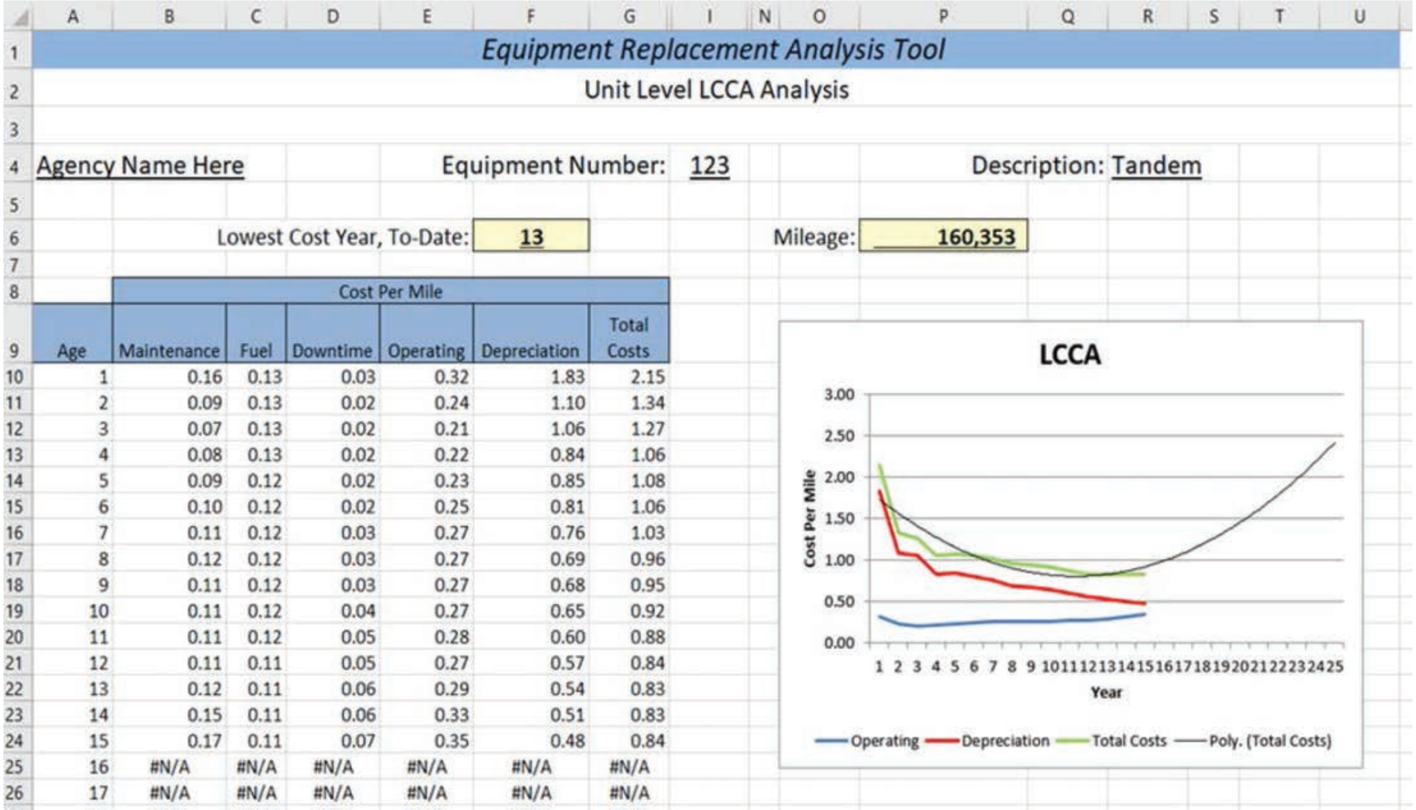
10			Annual Costs				Annual
11	Year	Annual Miles	Parts	Labor	Commercial	Fuel	Downtime Hours
12	1	7802	$340.93	$174.79	$121.00	$709.27	3
13	2	8995	$43.12	$73.65	$0.00	$817.74	1
14	3	15371	$80.39	$162.25	$0.00	$1,397.41	3
15	4	16701	$876.06	$198.20	$0.00	$1,518.30	4
16	5	14155	$430.87	$192.30	$344.87	$1,286.79	3
17	6	9696	$277.21	$461.18	$0.00	$881.42	8
18	7	11463	$977.12	$399.00	$0.00	$1,042.07	12
19	8	14638	$388.33	$445.55	$291.68	$1,330.73	8
20	9	12671	$456.77	$155.36	$0.00	$1,151.91	10
21	10	10678	$340.93	$115.96	$0.00	$970.73	18
22	11	13112	$877.72	$298.54	$0.00	$1,192.00	32
23	12	15371	$567.88	$277.26	$0.00	$1,397.41	11
24	13	9700	$1,076.54	$901.98	$187.93	$881.82	17
25	14	12155	$2,988.00	$1,016.33	$975.81	$1,105.00	30

Figure 22. Data entry for unit-level LCCA.

24	13	9700	$1,076.54	$901.98	$187.93	$881.82	17
25	14	12155	$2,988.00	$1,016.33	$975.81	$1,105.00	30
26	15	9967	$2,298.44	$567.30	$457.26	$906.09	47
27	16						
28	17						
29	18						

DataEntry | LCCA

Figure 23. LCCA tab selection.



Equipment Replacement Analysis Tool

Unit Level LCCA Analysis

Agency Name Here — Equipment Number: 123 — Description: Tandem

Lowest Cost Year, To-Date: 13 — Mileage: 160,353

	Cost Per Mile					
Age	Maintenance	Fuel	Downtime	Operating	Depreciation	Total Costs
1	0.16	0.13	0.03	0.32	1.83	2.15
2	0.09	0.13	0.02	0.24	1.10	1.34
3	0.07	0.13	0.02	0.21	1.06	1.27
4	0.08	0.13	0.02	0.22	0.84	1.06
5	0.09	0.12	0.02	0.23	0.85	1.08
6	0.10	0.12	0.02	0.25	0.81	1.06
7	0.11	0.12	0.03	0.27	0.76	1.03
8	0.12	0.12	0.03	0.27	0.69	0.96
9	0.11	0.12	0.03	0.27	0.68	0.95
10	0.11	0.12	0.04	0.27	0.65	0.92
11	0.11	0.12	0.05	0.28	0.60	0.88
12	0.11	0.11	0.05	0.27	0.57	0.84
13	0.12	0.11	0.06	0.29	0.54	0.83
14	0.15	0.11	0.06	0.33	0.51	0.83
15	0.17	0.11	0.07	0.35	0.48	0.84
16	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
17	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

#N/A designates no data available.

Figure 24. Sample unit-level LCCA results.

differently. Whether a unit has reached its optimal life cycle cannot be known until after the fact. Looking at the graph in Figure 24, the total cost curve levels out in years 12 through 15. However, future maintenance costs cannot be easily predicted, and it is uncertain whether the total cost curve will continue at a level trajectory or begin to rise sharply. A condition assessment of the unit may indicate future needed repairs and give an indication of anticipated costs.

Because it is not known if the unit has reached its optimal life, the unit-level LCCA depicts the "Lowest Cost Year, To-Date" in Cell F6 based on the total costs calculated in Column G. The corresponding mileage is shown in Cell P6.

A trend line is provided on the graph to help visualize the possible future cost trend. The tool is set to analyze up to 25 years of data. The trend line on the graph extends the full 25 years, even if only 15 years of data are available, as in the example.

CHAPTER 6

Equipment Replacement Processes

This chapter describes how to use the tool to support the replacement process.

6.1 Replacement Process

The guide outlines a 12-step, systematic process for annual equipment replacement.

Step 1. Review and Update Replacement Factors

This step is similar to the initial configuration for the optimization tool discussed in Chapter 3. Each year before beginning the equipment replacement process, review the replacement factors in the configuration file to make sure they are still valid. Updating the replacement factors is done in the same manner as in the initial configuration. The replacement cost is one factor that is likely to change each year.

Step 2. Download Equipment Data

Updated equipment data are needed each year. New equipment units likely will have been added in the past year, some units will have been purged from the fleet, and all units will have one additional year of cost and utilization history. Chapter 4 described downloading and inputting data into the optimization tool.

Step 3. Review Data and Correct Errors

This is a very important step in the process. The tool does not edit the data and this step must be performed externally to the tool. The guide provides examples of common errors and illustrates some of the edit routines that will help ensure that the data are appropriate and ready for use.

Step 4. Upload Data to the Optimization Tool

Once the downloaded data are corrected, the data can be uploaded to the optimization tool as described in Chapter 4. If old data exist in the tool, the data should be deleted entirely to prevent possible duplication of data. However, if keeping the old data is desired, the data can be copied into a separate folder and data from the original files can then be deleted.

With Steps 1 through 4 completed, the updated tool is ready to support the equipment cost analyses and replacement process.

Step 5. Perform Class-Level LCCA

A class-level LCCA can be performed as described in Chapter 5 for all equipment classes for which data has been uploaded to the tool (Step 4). At this point, it might be appropriate to use the output from the LCCA to update replacement targets. For instance, if the user's current replacement targets for the class of ½-ton pickup are 8 years and 125,000 miles, an updated LCCA should determine if these are optimal replacement targets.

Step 6. Identify Target Replacement Units

The tool identifies individual equipment units as possible replacement candidates based on the replacement target values for each equipment class in the configuration file. If the replacement targets are updated after completing the class-level LCCA in Step 5, the new target values will be used.

To identify the vehicles that have been flagged as replacement candidates, click on the ReplacementTargets tab at the bottom of the spreadsheet, shown in Figure 25.

The ReplacementTargets sheet, shown in Figure 26, displays the equipment units that for which one or both of the following criteria are reached:

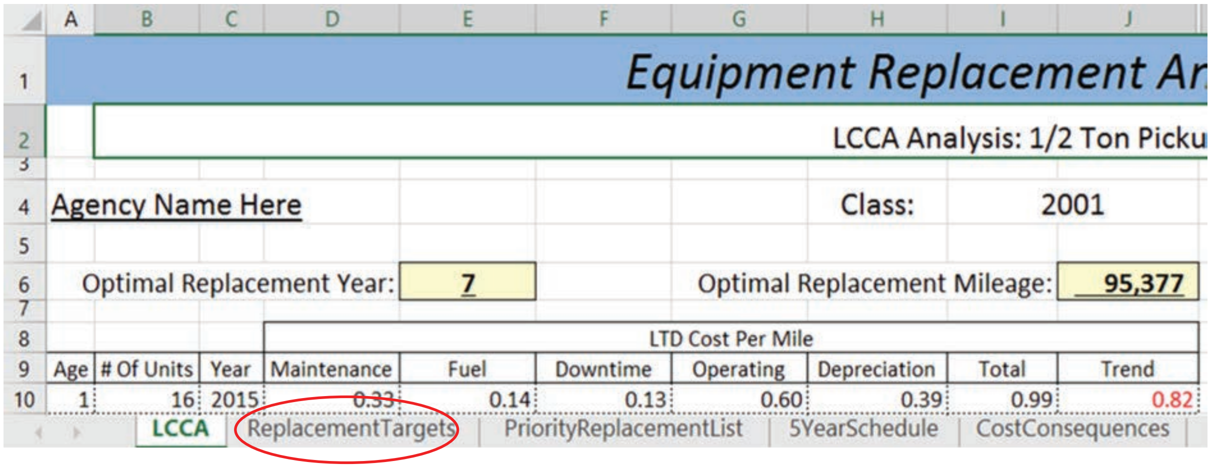


Figure 25. Replacement targets tab.

- Accumulated mileage or hours reach the replacement target mileage or hours set in the configuration file.
- Accumulated total cost per mile or hour exceeds the class average by 25%.

Equipment with the highest percentage over class average LTD cost is listed first.

Consider performing the Refresh Data function to ensure that the tool shows the correct replacement candidates.

An "X" in the Exceeds Replacement Target? column indicates that the unit has exceeded its replacement target for miles or hours. This does not necessarily mean the unit should be replaced but that it should be evaluated for replacement.

Note: Column J, Condition Assessment Score, is blank when opening this sheet. This column is used for manually entering condition assessment scores, as discussed in Step 7.

Print a copy of the replacement target results. A hard copy is often easier to review and can be used to support the remaining process and to act as a backup for records.

Step 7. Perform Condition Assessments

Replacement decisions should consider the current condition of a unit. This step is not required but is strongly recommended, as unassessed equipment will not be placed on the resulting priority replacement list (see Figure 31).

The tool contains an Excel spreadsheet to help perform the condition assessments and arrive at a condition score. The spreadsheet is not linked to other files in the tool, and the condition scores must be manually entered.

To access the Condition Assessment Form, open the tool folder, **C:/Equipment Replacement Optimization Tool,** and click on "**05Condition Assessment Form –v5.xlsx,**" shown in Figure 27.

	A	B	G	H	I	J
1	Equipment Number	Description	% Over Class AVG Cost	LTD Miles or Hours	Exceeds Replacement Target?	Condition Assessment Score
2	TE0529	1/2 Ton Pickup	70%			
3	TE0505	1/2 Ton Pickup	49%			
4	TE0510	1/2 Ton Pickup	44%			
5	TE0485	1/2 Ton Pickup	44%			
6	TE0223	1/2 Ton Pickup	36%	113,129	X	
7	TE0253	1/2 Ton Pickup	34%	120,701	X	
8	TE0392	1/2 Ton Pickup	33%			
9	TE0260	1/2 Ton Pickup	31%	125,164	X	
10	TE0456	1/2 Ton Pickup	28%			
11	TE0018	1/2 Ton Pickup	27%	127,563	X	
12	TE0394	1/2 Ton Pickup	23%	110,544	X	
13	TE0427	1/2 Ton Pickup	22%	119,087	X	

Figure 26. Sample of replacement targets sheet.

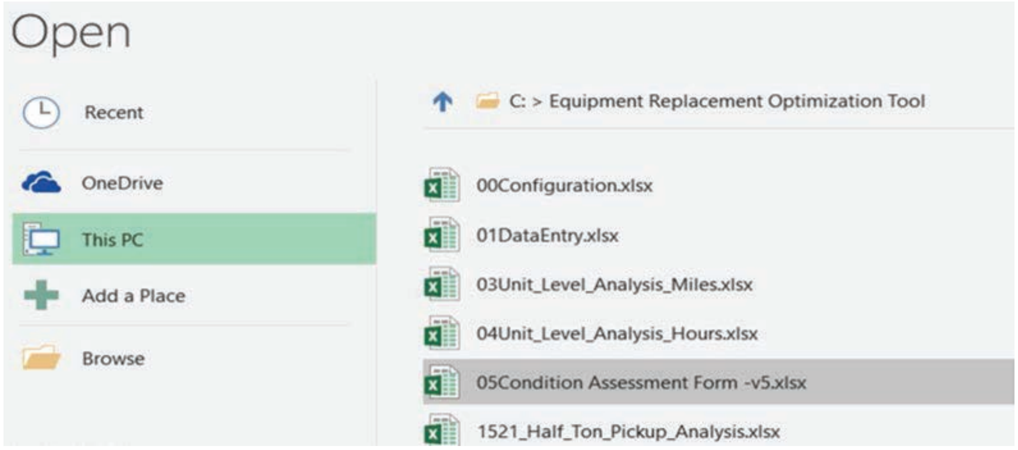


Figure 27. Open condition assessment form.

Once opened, the form will display the spreadsheet shown in Figure 28. The guide provides detailed instructions for completing the assessments.

It is best to download the electronic version of the condition assessment form onto laptops or other mobile devices for use by evaluators performing the assessment. However, hard copies of blank forms may be printed out for the technicians and the results entered on the electronic spreadsheets afterward.

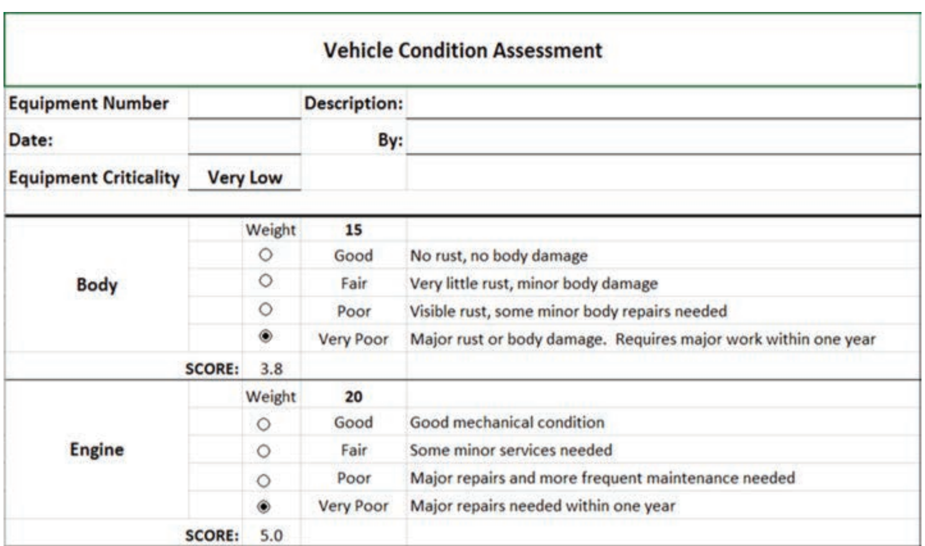
Because the condition assessment form is not linked to the other spreadsheets in the tool, maintain a file external to the tool to record and track the condition scores. Once the assessments are completed, manually enter the scores into Column J of the ReplacementTargets tab of each class spreadsheet, as shown in Figure 29.

Step 8. Determine Replacement Priorities

After entering the condition assessment scores, the tool will generate a prioritized list showing the replacement ranking for each candidate unit. To view the prioritized list, click on the PriorityReplacementList tab at the bottom of the spreadsheet, as shown in Figure 30.

Review the PriorityReplacementList results. Figure 31 shows the results for the ½-ton pickup class example. This priority replacement ranking is a key input to developing the annual equipment replacement program. The fleet manager can use this information to decide which units are the most important to replace.

Note: If condition assessment scores are not entered manually into the tool, equipment will not be included on



Vehicle Condition Assessment			
Equipment Number		Description:	
Date:		By:	
Equipment Criticality	Very Low		
Body	Weight	15	
	○	Good	No rust, no body damage
	○	Fair	Very little rust, minor body damage
	○	Poor	Visible rust, some minor body repairs needed
	●	Very Poor	Major rust or body damage. Requires major work within one year
SCORE:	3.8		
Engine	Weight	20	
	○	Good	Good mechanical condition
	○	Fair	Some minor services needed
	○	Poor	Major repairs and more frequent maintenance needed
	●	Very Poor	Major repairs needed within one year
SCORE:	5.0		

Figure 28. Vehicle condition assessment form.

	A	B	G	H	I	J
1	Equipment Number	Description	% Over Class AVG Cost	LTD Miles or Hours	Exceeds Replacement Target?	Condition Assessment Score
2	TE0529	1/2 Ton Pickup	70%			55
3	TE0505	1/2 Ton Pickup	49%			47
4	TE0510	1/2 Ton Pickup	44%			87
5	TE0485	1/2 Ton Pickup	44%			67
6	TE0223	1/2 Ton Pickup	36%	113,129	X	38
7	TE0253	1/2 Ton Pickup	34%	120,701	X	61
8	TE0392	1/2 Ton Pickup	33%			88
9	TE0260	1/2 Ton Pickup	31%	125,164	X	52
10	TE0456	1/2 Ton Pickup	28%			54
11	TE0018	1/2 Ton Pickup	27%	127,563	X	71
12	TE0394	1/2 Ton Pickup	23%	110,544	X	69
13	TE0427	1/2 Ton Pickup	22%	119,087	X	51

Figure 29. Entry of condition assessment scores.

	A	B	G	H	I	J	O
1	Equipment Number	Description	% Over Class AVG Cost	LTD Miles or Hours	Exceeds Replacement Target?	Condition Assessment Score	
2	TE0529	1/2 Ton Pickup	70%			55	
3	TE0505	1/2 Ton Pickup	49%			47	
4	TE0510	1/2 Ton Pickup	44%			87	
5	TE0485	1/2 Ton Pickup	44%			67	

LCCA | ReplacementTargets | PriorityReplacementList | 5YearSchedule | CostConsequences

Figure 30. Priority replacement list tab.

	A	B	C	D	E
1	Equipment Replacement Analysis Tool				
2	Agency Name Here		Class:		2001
3	1/2 Ton Pickup Priority Replacement List				
4					
5					
6					
7	Equipment Number	Description	Final Ran	Condition Assessment Score	
8	TE0505	1/2 Ton Pickup	1	47	
9	TE0223	1/2 Ton Pickup	2	38	
10	TE0529	1/2 Ton Pickup	3	55	
11	TE0260	1/2 Ton Pickup	4	52	
12	TE0485	1/2 Ton Pickup	5	67	
13	TE0456	1/2 Ton Pickup	6	54	
14	TE0427	1/2 Ton Pickup	7	51	
15	TE0253	1/2 Ton Pickup	7	61	
16	TE0510	1/2 Ton Pickup	9	87	
17	TE0394	1/2 Ton Pickup	10	69	
18	TE0018	1/2 Ton Pickup	11	71	

Figure 31. Sample priority replacement list.

the Priority Replacement List. The de facto priority replacement ranking will be that shown on the ReplacementTargets tab in Figure 26.

At this point in the process, the following information will be available for use in making replacement decisions:

- The units that have exceeded their replacement targets based on updated replacement targets generated by the class-level LCCA.
- The condition, including mission criticality, of each unit.
- The units that are the highest priority for replacement based on utilization and LTD cost relative to other units in the same class.

At this point, the process is considered complete if there are sufficient funds to replace all of the targeted units. However, this is normally not the case and additional analysis would be required to arrive at an optimal replacement program.

Step 9. Perform Unit-Level LCCA

In order to perform a unit-level LCCA, annual cost and utilization data must be available for each year of a unit's life starting with the first year that the unit was placed in service. The unit-level LCCA is performed as described in Chapter 5.

The unit-level LCCA provides additional cost information to help determine which specific units should be replaced. The fleet manager may then re-prioritize units for replacement.

Step 10. Finalize Replacement Program

Using the results from Steps 8 and 9, the fleet manager can finalize the equipment replacement program for the year.

Step 11. Develop a 5-Year Plan

Establishing a 5-Year Plan is not needed to develop the annual replacement program. The plan, however, is an important tool the fleet manager can use to support the need for future funding for equipment replacement. The tool generates the 5-Year Plan automatically based on the target replacement age in the configuration file.

To view the 5-Year Plan, click on the 5YearSchedule tab at the bottom of the spreadsheet, as shown in Figure 32.

Using the sample "**1521_Half_Ton_Pickup_Analysis**" spreadsheet, Figure 33 displays the results.

All units in the equipment class that have exceeded or will exceed their replacement age in the next 5 years are listed. The Backlog column represents the cost of the replacement needs backlog based on the target replacement values entered into the configuration file. Units listed as backlog have already passed their target replacement age.

Units that will be due for replacement in the next 5 years are shown in the year in which they will be due, with replacement cost adjusted using the inflation rate entered into the configuration file.

Step 12. Analyze Cost Consequences

This step is not needed to develop the annual replacement budget, but it can provide additional information, which the fleet manager can use to support future budget requests. The tool estimates the cost consequences of not replacing equipment at the optimal life cycle. It answers the question, "What does it cost to keep units beyond their economic life?" This analysis is completed on a class basis and can be viewed in each class analysis spreadsheet.

To review the cost consequences, click on the CostConsequences tab in the analysis file for the desired class, as shown in Figure 34.

The Cost Consequences sheet displays the Annual Class Cost, as shown in Figure 35 using the sample "**1521_Half_**

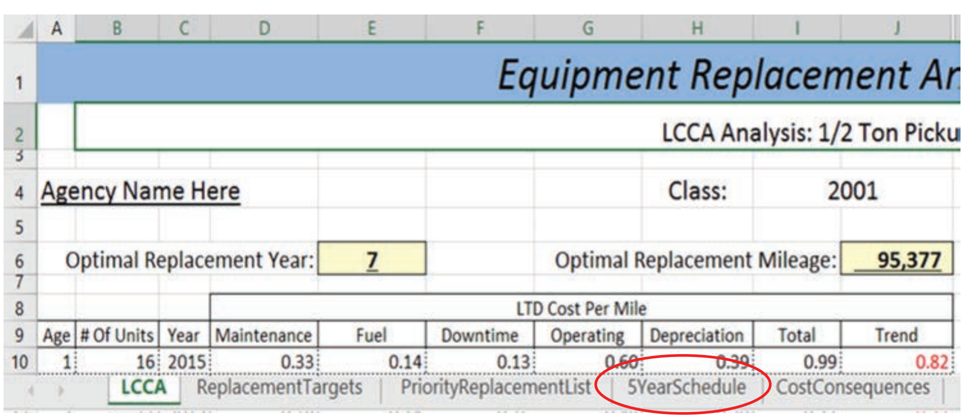


Figure 32. 5-year plan tab selection.

Equipment Replacement Analysis Tool									
	Agency Name Here			Class: 2001					
			5-Year Replacement Schedule: 1/2 Ton Pickups						
	Replacement Cost:	$ 27,500							
	Inflation Rate:	2.5%							
					5-Year Annual Replacement Needs				
				Backlog	2016	2017	2018	2019	2020
Equipment Number	Description	In- Service Year	Until Replac	$ 9,157,500	$ 2,117,500	$ 1,804,000	$ 202,245	$ 384,988	$ -
TE0351	1/2 Ton Pickup	1996	-12	$ 27,500					
TE0352	1/2 Ton Pickup	1996	-12	$ 27,500					
TE0353	1/2 Ton Pickup	1997	-11	$ 27,500					
TE0001	1/2 Ton Pickup	1998	-10	$ 27,500					
TE0002	1/2 Ton Pickup	1998	-10	$ 27,500					
TE0003	1/2 Ton Pickup	1998	-10	$ 27,500					
TE0004	1/2 Ton Pickup	1998	-10	$ 27,500					
TE0344	1/2 Ton Pickup	1999	-9	$ 27,500					

- in 2020 column designates years past due.

Figure 33. Sample 5-year plan results.

Ton_Pickup_Analysis" spreadsheet. The annual class cost is the total estimated annual cost of that equipment class over multiple replacement cycles based on the LCCA. The annual class cost is determined by multiplying the LTD cost per mile or hour by the average annual mileage or hours and by the number of units in the equipment class.

In the example, the class-level LCCA (see Figure 17) determined the optimal replacement cycle for the class of ½-ton pickups to be 7 years. If the pickups are replaced routinely every 7 years, the cost to own and operate all units in the class will be $5,202,514 per year, as shown in Figure 35. If the equipment is routinely replaced on any other yearly cycle (i.e., either earlier or later than a 7-year cycle), the cost to own and operate the pickups will be higher. For example, if the pickups were replaced on a 10-year cycle, the cost would be $5,346,124, or about $145,000 more annually.

By using the cost consequences function in the tool, a fleet manager can demonstrate the cost of delayed equipment replacement, building a business case to support appropriate funding for the equipment replacement budget.

"Number of Units in Class," Cell E6, is the number of units used by the tool for the LCCA calculation. The LCCA calculation does not evaluate equipment units that were removed from the data set before importing into the tool. In this example, 524 units were used from the downloaded data set. If needed, this number on the spreadsheet can be changed to include all vehicles in the class.

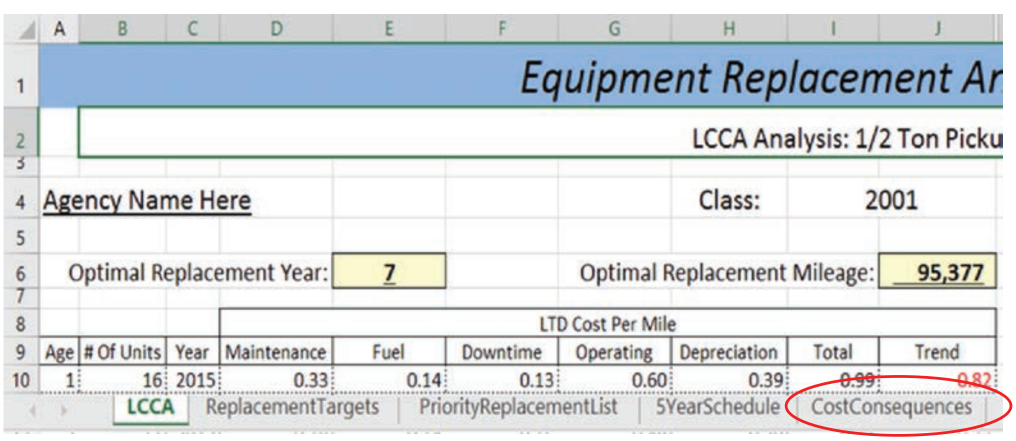


Figure 34. Cost consequences tab selection.

	A	B	D	E	F
1	*Equipment Replacement Analysis Tool*				
2			Cost Consequences		
3	Agency Name Here			Class:	2001
4					
5			Average Annual Mileage Per Unit:	13,625	
6			No of Units in Class:	524	
7					
8	Replacement Cycle	LTD $ Per Mi/Hour	Annual Unit Total Cost	Annual Class Cost	
9	1	0.82	$ 11,206	$ 5,871,933	
10	2	0.79	$ 10,824	$ 5,671,785	
11	3	0.77	$ 10,510	$ 5,507,069	
12	4	0.75	$ 10,263	$ 5,377,783	
13	5	0.74	$ 10,084	$ 5,283,929	
14	6	0.73	$ 9,972	$ 5,225,506	
15	7	0.73	$ 9,928	$ 5,202,514	Optimal
16	8	0.73	$ 9,952	$ 5,214,953	
17	9	0.74	$ 10,044	$ 5,262,823	
18	10	0.75	$ 10,203	$ 5,346,124	
19	11	0.77	$ 10,429	$ 5,464,857	
20	12	0.79	$ 10,723	$ 5,619,020	
21	13	0.81	$ 11,085	$ 5,808,615	
22	14	0.85	$ 11,515	$ 6,033,640	
23	15	0.88	$ 12,012	$ 6,294,097	
24	16	0.92	$ 12,576	$ 6,589,985	
25	17	0.97	$ 13,209	$ 6,921,304	

Figure 35. Sample cost consequences results.

6.2 Saving Analysis Results

Although it is not necessary, it is a good idea to save the results of the replacement analysis and the outputs from the tool. This will allow reviewing and referring back to the results over time.

To save paper copies, simply print out the analysis results and file them appropriately. To save the results electronically, it is recommended that they be saved as a PDF. The process for saving to a PDF is slightly different depending on the operating system being used. The following steps use Windows 10 and Microsoft Office 2010.

Step 1. Click on the File Button

Click on the File button in the upper left corner of the screen as would normally be done when saving an Excel file (see Figure 36).

Step 2. Click on Print

In the screen that opens, similar to the one shown in Figure 37, click on Print.

Step 3. Print to PDF

In the screen that opens, similar to the one shown in Figure 38, click on the print icon to show and select "Microsoft Print to PDF."

Step 4. Select Folder Location

In the dialog box that opens, shown in Figure 39, select the desired location for saving the work. Click on Save and the PDF will be created.

This process can be used to save any of the tabs or screens from the tool.

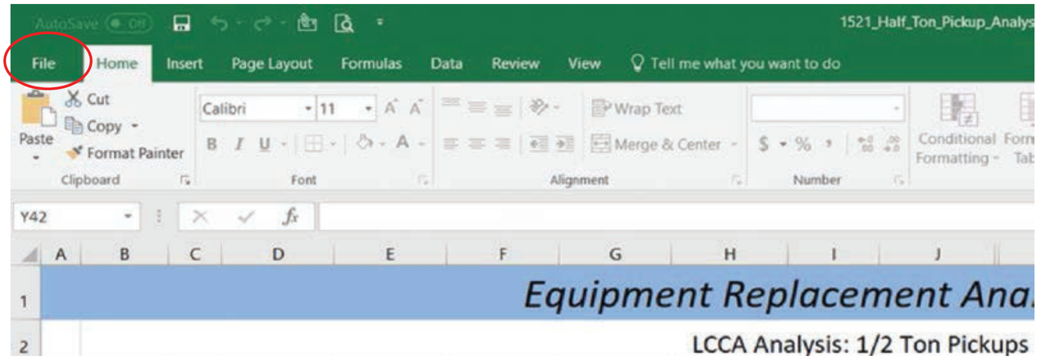


Figure 36. File button for saving work.

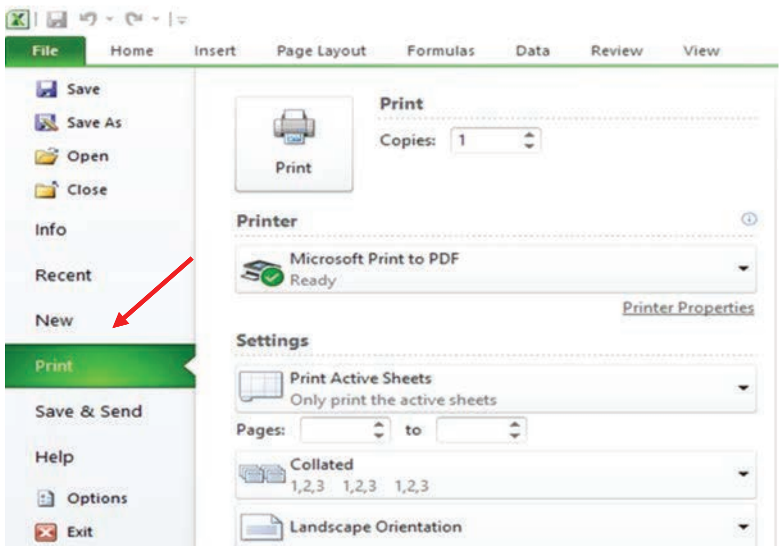


Figure 37. Print button.

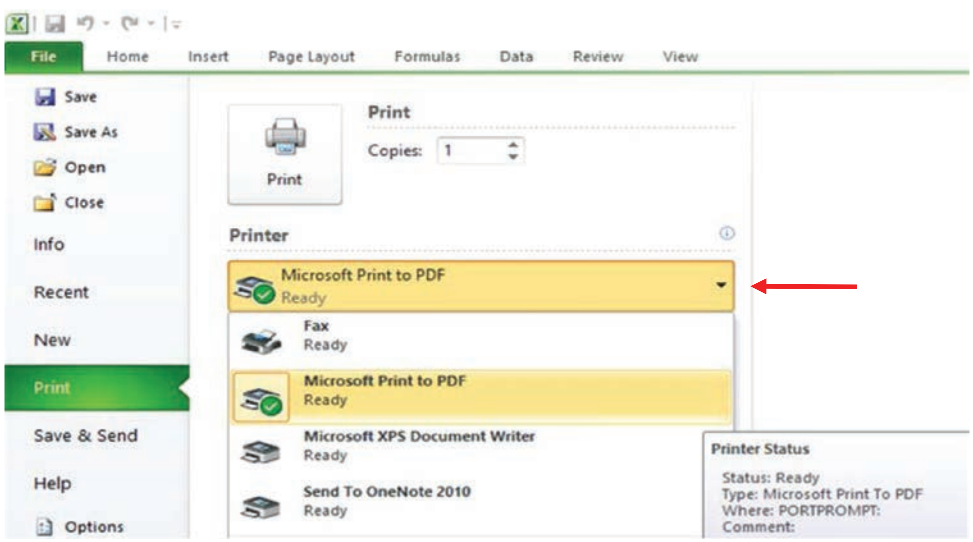


Figure 38. Print selection.

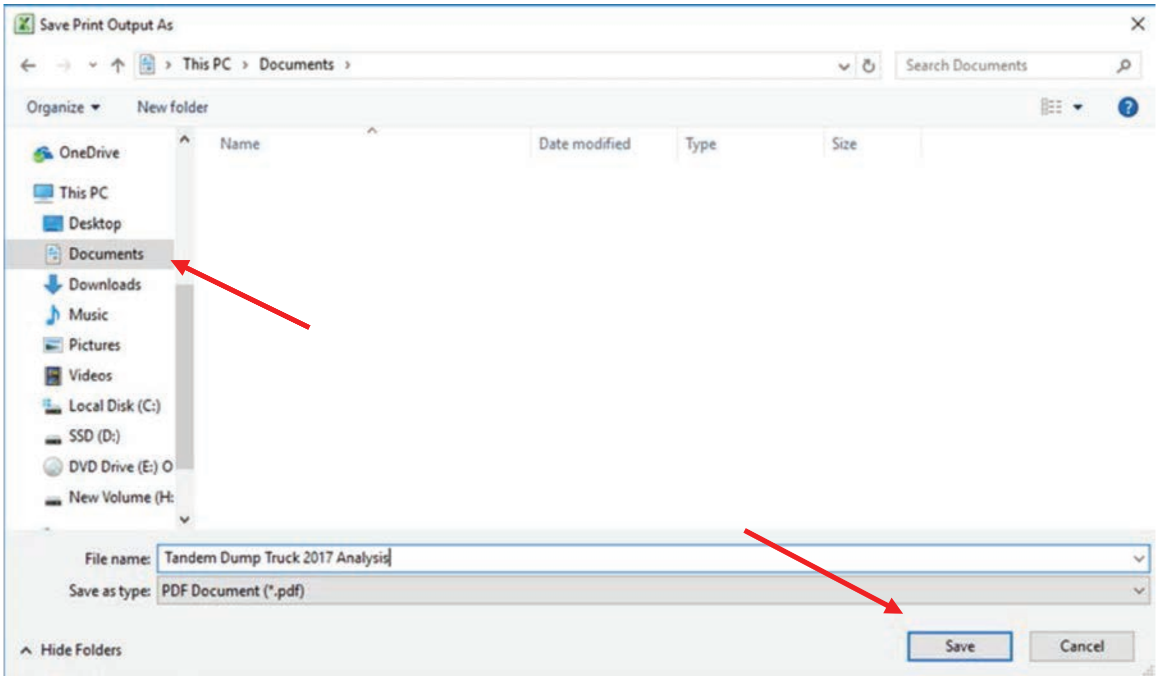


Figure 39. Selecting the folder.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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