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DEPARTMENT OF TRANSPORTATION

Optimizing the Life Cycle of PennDOT Equipment

FINAL REPORT
6/23/2014

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16. Abstract

PennDOT keeps detailed records of acquisition, maintenance and repair costs, and resale value of its fleet. The information in these records can be used to revise and update decision rules concerning when to acquire, perform maintenance on, perform repairs on, and sell off vehicles by determining evidence-bases for optimum equipment life cycles and replacement cycles. This project proceeded in three tasks: (1) A comprehensive literature search was conducted on topics related to equipment life cycle and replacement cycle methodologies used by other state departments of transportation and relevant private sector industries (e.g., construction and transportation industry practices). In addition, a survey gathered information about other states' methodologies and best practices concerning: (a) equipment life cycles; (b) equipment replacement cycles; and (c) equipment maintenance outsourcing practices. (2) A database was created to organize and store all relevant information provided by PennDOT for a given unit of equipment, type of equipment (i.e., dump trucks [single-, tandem-, tri-axle], excavators [rubber tired and tracked], front-end loaders, backhoes, and crew-cabs), and equipment class code (ECC). Statistical analyses examined factors that influence equipment life cycles, with goals of predicting both the likelihood of repairs/replacements of components of vehicle systems, and outcomes such as cumulative cost of maintenance and repairs. Analyses were conducted separately by each major type and class of equipment. (3) Findings of these analyses contributed to creation of an Equipment Life Cycle Prediction Tool that can be used to estimate future costs of maintenance and repair for particular pieces of equipment, prioritize among multiple pieces of equipment for replacement based on age and maintenance cost history, and examine alternative equipment replacement budget allocation scenarios for a given work unit. The Prediction Tool enables users to consider projected costs of ownership for individual pieces of equipment and for various groupings of pieces of equipment (e.g., within equipment types, across equipment types, within work units, and/or across work units) in making equipment maintenance and replacement decisions. Prediction Tool User Manual and Administrator's Manuals were also provided.

17. Key Words Equipment life cycle, life cycle prediction tool, equipment replacement budget, equipment maintenance and repair costs, single axle truck, tandem axle truck, tri-axle truck, excavator, front-end loader, crew cab, backhoe.	**18. Distribution Statement** No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161

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EXECUTIVE SUMMARY

PennDOT spends $130 million or more each year on maintenance of its fleet, which numbers in the thousands of vehicles and units of equipment. Current maintenance practices are itemized in *Publication 177, Equipment Managers Manual*. Through the SAP Plant Maintenance program, PennDOT keeps detailed records of acquisition, maintenance and repair costs, and resale value of its fleet. The rules underlying decisions concerning when to acquire, perform maintenance on, perform repairs on, and sell off vehicles and equipment were last updated in the late 1990s. The information in the SAP records can be used to revise and update these decision rules by determining evidence-bases for optimum equipment life cycles and replacement cycles. Given the size and value of the fleet, even small enhancements to maintenance decision rules could yield very substantial gains in the dollar value of returns on PennDOT's investments in its fleet. This project proceeded in three tasks, as follows:

TASK 1: LITERATURE SEARCH AND SURVEY

A comprehensive literature search was conducted on topics related to equipment life cycle and replacement cycle methodologies used by other state departments of transportation and relevant private sector industries (e.g., construction and transportation industry practices). The Task 1 literature search findings were summarized in a 40-page report.

Table 1.1. List of Topics and Numbers of Studies Cited

1. Equipment/Fleet
A. Maintenance (11) B. Acquisition (7) C. Outsourcing (3)
2. Equipment/Fleet Management
A. Repair vs. Replace (20) B. Management Programs/Software (13) C. Life Cycle (39) D. Automation (2) E. Best Practices and Performance Measurement (5)
3. Economics
A. Budgeting (7) B. Depreciation (4)

Note. Sixty three reports and research studies are included in this review. Many studies relate to more than one topic, and therefore the numbers of citations above do not sum to 63.

In addition, a survey/questionnaire to collect information from other state DOTs was conducted. The purpose of this survey was to gather information about other states' methodologies and best practices concerning: (a) equipment life cycles; (b) equipment replacement cycles; and (c) equipment maintenance outsourcing practices. Twenty three completed surveys were received. Respondents represented 19 state DOTs and 1 Canadian province. Responses were received from 4 districts of the Mississippi DOT.

Most respondents to this survey (87%) reported that their department has established life cycles for its fleet. It is noteworthy that PennDOT possesses the largest fleet of any respondent DOT in terms of most types of equipment represented on the survey (backhoe, crew cab, excavator, loader, single-axle dump truck, tandem-axle dump truck, and tri-axle dump truck), particularly crew cabs and tandem-axle dump trucks. 'Years of Service' was the most frequently cited basis for equipment life cycles for all types of equipment, endorsed by 88% or more of respondents (except for tri-axle trucks, for which Years of Service was endorsed by 56% of respondents). 'Hours of Operation' was endorsed by most respondents (50% or more) as a basis for equipment life cycles for backhoes, crew cabs, excavators, loaders, and single-axle trucks. 'Mileage' was endorsed by most respondents (50% or more) as a basis for equipment life cycles for single- and tandem-axle trucks. Task 1 survey findings were summarized in a 35-page report, and in a matrix format to facilitate comparison of equipment life cycle policies and practices across jurisdictions.

TASK 2: REVIEW AND ANALYZE PENNDOT'S FLEET MODEL POLICIES AND PRACTICES

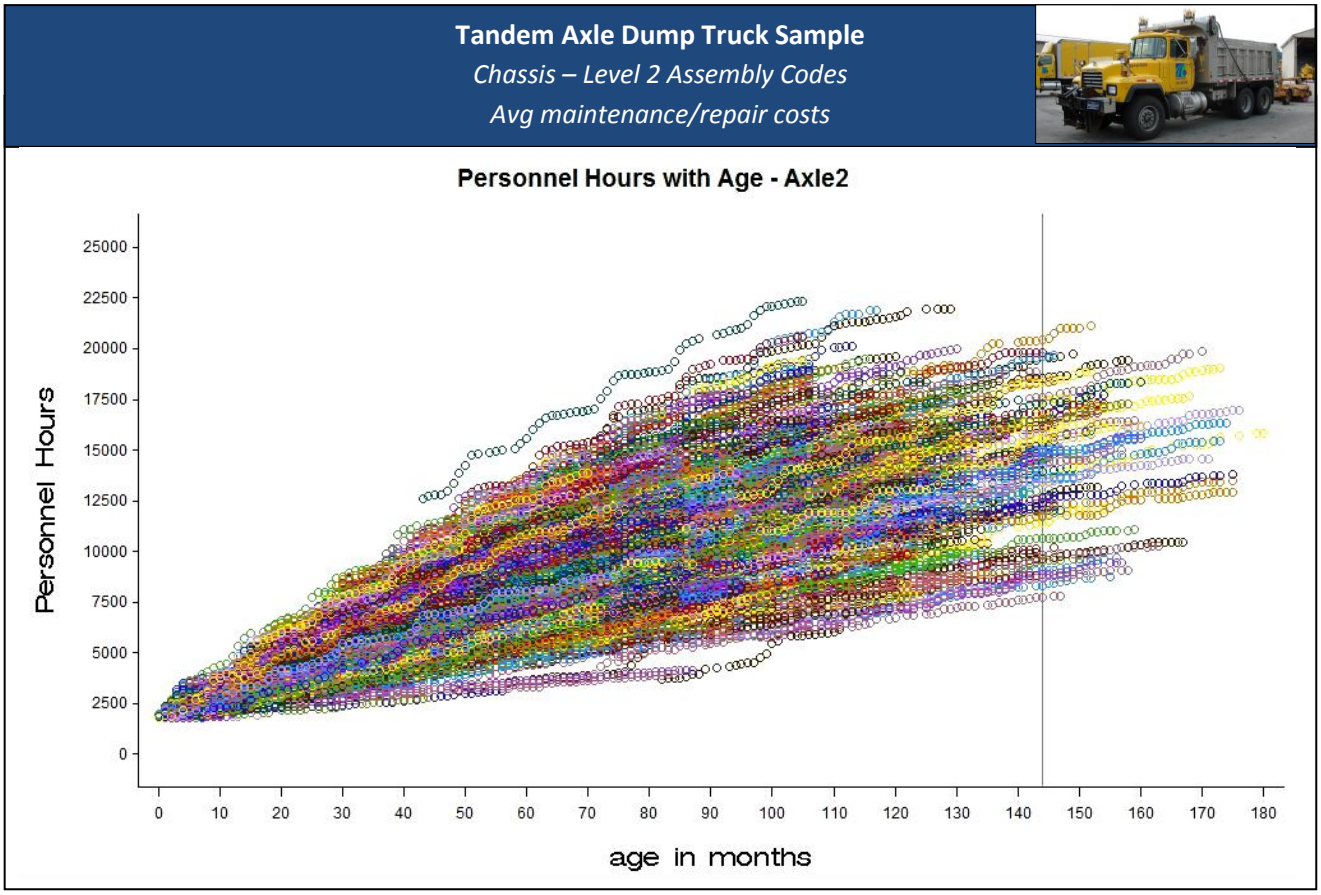
A database was created to organize and store all relevant information provided by PennDOT for a given unit of equipment, type of equipment (i.e., dump trucks [single-, tandem-, tri-axle], excavators [rubber tired and tracked], front-end loaders, crew-cabs, and backhoes), and equipment class code (ECC). Data files were extracted from this database as needed to perform statistical analyses that examined factors that influence equipment life cycles, with goals of predicting both the likelihood of repairs/replacements of components of vehicle systems, and outcomes such as cumulative cost of maintenance and repairs. Analyses were conducted separately by each major type and class of equipment.

Preliminary analyses that are described in detail in the Task 2 report yielded several findings that shaped the decisions about the most productive approach to modeling equipment life cycles using data from the equipment maintenance and repair records. Among these were:

1. Monthly costs increase for most Level 1 Assembly systems (cab/body, chassis, electrical, engine, hydraulic, miscellaneous, powertrain, and winter equipment) during the first 10 years or so of ownership, but the rate of increase is much greater for some systems than others. (Note that PennDOT excluded four additional Level 1 Assembly categories from consideration for this research: statewide radio, unnumbered equipment, auction surplus, and administration.)
2. Cumulative personnel hours charged to equipment, age in months, and cumulative fuel usage reliably relate to increasing costs of maintenance and repair of equipment.
3. Trends in and levels of costs related to aging of Level 1 Assembly systems vary substantially among types of equipment; costs of some Level 1 systems show little or no relationship to equipment aging.
4. Trends in and levels of costs related to aging of Level 2 Assembly systems vary substantially among types of equipment; costs of some Level 2 systems show little or no relationship to equipment aging.
5. Because maintenance and repair costs for some Level 1 and 2 Assembly systems are strongly related to aging whereas others are not, longitudinal growth modeling focused on trends in total monthly and cumulative costs. Costs for Level 1 and 2 Assembly systems are represented descriptively in the Task 2 report.

Figure 2.3 displays personnel hour trajectories for tandem axle trucks. Each series of small circles of the same color represents the data for one truck (for Level 2 Assembly, chassis) as hours increased over time. In the first months of life span of these trucks, shown in the lower-left corner of the graph, they all have relatively few personnel hours charged. After 5 years (60 months), the width of the display of trajectories is much broader than in the early months. At 10 years (120 months), the graph is broader still, with some trucks of that age having almost five times more hours than others. This pattern of increasingly disparate hours charged as the equipment ages reveals that some pieces of equipment have been operated much more than others of the same age. Similar graphs for other types of equipment were presented in the Task 2 report.

Figure 2.3. Personnel Hours Trajectories for Tandem Axle Dump Trucks



The prediction tool uses equations derived from the data analyses described in the Task 2 report. The basic prediction equation, and the equation parameters applied for each piece of equipment of each type and age, are listed Table 3.1. Equation parameters relate equipment age in months and cumulative personnel hours to cumulative maintenance and repair costs for each type of equipment included in this study. The parameters represent the degree of relationship during the five-year observation period between equipment age in months and monthly maintenance/repair costs, and between cumulative hours and monthly maintenance/repair costs. Although the model

parameters are not standardized, the magnitudes of relationships represented by the values can be compared within a column. Higher positive values indicate that greater age in months and greater cumulative hours are associated with greater monthly maintenance costs. In two cases, parameters for cumulative hours are negative (17 and 18 year old backhoes); negative values indicate that for pieces of equipment of that age, those with relatively less cumulative hours had higher monthly maintenance/repair costs during the observation period. Blank cells in Table 3.1 indicate that there were no pieces of equipment of that age, or insufficient numbers for analysis purposes (e.g., single axle trucks for ages 15-18 years). In addition to prediction equations, cost ratio and equipment replacement prioritization metrics were developed for use by the tool.

TASK 3: CREATE AN EQUIPMENT LIFE CYCLE PREDICTION TOOL AND MANUAL

Findings of data analyses contributed to creation of an Equipment Life Cycle Prediction Tool that can be used to estimate future costs of maintenance and repair for particular pieces of equipment, prioritize among multiple pieces of equipment for replacement based on age and maintenance cost history, and examine alternative equipment replacement budget allocation scenarios for a given work unit. The Prediction Tool enables users to consider projected costs of ownership for individual pieces of equipment and for various groupings of pieces of equipment (e.g., within equipment types, across equipment types, within work units, and/or across work units) in making equipment maintenance and replacement decisions. Prediction Tool User Manual and Administrator's Manuals were also provided.

TASK 4: ORAL PRESENTATION OF PREDICTION TOOL AND FINAL WRITTEN REPORT

An oral presentation and demonstration of the Prediction Tool was conducted at PennDOT's Fleet Management Division on June 6, 2014. In addition to the researchers (Vance and Renz in person, Coccia and Karchner by conference call), attending for PennDOT were staff members from the Fleet Management and Research Divisions. The researchers provided copies of the Executive Summary and the User's Manual as meeting handouts. A brief overview of the project was provided, followed by an in-depth demonstration of the features and functions of the Prediction Tool. There was opportunity for questions and discussion throughout the two-hour presentation.

Table 3.1. Longitudinal Growth Model Parameters Relating Cumulative Personnel Hours and Equipment Age in Months to Cumulative Maintenance and Repair Costs

Age in Years	Equipment Type													
	Single Axle		Tandem Axle		Tri-Axle		Crew Cab		Excavator		Loader		Backhoe	
	Hours	Months	Hours	Months	Hours	Months	Hours	Months	Hours	Months	Hours	Months	Hours	Months
1	0.21	276.7	0.63	282.4	0.86	586.6	0.04	185.7	1.48	138.0	0.61	134.0	1.48	64.7
2	0.77	238.5	1.01	299.6	0.57	802.9	0.48	153.0	1.54	155.4	0.99	189.5	0.85	156.6
3	1.19	298.2	1.55	394.6	2.00	527.1	0.67	188.7	2.17	273.6	1.41	260.6	2.00	145.9
4	1.61	385.7	2.04	484.4	2.48	779.1	1.01	221.7	3.03	345.9	1.11	374.7	2.40	212.4
5	1.81	469.9	2.23	559.5	2.15	626.5	1.06	278.0	3.53	361.0	1.14	459.1	1.99	301.3
6	2.08	565.8	2.32	652.8	2.92	767.9	1.25	356.6	4.25	294.5	1.31	521.4	1.40	304.7
7	1.66	637.0	1.63	805.4	1.76	864.9	1.42	340.9	3.35	360.8	1.21	475.2	2.13	319.9
8	2.08	643.6	2.47	754.7	1.72	1078.7	1.23	377.2	3.13	351.9	1.22	475.0	2.22	382.8
9	2.13	690.1	2.40	810.0	2.47	1185.6	1.45	369.9	4.11	413.5	1.39	468.5	1.58	356.1
10	2.07	701.6	2.65	784.2	3.25	1148.1	1.38	253.9	4.21	424.8	1.41	490.8	1.45	280.1
11	1.95	689.6	2.59	774.5	7.86	873.8	1.80	226.6	4.58	483.7	1.43	460.9	1.12	463.2
12	2.57	507.7	3.02	765.1	3.87	581.3	1.83	246.2	3.71	443.2	1.33	392.8	1.47	321.7
13	4.48	371.1	2.80	725.3			2.65	171.3	4.89	542.3	1.08	369.2	1.87	274.0
14	2.93	394.1	3.20	690.0			3.84	68.0	5.19	446.6	0.80	390.7	0.01	473.5
15			2.88	622.3					3.89	653.9	1.48	341.6	5.12	260.6
16									4.73	452.6	2.06	280.6	0.41	471.4
17									2.61	426.7	2.24	264.8	-0.75	304.6
18									6.37	129.4	1.55	268.4	-2.93	399.0

Note. Predicted cumulative maintenance cost at age N (in years) for a given piece of equipment is calculated using this equation:

Predicted Maintenance Cost at Age_N = (HoursParam * Avg Hours per Year) + (MonthsParam * 12) + Cumulative Maintenance Cost at Age_{N-1}

where for a given piece of equipment **Age_N** is a future age (e.g., for a 10-year old truck, future ages are 11, 12, 13, etc., up to the limit of predictability shown in the table), **Hours** and **Months Parameters** are from the table for a specific future age, **Average Hours per Year** is total usage hours for the piece of equipment as of the last update divided by its age in years, and **Cumulative Maintenance Cost at Age_{N-1}** is the cumulative cost for the previous year.

TASK 1: LITERATURE SEARCH AND SURVEY

I. INTRODUCTION

A literature search on topics relating to equipment life cycle and replacement cycle methodologies was conducted. The search included such literature topics and domains as: equipment life cycles; fleet life cycles; life cycle cost analyses; equipment replacement optimization; fleet management; logistics management; maintenance management; and engineering economics. Of particular importance were literature searches of transportation resources such as the Transportation Research Board's (TRB) TRID database, which includes domestic and selected international sources (European literature, and the Australian Road Research Board Library), and for current research, the TRB Research-in-Progress database. Searches were also conducted via the Google and Google Scholar online search engines.

The Literature Review report is organized into three sections:

I. Introduction
II. Synopsis of Findings: The Literature on Equipment Life Cycles
III. Listing of References, Abstracts, and Relevant Topics of Articles and Reports Cited

Section II provides a synopsis of findings for topics. For each topic listed in Section II, the count of relevant citations is shown, along with the associated citation numbers. Table 1.1 summarizes a list of topics and the numbers of citations per topic. The settings for the 63 studies and articles cited in this report represent a range of industries (departments of transportation, public transportation, construction, maritime) and vehicle types (passenger vehicle, heavy duty, tractor-trailer, bus). A complete listing of citations, including references and abstracts for each article and study, is included in Section III of the Literature Review report.

Table 1.1. List of Topics and Numbers of Studies Cited

4. Equipment/Fleet
D. Maintenance (11)
E. Acquisition (7)
F. Outsourcing (3)
5. Equipment/Fleet Management
A. Repair vs. Replace (20)
B. Management Programs/Software (13)
C. Life Cycle (39)
D. Automation (2)
E. Best Practices and Performance Measurement (5)
6. Economics
C. Budgeting (7)
D. Depreciation (4)

Note. Sixty three reports and research studies are included in this review. Many studies relate to more than one topic, and therefore the numbers of citations above do not sum to 63.

II. SYNOPSIS OF FINDINGS: THE LITERATURE ON EQUIPMENT LIFE CYCLES

This section provides a synopsis of findings for topics. For each topic listed in this section, the count of relevant citations is shown, along with the associated citation numbers. A complete listing of citations, including references and abstracts for each article and study, is included in Section III of the Literature Review report. Many studies relate to more than one topic, and are therefore counted as relevant to multiple topics.

I. Equipment / Fleet

Citation Count: 10
Citations: 4, 6, 8, 9, 21, 22, 24, 50, 58, 60

A. Maintenance

Citation Count: 11
Citations: 4, 6, 8, 21, 22, 29, 36, 42, 49, 54, 60

- Today's vehicles and equipment are the highest quality ever built; with faster replacement cycles, the overall quality of the fleet will increase at an accelerated pace. However, new technologies such as hybrid powertrains mean new maintenance issues.
- In fleet management, replacement costs exhibit economies of scale while maintenance and repair costs represent dis-economies of scale. This distinction is important in considering optimal fleet investments – replacement costs are more predictable than the risks of continuing maintenance and repair costs of vehicles and equipment that are not replaced. Maintenance parts and supplies can be differentiated between "just in case," items that can be purchased in bulk but which must be stored and accounted for, and "just in time," items that can be delivered quickly. Bulk purchases may provide savings on purchase prices that are not available for just in time purchases, but just in time purchases avoid the costs of maintaining an inventory.

B. Acquisition

Citation Count: 7
Citations: 6, 9, 10, 21, 24, 35, 50

- A fundamental financial question in making decisions about equipment acquisition is whether the costs should be to use the equipment or to own and use the equipment. Answering this question will help to determine which acquisition method to follow: (1) rental, (2) lease, (3) cash purchase, (4) lease purchase, or (5) cash purchase with trade or buyback guarantee. Careful analysis of the work to be performed and the best equipment to perform it, the number of pieces of equipment required, and the duration of the requirement are also key considerations.
- With constrained budgets and pressures to slash operating expenses, buying quality merchandise and performing proper maintenance are paramount. Buying robust equipment allows for extended replacement cycles, as does proper and consistent maintenance. Extending preventive maintenance intervals should also be considered for robust equipment. Other strategies for stretching fleet purchasing dollars include:

purchasing vehicles suitable for multiple tasks, such as multi-body truck chassis that can mount a dump body, a flat bed, or a water tank; purchasing equipment with stainless steel bodies that resist corrosion and reduce the need for frequent washing; and simplifying the bidding process to attract more vendors, lowering costs by increasing competition.

C. Outsourcing

Citation Count: 3
Citations: 11, 58, 63

To make informed decisions about whether maintenance and repair services should be performed in-house or contracted out, government officials must have a valid way to analyze and compare costs. Activity-based costing (ABC), also called "full cost accounting," provides a means to compare in-house vs. contracted-out services. ABC captures the full costs of providing a public service or product, including direct and indirect or overhead costs. Traditional accounting methods used by government agencies assign costs to broad categories such as personnel, supplies and equipment, and other line-item expenditures. ABC defines a unit of work, such as routine equipment maintenance, the resources required to perform it, its outputs, outcomes, or results, and all related costs, usually expressed as cost per unit. The definition of an activity is crucial for ABC. Examples of activities include receiving and processing payments for annual passes for state parks, and performing scheduled maintenance for a fleet of dump trucks.

One challenge of ABC in determining in-house costs is calculating overhead costs for an activity. These must be comprehensive, including the hidden cost advantages of special tax privileges and tax and regulatory exemptions. Determining contractor costs for an activity are usually straightforward, as they are usually enumerated in a proposal and contract. Hidden costs associated with a contract that may be harder to determine include costs of administering the contract, such as preparing an RFP, contract negotiations, change orders and amendments, monitoring and oversight, and processing invoices and payments to contractors. Contract administration costs have been estimated as typically falling in a range of 10 to 20% of the contract amount. Another category of costs that should not be overlooked is one-time conversion costs, such as unemployment compensation and severance pay for former employees laid off due to outsourcing, and costs associated with unused facilities and equipment.

In comparing in-house to outsourcing costs, it is advisable to calculate costs over several performance periods. If costs fluctuate on a seasonal basis, for example, several performance periods will allow for better estimation. Other factors to consider include cross-subsidizing of in-house costs, whereby services are provided by another in-house unit. The costs of these services must be included in the calculation. All capital items such as buildings, vehicles, and equipment should be depreciated. Interest due on any relevant debt should be included, as should any special costs such as legal fees. Finally, it should be noted that costs are only one factor to consider in comparing in-house vs. contracted-out services. Other factors include service quality, operational flexibility and reliability, ease of transitioning, support from political leadership, and more.

II. Equipment / Fleet Management

Citation Count: 47

Citations: 1, 2, 3, 4, 5, 8, 9, 10, 12, 13, 14, 15, 16, 18, 19, 20, 22, 26, 27, 28, 29, 30, 31, 32, 33, 34, 36, 37, 38, 39, 41, 42, 43, 44, 47, 48, 49, 52, 53, 54, 55, 56, 57, 59, 60, 61, 62

A. Repair vs. Replace

Citation Count: 20

Citations: 1, 12, 13, 14, 15, 16, 20, 22, 24, 26, 27, 29, 31, 33, 39, 44, 48, 55, 56, 59

- When vehicle parts are damaged in crashes, a basic choice is whether to repair them when possible, or replace them. Taking into account economic and environmental considerations for non-structural damage to passenger cars, it was found that the environmental impact was generally lower when the part was repaired rather than replaced. Many factors must be considered, however, in making the optimal choice in a given case.
- If repair/rebuild costs approach 50% of a vehicle's present market value, especially in the case of an accident, replacement is generally indicated over repair based on the economics involved.
- A fleet asset life optimization model was developed for six equipment classes, three on-road and three off-road. Factors included salvage values, market value decline, and cost of operation and use as equipment ages. The model identifies the optimal disposal point for each equipment class. Benefits of using the model include reducing overall costs, improving the age of the fleet, and improving overall utilization and readiness to serve the public.
- Deterministic dynamic programming provides a solution to the equipment replacement optimization problem, with and without annual budget considerations. Software based on this approach estimates substantial cost savings.
- Oregon DOT developed a software tool to facilitate equipment replacement decisions based on available equipment data and qualitative data input by equipment crews regarding actual use of specific pieces of equipment. Results using this software indicate that total equipment life cycle costs are minimized by replacing the oldest equipment first. Costs should include both costs of maintenance as equipment ages and costs of under-utilized equipment -- if assets providing similar service are not equally utilized, overall fleet costs increase.
- Texas DOT developed a life cycle methodology for equipment replacement decisions based on its comprehensive equipment operating system database. This computerized menu-driven software system allows a fleet manager to prioritize units for replacement based on comparisons among all units within any desired class of equipment, based on individual life cycle cost trends. Units with costs increasing at a faster rate relative to others in the class have higher replacement priority. Optimization of fleet life cycle costs means minimizing the sum of maintenance and replacement (new equipment price minus resale value) costs.
- Virginia DOT found that decisions to repair vs. replace equipment could be improved by considering a statistic calculated for each piece of equipment: the ratio between the average labor and parts per dollar of fuel (or per mile) year to date and the

average labor and parts per dollar of fuel (or per mile) life to date. In general, higher ratios indicate increasing costs for maintaining a piece of equipment which may make it a candidate for replacement rather than repair.

B. Management Programs/Software

Citation Count: 13

Citations: 5, 11, 15, 22, 28, 33, 38, 43, 47, 52, 56, 57, 62

- Numerous agencies have developed software programs to aid in fleet management decision making. Among them are:
  - Texas DOT created a computerized menu-driven software system, the Texas Equipment Replacement Model, which allows a fleet manager to prioritize units for replacement based on comparisons among all units within any desired class of equipment, based on individual life cycle cost trends.
  - Louisiana DOTD (Department of Transportation and Development) developed a software tool to evaluate qualitative and cost aspects of contracting out services. Criteria used by this tool may be altered by the user, allowing the tool to be used in a variety of settings.
  - The Bus Size Evaluation Tool is a user-friendly and easily-modifiable software tool that includes a life cycle cost calculator and a template of weighted factors to help transit agencies select buses most suited to their needs.
  - Oregon DOT developed a software tool to facilitate equipment replacement decisions based on available equipment data and qualitative data input by equipment crews regarding actual use of specific pieces of equipment. An electronic process was also designed to collect data from maintenance crews for future integration into the software tool.
  - Equipment replacement optimization (ERO) software consists of three main components: a data cleaner and analyzer, which reads and "cleans" raw data and provides cost estimates and forecasts; a dynamic programming optimization engine that minimizes total cost of ownership over a defined horizon; and a graphical user interface (GUI) that allows a user to specify parameters used by the software tool to make estimates and forecasts.

C. Life Cycle

Citation Count: 39

Citations: 2, 3, 4, 5, 8, 9, 10, 11, 12, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 30, 31, 32, 34, 35, 37, 39, 40, 41, 42, 44, 45, 46, 47, 53, 54, 55, 56, 61

- Life cycle costing is a method of evaluating the total cost of an asset over its whole life. Cross-sectional and time series analyses of purchase, maintenance, and replacement costs can lead to significant cost savings in operational and purchasing decisions.
- An environmentally-focused life cycle optimization model was developed for automobile replacement decisions to address the "inefficient old vehicle" aspect of this problem. The model accounts for advancing technologies that reduce vehicle emissions (carbon monoxide, non-methane hydrocarbon, nitrogen oxide, carbon

dioxide) and the comparative inefficiencies of older vehicles. The model shows that vehicles have different optimal lifetimes depending on the decade in which they were manufactured as well as annual vehicle mileage. The model can influence policies on vehicle emission controls, decisions on retiring vehicles, and improving fuel economies.

- In the shipping industry, failures to meet schedules and/or budgets are common despite availability of the life cycle approach to project management. Integrating Project Risk Management (PRM) and Life Cycle Assessment (LCA) methods has the potential to improve project management in complex systems, thereby improving a ship's service life and operability. The PRM approach, in particular, considers both internal and external risks and assists a manager in estimating the importance of each project component and phase.

D. Automation

Citation Count: 2
Citations: 19, 62

- Electronic control modules (ECMs) in today's heavy-duty construction machinery and trucks fleet managers can actively monitor the costs of owning and operating equipment. In addition to their role in reducing tailpipe emissions, these devices can provide real-time reports of operating efficiency and contribute to life cycle costing, thereby enhancing performance, fuel economy, and longevity.
- A study by University of Minnesota researchers identified data quality as a key to effective fleet life cycle costing analysis. Technologies for gathering and transmitting data from truck engine computers to the maintenance information system were tested. Problems with technology compatibility and proprietary engine software were encountered, necessitating alternative management strategies. With good data, decision makers can determine how long assets should be kept and maintained.

E. Best Practices and Performance Measurement

Citation Count: 6
Citations: 7, 36, 51, 52, 53, 60

- The cost of running a vehicle fleet goes beyond the purchase price -- it includes insurance, registration, fuel, maintenance, parking, accident repair, refurbishment, etc. Effective management of these costs should begin with justification of the number and type of vehicles needed to meet operational requirements, management of life cycle costs, and active reduction in the environmental impact of a fleet.
- Minnesota DOT conducted a benchmarking study to assess its fleet management practices. A regional study was followed by a national assessment of the number, types, and effectiveness of performance measures used by leading state departments of transportation. Results revealed that MnDOT could improve its performance measurement process with appropriate measures and reporting periods (monthly, quarterly, annually) at the state, district, and shop levels. Recommendations addressed control limits, performance indices, strategic planning, predictive maintenance,

purchasing standards, cost/benefit analysis, fleet asset centralization, internal rental rates, bar coding, asset replacement, and more.
- A review of technical advancements in five systems that make up earthmoving equipment (implement, traction, structure, power train, and control and information), particularly the integration of systems into balanced equipment design, has significant implications and relevance for civil designers, contractors, equipment suppliers, educators teaching the technical basics of equipment, and researchers.

III. Economics

Citation Count: 22
Citations: 2, 6, 7, 10, 12, 18, 21, 23, 24, 25, 26, 30, 35, 45, 46, 50, 53, 54, 55, 59, 61, 63

A. Budgeting

Citation Count: 7
Citations: 2, 6, 7, 13, 29, 54, 63

- With constrained budgets and pressures to slash operating expenses, buying quality merchandise and performing proper maintenance are paramount. Buying robust equipment allows for extended replacement cycles, as does proper and consistent maintenance. Thoroughly analyzing the size and capabilities of the fleet vs. demands is necessary for efficient use of fleet budgets.
- A deterministic dynamic programming (DDP) optimization model was applied to the equipment replacement optimization problem and tested using Texas DOT vehicle fleet data. The solution to the keep/replace decision can be applied with and without budget considerations.

B. Depreciation

Citation Count: 4
Citations: 12, 25, 26, 46

- In the presence of taxes, economic depreciation schedules of equipment depend on several factors, including the depreciation schedules imposed by government. If the resulting economic depreciation schedule offers quicker write-offs than the imposed one, the firm could argue that, based on economic rationale, the imposed schedule should be changed to equal the economic schedule. Stable depreciation schedules are tax neutral (for a range of tax rates) in that the replacement decision is not changed by the tax system.

RESPONSES TO SURVEY OF EQUIPMENT LIFE CYCLES

An online survey to collect information from other state DOTs was conducted. The purpose of this survey was to gather information about other states' methodologies and practices concerning: (a) equipment life cycles; (b) equipment replacement practices; and (c) equipment maintenance outsourcing practices. This questionnaire was designed by the researchers and distributed after review and approval by Michael Connor, the project's Technical Advisor. Research Division Manager Michael Bonini distributed an email request to complete the survey to his counterparts in other DOTs, along with a link to the survey website. This invitation was distributed on October 31, 2012, with a requested response date by November 16, 2012. A reminder email was distributed on November 9, 2012. Twenty three completed surveys were received. Respondents represented 19 state DOTs and 1 Canadian province. Responses were received from 4 districts of the Mississippi DOT.

The Survey Responses report summarizes the responses to each survey question. A brief Summary of some of the main findings is presented here.

Summary of Findings

Most respondents to this survey (87%) reported that their department has established life cycles for its fleet. It is noteworthy that PennDOT possesses the largest fleet of any respondent DOT in terms of most types of equipment represented on the survey (backhoe, crew cab, excavator, loader, single-axle dump truck, tandem-axle dump truck, and tri-axle dump truck), particularly crew cabs and tandem-axle dump trucks. Missouri and Ohio also possess large numbers of single- and tandem-axle dump trucks.
Other noteworthy findings include:

- 'Years of Service' was the most frequently cited basis for equipment life cycles for all types of equipment, endorsed by 88% or more of respondents (except for tri-axle trucks, for which Years of Service was endorsed by 56% of respondents).
- 'Hours of Operation' was endorsed by most respondents (50% or more) as a basis for equipment life cycles for backhoes, crew cabs, excavators, loaders, and single-axle trucks.
- 'Mileage' was endorsed by most respondents (50% or more) as a basis for equipment life cycles for single- and tandem-axle trucks.
- A plurality of respondents (40%) chose 'Other' as the primary reason for establishing equipment life cycles, with most citing multiple specific reasons.
- Regarding maintenance and repair services that are performed 'In-house,' 'Outsourced,' 'Both,' or 'Neither,' similar patterns of responses were found for all types of equipment. Preventive maintenance and minor repairs are most likely to be performed in-house (endorsed by 58% or more of respondents). Major repairs and overhaul/rehabilitation services are most often performed both in-house and outsourced (endorsed by 56% or more of respondents, except for tri-axle trucks endorsed by 42% of respondents). Outsourcing decisions commonly vary by region (endorsed by 39% or more of respondents).

- The two most common reasons for outsourcing equipment maintenance and repair were 'To expand capacity' (endorsed by 61% of respondents) and 'To access needed skills and expertise' (endorsed by 57% of respondents).
- In order of importance of factors determining when a piece of equipment is sold, beginning with the most important: 'Mileage/usage hours,' 'Costs of maintenance and repair,' 'Equipment age,' 'Resale value,' and 'Warranty expiration.'

TASK 2: REVIEW AND ANALYZE PENNDOT'S FLEET MODEL POLICIES AND PRACTICES

The ultimate goal of this project was to create an electronic equipment life cycle prediction tool that enables users to estimate and minimize projected Total Cost of Ownership (TCO) and maximize equipment readiness and reliability for individual equipment units, equipment class codes (ECC), and/or types of equipment (i.e., dump trucks [single-, tandem-, tri-axle], excavators [rubber tired and tracked], front-end loaders, and crew-cabs). This tool employs decision algorithms derived from analyses of the life histories of individual equipment units according to data contained in the SAP Plant Maintenance program, such as age, maintenance and repair costs and history, and resale value. This tool enables users to consider alternative scenarios in making projections, such as PennDOT's actual equipment budget vs. no budgetary limitations.

The data available from the SAP Plant Maintenance program, with detailed information for a 5-year observation window from 2007 to 2012, presented analytic challenges by virtue of the dynamics of equipment life cycles. Figure 2.1 provides a visual overview of some of these dynamics, albeit in simplified form, for 10 hypothetical tandem-axle dump trucks. In its current fleet for a given type of equipment, PennDOT has units that were acquired at different times and therefore have different maintenance histories and ages. In addition to regularly scheduled maintenance, individual units may have been unavailable for service on occasion due to unexpected breakdowns, and each unit therefore is likely to have a unique total cost of maintenance and repairs accumulated over its lifetime to date (values shown in Figure 2.1 are fictitious). If one considers a cohort of similar units purchased in a given year (e.g., tandem dump trucks purchased in 2000), in 2012 it was probably the case that some of these units were still in service, some had been sold at the end of their expected life service, and some perhaps were sold before their expected life term due to catastrophic damage in a crash (i.e., were totaled); thus, for some units of a cohort the life cycle had ended at the time of data analyses, whereas for others it continued. These life cycle dynamics combined to yield considerable variability in 2012 summary metrics shown in the right columns of Figure 2.1, such as resale value, total cost of maintenance and repairs, and total fuel usage.

A goal of the analyses of data described in the Task 2 report was to reveal sources of variability in the equipment maintenance and repair records to develop a deep understanding of equipment life cycle dynamics. Achieving this goal required processing the electronic records to extract and prepare relevant data for analysis. The focus of initial work was to determine the distributional characteristics of specific variables in the records and to ensure that the researchers were properly interpreting their meaning. We next began exploratory analyses of the records for each type of equipment (backhoes, crew cabs, excavators, loaders, single axle trucks, tandem axle trucks, and tri-axle trucks) to determine how to model trends in cumulative ownership costs over the life cycle of each piece (e.g., whether to model growth trends using each maintenance/repair record, or to smooth out trends by calculating moving averages). A third phase of analyses was to identify data models with optimum fit to the observed data for each type of equipment. A fourth and final phase was to examine financial aspects of equipment ownership, particularly equipment depreciation and sale prices for auctioned equipment.

Figure 2.1. Sample Life Histories and Metrics for Ten Tandem-axle Dump Trucks

Equip-ment	Pre-Observation Window								Observation Window					September 2012 Metrics			
	Pre-2000	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Equip Age[a]	Resale Value[b]	Total Maint/ Repair Cost[b]	Total Fuel Usage[c]
1			A						M	M R	M	M	M	134	22	10	6,300
2				A					M R	M	M R	M	M	127	26	9.2	6,100
3								A	M	M	M	M	M R	75	21	6	3,300
4										A	M	M R	M	51	58	4	3,000
5	A								M	M R	M R	M R	M	155	19	14	7,000
6	A								S					148	20	11	5,500
7												A	M	29	70	2	1,000
8		A							M	M	M	M R	M R	147	15	10.5	6,900
9			A						M R	M	M	M R	M	125	19	10	5,200
10	A								T					71	28	4	3,000

A = Equipment Acquired;
M = Scheduled Maintenance;
R = Unscheduled Repair;
S = Equipment Sold;
T = Equipment Total Loss

[a] Age of equipment in months in Sept 2012 or at time of sale.
[b] In thousands of dollars.
[c] In gallons.

Analyses of Equipment Records and the Life Cycle Prediction Tool

Initial analyses revealed that records were provided for 4,400 pieces of equipment. Table 2.1 presents a summary of key elements of the information in these records, including the number of pieces of each equipment type, the total number of maintenance/repair records for each type, average cost per record, the minimum and maximum costs observed in these records, and total costs of maintenance and repairs summed across all records for each equipment type.

Table 2.1. Summary Statistics for Maintenance/Repair Records by Type of Equipment

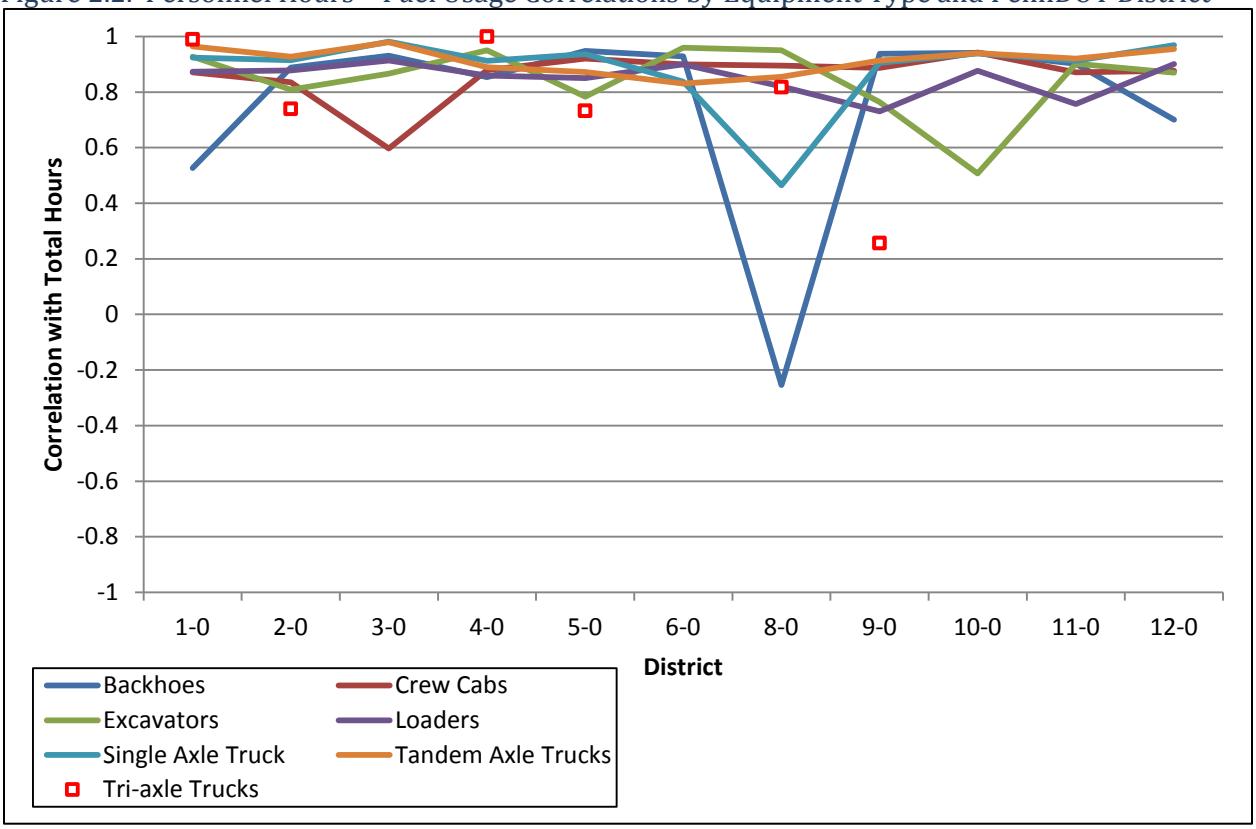
Equipment Type	Number of Pieces	Number of Records	Average Cost of Maintenance/ Repair	Minimum Cost of Maintenance/ Repair	Maximum Cost of Maintenance/ Repair	Total Cost of All Records
Backhoe	139	14,861	$197.59	$0.00	$17,481.50	$2,934,953.80
Crew Cab	1,237	115,338	$171.68	$0.00	$15,828.74	$19,790,479.49
Excavator	153	18,341	$214.04	$0.00	$26,476.72	$3,924,346.59
Loader	561	54,159	$206.63	$0.00	$23,250.03	$11,187,948.98
Single Axle	710	168,382	$152.32	$0.00	$13,232.29	$25,638,916.27
Tandem Axle	1,585	356,865	$156.75	$0.00	$18,655.62	$55,909,097.56
Tri-Axle	55	15,178	$187.02	$0.00	$39,754.38	$2,838,363.73
All Records	***4,440***	***743,124***				

A basic question that the researchers considered was how to represent age and usage of the equipment. The data files provided included start-up date for each piece of equipment, from which a unit's age in months at the time of each maintenance/repair event was calculated. PennDOT tracks metrics for personnel hours charged to equipment and fuel usage for each piece of equipment, and considers both metrics to be important indicators of usage. Metrics for cumulative personnel hours and fuel usage for each piece of equipment were also provided. To investigate how closely aligned these metrics are as indicators of usage, correlations between these variables were examined with breakdowns by district and equipment type.

Results of these analyses are shown in Figure 2.2. The graph plots correlations between fuel usage and personnel hours for backhoes (blue line), crew cabs (red line), excavators (green line), loaders (purple line), single axle trucks (teal line), tandem axle trucks (orange line), and tri-axle trucks (red blocks) for each district. Most of the correlations shown in this graph are high positive correlations (greater than .80). For most types of equipment for most districts, fuel usage and personnel hours are in close agreement. There are some exceptions, however, for particular types of equipment and districts. The most striking of these are correlations of -.25 for backhoes for District 8-0 and .26 for tri-axle trucks for District 9-0. In each of these cases, there is basically no relationship between hours and fuel usage. Also noteworthy are moderate correlations (about .45 to .55) for crew cabs in District 3-0, excavators in District 10-0, and single axle trucks in District 8-0. It appears that personnel hours are recorded somewhat

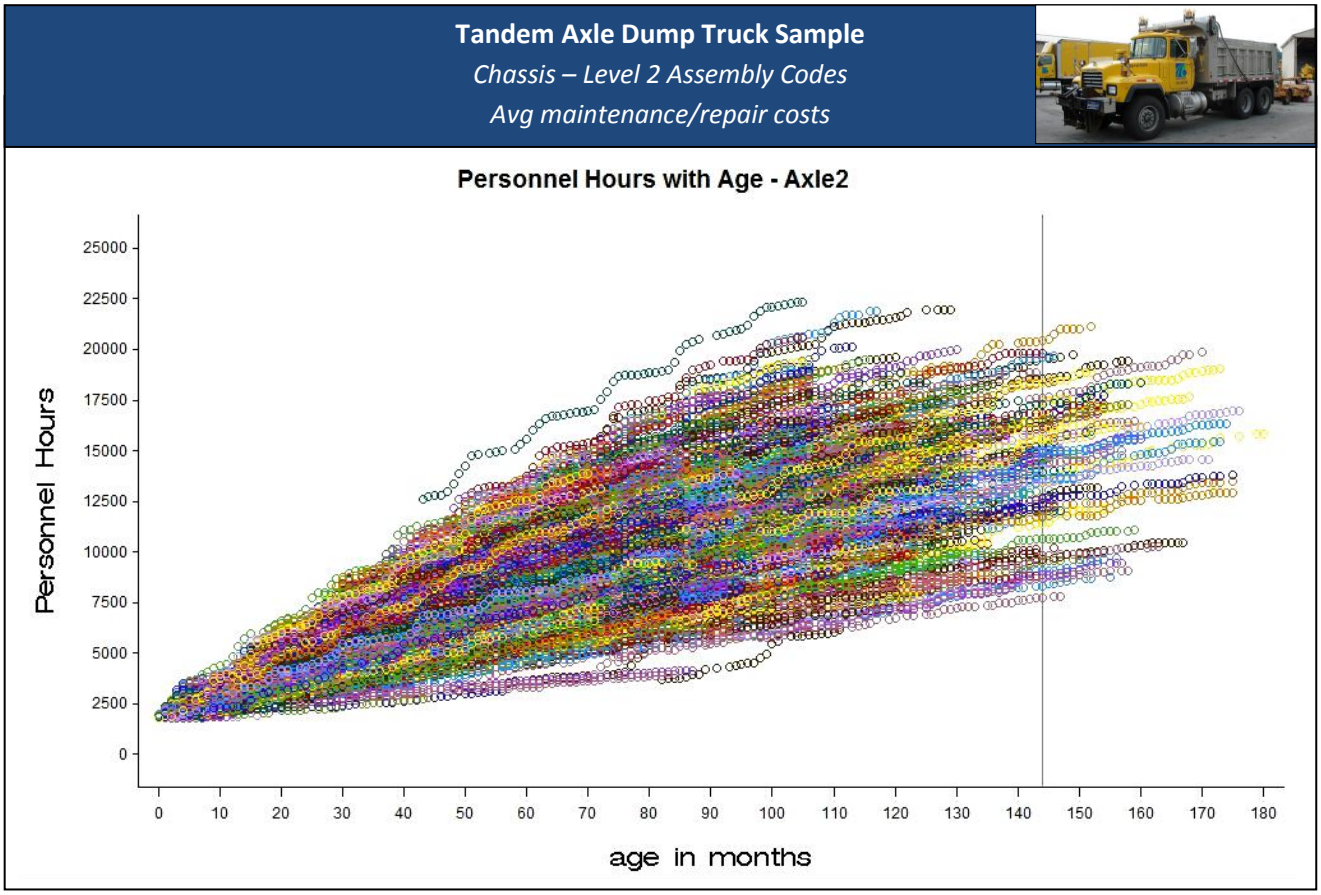
differently than fuel usage for these types of equipment in these districts. In general, however, 92% of the correlation coefficients depicted in Figure 3 are high (.70 or greater), and more than half are very high (.90 and greater). The magnitude of these correlations indicates that parallel analyses using either personnel hours or fuel usage will yield very similar results.

Figure 2.2. Personnel Hours – Fuel Usage Correlations by Equipment Type and PennDOT District



Another basic question investigated in preliminary analyses concerned the relationship between equipment age in months and usage. This question was investigated by directly comparing age in months to cumulative personnel hours, and age in months to cumulative fuel usage. To determine whether for a given type of equipment some pieces are used more than others throughout their life cycles, as indicated by personnel hours, graphs such as those shown in Figure 2.3 were presented. Figure 2.3 displays personnel hour trajectories for tandem axle trucks. Each series of small circles of the same color represents the data for one truck as hours increased over time. In the first months of life span of these trucks, shown in the lower-left corner of the graph, they all have relatively few personnel hours charged. After 5 years (60 months), the width of the display of trajectories is much broader than in the early months. At 10 years (120 months), the graph is broader still, with some trucks of that age having almost five times more hours than others. This pattern of increasingly disparate hours charged as the equipment ages reveals that some pieces of equipment have been operated much more than others of the same age. Similar graphs for other types of equipment were presented in the Task 2 report.

Figure 2.3. Personnel Hours Trajectories for Tandem Axle Dump Trucks



Preliminary analyses that are described in detail in the Task 2 report yielded several findings that shaped the decisions about the most productive approach to modeling equipment life cycles using data from the equipment maintenance and repair records. Among these were:

6. Monthly costs increase for most Level 1 Assembly systems (cab/body, chassis, electrical, engine, hydraulic, miscellaneous, powertrain, and winter equipment) during the first 10 years or so of ownership, but the rate of increase is much greater for some systems than others. (Note that PennDOT excluded four additional Level 1 Assembly categories from consideration for this research: statewide radio, unnumbered equipment, auction surplus, and administration.)
7. Cumulative personnel hours charged to equipment, age in months, and cumulative fuel usage reliably relate to increasing costs of maintenance and repair of equipment.
8. Trends in and levels of costs related to aging of Level 1 Assembly systems vary substantially among types of equipment; costs of some Level 1 systems show little or no relationship to equipment aging.
9. Trends in and levels of costs related to aging of Level 2 Assembly systems vary substantially among types of equipment; costs of some Level 2 systems show little or no relationship to equipment aging.

10. Because maintenance and repair costs for some Level 1 and 2 Assembly systems are strongly related to aging whereas others are not, longitudinal growth modeling focused on trends in total monthly and cumulative costs. Costs for Level 1 and 2 Assembly systems are represented descriptively in the Task 2 report.

EQUIPMENT LIFE CYCLE MODELS

The goal of longitudinal growth curve modeling is to find one or more equations that relate independent variables to dependent variables such that errors in predictions are minimized. The ability to predict future values based on a data model makes it possible to create a life cycle prediction tool. Because of the characteristics of the data set, particularly the fact the pieces of equipment from model years 1995 and later entered the five-year observation window (2007 – 2012) at different ages, the range of equipment ages that could be modeled varied by the type of equipment and depended on the number of pieces of equipment available of a particular age. Also, because of the differing numbers of pieces of equipment of a given age, and because initial analyses revealed that equipment age in months, cumulative personnel hours charged to equipment, and cumulative fuel usage related to overall maintenance/repair costs, modeling was conducted on an equipment age basis.

Figure 2.4 depicts the relationships relating equipment age in months and cumulative personnel hours to cumulative maintenance and repair costs for tandem axle trucks. The upper graph relates average monthly maintenance costs (the y-axis) to equipment age in months (the plotted points) based on age in years of ownership of the trucks (the x-axis). The upper graph shows that monthly costs are higher for older trucks, rising to about $800 per month. The lower graph shows that when trucks are relatively new (years 1 and 2), the relationship between cumulative hours and monthly maintenance costs is relatively low. For trucks three years and older, the relationship between cumulative fuel usage and monthly maintenance costs is stronger (coefficients greater than 1.0), indicating that older trucks with more hours have higher maintenance costs.

Taken together, the two graphs of Figure 2.4 show that both age of the equipment and history of use (indicated by cumulative hours) affect cumulative maintenance and repair costs. The Task 2 report provides comparable graphs for single axle trucks, tri-axle trucks, crew cabs, excavators, loaders, and backhoes. Table 2.2 shows a sample of the equations for predicting cumulative costs for tandem axle trucks from age in months, cumulative personnel hours, and cumulative fuel usage. Equations for model years 2005, 2006, and 2007 are shown. Similar equations were derived for other model years for tandem axle trucks, and for other types of equipment. These equations are the basis for the Equipment Life Prediction Tool.

Figure 2.4. Relationships of Average Monthly Maintenance/Repair Costs to Age in Months and Cumulative Personnel Hours: Tandem Axle Dump Trucks

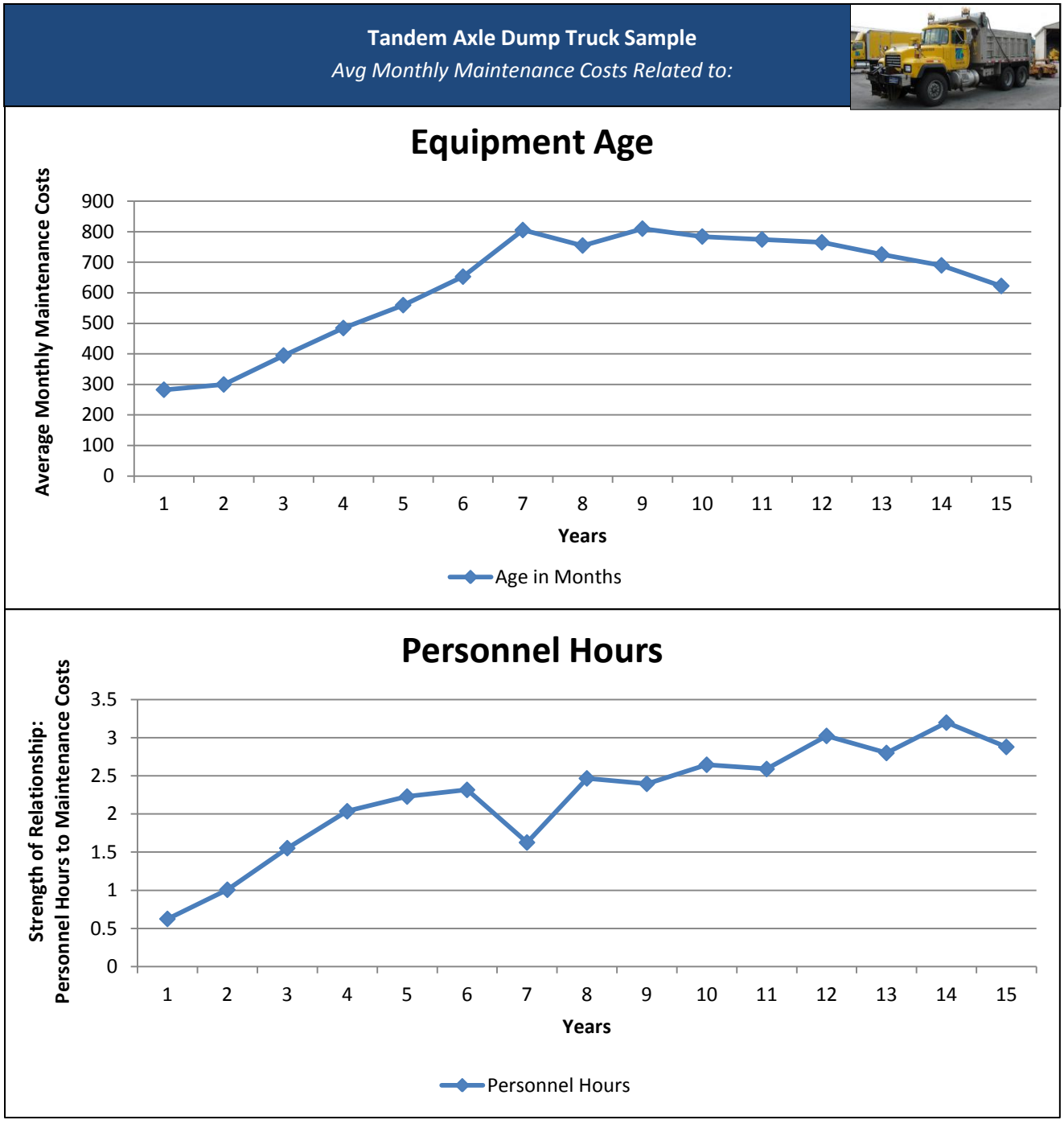


Table 2.2. Equations for Predicting Cumulative Costs for Tandem Axle Dump Trucks

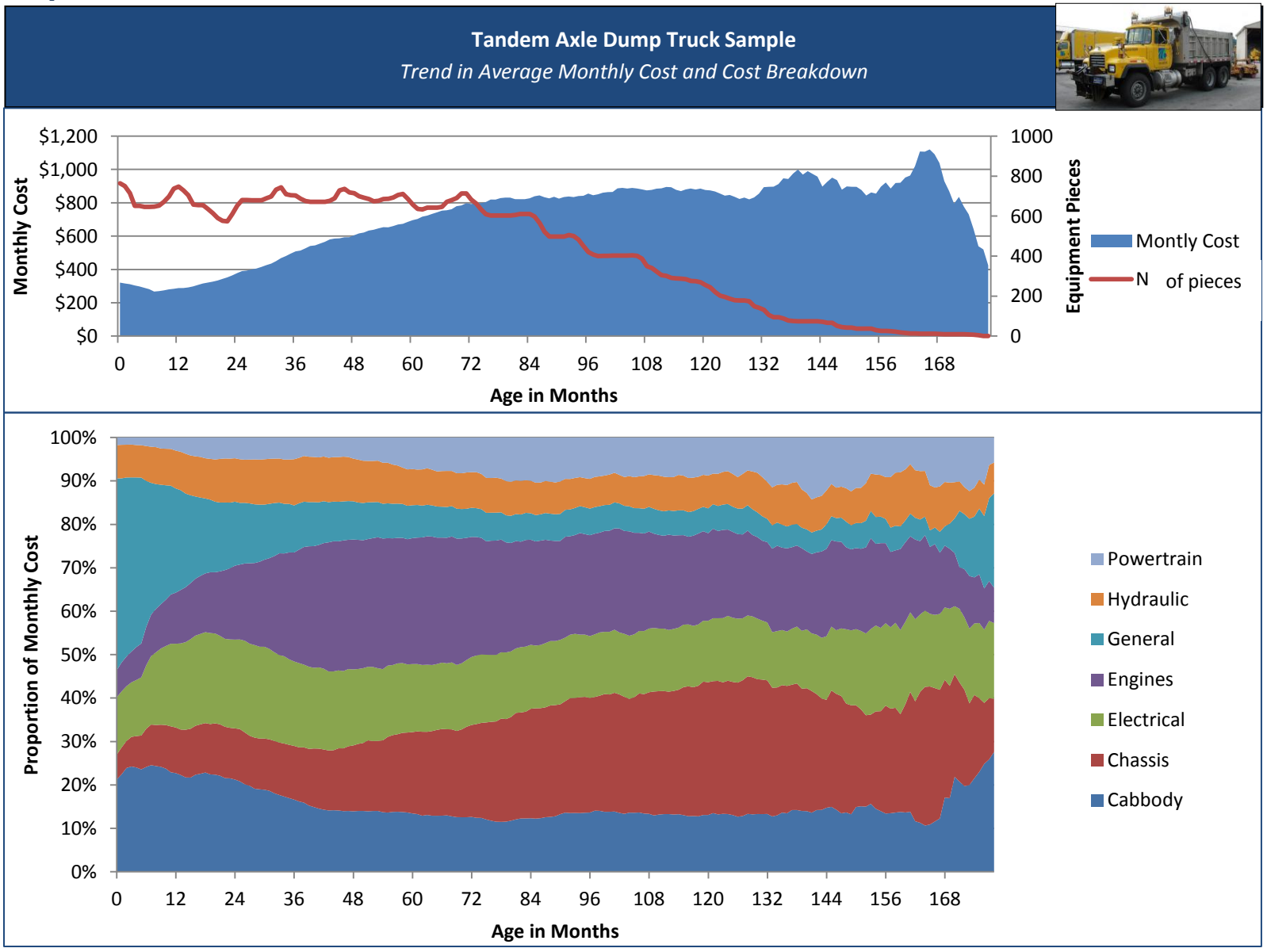
Tandem Axle Trucks		
Year	**Predicted Via**	**Linear Predictor (LP) Equations**
2005	Hours	LP= 52819 + 0.56*(Acq) + 277.25*(Time) + 13.06*(Time^2) - 0.09*(Time^3) + 0.07*(Hours) + 0.000090*(Hours^2)
	Fuel Use	LP= 53244 + 0.56*(Acq) + 277.25*(Time) + 13.06*(Time^2) - 0.09*(Time^3) + 0.14*(Fuel) + 0.000012*(Fuel^2)
2006	Hours	LP= -43211 + 1.48*(Acq) + 249.96*(Time) + 9.43*(Time^2) - 0.05*(Time^3) - 0.65*(Hours) + 0.000133*(Hours^2)
	Fuel Use	LP= -43955 + 1.48*(Acq) + 249.96*(Time) + 9.43*(Time^2) - 0.05*(Time^3) - 0.06*(Fuel) + 0.000018*(Fuel^2)
2007	Hours	LP= 5135 + 0.99*(Acq) + 135.34*(Time) + 8.98*(Time^2) - 0.05*(Time^3) - 0.23*(Hours) + 0.000124*(Hours^2)
	Fuel Use	LP= 5129 + 0.99*(Acq) + 135.34*(Time) + 8.98*(Time^2) - 0.05*(Time^3) + 0.08*(Fuel) + 0.000017*(Fuel^2)

Note. Acq = acquisition price, Time = age in months, Hours = cumulative personnel hours, Fuel = cumulative fuel usage.

Figure 2.5 summarizes life cycle trends in average monthly maintenance and repair costs (exclusive of acquisition costs) for tandem axle trucks, plus corresponding trends in proportional costs broken out by Level 1 Assembly Codes (powertrain, hydraulic, general, engines, electrical, chassis, and cab body). Two graphs are shown, an upper and a lower graph, and both have the same x-axis, which is age of equipment in months. The blue-shaded portion of the top graph depicts the trend in average monthly costs of maintenance and repairs (upper graph, left y-axis scale). This trend gradually increases for the first 72 months of the life span, and then remains fairly constant. The red line in the top graph shows the number of pieces of equipment in the sample at each month along the equipment age continuum (upper graph, right y-axis scale). The data shown in these graphs were assembled from trucks of varying ages as they appeared in the observation window from 2007 to 2012. Relatively more trucks were available for observation at younger ages, and relatively fewer trucks contributed to observations at older ages. After the nominal life span of these trucks (144 months), very few trucks were available to contribute to the data. Thus, the trend in monthly costs shown at the oldest ages should be interpreted with caution due to the small number of trucks at the upper age limit.

The bottom graph in Figure 2.5 shows the proportion of monthly costs at each point in the age continuum for the Level 1 Assembly categories (bottom graph, y-axis scale; color-coded areas for powertrain, hydraulic, general, engines, electrical, chassis, and cab body). The proportions add up to 100% at all ages; the widths of color bands indicate the proportion of total costs attributable to Assembly categories at each point in the age continuum. Thus, at 12 months approximately 20% of costs are spend on cab body, approximately 11% on chassis, and so on for the remaining Assembly categories. At 72 months, the proportion of costs spent on cab body

Figure 2.5. Trends in Average Monthly Maintenance/Repair Costs and Proportional Costs by Level 1 Assembly Categories: Tandem Axle Dump Trucks



falls to about 16% and the proportion of costs spent on chassis rises to about 20%. Note that the bottom graph should not be interpreted as revealing *amounts* spent at each age – at all points along the age continuum the bottom graph shows 100% of costs. Rather, the top graph shows the trend in total costs, and the bottom graph shows how the total costs at each point in the age continuum were spent. As with the top graph, Assembly category proportions at the high end of the equipment age range (greater than 144 months) are based on relatively few pieces; at the oldest ages, proportional costs tend to show more variability and should be interpreted with caution. The Task 2 report provides comparable graphs for single axle trucks, tri-axle trucks, crew cabs, excavators, loaders, and backhoes.

An important factor in determining optimal life cycles of equipment, in addition to maintenance and repair histories and costs, is the potential resale value of the equipment at each point in its life span. At the end of its useful life, PennDOT sells each piece of equipment at auction. Table 2.3 summarizes auction results by equipment type for equipment auctioned during the observation period of 2007 – 2012. For each type of equipment, the number of pieces sold, the average acquisition price, average number of months owned by PennDOT, average sale price, average depreciated value at the time of sale, and the average difference between the sale price and depreciated value are listed. For two types of equipment, backhoes and loaders, average sale prices are greater than depreciated values at the time of sale. For other equipment types, sale prices on average were somewhat lower than depreciated values at the time of sale. These findings may indicate the need for adjustments to the depreciation formula to align depreciated values more closely to actual sales prices, with formulas tailored to each type of equipment. To the extent that depreciated values inform decisions about when to sell a piece of equipment, it is important that these be as accurate (i.e., as close to the actual sale price) as possible.

Table 2.3. Auctioned Equipment: Values at Sale

Equipment Type	Number of Pieces	Average Acquisition Price	Average Number of Months Owned	Average Sale Price	Average PennDOT Depreciated Value at Sale	Average Difference (Sale - Depreciated Value)
Backhoes	54	$52,897	199	$10,765	$8,960	$1,806
Crew Cabs	36	$28,208	122	$1,943	$9,208	-$7,265
Gradall Excavators	32	$144,897	204	$8,526	$23,306	-$14,779
Loaders	243	$69,203	180	$20,218	$14,477	$5,804
Single Axle Trucks	177	$66,634	153	$8,089	$17,516	-$9,427
Tandem Axle Trucks	546	$75,046	152	$17,241	$18,552	-$1,311
Tri-axle Trucks	19	$90,719	133	$22,188	$26,022	-$3,833

Note. Depreciated Value is PennDOT depreciation per year, calculated as 10% depreciation per year from 90% of the acquisition price, to a minimum depreciated value of 10% of the acquisition price.

ANALYSES OF EQUIPMENT RECORDS AND THE LIFE CYCLE PREDICTION TOOL

Findings of the analyses summarized in the Task 2 report contributed to creation of a life cycle prediction tool that estimates future maintenance/repair costs from attributes of individual equipment units and/or equipment types (principally age in months, cumulative personnel hours charged to equipment, and cumulative fuel usage). In addition to life history factors that affect total costs of ownership (TCO), resale value, and the likelihood of expenditures for particular equipment systems (Level 1 Assembly categories) for particular pieces of equipment, financial planning and budgeting considerations are important. In financial terms, expenditures on equipment acquisition, maintenance, and repair are investments rather than costs, and the question of optimum equipment life cycle is a question of maximizing return on investments in the entire equipment fleet while achieving the mission of a fleet that is reliable and ready for use.

For a given equipment life cycle, PennDOT owns and maintains a piece of equipment from acquisition until it reaches the end of its life cycle, at which point it is sold at auction. For each type of equipment, alternative life cycles can be considered. Table 2.4 summarizes relevant statistics for life cycles from one to fifteen years for tandem axle dump trucks. The Task 2 report provides the same statistics for single axle trucks, tri-axle trucks, crew cabs, excavators, loaders, and backhoes. A life cycle of one year means that all pieces of equipment are owned for one year and then sold at auction; a life cycle of two years means that all pieces of equipment are owned for two years and then sold at auction; and so on up to the maximum life cycle. Shown in the tables are: (a) the number of pieces of equipment on which the statistics for each life cycle are based; (b) mean cumulative maintenance and repair costs through the end of each life cycle; (c) mean cumulative personnel hours charged to the equipment through the end of each life cycle; (d) mean cumulative fuel usage for the equipment through the end of each life cycle; (e) the ratio of cumulative maintenance and repair costs/cumulative personnel hours; (f) the ratio of cumulative maintenance and repair costs/cumulative fuel usage.

Cost ratios express the efficiency of each life cycle as a ratio of cumulative maintenance and repair costs to cumulative amount of use as measured by personnel hours charged to equipment (Cost Ratio 1) and fuel usage (Cost Ratio 2). The cost ratios were lowest for a one-year life cycle, and increased with each successively longer life cycle. With longer life cycles, increasing maintenance and repair costs outpaced increasing usage, whether measured by hours or fuel usage. Cost ratios for tandem axle trucks are plotted in Figure 2.6. The points in each trendline indicated by a circle (rather than a square or triangle) reveal the optimal lifecycle of 12 years calculated from these ratios. The rate of increase in maintenance and repair costs relative to usage (measured by either hours or fuel usage) was steeper after a 12 year life cycle. PennDOT's current life cycle of 12 years for these trucks is thus supported by the data in Table 2.4.

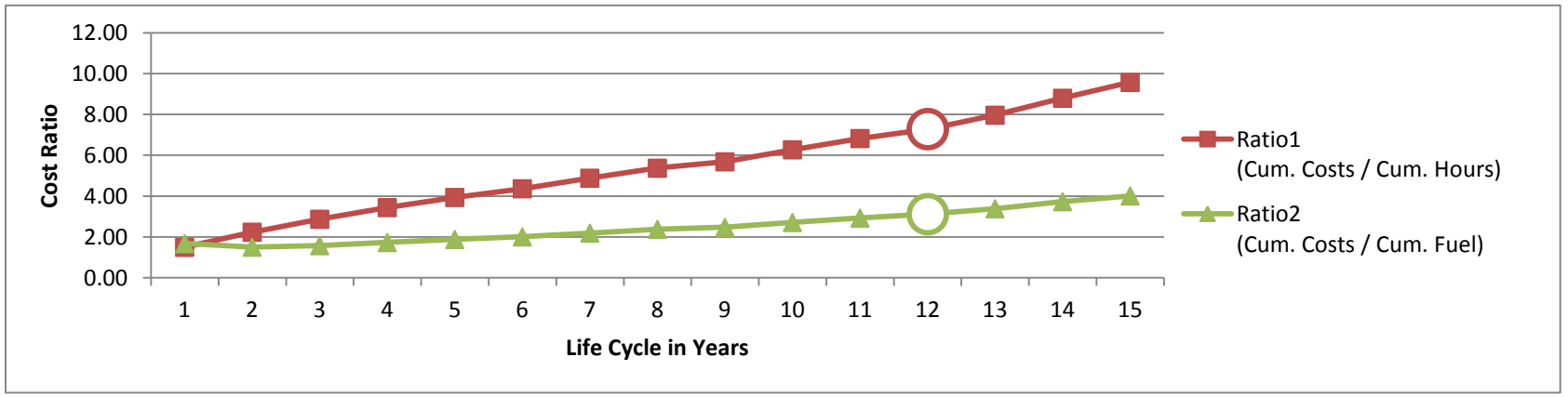
PennDOT's current equipment life cycles and recommended life cycles based on the analyses summarized in the Task 2 report are listed in Table 2.5. In addition, life cycle analyses were conducted using a single model year cohort of vehicles for types of equipment with sufficient numbers for analysis purposes (model year 2000 for single axle trucks, tandem axle trucks, tri-axle trucks, and crew cabs; model year 1995 for loaders). These supplemental analyses supported the life cycle recommendations shown in Table 2.5 with two exceptions: For tri-axle trucks, the single cohort analysis indicated that a 9 year life cycle produced the greatest cost efficiency (versus the 7 year life cycle in Table 2.5); for crew cabs, the single cohort analysis

Table 2.4. Summary Statistics for Alternative Life Cycles for Tandem Axle Trucks

	Life Cycle in Years							
	1	2	3	4	5	6	7	8
N	811	777	799	772	792	742	691	625
Cumulative Costs	$4,088.80	$9,118.30	$16,165.43	$24,118.02	$32,297.43	$41,328.24	$51,386.75	$61,129.38
Cumulative Hours	2724.52	4068.10	5623.00	6996.50	8192.21	9462.39	10518.08	11373.59
Cumulative Fuel	2434.66	6046.43	10226.28	13918.48	17132.74	20547.22	23385.08	25684.86
Ratio1 (Cum. Costs / Cum. Hours)	1.50	2.24	2.87	3.45	3.94	4.37	4.89	5.37
Ratio2 (Cum. Costs / Cum. Fuel)	1.68	1.51	1.58	1.73	1.89	2.01	2.20	2.38

	Life Cycle in Years						
	9	10	11	12	13	14	15
N	421	354	251	113	66	25	11
Cumulative Costs	$70,906.06	$81,486.10	$92,408.63	$100,703.54	$115,381.35	$129,088.34	$153,155.77
Cumulative Hours	12467.15	12983.83	13537.79	13840.08	14478.98	14671.61	15998.83
Cumulative Fuel	28624.52	30013.46	31502.59	32315.19	34032.67	34550.49	38118.29
Ratio1 (Cum. Costs / Cum. Hours)	5.69	6.28	6.83	7.28	7.97	8.80	9.57
Ratio2 (Cum. Costs / Cum. Fuel)	2.48	2.71	2.93	3.12	3.39	3.74	4.02

Figure 2.6. Plots of Cumulative Cost Ratios by Personnel Hours (1) and Fuel Usage (2): Tandem Axle Trucks



indicated that a 9 year life cycle produced the greatest cost efficiency (versus the 8 and 11 year life cycles in Table 2.5). Thus, both sets of analyses indicated that life cycles for tri-axle trucks should be shortened, and life cycles for specialized crew cabs should be lengthened.

Table 2.5. Current and Recommended Equipment Life Cycles

Type of Equipment	Current Life Cycle	Recommended Life Cycle
Single Axle Trucks	12	11
Tandem Axle Trucks	12	12
Tri-axle Trucks	12	7
Crew Cabs	8	8
Specialized Crew Cabs*	8	11
Excavators	12	14
Loaders	15	12
Backhoes	15	13

* Specialized crew cabs are crew cabs that are so designated at the end of a typical life of 8 years, after which they support special operations.

A consideration in changing current equipment life cycles is the number of pieces of equipment of each type that would be replaced each year with a different life cycle, and the replacement costs for that number of pieces. For recommended life cycles that are shorter than currently (i.e., single and tri-axle trucks, loaders and backhoes), shorter life cycles mean more pieces replaced each year and therefore greater annual replacement costs. For example, assuming a current fleet of 700 single-axle trucks, an 11-year life cycle would require replacing about 64 trucks per year whereas a 12-year life cycle would require replacing about 58 trucks per year, for a difference of about 6 trucks per year. The average monthly costs for maintenance of these replacement trucks in the first year of their life cycles are hundreds of dollars less per truck per month than the maintenance costs of trucks during their twelfth year, partially offsetting the replacement costs.

Conversely, longer life cycles (i.e., specialized crew cabs and excavators) mean fewer pieces replaced each year and therefore lower annual replacement costs. Assuming a current fleet of 150 excavators, a 14-year life cycle would require replacing about 11 vehicles per year whereas a 12-year life cycle would require replacing 12 to 13 vehicles per year, for a difference of 1 to 2 vehicles per year. Annual replacement costs for a longer life cycle would be less, although this difference would be partially offset by higher monthly maintenance costs for older equipment. Equipment replacement (or acquisition) costs were factored into life cycle calculations by including annual depreciation in the supplemental analyses. In general, costs for longer life cycles are less than costs for shorter life cycles, because total life costs are amortized over a longer period. Life cycle analyses reveal the overall optimal life cycles for each type of equipment considering multiple factors. By the same token, if total costs of ownership were not a concern, then replacing each piece of equipment upon warranty expiration would save on costs of maintenance and repair while providing a reliable fleet, but at considerably greater cost than longer life cycles.

The prediction tool developed during Task 3 applied equations derived from the growth curve models to data from equipment records (age in months, fuel usage) to predict outcomes such as

cumulative total maintenance costs and Level 1 Assembly costs. Predictions are for individual units (i.e., a specific tandem-axle dump truck). Predictions are based on equipment age, usage, and history of maintenance/repair costs, and the user can specify hypothetical values for usage and maintenance costs to explore alternative scenarios (e.g., the cost of performing a major engine overhaul vs. not). Supplemental predictions, such as the likelihood of costs for a specific system (e.g., to a suspension system), are based on Level 1 Assembly probabilities. Equipment can be prioritized for replacement comparing units of a given type, or across types, ages, and/or organizational units. Replacement decisions can also be considered with respect to user-specified equipment replacement budgets.

TASK 3: CREATE AN EQUIPMENT LIFE CYCLE PREDICTION TOOL AND MANUAL

Upon acceptance of the Task 2 report by PennDOT, the research team began work on the equipment life cycle prediction tool and manual. Based on discussions with Technical Advisor Michael Connor and members of the project review panel during monthly meetings, a PowerPoint presentation was created to illustrate possible design alternatives for the tool. These alternatives were reviewed and discussed during an initial prediction tool design meeting held at the Fleet Management Division on July 19, 2013. Meeting minutes and the PowerPoint presentation are included in Appendix A.

Work to design and program the prediction tool continued during August, September, and October 2013. As work progressed, questions about design details were communicated to Connor by telephone or email as needed. At the September monthly meeting, a version of the prediction tool with its three basic functions (i.e., predicting future costs for a particular piece of equipment, prioritizing pieces of equipment for replacement, and considering pieces of equipment for replacement within the constraints of an annual budget for new equipment) was presented and discussed. This meeting produced a number of design suggestions and requests, which are documented in the meeting minutes (see Appendix B). PennDOT provided additional feedback by email on October 4, 2013.

The next version of the prediction tool was provided to PennDOT on October 24, 2013. Also provided were a User's Manual and an Administrator's Manual. Successive versions of the prediction tool were provided from November 2013 through June 2014, based on PennDOT feedback, along with updated manuals. Final versions of these manuals are included in Appendices C and D, respectively. The Administrator's Manual explains how to update the equipment records used by the prediction tool.

The prediction tool uses equations derived from the data analyses described in the Task 2 report. The basic prediction equation, and the equation parameters applied for each piece of equipment of each type and age, are listed Table 3.1. Equation parameters relate equipment age in months and cumulative personnel hours to cumulative maintenance and repair costs for each type of equipment included in this study. The parameters represent the degree of relationship during the five-year observation period between equipment age in months and monthly maintenance/repair costs, and between cumulative hours and monthly maintenance/repair costs. Although the model parameters are not standardized, the magnitudes of relationships represented by the values can be compared within a column. Higher positive values indicate that greater age in months and greater cumulative hours are associated with greater monthly maintenance costs. In two cases, parameters for cumulative hours are negative (17 and 18 year old backhoes); negative values indicate that for pieces of equipment of that age, those with relatively less cumulative hours had higher monthly maintenance/repair costs during the observation period. Blank cells in Table 3.1 indicate that there were no pieces of equipment of that age, or insufficient numbers for analysis purposes (e.g., single axle trucks for ages 15-18 years).

In addition to prediction equations, cost ratio and equipment replacement prioritization metrics were developed for use by the tool.

Table 3.1. Longitudinal Growth Model Parameters Relating Cumulative Personnel Hours and Equipment Age in Months to Cumulative Maintenance and Repair Costs

Age in Years	Equipment Type													
	Single Axle		Tandem Axle		Tri-Axle		Crew Cab		Excavator		Loader		Backhoe	
	Hours	Months	Hours	Months	Hours	Months	Hours	Months	Hours	Months	Hours	Months	Hours	Months
1	0.21	276.7	0.63	282.4	0.86	586.6	0.04	185.7	1.48	138.0	0.61	134.0	1.48	64.7
2	0.77	238.5	1.01	299.6	0.57	802.9	0.48	153.0	1.54	155.4	0.99	189.5	0.85	156.6
3	1.19	298.2	1.55	394.6	2.00	527.1	0.67	188.7	2.17	273.6	1.41	260.6	2.00	145.9
4	1.61	385.7	2.04	484.4	2.48	779.1	1.01	221.7	3.03	345.9	1.11	374.7	2.40	212.4
5	1.81	469.9	2.23	559.5	2.15	626.5	1.06	278.0	3.53	361.0	1.14	459.1	1.99	301.3
6	2.08	565.8	2.32	652.8	2.92	767.9	1.25	356.6	4.25	294.5	1.31	521.4	1.40	304.7
7	1.66	637.0	1.63	805.4	1.76	864.9	1.42	340.9	3.35	360.8	1.21	475.2	2.13	319.9
8	2.08	643.6	2.47	754.7	1.72	1078.7	1.23	377.2	3.13	351.9	1.22	475.0	2.22	382.8
9	2.13	690.1	2.40	810.0	2.47	1185.6	1.45	369.9	4.11	413.5	1.39	468.5	1.58	356.1
10	2.07	701.6	2.65	784.2	3.25	1148.1	1.38	253.9	4.21	424.8	1.41	490.8	1.45	280.1
11	1.95	689.6	2.59	774.5	7.86	873.8	1.80	226.6	4.58	483.7	1.43	460.9	1.12	463.2
12	2.57	507.7	3.02	765.1	3.87	581.3	1.83	246.2	3.71	443.2	1.33	392.8	1.47	321.7
13	4.48	371.1	2.80	725.3			2.65	171.3	4.89	542.3	1.08	369.2	1.87	274.0
14	2.93	394.1	3.20	690.0			3.84	68.0	5.19	446.6	0.80	390.7	0.01	473.5
15			2.88	622.3					3.89	653.9	1.48	341.6	5.12	260.6
16									4.73	452.6	2.06	280.6	0.41	471.4
17									2.61	426.7	2.24	264.8	-0.75	304.6
18									6.37	129.4	1.55	268.4	-2.93	399.0

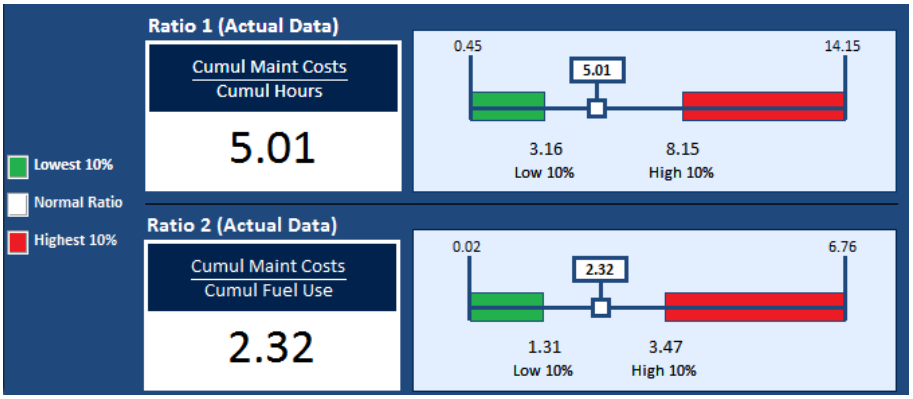
Note. Predicted cumulative maintenance cost at age N (in years) for a given piece of equipment is calculated using this equation:

Predicted Maintenance Cost at Age_N = (HoursParam * Avg Hours per Year) + (MonthsParam * 12) + Cumulative Maintenance Cost at Age_{N-1}

where for a given piece of equipment **Age_N** is a future age (e.g., for a 10-year old truck, future ages are 11, 12, 13, etc., up to the limit of predictability shown in the table), **Hours** and **Months Parameters** are from the table for a specific future age, **Average Hours per Year** is total usage hours for the piece of equipment as of the last update divided by its age in years, and **Cumulative Maintenance Cost at Age_{N-1}** is the cumulative cost for the previous year.

COST RATIOS

The prediction of future costs portion of the tool presents two ratios that express cumulative maintenance costs relative to cumulative usage of a piece of equipment. Cost Ratio 1 is calculated as cumulative maintenance and repair costs divided by cumulative personnel hours charged to the equipment. Cost Ratio 2 is calculated as cumulative maintenance and repair costs divided by cumulative fuel use for the equipment. Both ratios are calculated as of the date of last update of the database.



In addition to numerical values, horizontal line graphs display these cost ratios relative to the ratios for other pieces of equipment of the same type. The end points of these graphs range from the lowest observed ratio (the left end point) to the highest ratio (the right end point) for any piece of equipment of this type. The lowest and highest 10% areas of the ranges are shaded in green and red, respectively. For pieces of equipment with ratios that fall into the lowest and highest 10% areas, the numerical values are shown in green or red shaded blocks.

The relative standing of the cost ratios for a selected piece of equipment compared to other pieces of the same type provides a type of efficiency metric -- for example, to determine whether the maintenance costs to date for a piece compared to its amount of use (defined by hours charged and fuel usage) are relatively high or low. This information may be helpful in making decisions about this piece, such as whether to continue to maintain and repair it or to replace it.

REPLACEMENT PRIORITY QUOTIENT

The prioritizing equipment for replacement and budgeting portions of the tool use a Replacement Priority Quotient as the basis for comparing and rank ordering pieces of equipment. The Replacement Priority Quotient for each piece of equipment is calculated as:

Priority Quotient = (Age in Years - Life Cycle) + (Cost Ratio - Average Cost Ratio) + 40

where **Age in Years** is the piece of equipment's age in years (rounded to a whole number) from start-up date to present; **Life Cycle** is the stated life cycle in years for this type of equipment; **Cost Ratio** for this piece of equipment is either Cost Ratio 1 (cumulative maintenance and repair

costs / cumulative hours), Cost Ratio 2 (cumulative maintenance and repair costs / cumulative fuel usage), or (Cost Ratio 1 + Cost Ratio 2)/2; **Average Cost Ratio** is the average cost ratio for equipment of the same type and age; and **40** is a constant that adjusts Priority Quotients so that most have positive values. In addition to Priority Quotients calculated using PennDOT's official life cycle for each type of equipment, the prediction tool gives the user an option to set life cycles of their choosing; recommended limits for life cycles are provided according to the statistical reliability of the prediction equations used by the tool.

A Replacement Priority Quotient thus represents a piece of equipment's age relative to its life cycle, and its cost ratio relative to the average cost ratio for other pieces of equipment of the same type and age. In a set of equipment, the oldest piece relative to its life cycle with the highest relative cost ratio for its age and type has the highest Priority Quotient. Conversely, the youngest piece of equipment relative to its life cycle with the lowest relative cost ratio for its age and type has the lowest Priority Quotient.

RECALIBRATING PREDICTION EQUATIONS

As documented in this report and the Task 2 report, the prediction tool uses equations derived from analyses of data contained in PennDOT's equipment maintenance and repair records. The maintenance and repair records provided detailed information for the period from July 2007 through September 2012, and summary information for equipment that was owned and operated prior to 2007. In addition, records were provided for the period from September 2012 to May 2014. As explained in the Administrator's Manual, PennDOT also has the capability to regularly update the data used by the prediction tool. The prediction tool can thus be kept current with respect to PennDOT's fleet for the types and pieces of equipment covered by the tool.

We note, however, that because the equations used by the tool represent maintenance and repair practices during a specific window of time (July 2007 to September 2012), the equations will gradually lose their predictive value as equipment and/or maintenance practices change. To maintain currency and predictive power, maintenance records may need to be reanalyzed periodically (e.g., every 10 years or so) and the prediction equations used by the tool confirmed or reestablished as needed based on results of those analyses. In general, the need to reestablish prediction equations depends on equipment life cycles – sooner for equipment with shorter life cycles (i.e., crew cabs) than for equipment with longer life cycles (i.e., loaders and backhoes).

TASK 4: ORAL PRESENTATION OF PREDICTION TOOL AND FINAL WRITTEN REPORT

An oral presentation and demonstration of the Prediction Tool was conducted at PennDOT's Fleet Management Division on June 6, 2014. In addition to the researchers (Vance and Renz in person, Coccia and Karchner by conference call), attending for PennDOT were staff members from the Fleet Management and Research Divisions. The researchers provided copies of the Executive Summary (included at the beginning of this report) and the User's Manual (included as Appendix C of this report) as meeting handouts. A brief overview of the project was provided, followed by an in-depth demonstration of the features and functions of the Prediction Tool. There was opportunity for questions and discussion throughout the two-hour presentation.

APPENDIX A.
MINUTES AND POWERPOINT PRESENTATION FOR PREDICTION TOOL DESIGN MEETING: JULY 19, 2013

Vance & Renz	**Project No. 110601** "Optimizing the Life Cycle of PennDOT Equipment" Monthly Meeting - July 19, 2013
Location:	Fleet Management
PennDOT Attendees:	Jim Smith, Fleet Management Division Michael Connor, Fleet Management Division Robin Honaberger, Fleet Management Division Stephen Fickes, Fleet Management Division Lisa Tarson, Research Division (via phone)
Contractor Attendees:	Robert Vance, Vance & Renz, LLC (Prime) Michael Renz, Vance & Renz, LLC Perry Croyle, Pennoni Associates, Inc (via phone) James Karchner, SF&Co. (via phone)

A monthly project status meeting was held on Friday, July 19, 2013 from 9:00 - 11:15 AM. The meeting agenda is attached. The following is a summary of the meeting:

Vance began by asking if there was any feedback from the Task 2 report, which was reworked and resubmitted for review on 7/5/2013. Connor and Honaberger stated they had no feedback, and that the additions/edits to the report from the previous draft seemed appropriate. Jim Smith had not yet reviewed the report. Vance asked that any feedback be submitted by Friday, July 26. If no feedback is received, then the report should be deemed complete.

Vance next turned the group's attention to the prediction tool PowerPoint (attached). Vance led the group through the various screens of the prototype prediction tool, explaining how and why it was designed. Smith, Connor, Honaberger, and Fickes all made suggestions on how the tool could be designed to best suit their needs:

Future Costs Predictions

- Make it more obvious that upcoming costs are not a part of the cost ratios displayed on the entry screen
- What is a "good" or a "bad" cost ratio? Show the user if the current equipment is currently above or below the average cost ratio. Vance described how the tool could calculate average, top/bottom percentiles of cost ratios, and other methods of effectively defining what a "good" or "bad" cost ratio might be (e.g., top and bottom 10%).
- Graphs are great to help allow the users to "see" what the data means/represents. Make sure the graphs are simple but informative.

Equipment Replacement Prioritization

- Create an additional graph, based on the scatter plots of replacement, that is a bar chart with 1 bar for each piece of equipment, to easily compare many pieces of equipment within the fleet based on equipment type, cost ratios, and model year.

The data within the prediction tool was discussed. As per the previous monthly meeting, Connor and Honaberger said it was likely that Fleet Management would not globally update the data with current information, but the users could enter/edit their own information within the system. Smith said that "everything needs to be updated" and that Fleet Management will update the data once a year at the minimum. Smith also said that no users should be able to edit their information – to prevent errors in the data from occurring. Renz described how the tool could be designed so the users can "play" with temporary data to see how certain maintenance costs could affect the equipment life cycle predictions, without saving or overwriting the legitimate data entered by Fleet Management. Smith and Connor liked this feature and agreed the tool should work accordingly.

Renz stated the new prediction tool screens/charts would be created based on feedback from this meeting, and then shared with the group. Once the new screens/charts are complete, the next meeting will be scheduled based on everyone's availability. Now that the project is into the Task 3 prediction tool design/creation, meetings will need to be held more regularly than monthly. Meetings can occur using webinars and/or conference calls as needed. Vance said the new prediction tool screens/charts would be submitted by Friday, July 26 for review.

With no further questions or discussion, the meeting was adjourned.

Meeting Agenda

7/19/2013

Optimizing the Life Cycle of PennDOT Equipment
RFQ #110601
Fleet Management Division
Friday, July 19, 2013
9:00 – 11:00 AM

Conference call info:
605.475.4810
Access Code: 747853#

MONTHLY MEETING AGENDA

I. TASK 2: ANALYSES OF EQUIPMENT RECORDS

- Discussion of feedback regarding Task 2 Report (7/5/2013)

II. TASK 3: CREATE AN ELECTRONIC LIFE CYCLE PREDICTION TOOL

- A PowerPoint presentation will illustrate prediction tool design options including:
    - Future life cycle cost implications of a repair choice for a single piece of equipment
    - Prioritizing decisions (e.g., replacement decisions) among pieces of equipment of a specific type
    - Budget allocation decisions among several types of equipment in a fleet (e.g., district or county)

III. OPEN DISCUSSION AND WRAP-UP

Meeting PowerPoint

7/19/2013

Equipment Life Cycle

Optimizing the Life Cycle of PennDOT Equipment

Task 3
Prediction Tool Design Meeting

7/19/2013

Prediction Tool Design

Can be designed to help the user answer the following questions:

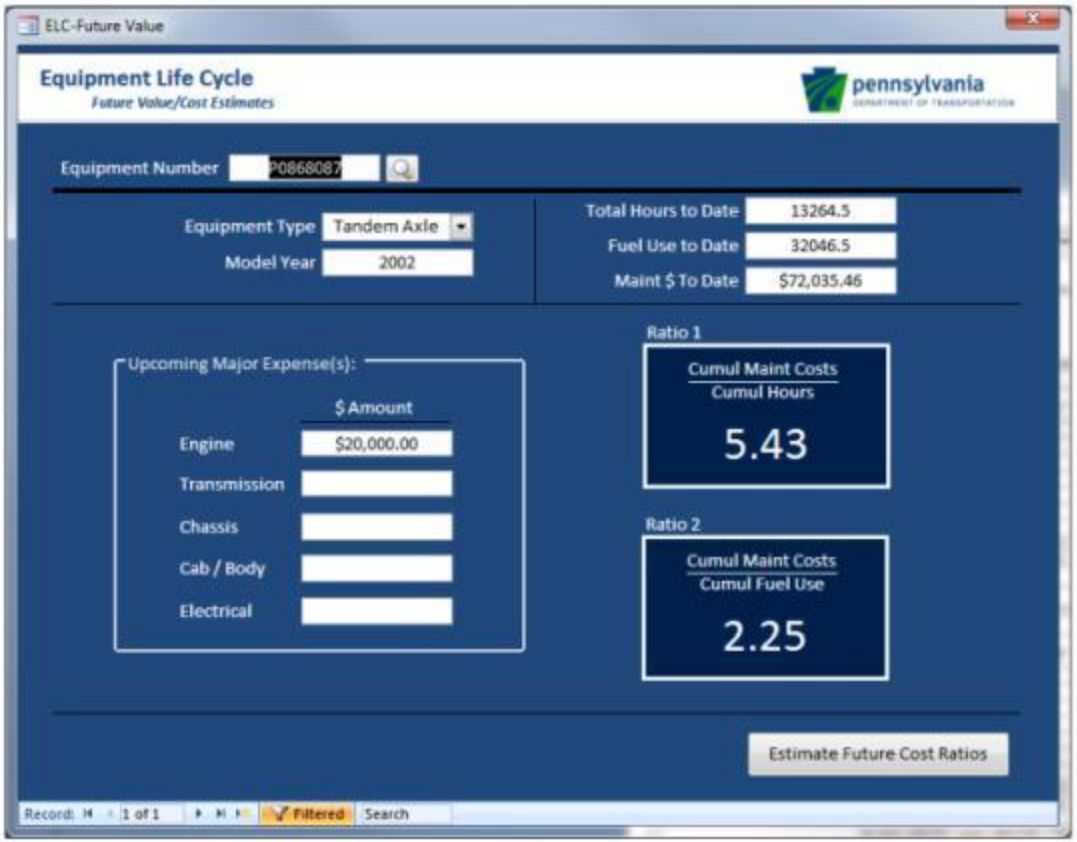
1. Considering 2 alternatives, spending significant money (e.g., $20K) on a major repair vs. not spending the money for **a given truck**, what are the implications of each alternative for future maintenance/repair costs and cost ratios?

2. For a **given set of equipment** owned by a district or county (e.g., 7 tandem trucks 10 years and older), what should be the priority order for replacing them?

3. Considering allocating equipment replacement budgets among **equipment types**, what do comparisons of cost ratios say about allocation decisions?

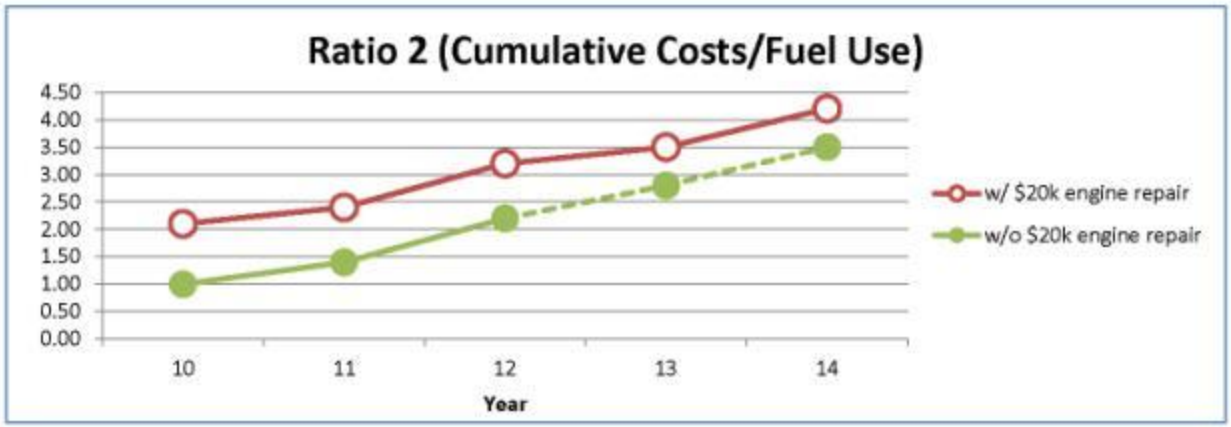
Equipment Life Cycle Prediction Tool

Scenario: Whether or not to spend $20k for an engine rebuild on a 10-year old truck. Project cost ratios out 2 vs. 4 years



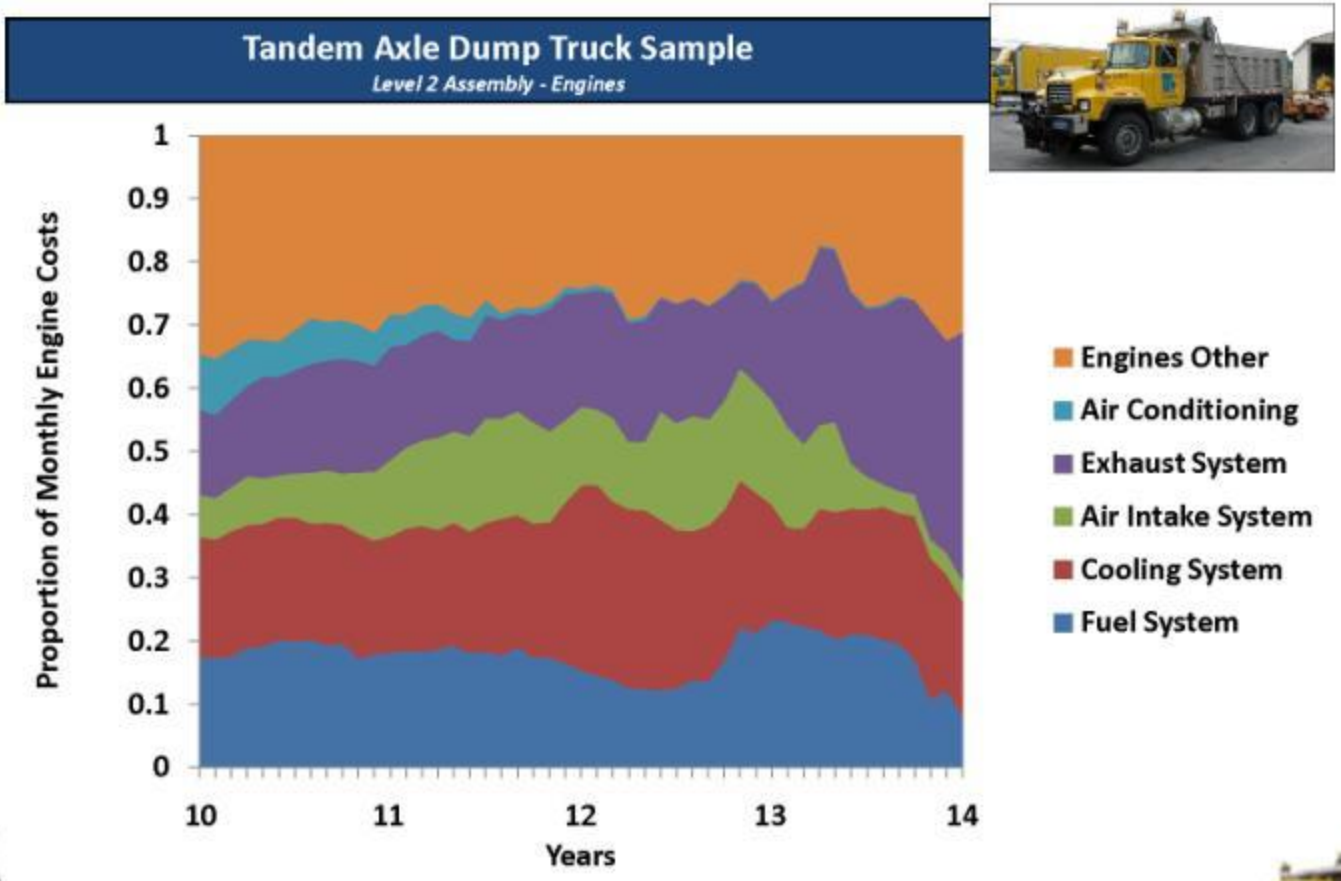
Cost Ratio Projections

10-year old tandem axle truck with and without $20k engine rebuild



Engine Repair Projections

10-year old tandem axle truck with $20k engine rebuild



Additional Prediction Tool Uses

- To prioritize pieces of equipment within an equipment type (e.g., tandem axle trucks) for replacement
  - By county, district, or department-wide

Prioritization Selection

ELC-Prioritize Equipment Replacement

Equipment Life Cycle

Prioritize Equipment Replacement

pennsylvania
DEPARTMENT OF TRANSPORTATION

Equipment Type: Tandem Axle

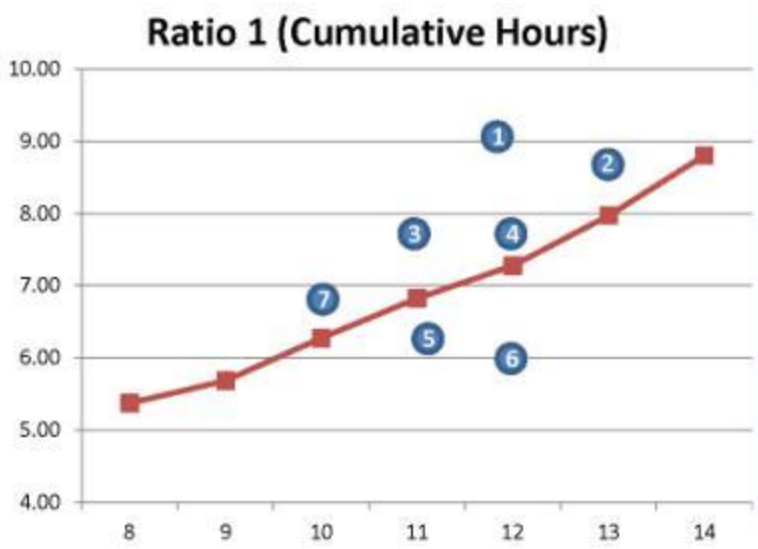
Select the equipment to prioritize replacement:

Prioritize	Equipment Number	Model Year	Acq. Date	Cum. Hours	Fuel Use to Date	Maint $ To Date	Ratio 1: Cum. Maint $ / Cum. Hours	Ratio 2: Cum. Maint $ / Cum. Fuel Use
☑	P0018372	2004	2/5/2002	3200	14050.7	$25,426.80	9.99	68.18
☑	P0022572	2001	3/8/2004	3800	10274.6	$15,888.18	1.38	60.76
☑	P0028072	2004	3/8/2004	4050	10274.6	$15,888.18	1.38	60.76
☐	P0048072	2002	2/5/2002	4250	14050.7	$25,426.80	9.99	68.18
☑	P0848087	2006	4/18/2012	350	1318.4	$2,541.00	5.34	50.38
☐	P0868017	2009	8/1/2009	908	5871.8	$6,978.65	1.05	75.12
☐	P0868087	2011	7/8/2011	760	2318.9	$5,496.88	2.37	66.07
☐	P0868087	2009	8/1/2009	1308	5871.8	$6,978.65	1.05	75.12
☑	P0918087	2005	5/28/2010	600	3218.2	$7,208.50	6.05	68.15
☑	P1018087	2000	2/6/2010	1200	3100.7	$8,803.80	7.55	43.85
☐	P1078087	2007	10/12/2007	2742	7058.2	$9,428.45	0.55	67.8
☑	P1078317	2003	10/12/2007	2300	8000.7	$12,000.50	0.55	67.8

Prioritize Equipment Replacement

Record: 1 of 12 | Filtered | Search

Equipment Replacement Prioritization



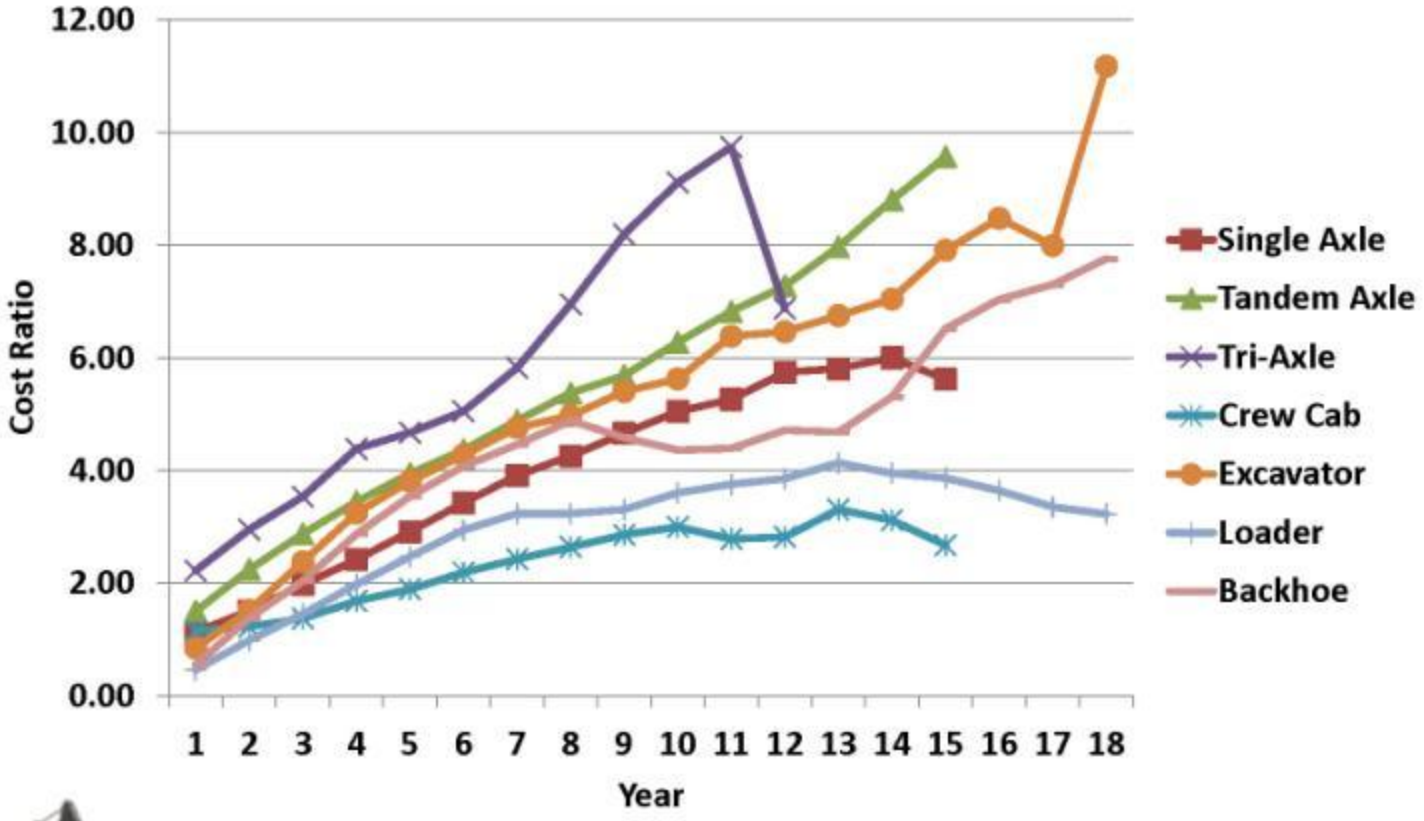
Priority of replacement:

Priority	Equipment Number	Model Year	Ratio 1 Cum. Maint $ / Cum. Hours	Ratio 2 Cum. Maint $ / Cum. Fuel Use
1	P1018087	2000	8.97	6.62
2	P1078317	2003	7.85	6.31
3	P0018372	2001	7.68	5.9
4	P0918087	2003	6.05	5.75
5	P0028072	2004	6.01	5.58
6	P0022572	2005	5.92	4.98
7	P0848087	2006	5.87	4.76

Additional Prediction Tool Uses

- To allocate equipment budgets among equipment types (single-, tandem-, tri-axle trucks, crew cabs, loaders, excavators, backhoes)
  - By county, district, or department-wide
  - Based on current fleet mix, budget, and cost-efficiency ratio (cumulative maintenance-repair costs/cumulative fuel usage)
  - Provides mix of new equipment purchases that yields the best cost-efficiency ratio overall over the next x years
  - Does *not* take into account mission or specific operational needs

Ratio 1 by Years and Equipment Type



Discussion / Next Steps

- Continue designing and building the Life Cycle Prediction Tool

APPENDIX B.
MINUTES FOR PREDICTION TOOL DESIGN MEETING: SEPTEMBER 13, 2013

Vance & Renz	**Project No. 110601** "Optimizing the Life Cycle of PennDOT Equipment" Monthly Meeting - September 13, 2013
Location:	Via Conference Call
PennDOT Attendees:	Michael Connor, Fleet Management Division Robin Honaberger, Fleet Management Division Stephen Fickes, Fleet Management Division Doug Gilmer, Fleet Management Division Lisa Tarson, Research Division Sean Oldfield, Research Division
Contractor Attendees:	Robert Vance, Vance & Renz, LLC (Prime) Michael Renz, Vance & Renz, LLC Michael Coccia, Subcontractor Perry Croyle, Pennoni Associates, Inc James Karchner, SF&Co.

A monthly project status meeting was held on Friday, September 13, 2013 from 9:00 - 10:00 AM. The meeting agenda is attached. The following is a summary of the meeting:

Vance noted that a link to download the first version of the Prediction Tool had been sent to the group on 9/11/13, and asked if everyone had succeeded in downloading and launching the application. Everyone except Croyle indicated that they had -- the older version of Microsoft Access installed on Croyle's computer was not compatible with the application, and he indicated that he would install the application on a different computer.

Next, Vance led the group through the various screens of the Prediction Tool, explaining how and why it was designed. He noted that the first two capabilities available from the main screen were functional:

- Future life cycle cost implications of a repair choice for a single piece of equipment
- Prioritizing decisions (e.g., replacement decisions) among pieces of equipment of a specific type

The third capability, Equipment Budget Allocation, was not yet functional. Connor, Honaberger, Fickes, and Gilmer all made suggestions on how the tool could be designed to best suit their needs:

Future Costs Predictions

- Make it possible to view all essential information that was provided for each piece of equipment (make, start-up date, acquisition price, type of transmission, etc.)

- Provide a horizontal scale to show where the cost ratio for a piece of equipment falls relative to minimum and maximum values
- Default to showing Single or Tandem axle trucks, rather than backhoes
- Make it possible to filter by equipment make

Equipment Replacement Prioritization

- Make it so that prioritization of equipment for replacement could be based on Cost Ratio 1 (hours), Cost Ratio 2 (fuel usage), or both
- Show equipment make and type on report
- Add a 'check all' button to allow user to check each piece of equipment at once

Renz stated the new Prediction Tool screens/charts would be created based on feedback from this meeting, and then shared with the group. Vance indicated that the researchers would need to continue to work with Connor and his team to determine details about screens, functions, and output.

Meeting Agenda

9/13/2013

Optimizing the Life Cycle of PennDOT Equipment
RFQ #110601
Fleet Management Division
Friday, September 13, 2013
9:00 – 11:00 AM

Conference call info:
605.475.4810
Access Code: 747853#

MONTHLY MEETING AGENDA

IV. TASK 3: CREATE AN ELECTRONIC LIFE CYCLE PREDICTION TOOL

- The Life Cycle Prediction Tool will be reviewed regarding these capabilities:
    - Future life cycle cost implications of a repair choice for a single piece of equipment
    - Prioritizing decisions (e.g., replacement decisions) among pieces of equipment of a specific type
- The Prediction Tool uses data that are provided in September 2012, at the beginning of the contract period; a data request to update the data to September 2013 will be provided and discussed
- As discussed during the July 2013 meeting, a protocol will be developed to periodically update the data used by the prediction tool; this procedure will be discussed further

V. OPEN DISCUSSION AND WRAP-UP

APPENDIX C .
USER'S MANUAL

pennsylvania
DEPARTMENT OF TRANSPORTATION

FLEET MANAGEMENT DIVISION

Equipment Life Cycle Prediction Tool

User's Manual

6/23/2014

Table of Contents

Chapter 1

Overview

A manual for using the various features of the Equipment Life Cycle Prediction Tool.

To help ease the process of deciding which pieces of equipment should be replaced or are coming to the end of their life cycle, this Prediction Tool has been developed as the outcome of a research project.

This manual describes in detail the functions of the screens of the Prediction Tool:

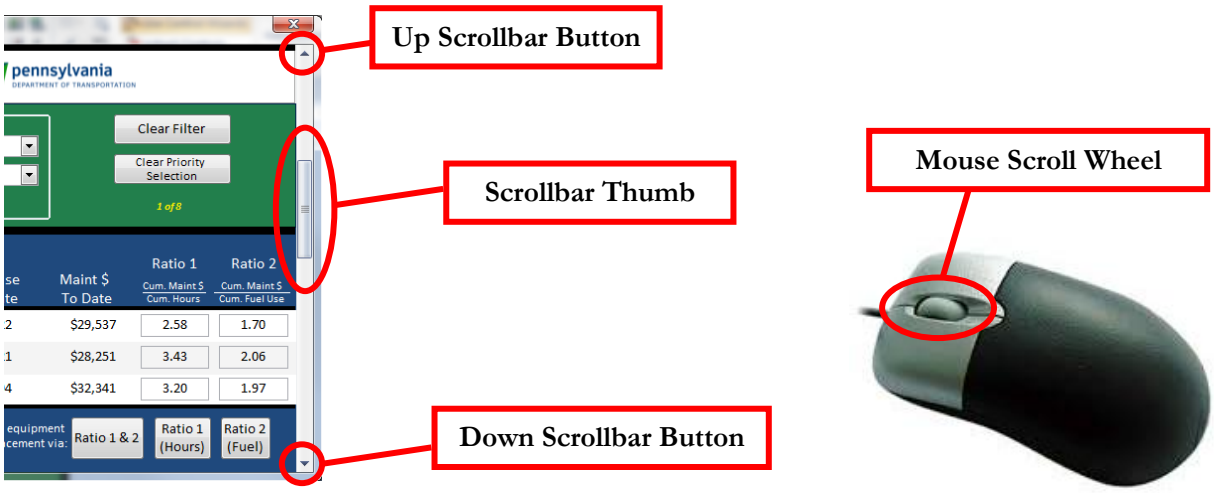
- Main Menu
- Maintenance Cost Predictions
- Prioritize Equipment Replacement
- Equipment Budget Allocation

Screenshots and detailed descriptions make learning how the Prediction Tool works quick and easy. For questions about its purposes and uses, please contact your Fleet Operations representative (miconnor@pa.gov).

You can download the Prediction Tool via the BOMO Intranet on the Fleet Management webpage, under the Monthly Reports/Data Trends Analysis section. Download the Prediction Tool to your local computer, and run it locally. DO NOT LAUNCH THE PREDICTION TOOL FROM THE WEBPAGE! Microsoft Access must be installed on your local computer to run the Prediction Tool.

Once you have downloaded the file to a directory on your local computer, double click on it to launch the Prediction Tool.

Scrolling



As you work with the Prediction Tool, a window may open with more information than is visible in the window. In these instances, a scrollbar will appear along the right margin of the window. There are multiple ways to scroll through the window to view all of its information. If your mouse has a scroll wheel, rolling the wheel backward and forward will scroll the window down and up accordingly. You can also scroll up and down by clicking on the Up or Down scrollbar buttons (see illustration above). To use the scrollbar thumb, place your pointer ( ) on it, left click and hold, then drag it up and down. This is the fastest method for quickly scrolling to the top or bottom of the window.

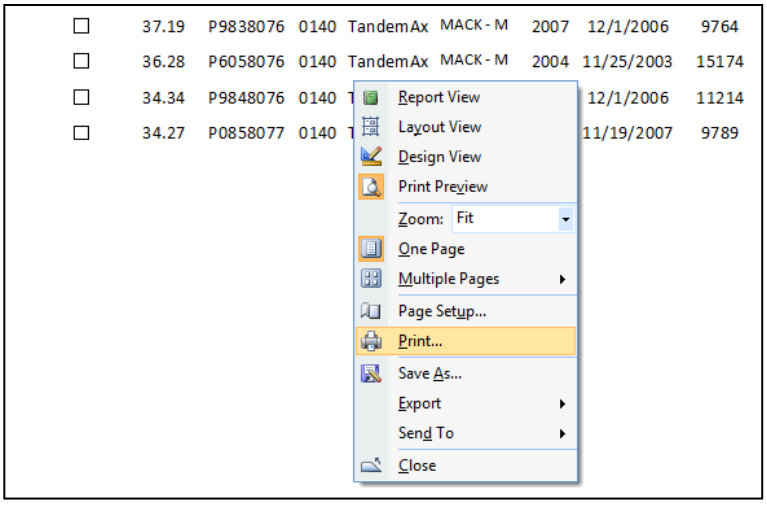
Reports

When you run a report and are viewing it on screen, use the toolbar buttons on the lower left of the window to view successive pages of the report.

Clicking on the button will take you to the first page of the report. The button will take you to the previous page. The button will take you to the next page. The button will take you to the last page of the report. To jump directly to a page, type the page number into the box and hit the Enter key on your keyboard.

If you do not see or cannot access these buttons at the bottom of the screen, you can use the left and right arrow keys on your keyboard to go to the previous and next pages, respectively.

To print the reports on your printer, type Ctrl-P (hold down the Ctrl, or control, key on your keyboard and hit the "P" key). Alternatively, you can right-click anywhere on the report to bring up a menu:



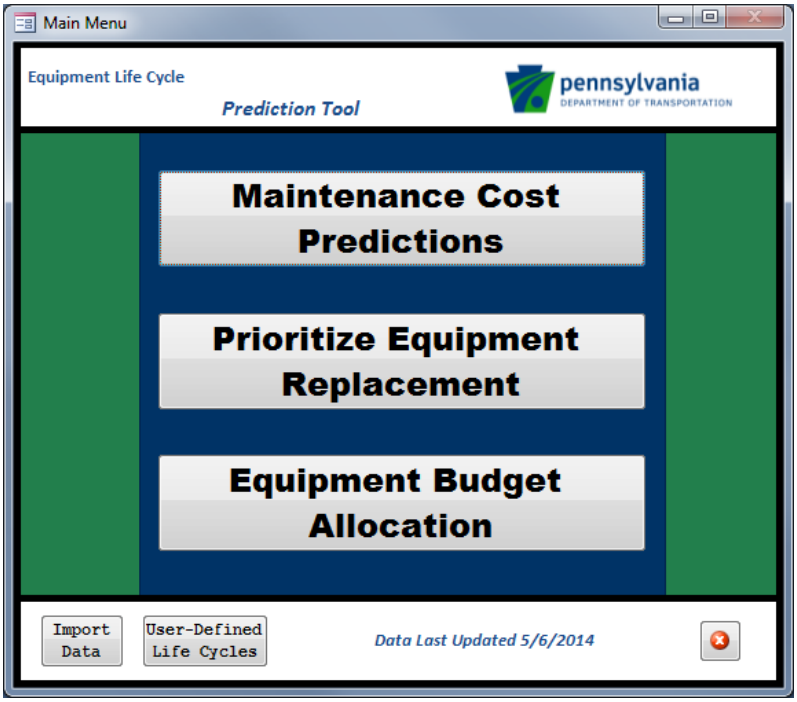
Click on Print (as highlighted in the illustration above). A standard print window will open allowing you to select the printer, the specific pages to print, and the number of copies to print (as well as other printing properties if you click on the print window's Properties button).

Chapter 2

Main Menu

Prediction Tool Starting Point

The Main Menu will appear when you launch the Prediction Tool:



Main Menu Buttons

There are three large buttons on the Main Menu:

1. Maintenance Cost Predictions
2. Prioritize Equipment Replacement
3. Equipment Budget Allocation

Clicking on these buttons will open screens for the main functions of the Prediction Tool. These functions are described in Chapters 3, 4, and 5 of this manual.

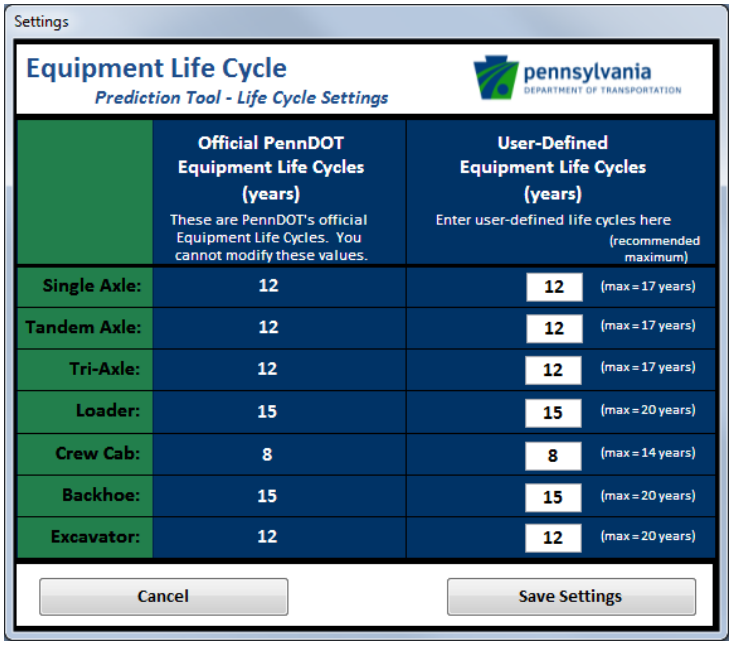
There are three small buttons located at the bottom corners of the Main Menu. The leftmost is an Import Data button -- this is for use by System Administrators only! Next to this is a User-Defined Life Cycles button. User-defined life cycles are explained in the next section of this chapter. On the far right is an Exit button . Click this to exit the Prediction Tool.

A "*Data Last Updated mm/dd/yyyy*" message appears at the bottom center of the Main Menu screen. If this date is more than three months ago, you may need to obtain an updated copy of the Prediction Tool from the PennDOT Shared drive (see Chapter 1).

User-Defined Life Cycles

The life cycle of a type of equipment is the duration in years that a piece of equipment of that type is expected to remain a functional part of the equipment fleet. PennDOT has established life cycles for each equipment type, shown in the Official PennDOT Equipment Life Cycles column in the illustration below. Official life cycles are noted in Maintenance Cost Prediction reports (see Chapter 3) and are used in calculating Replacement Priority Quotients (see Chapter 4). By default, Replacement Priority Quotients are calculated using official life cycles, but you can also specify user-defined life cycles to use in these calculations.

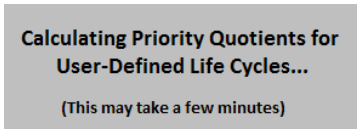
Clicking the User-Defined Life Cycles button on the Main Menu allows you to specify user-defined equipment life cycles. An Equipment Life Cycle window will open showing the official PennDOT life cycles and the current values for the user-defined life cycles.



To change the values of the user-defined life cycles, click into the boxes and type the new values. Note that user-defined values must be at least 1 year, at most 99 years and should be whole numbers – if you type a

decimal value, it will be rounded it to the nearest whole number. The Prediction Tool uses equations derived from analyses of PennDOT's equipment repair records. When a piece of equipment reaches the end of its life cycle, PennDOT typically sells it at auction. This limits the reliable range of the prediction equations, and the Prediction Tool therefore has a maximum user-defined life cycle for each type of equipment. Life cycle recommended maximums are shown to the right of the data boxes.

Once you enter life cycle values, click the Save Settings button. A message will appear while the required calculations are performed, which can take a few minutes to complete. Note that you must wait for these calculations to finish before proceeding.



Once the calculations are complete and the user-defined life cycles are saved, the Equipment Life Cycle window will close. If you decide not to change the user-defined life cycles shown in this window when you first open it, or decide not to save any changes you made to them, click the Cancel button to close the window.

Note that once you have saved user-defined life cycles, they will be used in any Prioritize Equipment Replacement (see Chapter 4) and Equipment Budget Allocation (see Chapter 5) analyses that you perform when the Use User-Defined Life Cycles box is checked. Before running these analyses, you may want to click the Edit User-Defined Life Cycles button to verify that the user-defined life cycles are the values that you intend.

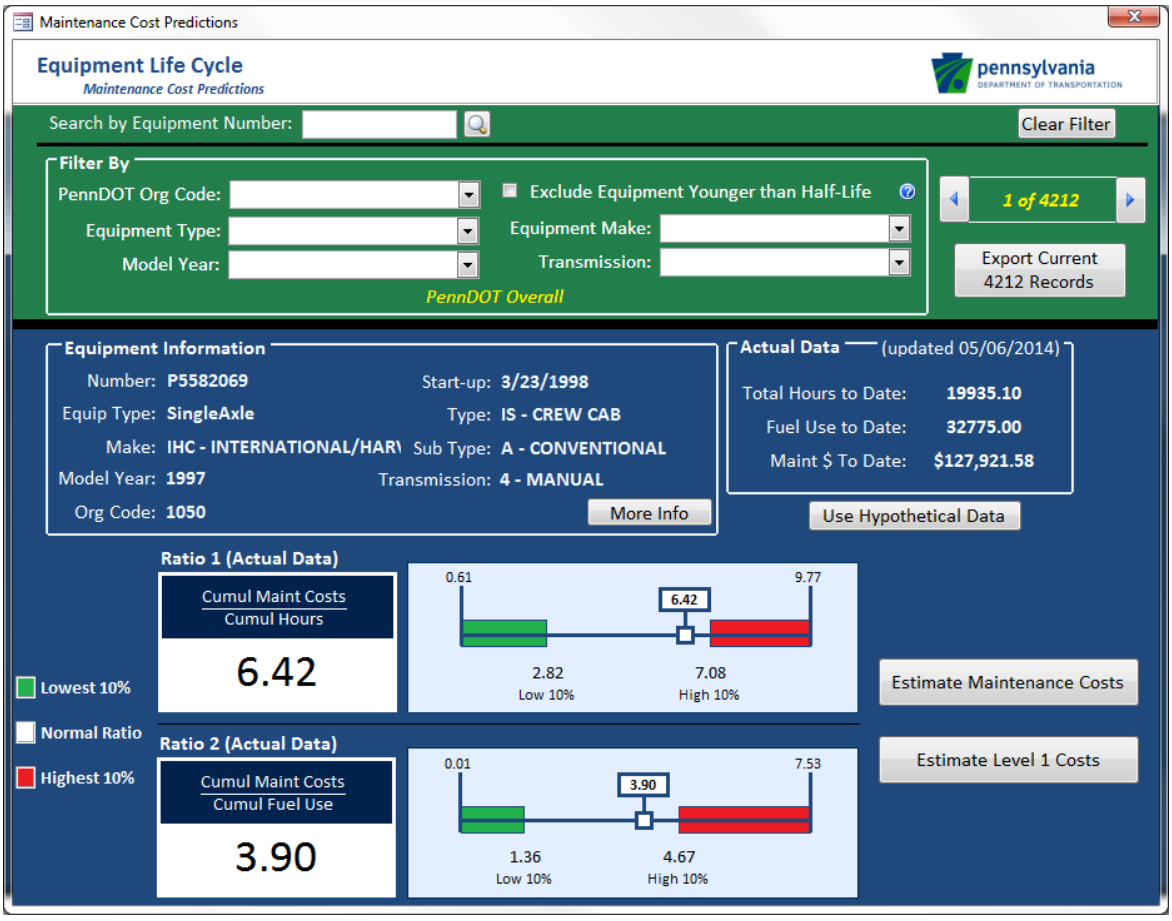
Chapter 3

Maintenance Cost Predictions

The Maintenance Cost Predictions screen allows you to select a specific piece of equipment and:

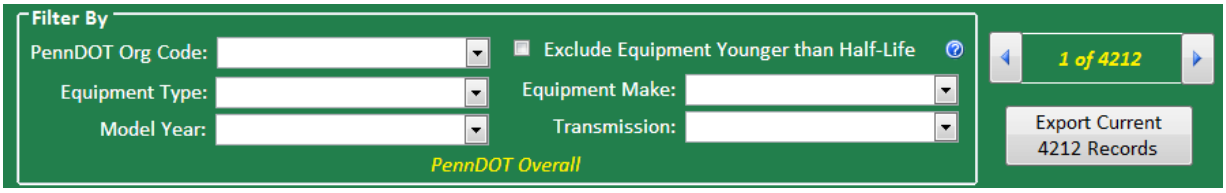
- view its essential information
- examine its history of maintenance and repair costs to date
- estimate its future maintenance costs
- estimate its future maintenance costs for hypothetical expenditure scenarios

To open this screen from the Main Menu, click the first large button **Maintenance Cost Predictions**.



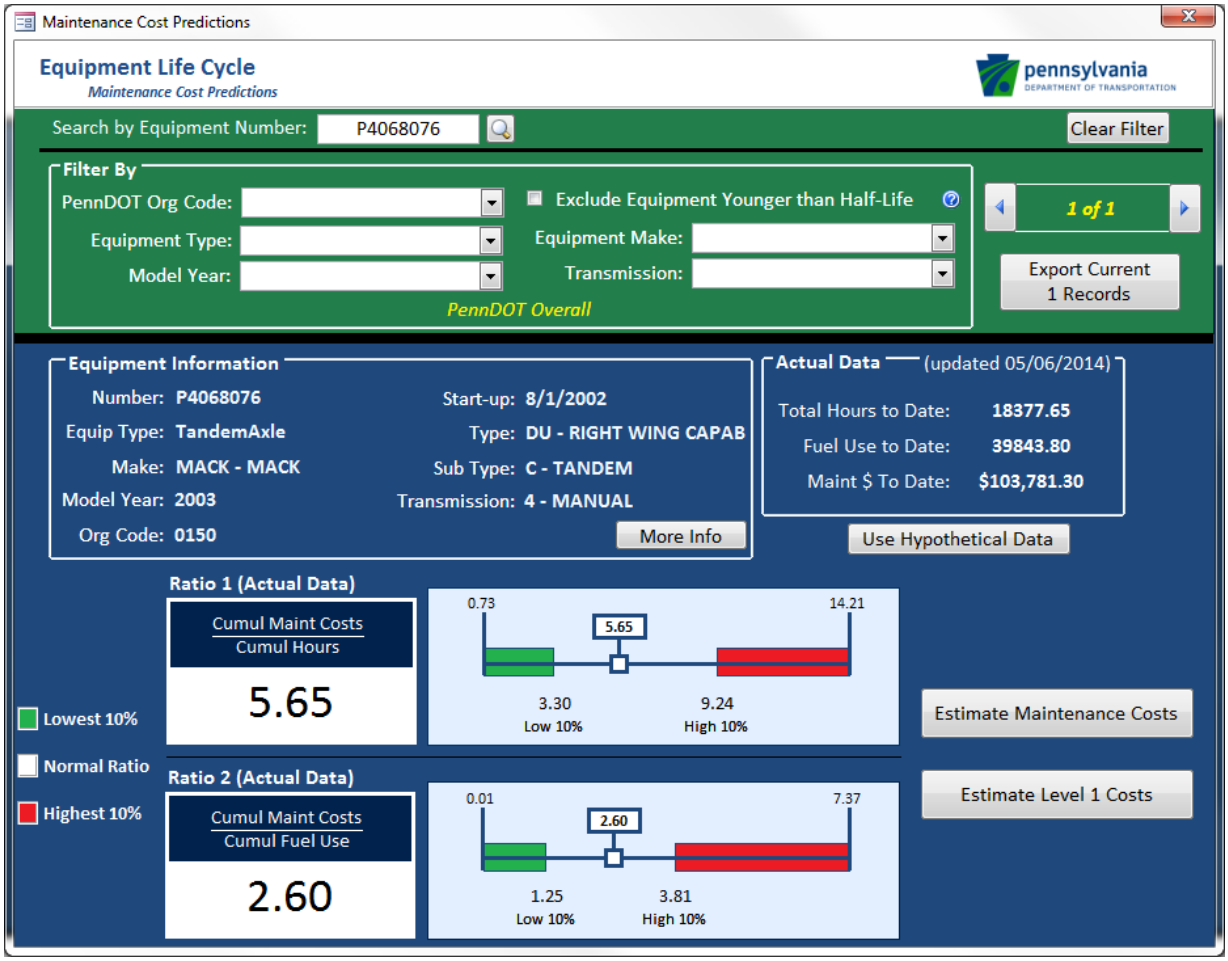
Search Functions

The green section of the screen provides several ways to search for a specific piece of equipment:



Search by Equipment Number

If you know the Equipment Number, enter it into the box, then hit the Enter key on your keyboard or click the  button to the right. Essential information about this piece of equipment will appear in the blue section of the screen. You may use wildcards ('*') in your search. You can find the tandem axle truck shown in the example below by entering 'P4068076', 'P406*', '*8076*', and other combinations of portions of the Equipment Number plus wildcards.



Filter By

You may also find a specific piece of equipment by searching the database using five filters, including PennDOT Organizational Code, Equipment Make, Equipment Type, Transmission Type, and Model Year. Click the down arrow (▼) at the right side of a filter box, and then choose from the drop-down menu by clicking one of the options provided. Your choices will appear in yellow text in the lower right portion of the Filter By menu area as you build a search. You may use all five filters in a search, but note that some combinations of options yield null results (e.g., Equipment Make = CASE and Equipment Type = Tandem Axle will return 0 pieces of equipment because there are no tandem axle trucks made by CASE in PennDOT's inventory).

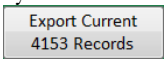
In the upper portion of the Filter By menu is a checkbox to "Exclude Equipment Younger than Half-Life." With this checked, any piece of equipment that is younger than half of its expected life cycle is not included in filter search results.

Search Results

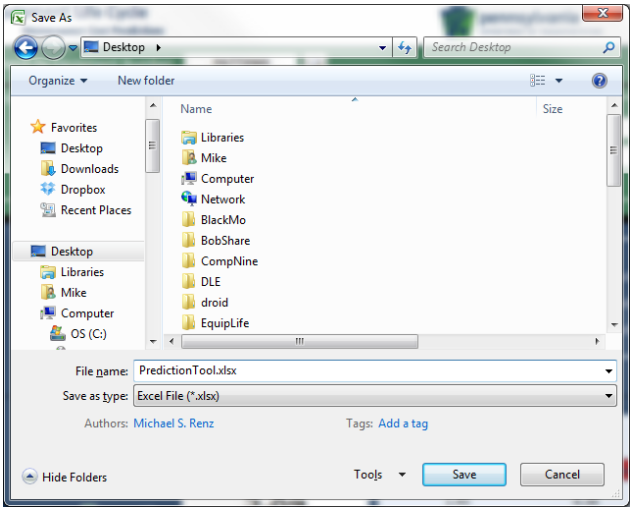
In most instances when you search for a piece of equipment using filters, or by Equipment Number using wildcards ('*'), the search yields more than one piece of equipment. The number of pieces that meet the search criteria appears in the green section to the right of the Filter By menu. You can view the information for each piece resulting from a search by clicking the directional arrows ◀ and ▶ .

If you searched by Equipment Number and obtain a null result, verify that you correctly entered the number into the search field. You can also try entering a partial number and a wildcard ('*'). If the piece of equipment does not appear in a search result, check the date of last update at the top of the Actual Data block in the upper right of the blue section of the screen. If this date is three months or more in the past, you may need to download a current version of the Prediction Tool. If you are using current data and the piece of equipment does not appear, it may be that PennDOT no longer owns it and it has been purged from the database. Contact your Fleet Operations representative to inquire further.

Export Current Records

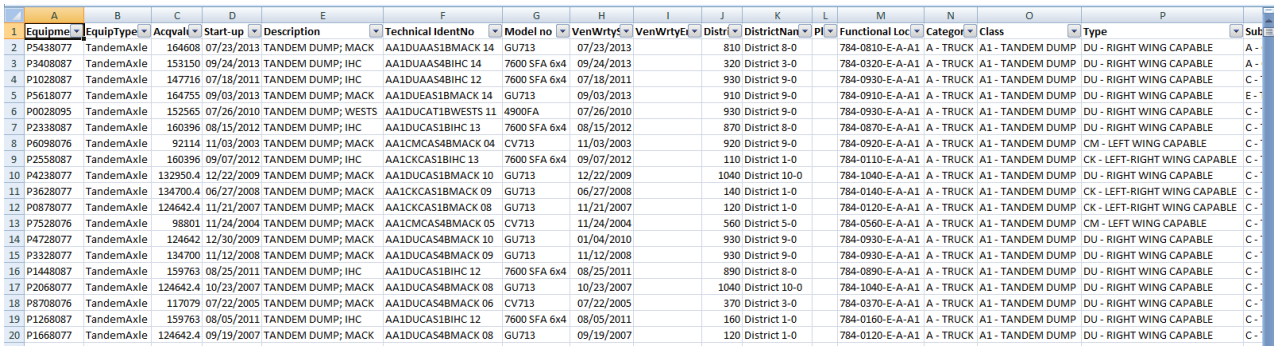
You can export the data for equipment returned by a search to an Excel spreadsheet. Click the 

button to the right of the Filter By menu. A Save As window appears that allows you to save a file containing essential information about the equipment, with a file name and in a directory of your choosing, as shown in the illustration.



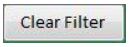
The Excel file contains a record for each piece of equipment returned by a search with the following data:

Equipment Number	Equipment Type	Acquired Value (purchase price)
Start-up Date	Description	Technical Identification Number
Model Number	District Number	District Name
Plant Maintenance Number	Functional Location Code	Equipment Category
Equipment Class	Equipment Class Type	Equipment Class Sub-type
Capacity	Transmission Type	Power Type
Manufacturer	Model Year	Total Costs Life
Total Hours	Total Fuel	Ratio 1
Ratio 2	Ratio 1 Priority Quotient	Ratio 2 Priority Quotient
Ratio 1 Priority Quotient User Defined	Ratio 2 Priority Quotient User Defined	Last Update



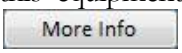
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	Equipme	EquipType	Acqval	Start-up	Description	Technical IdentNo	Model no	VenWrtyS	VenWrtyE	Distr	DistrictNan	Pl	Functional Loc	Categor	Class	Type	Sub
2	P5438077	TandemAxle	164608	07/23/2013	TANDEM DUMP; MACK	AA1DUAAS1BMACK 14	GU713	07/23/2013		810	District 8-0		784-0810-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	A -
3	P3408087	TandemAxle	153150	09/24/2013	TANDEM DUMP; IHC	AA1DUAAS4BIHC 14	7600 SFA 6x4	09/24/2013		320	District 3-0		784-0320-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	A -
4	P1028087	TandemAxle	147716	07/18/2011	TANDEM DUMP; IHC	AA1DUAAS4BIHC 12	7600 SFA 6x4	07/18/2011		930	District 9-0		784-0930-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
5	P5618077	TandemAxle	164755	09/03/2013	TANDEM DUMP; MACK	AA1DUEAS1BMACK 14	GU713	09/03/2013		910	District 9-0		784-0910-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	E -
6	P0028095	TandemAxle	152565	07/26/2010	TANDEM DUMP; WESTS	AA1DUCAT1BWESTS 11	4900FA	07/26/2010		930	District 9-0		784-0930-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
7	P2338087	TandemAxle	160396	08/15/2012	TANDEM DUMP; IHC	AA1DUCAS1BIHC 13	7600 SFA 6x4	08/15/2012		870	District 8-0		784-0870-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
8	P6098076	TandemAxle	92114	11/03/2003	TANDEM DUMP; MACK	AA1CMCAS4BMACK 04	CV713	11/03/2003		920	District 9-0		784-0920-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	CM - LEFT WING CAPABLE	C -
9	P2558087	TandemAxle	160396	09/07/2012	TANDEM DUMP; IHC	AA1CKCAS1BIHC 13	7600 SFA 6x4	09/07/2012		110	District 1-0		784-0110-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	CK - LEFT-RIGHT WING CAPABLE	C -
10	P4238077	TandemAxle	132950.4	12/22/2009	TANDEM DUMP; MACK	AA1DUCAS1BMACK 10	GU713	12/22/2009		1040	District 10-0		784-1040-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
11	P3628077	TandemAxle	134700.4	06/27/2008	TANDEM DUMP; MACK	AA1CKCAS1BMACK 09	GU713	06/27/2008		140	District 1-0		784-0140-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	CK - LEFT-RIGHT WING CAPABLE	C -
12	P0878077	TandemAxle	124642.4	11/21/2007	TANDEM DUMP; MACK	AA1CKCAS1BMACK 08	GU713	11/21/2007		120	District 1-0		784-0120-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	CK - LEFT-RIGHT WING CAPABLE	C -
13	P7528076	TandemAxle	98801	11/24/2004	TANDEM DUMP; MACK	AA1CMCAS4BMACK 05	CV713	11/24/2004		560	District 5-0		784-0560-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	CM - LEFT WING CAPABLE	C -
14	P4728077	TandemAxle	124642	12/30/2009	TANDEM DUMP; MACK	AA1DUCAS4BMACK 10	GU713	01/04/2010		930	District 9-0		784-0930-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
15	P3328077	TandemAxle	134700	11/12/2008	TANDEM DUMP; MACK	AA1DUCAS4BMACK 09	GU713	11/12/2008		930	District 9-0		784-0930-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
16	P1448087	TandemAxle	159763	08/25/2011	TANDEM DUMP; IHC	AA1DUCAS1BIHC 12	7600 SFA 6x4	08/25/2011		890	District 8-0		784-0890-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
17	P2068077	TandemAxle	124642.4	10/23/2007	TANDEM DUMP; MACK	AA1DUCAS4BMACK 08	GU713	10/23/2007		1040	District 10-0		784-1040-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
18	P8708076	TandemAxle	117079	07/22/2005	TANDEM DUMP; MACK	AA1DUCAS4BMACK 06	CV713	07/22/2005		370	District 3-0		784-0370-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
19	P1268087	TandemAxle	159763	08/05/2011	TANDEM DUMP; IHC	AA1DUCAS1BIHC 12	7600 SFA 6x4	08/05/2011		160	District 1-0		784-0160-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -
20	P1668077	TandemAxle	124642.4	09/19/2007	TANDEM DUMP; MACK	AA1DUCAS4BMACK 08	GU713	09/19/2007		120	District 1-0		784-0120-E-A-A1	A - TRUCK	A1 - TANDEM DUMP	DU - RIGHT WING CAPABLE	C -

Clear Filter

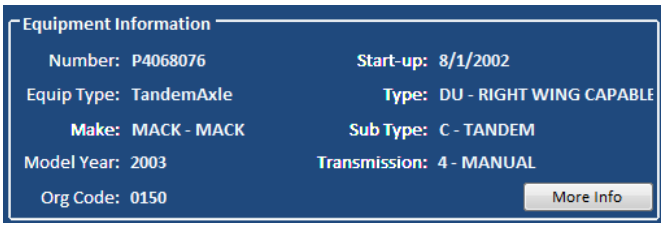
To begin a new search, first click the 

button in the upper right corner of the green section of the screen. Closing the Maintenance Cost Predictions window and then reopening it from the Main Menu also clears previous search criteria and results.

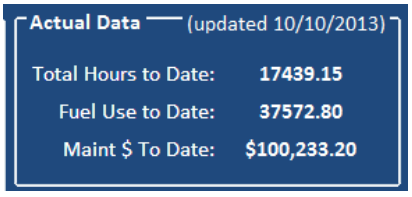
Equipment Information

The upper left portion of the blue section of the screen displays essential information about the selected piece of equipment, such as start-up date and equipment type. Additional information for this equipment can be viewed by clicking the 

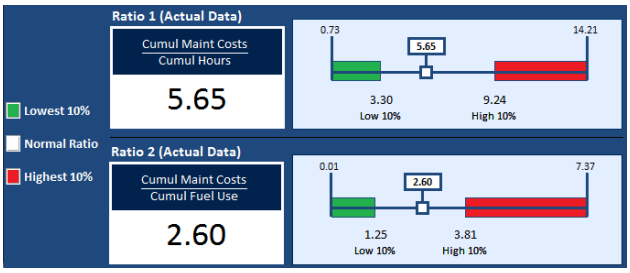
button in the lower right area of this block. If the selected piece of equipment happens to be a Knock-Out truck or Specialized Crew Cab, an orange-texted label will appear to notify you.



The Actual Data block in the upper right portion of the blue section of the screen shows the date of last update for the database. Also shown for the selected piece of equipment are the personnel hours charged to date (Total Hours to Date), fuel usage to date in gallons (Fuel Use to Date), and total maintenance and repair costs to date (Maint $ to Date).



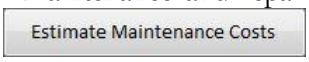
The lower portion of the blue section of the screen shows two cost ratios for the selected piece of equipment. Cost Ratio 1 is calculated as cumulative maintenance and repair costs divided by cumulative personnel hours charged to the equipment. Cost Ratio 2 is calculated as cumulative maintenance and repair costs divided by cumulative fuel use for the equipment. Both ratios are as of the date of last update of the database.



In addition to numerical values, horizontal line graphs display these cost ratios relative to the ratios for other pieces of equipment of the same type. The end points of these graphs range from the lowest observed ratio (the left end point) to the highest ratio (the right end point) for any piece of equipment of this type. The lowest and highest 10% areas of the ranges are shaded in green and red, respectively. For pieces of equipment with ratios that fall into the lowest and highest 10% areas, the numerical values are shown in green or red shaded blocks.

The relative standing of the cost ratios for a selected piece of equipment compared to other pieces of the same type provides a type of efficiency metric – you can determine whether the maintenance costs to date for a piece compared to its amount of use (defined by hours charged and fuel usage) are relatively high or low. This information may be helpful in making decisions about this piece, such as whether to continue to maintain and repair it or to replace it.

Estimate Maintenance Costs

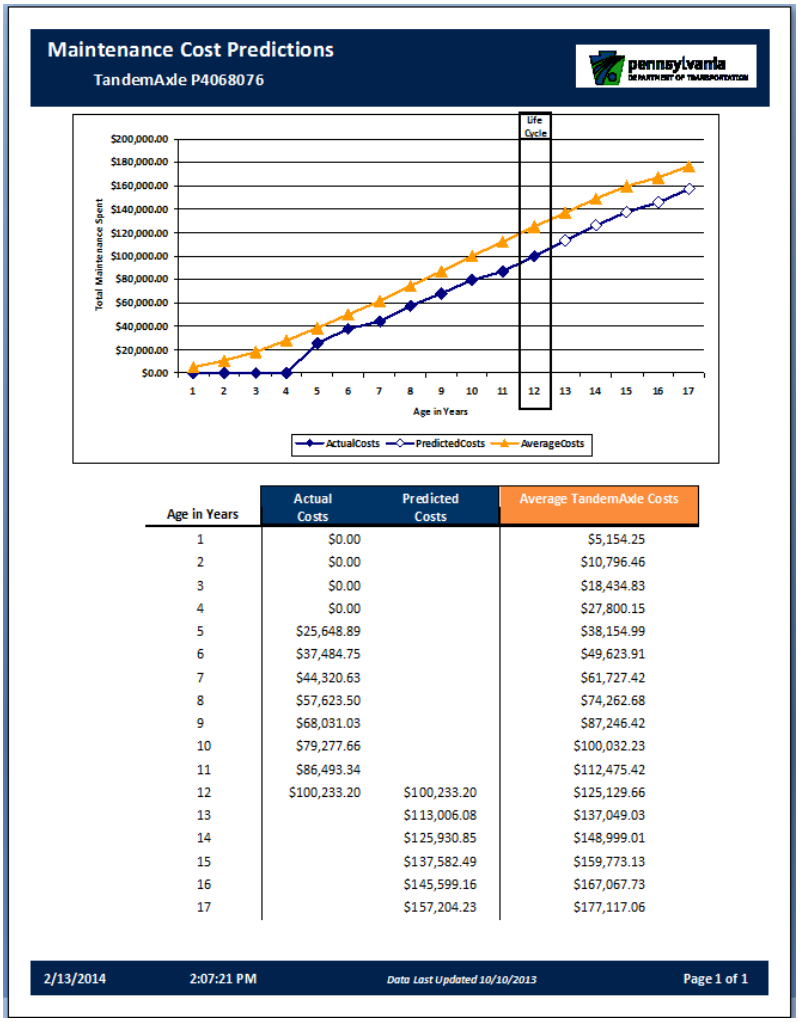
To view the history of overall maintenance and repair costs for a selected piece of equipment, and to estimate future costs, click the 

button in the lower right of the blue section of the screen. A Maintenance Cost Predictions report appears with a line graph that displays the history of annual cumulative costs to date, shown by the blue line with solid diamond symbols, plus the predicted future annual cumulative costs up to the annual limit of predictability for this type of equipment (predicted values are shown by open diamond symbols). Also displayed is the trend line for average annual cumulative costs for all pieces of equipment of this type (orange line with solid triangle symbols). The life cycle for this type of equipment is indicated by the vertical rectangle.

Examination of the graph may help you understand the history of costs expended for this piece of equipment compared to other equipment of the same type. Predicted future costs will generally follow the same trajectory as past costs.

The lower portion of the Maintenance Cost Predictions report numerically lists the actual costs and predicted costs for the selected piece of equipment, and average annual cumulative costs for equipment of this type. The values listed correspond to the values plotted in the graph above. As shown in the example, the early years for a specific piece of equipment may show values of zero ($0.00). This is due to PennDOT's SAP data system that provides the data for the Prediction Tool. Detailed equipment maintenance and repair records are not stored in the SAP system prior to FY 2007-2008, and the Prediction Tool therefore shows zero costs up until that time. Record keeping with the SAP system began in FY 2007-2008, and the first non-zero value listed in this report is the cumulative cost for a piece of equipment as of FY 2007-2008.

To print this report, type Ctrl-P, or right-click anywhere on the report and choose "Print..." from the pop-up menu.

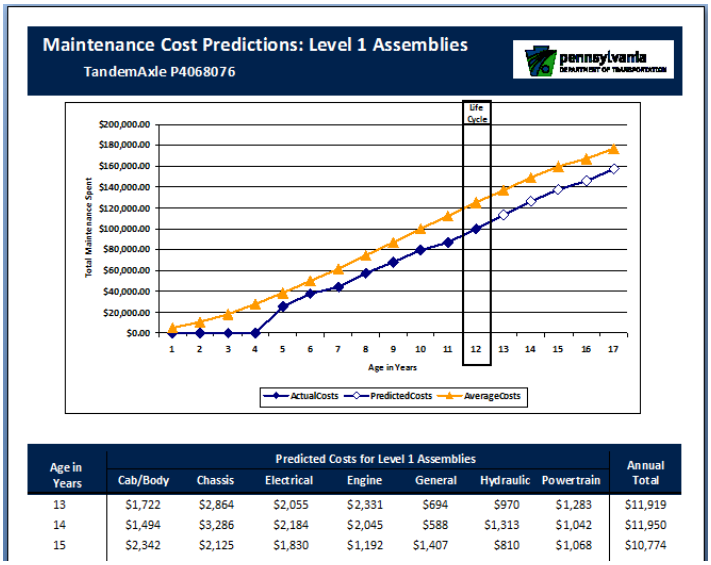


Age in Years	Actual Costs	Predicted Costs	Average TandemAxle Costs
1	$0.00		$5,154.25
2	$0.00		$10,796.46
3	$0.00		$18,434.83
4	$0.00		$27,800.15
5	$25,648.89		$38,154.99
6	$37,484.75		$49,623.91
7	$44,320.63		$61,727.42
8	$57,623.50		$74,262.68
9	$68,031.03		$87,246.42
10	$79,277.66		$100,032.23
11	$86,493.34		$112,475.42
12	$100,233.20	$100,233.20	$125,129.66
13		$113,006.08	$137,049.03
14		$125,930.85	$148,999.01
15		$137,582.49	$159,773.13
16		$145,599.16	$167,067.73
17		$157,204.23	$177,117.06

2/13/2014 2:07:21 PM *Data Last Updated 10/10/2013* Page 1 of 1

Estimate Level 1 Costs

To view the history of overall maintenance and repair costs for a selected piece of equipment, and to estimate future costs including a breakdown of predicted future costs by Level 1 Assembly cost categories (Cab/Body, Chassis, Electrical, Engine, General, Hydraulic, and Powertrain), click the Estimate Level 1 Costs button in the lower right portion of the blue section of the screen. A Maintenance Cost Predictions: Level 1 Assemblies report appears with a line graph that displays the history of annual cumulative costs to date, shown by the blue line with solid diamond symbols, plus the predicted future annual cumulative costs up to the annual limit of predictability for this type of equipment (predicted values are shown by open diamond symbols). Also displayed is the trend line for average annual cumulative costs for all pieces of equipment of this type (orange line with solid triangle symbols).



Age in Years	Predicted Costs for Level 1 Assemblies							Annual Total
	Cab/Body	Chassis	Electrical	Engine	General	Hydraulic	Powertrain	
13	$1,722	$2,864	$2,055	$2,331	$694	$970	$1,283	$11,919
14	$1,494	$3,286	$2,184	$2,045	$588	$1,313	$1,042	$11,950
15	$2,342	$2,125	$1,830	$1,192	$1,407	$810	$1,068	$10,774

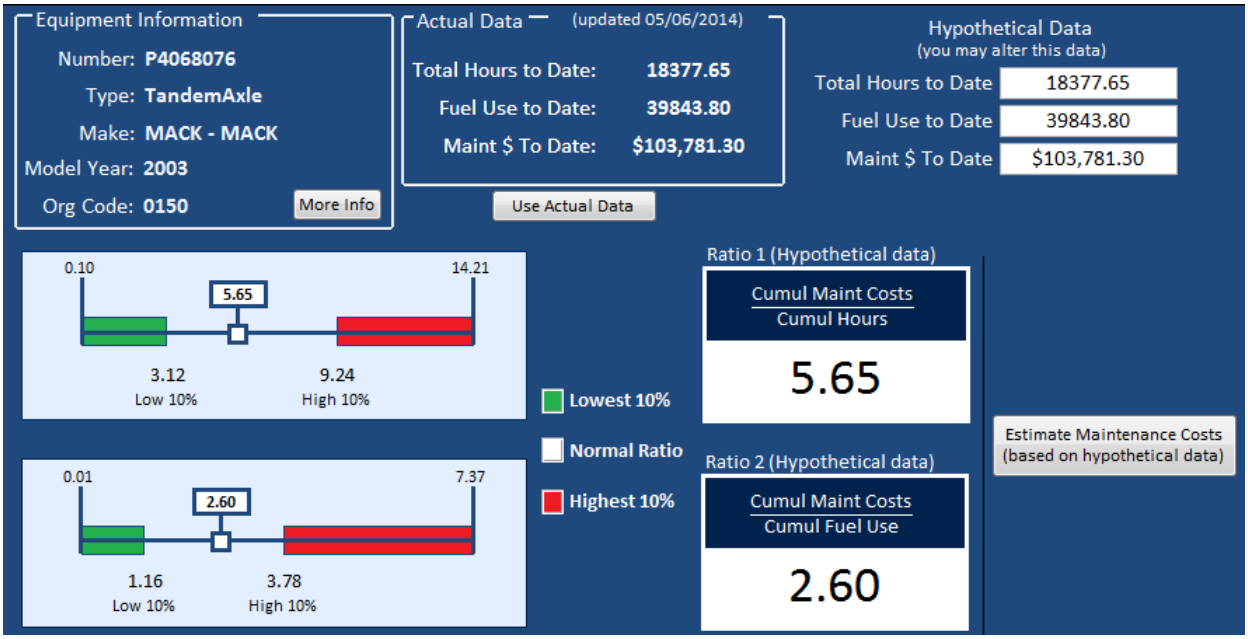
The lower portion of the report lists the predicted Level 1 Assembly costs up to the annual limit of predictability for this type of equipment. (Note that the upper limit of predictability for some types of equipment is shorter for Level 1 Assembly costs than for overall maintenance costs shown in the upper graph of this report. This is because of the relatively few number of pieces of equipment available at the oldest ages on which to base Level 1 Assembly cost estimates.)

To print this report, type Ctrl-P, or right-click anywhere on the report and choose "Print..." from the pop-up menu.

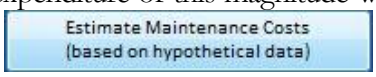
Use Hypothetical Data

In addition to estimating future maintenance and repair costs for a selected piece of equipment, assuming that these costs will continue along a typical trajectory, the Prediction Tool allows you to predict costs assuming different hypothetical future scenarios. You can assume that future cumulative maintenance costs will be higher or lower than typical, and/or that future use of the equipment (cumulative hours and fuel usage) will be more or less than typical.

To explore alternative hypothetical scenarios, click the Use Hypothetical Data button just below the Actual Data section of the screen. A Maintenance Cost Estimates Using Hypothetical Data screen opens showing the Equipment Information for the piece of equipment selected on the Maintenance Cost Predictions screen. The layout of the information and features on the Hypothetical Data screen are similar to the Cost Predictions screen. You can select a different piece of equipment using the search and filter functions in the green section at the top of this screen.



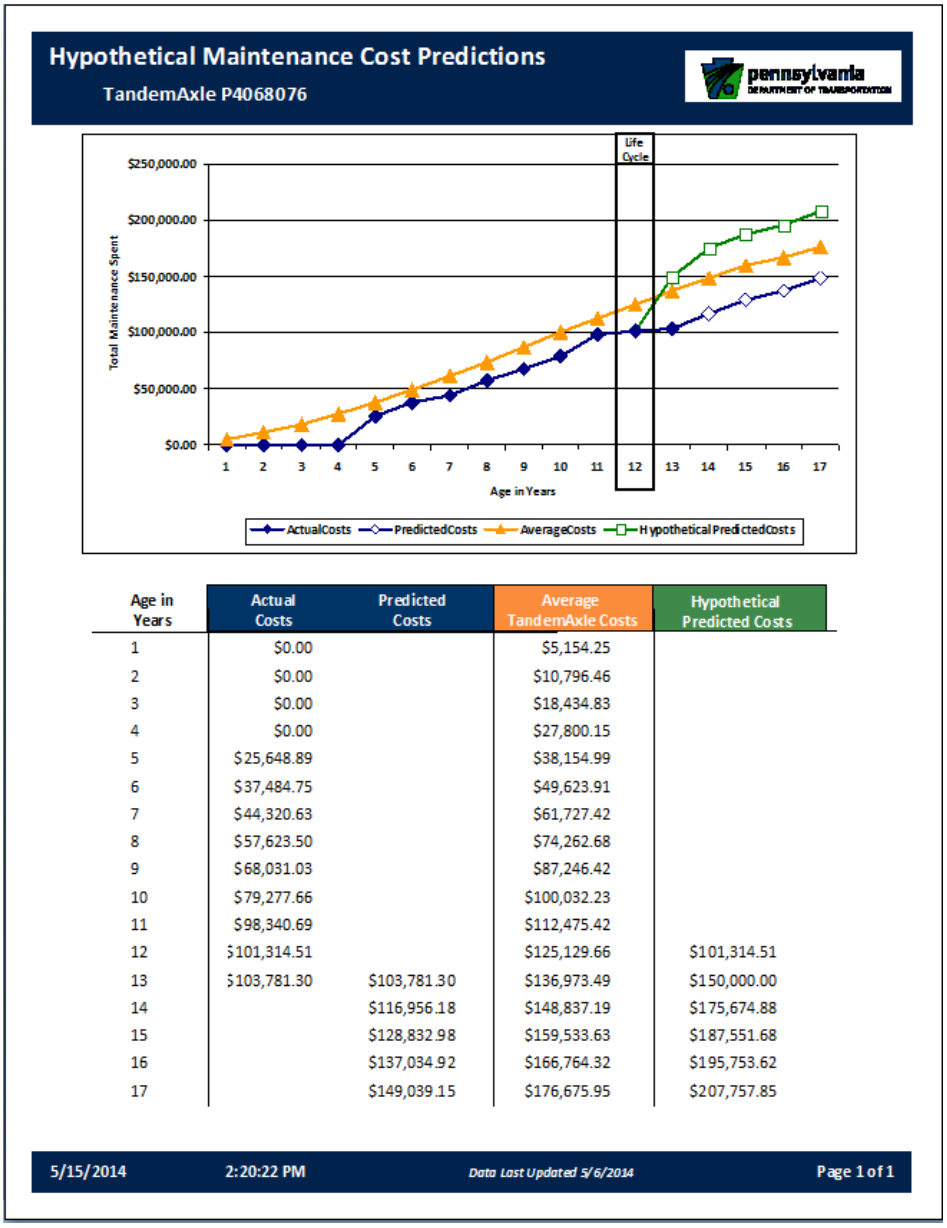
The blue section displays Equipment Information, Actual Data for cumulative use and maintenance costs, and horizontal line graphs showing Cost Ratios 1 and 2. In the upper right corner are three boxes into which you can enter alternative values for Total Hours to Date, Fuel Use to Date, and Maintenance Costs to Date. (Note that when this screen first opens these fields show their actual values.) To enter an alternative or hypothetical value, click into the box and delete the current value, then enter a new value.

In the example illustrated, suppose you are considering a major engine overhaul and other repairs and upgrades for a 10-year old truck. If performed, these upgrades will increase cumulative costs for this truck from $103,781 to $150,000. An expenditure of this magnitude will move both cost ratios into the highest 10% or red range. Click on the 

button in the lower right section of the screen to view the Hypothetical Maintenance Cost Predictions report.

The appearance of the Hypothetical Maintenance Cost Predictions report is similar to the Maintenance Cost Predictions report. In the upper portion is a line graph showing the history of annual cumulative costs to date, shown by the blue line with solid diamond symbols, plus the predicted future annual cumulative costs up to the annual limit of predictability for this type of equipment (predicted values are shown by open diamond symbols). Also displayed is the trend line for average annual cumulative costs for all pieces of equipment of this type (orange line with solid triangle symbols). The life cycle for this type of equipment is indicated by the vertical rectangle. Future hypothetical costs are shown by the green line with open square symbols. The values shown in the graph are listed numerically in the lower portion of the report.

In the example illustrated, increasing current expenditures from $103,781 to $150,000 would raise the trend line for cumulative costs for this truck from below average to above average, with predicted above average cumulative costs extending into the future. If you were actually considering such a scenario, this report could help you consider this scenario relative to alternatives such as replacing this truck, which is at the end of its normal life cycle, with a new one.



Age in Years	Actual Costs	Predicted Costs	Average TandemAxle Costs	Hypothetical Predicted Costs
1	$0.00		$5,154.25	
2	$0.00		$10,796.46	
3	$0.00		$18,434.83	
4	$0.00		$27,800.15	
5	$25,648.89		$38,154.99	
6	$37,484.75		$49,623.91	
7	$44,320.63		$61,727.42	
8	$57,623.50		$74,262.68	
9	$68,031.03		$87,246.42	
10	$79,277.66		$100,032.23	
11	$98,340.69		$112,475.42	
12	$101,314.51		$125,129.66	$101,314.51
13	$103,781.30	$103,781.30	$136,973.49	$150,000.00
14		$116,956.18	$148,837.19	$175,674.88
15		$128,832.98	$159,533.63	$187,551.68
16		$137,034.92	$166,764.32	$195,753.62
17		$149,039.15	$176,675.95	$207,757.85

To print this report, type Ctrl-P, or right-click anywhere on the report and choose "Print..." from the pop-up menu.

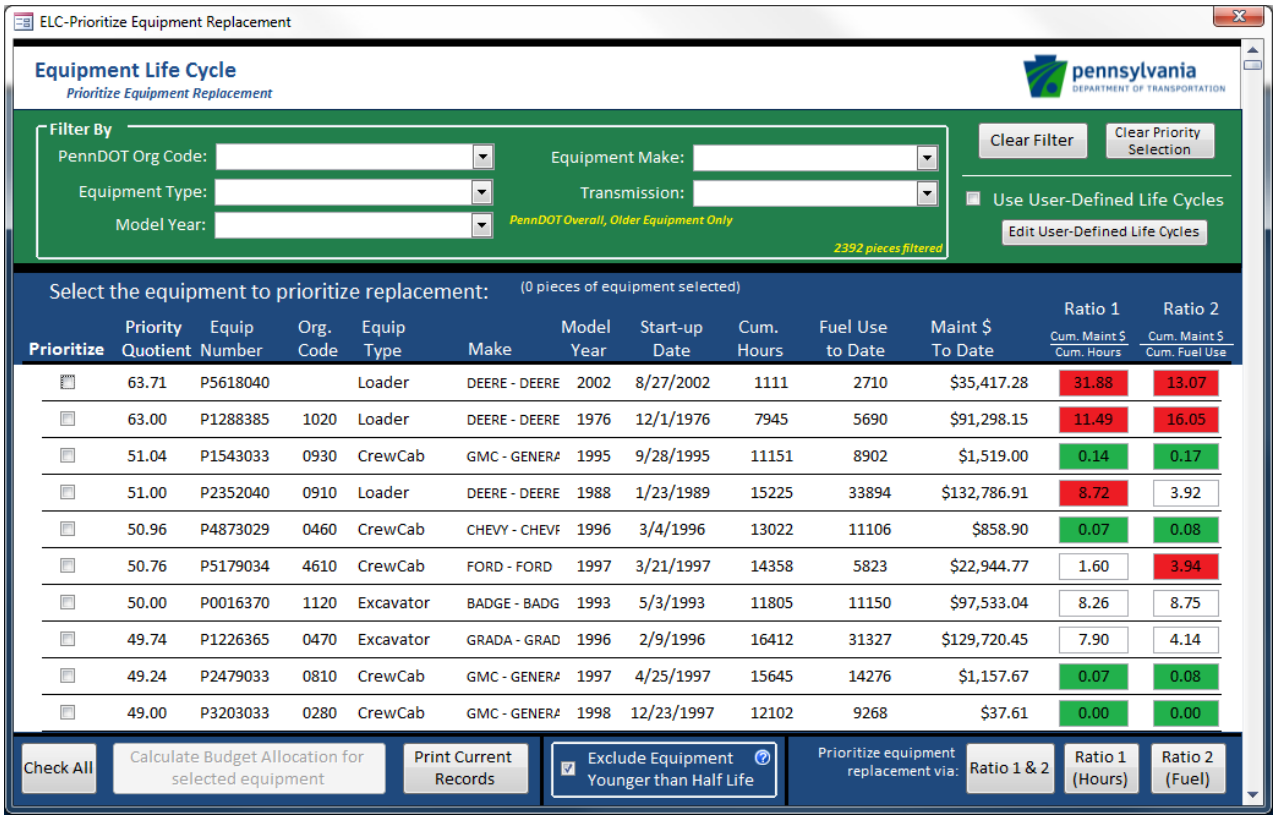
Click the 

button just below the actual data section of the Hypothetical Data screen to return to the Maintenance Cost Predictions screen.

Chapter 4

Prioritize Equipment Replacement

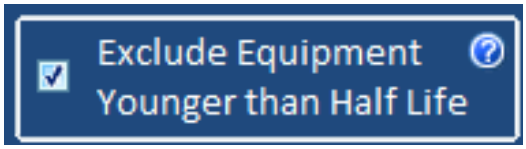
The Prioritize Equipment Replacement screen allows you to rank order specific pieces of equipment from among a chosen set of equipment in terms of priority for replacement. To open this screen from the Main Menu, click the second large button **Prioritize Equipment Replacement**.



Choosing Equipment to Prioritize

The Prioritize Equipment Replacement screen opens with all pieces of equipment in the database available for selection. You can search the database for the specific set of pieces of equipment to prioritize using five filters available in the Filter By section of this screen. Filters include PennDOT Organizational Code, Equipment Make, Equipment Type, Transmission Type, and Model Year. Click the down arrow ( ) at the right side of a filter box, and then choose from the drop-down menu by clicking one of the options provided. Your choices will appear in yellow text in the lower right portion of the Filter By menu area as you build a search. You may use all five filters in a search, but note that some combinations of options yield null results (e.g., Equipment Make = CASE and Equipment Type = Tandem Axle will return 0 pieces of equipment because there are no tandem axle trucks made by CASE in PennDOT's inventory). The number of pieces that result from your choices are shown in the lower right area of the Filter By block.

At the bottom of the screen is a checkbox to "Exclude Equipment Younger than Half Life." With this checked, any piece of equipment that is younger than half of its expected life cycle is not shown or used in prioritizing. This is the default option when you first access this screen.



When you have chosen a set of equipment to prioritize (e.g., single axle trucks for Monroe County), an ordered list of the pieces will appear as in the illustration. If the list includes more than 10 pieces of equipment, use the scrollbar on the right side of the screen to view the whole list. The pieces are ordered in order of Priority Quotient (shown in the second column of the listing), beginning with the piece having the highest quotient. Other essential information shown for each piece includes: Equipment Number; Organizational Code; Equipment Type, Make, and Model Year; Start-up Date; Cumulative Hours, Fuel Use, and Maintenance Costs; and Cost Ratios 1 and 2.

Replacement Priority Quotient

The Replacement Priority Quotient for each piece of equipment is calculated as:

$$\text{Priority Quotient} = (\text{Age in Years} - \text{Life Cycle}) + (\text{Cost Ratio} - \text{Average Cost Ratio}) + 40$$

where Age in Years is the piece of equipment's age in years (rounded to a whole number) from start-up date to present (defined as date of last data update); Life Cycle is the life cycle in years for this type of equipment; Cost Ratio for this piece of equipment is either Cost Ratio 1 (cumulative maintenance and repair costs / cumulative hours), Cost Ratio 2 (cumulative maintenance and repair costs / cumulative fuel usage), or (Cost Ratio 1 + Cost Ratio 2)/2; Average Cost Ratio is the average cost ratio for equipment of the same type and age; and 40 is a constant.

Note that by default Replacement Priority Quotients are calculated using Official PennDOT Equipment Life Cycles. You also have an option to calculate Replacement Priority Quotients using user-defined life cycles. See Chapter 2 for more about official vs. user-defined life cycles; a later section of this chapter explains how to prioritize equipment to replace based on user-defined life cycles.

A Replacement Priority Quotient thus represents a piece of equipment's age relative to its life cycle, and its cost ratio relative to the average cost ratio for other pieces of equipment of the same type and age. In a set of equipment, the oldest piece relative to its life cycle with the highest relative cost ratio for its age and type

has the highest Priority Quotient. Conversely, the youngest piece of equipment relative to its life cycle with the lowest relative cost ratio for its age and type has the lowest Priority Quotient.

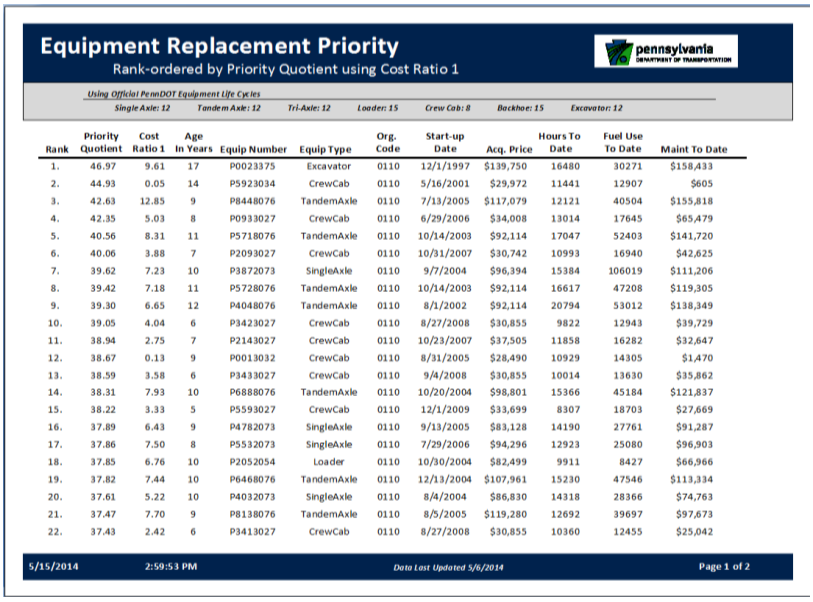
Selecting Pieces to Prioritize

Once you choose a set of equipment to prioritize, you can select specific pieces of equipment from among the set, or you can prioritize all of them. To prioritize all pieces in the set, click the Check All button in the lower left corner of the screen. To prioritize a subset of the pieces, check the boxes in the left column under the Prioritize heading for the pieces you wish to include in the subset. In the same manner, you can click the Check All button, and then uncheck any pieces that you do not wish to include in the prioritization. The number of pieces you have selected is shown at the top middle of the blue section on the screen. Note that Knock-Out trucks and Specialized Crew Cabs are not available to prioritize – their special status means that PennDOT has already determined that they will be replaced.

Equipment Replacement Priority Report

Once you have identified the set or subset of pieces of equipment to prioritize (by checking the desired pieces), you can create an Equipment Replacement Priority report by clicking any of the buttons in the lower right corner of the screen. These buttons determine which cost ratio is used to calculate the Priority Quotients used for ranking the pieces of equipment in the report. (Note that Cost Ratio 1 is used to calculate the Priority Quotients shown on the Prioritize Equipment Replacement screen, but you can choose the cost ratio to use in creating the report.)

The Equipment Replacement Priority report lists the selected pieces of equipment in rank order of Priority Quotient. The report heading indicates which Cost Ratio was used in calculating the Priority Quotients. The gray section shows which life cycles (Official PennDOT or User-Defined) were used when calculating Priority Quotients shown in the report. Considering the equipment listed, those ranked at the top of the list should be considered first for replacement.



Equipment Replacement Priority

Rank-ordered by Priority Quotient using Cost Ratio 1

pennsylvania DEPARTMENT OF TRANSPORTATION

Using Official PennDOT Equipment Life Cycles

Single Axle: 12 Tandem Axle: 12 Tri-Axle: 12 Loader: 15 Crew Cab: 8 Backhoe: 15 Excavator: 12

Rank	Priority Quotient	Cost Ratio 1	Age In Years	Equip Number	Equip Type	Org. Code	Start-up Date	Acq. Price	Hours To Date	Fuel Use To Date	Maint To Date
1.	46.97	9.61	17	P0023375	Excavator	0110	12/1/1997	$139,750	16480	30271	$158,433
2.	44.93	0.05	14	P5923034	CrewCab	0110	5/16/2001	$29,972	11441	12907	$605
3.	42.63	12.85	9	P8448076	TandemAxle	0110	7/13/2005	$117,079	12121	40504	$155,818
4.	42.35	5.03	8	P0933027	CrewCab	0110	6/29/2006	$34,008	13014	17645	$65,479
5.	40.56	8.31	11	P5718076	TandemAxle	0110	10/14/2003	$92,114	17047	52403	$141,720
6.	40.06	3.88	7	P2093027	CrewCab	0110	10/31/2007	$30,742	10993	16940	$42,625
7.	39.62	7.23	10	P3872073	SingleAxle	0110	9/7/2004	$96,394	15384	106019	$111,206
8.	39.42	7.18	11	P5728076	TandemAxle	0110	10/14/2003	$92,114	16617	47208	$119,305
9.	39.30	6.65	12	P4048076	TandemAxle	0110	8/1/2002	$92,114	20794	53012	$138,349
10.	39.05	4.04	6	P3423027	CrewCab	0110	8/27/2008	$30,855	9822	12943	$39,729
11.	38.94	2.75	7	P2143027	CrewCab	0110	10/23/2007	$37,505	11858	16282	$32,647
12.	38.67	0.13	9	P0013032	CrewCab	0110	8/31/2005	$28,490	10929	14305	$1,470
13.	38.59	3.58	6	P3433027	CrewCab	0110	9/4/2008	$30,855	10014	13630	$35,862
14.	38.31	7.93	10	P6888076	TandemAxle	0110	10/20/2004	$98,801	15366	45184	$121,837
15.	38.22	3.33	5	P5593027	CrewCab	0110	12/1/2009	$33,699	8307	18703	$27,669
16.	37.89	6.43	9	P4782073	SingleAxle	0110	9/13/2005	$83,128	14190	27761	$91,287
17.	37.86	7.50	8	P5532073	SingleAxle	0110	7/29/2006	$94,296	12923	25080	$96,903
18.	37.85	6.76	10	P2052054	Loader	0110	10/30/2004	$82,499	9911	8427	$66,966
19.	37.82	7.44	10	P6468076	TandemAxle	0110	12/13/2004	$107,961	15230	47546	$113,334
20.	37.61	5.22	10	P4032073	SingleAxle	0110	8/4/2004	$86,830	14318	28366	$74,763
21.	37.47	7.70	9	P8138076	TandemAxle	0110	8/5/2005	$119,280	12692	39697	$97,673
22.	37.43	2.42	6	P3413027	CrewCab	0110	8/27/2008	$30,855	10360	12455	$25,042

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To print this report, type Ctrl-P, or right-click anywhere on the report and choose "Print..." from the pop-up menu.

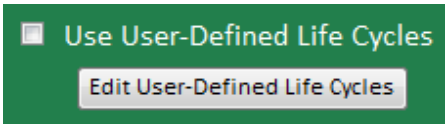
Prioritizing Equipment Across Org Codes and Equipment Types

You can continue to build a list of pieces of equipment to prioritize by choosing other options from the Filter By menu and checking specific pieces of equipment from the lists. Each Equipment Replacement Priority report includes all of the equipment that you selected. You can include pieces from several Organizational Codes, Equipment Makes, Equipment Types, Transmission Types, and Model Years. The Priority Quotient is the common denominator for comparing a list of pieces of equipment of different types (e.g., trucks and loaders).

To create a new priority replacement list, clear your selections by clicking the Clear Priority Selection button to select a different set of pieces of equipment, and the Clear Filter button to choose different filter criteria.

Note that once you have filtered and checked a piece of equipment to be prioritized, it remains checked until you clear your priority selections. A checked piece of equipment will thus appear on each Equipment Replacement Priority Report you request until you clear your priority selections. This feature enables you to build an Equipment Replacement Priority report that includes pieces of equipment of different types from multiple work units, etc., but it means that you must clear your priority selections before choosing a new set of equipment to prioritize. Exiting the Prediction Tool also clears your priority selections.

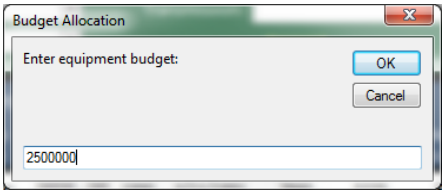
User-Defined Life Cycles



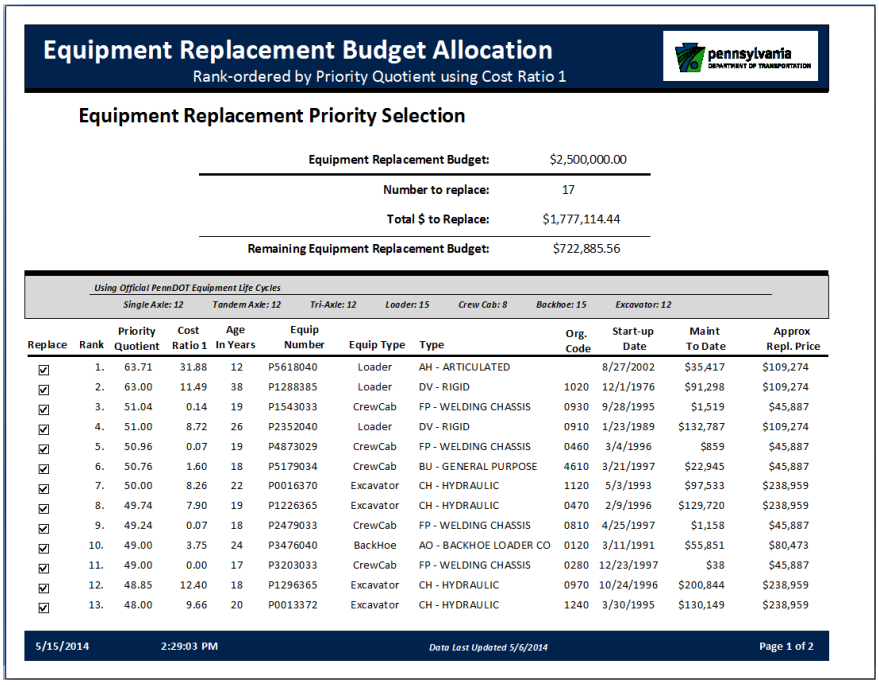
You can prioritize equipment to replace using your own user-defined equipment life cycles. To do so, check the "Use User-Defined Life Cycles" checkbox before requesting an Equipment Replacement Priority report. To edit the user-defined life cycles, click the Edit User-Defined Life Cycles button. This will open the Equipment Life Cycle window described on p. 6 of this manual.

Calculate Budget Allocation

You can examine a prioritized list of equipment for replacement relative to a budget for new equipment. Once you have built a list of equipment to prioritize for replacement, click the Calculate Budget Allocation for selected equipment button in the lower left corner of the screen. A window will appear that asks you to enter an equipment budget. Enter a dollar amount and click OK. An Equipment Replacement Budget Allocation report will appear.



Please refer to Chapter 5 for a more detailed description of this report and other Equipment Budget Allocation functions available through the Prediction Tool.



Equipment Replacement Budget Allocation

Rank-ordered by Priority Quotient using Cost Ratio 1

pennsylvania DEPARTMENT OF TRANSPORTATION

Equipment Replacement Priority Selection

Equipment Replacement Budget:	$2,500,000.00
Number to replace:	17
Total $ to Replace:	$1,777,114.44
Remaining Equipment Replacement Budget:	$722,885.56

Using Official PennDOT Equipment Life Cycles

Single Axle: 12 *Tandem Axle: 12* *Tri-Axle: 12* *Loader: 15* *Crew Cab: 8* *Backhoe: 15* *Excavator: 12*

Replace	Rank	Priority Quotient	Cost Ratio 1	Age In Years	Equip Number	Equip Type	Type	Org. Code	Start-up Date	Maint To Date	Approx Repl. Price
☑	1.	63.71	31.88	12	P5618040	Loader	AH - ARTICULATED		8/27/2002	$35,417	$109,274
☑	2.	63.00	11.49	38	P1288385	Loader	DV - RIGID	1020	12/1/1976	$91,298	$109,274
☑	3.	51.04	0.14	19	P1543033	CrewCab	FP - WELDING CHASSIS	0930	9/28/1995	$1,519	$45,887
☑	4.	51.00	8.72	26	P2352040	Loader	DV - RIGID	0910	1/23/1989	$132,787	$109,274
☑	5.	50.96	0.07	19	P4873029	CrewCab	FP - WELDING CHASSIS	0460	3/4/1996	$859	$45,887
☑	6.	50.76	1.60	18	P5179034	CrewCab	BU - GENERAL PURPOSE	4610	3/21/1997	$22,945	$45,887
☑	7.	50.00	8.26	22	P0016370	Excavator	CH - HYDRAULIC	1120	5/3/1993	$97,533	$238,959
☑	8.	49.74	7.90	19	P1226365	Excavator	CH - HYDRAULIC	0470	2/9/1996	$129,720	$238,959
☑	9.	49.24	0.07	18	P2479033	CrewCab	FP - WELDING CHASSIS	0810	4/25/1997	$1,158	$45,887
☑	10.	49.00	3.75	24	P3476040	BackHoe	AO - BACKHOE LOADER CO	0120	3/11/1991	$55,851	$80,473
☑	11.	49.00	0.00	17	P3203033	CrewCab	FP - WELDING CHASSIS	0280	12/23/1997	$38	$45,887
☑	12.	48.85	12.40	18	P1296365	Excavator	CH - HYDRAULIC	0970	10/24/1996	$200,844	$238,959
☑	13.	48.00	9.66	20	P0013372	Excavator	CH - HYDRAULIC	1240	3/30/1995	$130,149	$238,959

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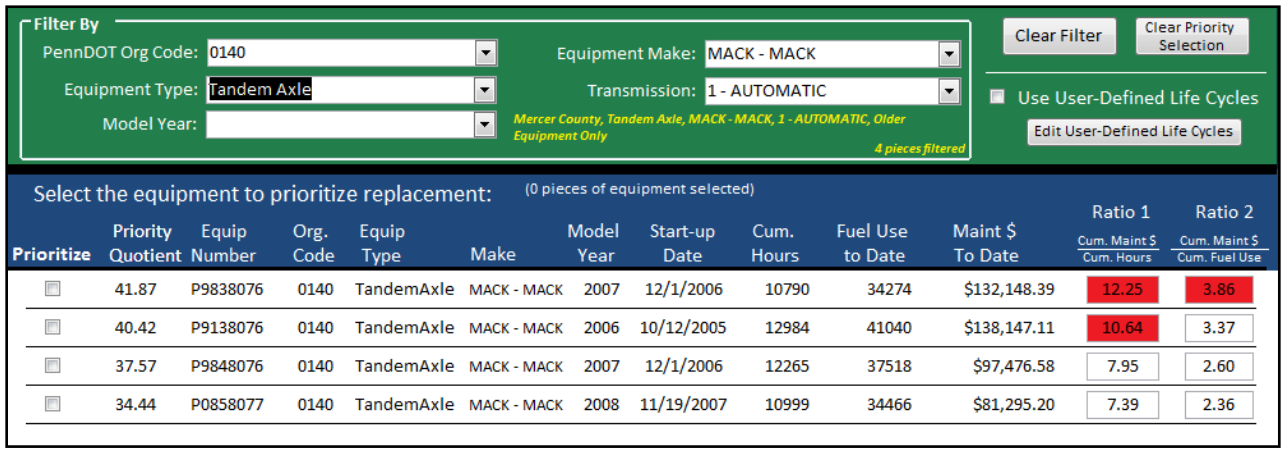
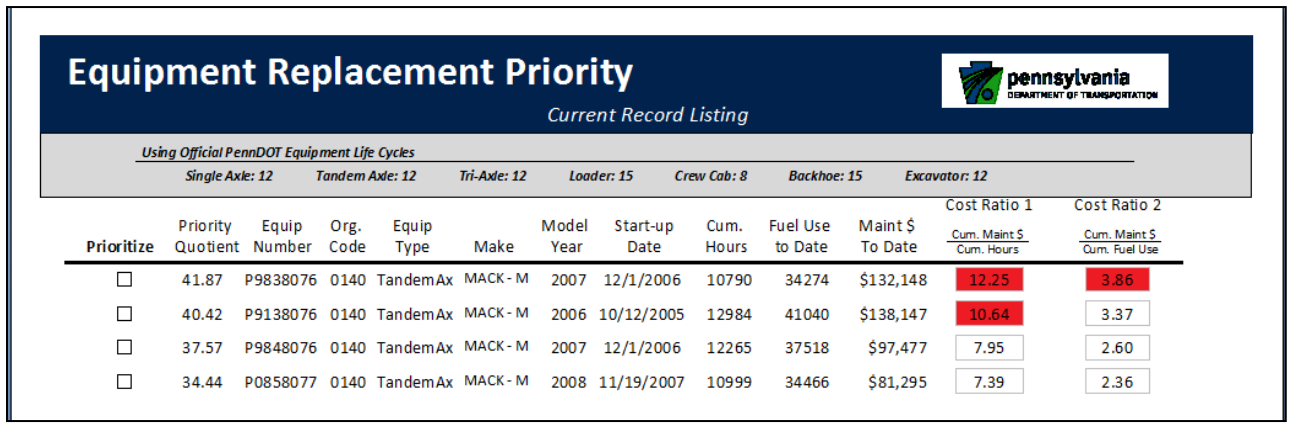
To print this report, type Ctrl-P, or right-click anywhere on the report and choose "Print..." from the pop-up menu.

Print Current Records

Clicking on the Print Current Records button generates a report of all of the pieces of equipment currently displayed (on screen and in the scrollable hidden portion of the window), not just those pieces of equipment that have been checked/selected for prioritization.



Prioritize	Priority Quotient	Equip Number	Org. Code	Equip Type	Make	Model Year	Start-up Date	Cum. Hours	Fuel Use to Date	Maint $ To Date	Ratio 1 Cum. Maint $ / Cum. Hours	Ratio 2 Cum. Maint $ / Cum. Fuel Use
☐	41.87	P9838076	0140	TandemAxle	MACK - MACK	2007	12/1/2006	10790	34274	$132,148.39	12.25	3.86
☐	40.42	P9138076	0140	TandemAxle	MACK - MACK	2006	10/12/2005	12984	41040	$138,147.11	10.64	3.37
☐	37.57	P9848076	0140	TandemAxle	MACK - MACK	2007	12/1/2006	12265	37518	$97,476.58	7.95	2.60
☐	34.44	P0858077	0140	TandemAxle	MACK - MACK	2008	11/19/2007	10999	34466	$81,295.20	7.39	2.36



Prioritize	Priority Quotient	Equip Number	Org. Code	Equip Type	Make	Model Year	Start-up Date	Cum. Hours	Fuel Use to Date	Maint $ To Date	Cost Ratio 1 Cum. Maint $ / Cum. Hours	Cost Ratio 2 Cum. Maint $ / Cum. Fuel Use
☐	41.87	P9838076	0140	TandemAx	MACK - M	2007	12/1/2006	10790	34274	$132,148	12.25	3.86
☐	40.42	P9138076	0140	TandemAx	MACK - M	2006	10/12/2005	12984	41040	$138,147	10.64	3.37
☐	37.57	P9848076	0140	TandemAx	MACK - M	2007	12/1/2006	12265	37518	$97,477	7.95	2.60
☐	34.44	P0858077	0140	TandemAx	MACK - M	2008	11/19/2007	10999	34466	$81,295	7.39	2.36

To print this report, type Ctrl-P, or right-click anywhere on the report and choose "Print..." from the pop-up menu.

Chapter 5

Equipment Budget Allocation

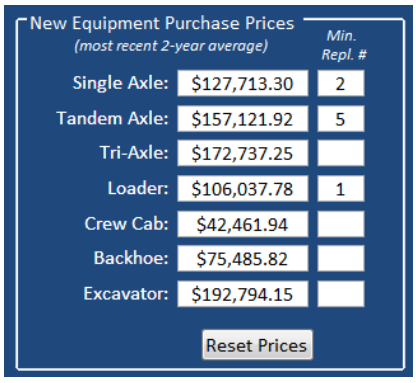
The current fleet can be examined from a budgetary standpoint -- given a budget for purchasing new equipment, which pieces of equipment should be at the top of the replacement list? How many pieces can actually be replaced for a given budget at current acquisition prices for new equipment? To explore possible answers to these questions, click the third large button on the Main Menu, **Equipment Budget Allocation**

Choose an Organizational Unit

Budgets for purchasing new equipment are allocated to organizational units (districts and counties). To begin, choose a unit from the drop-down menu at the top of the Equipment Budget Allocation screen. The unit name appears to the right of the window, and the Current Fleet Mix table lists the number of pieces of each type of equipment (single, tandem, and tri-axle trucks; loaders; crew cabs; backhoes; excavators) for this organizational unit. This table also shows the number of pieces of each type of equipment with Cost Ratio 1 values (cumulative maintenance costs / cumulative hours charged) that fall into the lowest 10%, the highest 10%, and the middle 80% (the "normal range") of the cost ratio distributions.

At the top of the blue section of the screen is a checkbox to "Exclude Equipment Younger than Half-Life." With this option checked, any piece of equipment that is younger than half of its expected life cycle is not shown or used in equipment budget allocations.

You can calculate budget allocations using your own user-defined equipment life cycles. To do so, check the "Use User-Defined Life Cycles" checkbox before requesting an Equipment Replacement Budget Allocation report. To edit the user-defined life cycles, click the Edit User-Defined Life Cycles button. This will open the Equipment Life Cycle window described on page 6 of this manual.



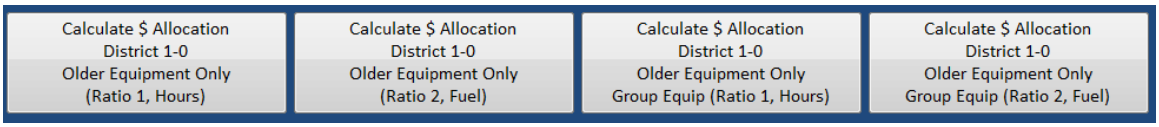
New Equipment Purchase Prices for each type of equipment are listed on the right side of the screen. Prices listed are the average prices paid by PennDOT during the two most recent years for each type of equipment. If you know that the price your unit pays for a type of equipment is different than the price listed, you can change the purchase price by deleting the value that shows in the field and entering a different price. Clicking the Reset Prices button restores the system default values.

If you know that there are minimum numbers of certain types of equipment that your unit is going to purchase -- for example, you know that you will acquire 2 new single axle trucks, 5 new tandem axle trucks, and 1 new loader -- you can enter these minimum replacement numbers in the column to the right of the purchase prices. The Equipment Replacement Budget Allocation report will include at least the designated number of each type on the recommended replacement list, up to the limit of the overall budget.

Next, enter a dollar value for your Equipment Budget in the field near the top of the screen.

Calculate Budget Allocation

To create an Equipment Replacement Budget Allocation report, click one of the Calculate $ Allocation buttons along the bottom of the screen. You can choose whether the calculation is performed using Cost Ratio 1 (cumulative maintenance costs / cumulative hours charged) or Cost Ratio 2 (cumulative maintenance costs / cumulative fuel usage), and whether you want to group the results by equipment type or just list all equipment types together.



Clicking any of these four buttons begins the budget allocation calculation. When the calculation begins, a progress bar appears above the buttons. If calculating budget allocations for large organizational units (e.g., PennDOT Overall, Districts), the calculations could take some time to complete. After the calculations are complete, the Equipment Replacement Budget Allocation report appears.

The Equipment Replacement Budget Allocation report shows the name of the organizational unit, the equipment budget amount, the recommended number of pieces of equipment for replacement within the limit of the budget amount, the total dollar amount that would be spent on that number of pieces, and the

Equipment Replacement Budget Allocation
Rank-ordered by Priority Quotient using Cost Ratio 1

pennsylvania DEPARTMENT OF TRANSPORTATION

District 1-0, Older Equipment (> Half-life) Only

Equipment Replacement Budget:	$2,500,000.00
Number to replace:	21
Total $ to Replace:	$2,481,115.78
Remaining Equipment Replacement Budget:	$18,884.22

Using Official PennDOT Equipment Life Cycles

Single Axle: 12 *Tandem Axle: 12* *Tri-Axle: 12* *Loader: 15* *Crew Cab: 8* *Backhoe: 15* *Excavator: 12*

Replace	Rank	Priority Quotient	Cost Ratio 1	Age In Years	Equip Number	Equip Type	Type	Org. Code	Start-up Date	Maint To Date	Approx Repl. Price
☑	1.	49.00	3.75	24	P3476040	BackHoe	AO - BACKHOE LOAD	120	3/11/1991	$55,851	$75,486
☑	2.	46.97	9.61	17	P0023375	Excavator	CH - HYDRAULIC	110	12/1/1997	$158,433	$192,794
☑	3.	46.25	9.81	18	P0023373	Excavator	CH - HYDRAULIC	120	11/15/1996	$137,682	$192,794
☑	4.	44.93	0.05	14	P5923034	CrewCab	FP - WELDING CHASS	110	5/16/2001	$605	$42,462
☑	5.	44.71	8.45	16	P5026040	BackHoe	AO - BACKHOE LOAD	160	2/11/1999	$73,359	$75,486
☑	6.	44.32	7.87	18	P1306365	Excavator	CH - HYDRAULIC	130	11/8/1996	$152,515	$192,794
☑	7.	43.49	12.03	9	P4772073	SingleAxle	DU - RIGHT WING CA	140	7/15/2005	$130,687	$127,713
☑	8.	42.82	4.28	9	P9693037	CrewCab	KV - FOREMANS BOD	160	12/19/2005	$72,877	$42,462
☑	9.	42.63	12.85	9	P8448076	TandemAxle	DU - RIGHT WING CA	110	7/13/2005	$155,818	$157,122
☑	10.	42.45	9.80	12	P4608076	TandemAxle	DU - RIGHT WING CA	130	2/3/2003	$159,595	$157,122

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remaining dollar amount of the budget that would be left unspent. The gray section shows which life cycles (official PennDOT or user-defined) were used to calculate Priority Quotients for this report. The rest of the report provides a list of the unit's equipment in rank order of Priority Quotient beginning with the

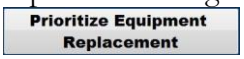
highest quotient. (Priority Quotients are calculated using either Cost Ratio 1 or 2, depending on the button selected on the Equipment Budget Allocation screen.)

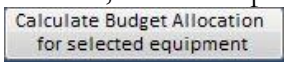
The specific pieces recommended for replacement are shown by a checkmark in the left column under the "Replace" heading. Additional information listed for each piece includes Age in Years, Equipment Number, Equipment Type, Type, Organizational Code, Start-up Date, Maintenance Costs to Date, and Approximate Replacement Price. Note that Knock-Out trucks and Specialized Crew Cabs are not included in the analysis – their special status means that PennDOT has already determined that they will be replaced.

The Equipment Replacement Budget Allocation report grouped by equipment types shows the Priority Quotient rank for a piece of equipment calculated across all pieces for the organizational unit – ranks are not calculated within equipment type.

To print this report, type Ctrl-P, or right-click anywhere on the report and choose "Print..." from the pop-up menu.

The algorithm used to create the Equipment Replacement Budget Allocation report uses your specified criteria to allocate as much of the equipment replacement budget as possible without exceeding it. It begins with the budget amount, then considers the minimum number of pieces of each type of equipment to replace, the purchase price for each type, and finally the Priority Quotients for individual pieces that make up the unit's current fleet. If you specified minimum replacement numbers, it allocates the budget to meet those minimum numbers until the remaining budget does not allow for purchase of another piece on the minimum list. At that point there may be sufficient dollars remaining in the budget to purchase one or more lower cost pieces of a different type, in which case that piece or pieces will be check marked as recommended for replacement even if you did not designate a minimum replacement number for that type of equipment.

As noted above, the analysis performed by the Equipment Budget Allocation screen considers all of the equipment assigned to a specific organizational unit. You may wish to limit this analysis to certain types of equipment (e.g., single and tandem axle trucks), or you may wish to include multiple organizational units in a single analysis (e.g., single and tandem axle trucks for three counties in a district). To perform a budget allocation analysis including only pieces of equipment that you have selected, click the 

button on the Main Menu, choose among the filter options in the Filter By menu on the Prioritize Equipment Replacement screen, select the specific pieces of equipment to include in the budget allocation analysis, and click the 

button in the lower left corner of the screen to obtain a report that includes only the selected pieces of equipment. See Chapter 4 for additional instructions on filtering and selecting pieces of equipment for replacement.

Glossary of Terms

Glossary

Budget Allocation

Given a budget for purchasing new equipment, an equipment budget allocation analysis recommends the specific pieces of equipment that should be at the top of the replacement list.

Cost Ratio 1

Cost Ratio 1 for a specific piece of equipment is calculated as cumulative maintenance and repair costs divided by cumulative personnel hours charged to the equipment.

Cost Ratio 2

Cost Ratio 2 for a specific piece of equipment is calculated as cumulative maintenance and repair costs divided by cumulative fuel use for the equipment.

Equipment Life Cycle

The life cycle of a type of equipment is the duration in years that a piece of equipment of that type is expected to remain a functional part of the equipment fleet. The Prediction Tool uses Official PennDOT Equipment Life Cycles by default; alternatively, a user can specify User-Defined Equipment Life Cycles.

Highest 10%

Cost Ratio values that fall into the highest 10% of the cost ratio distributions for a type of equipment.

Level 1 Costs

Level 1 Assembly cost categories (Cab/Body, Chassis, Electrical, Engine, General, Hydraulic, and Powertrain).

Lowest 10%

Cost Ratio values that fall into the lowest 10% of the cost ratio distributions for a type of equipment.

Normal Ratio

Cost Ratio values that fall into the middle 80% (i.e., the "normal range") of the cost ratio distributions for a type of equipment.

Replacement Priority Quotient

The Replacement Priority Quotient for each piece of equipment is calculated as:

Priority Quotient = (Age in Years - Life Cycle) + (Cost Ratio - Average Cost Ratio) + 40

where Age in Years is the piece of equipment's age in years (rounded to a whole number) from start-up date to present (defined as date of last data update); Life Cycle is the stated life cycle in years for this type of equipment (Official PennDOT Life Cycle by default, or User-Defined Life Cycle as an alternative); Cost Ratio for this piece of equipment is either Cost Ratio 1 (cumulative maintenance and repair costs / cumulative hours), Cost Ratio 2 (cumulative maintenance and repair costs / cumulative fuel usage), or (Cost Ratio 1 + Cost Ratio 2)/2; Average Cost Ratio is the average cost ratio for equipment of the same type and age; and 40 is a constant.

A Replacement Priority Quotient thus represents a piece of equipment's age relative to its life cycle, and its cost ratio relative to the average cost ratio for other pieces of equipment of the same type and age. In a set of equipment, the oldest piece relative to its life cycle with the highest relative cost ratio for its age and type has the highest Priority Quotient. Conversely, the youngest piece of equipment relative to its life cycle with the lowest relative cost ratio for its age and type has the lowest Priority Quotient.

APPENDIX D.
ADMINISTRATOR'S MANUAL

pennsylvania
DEPARTMENT OF TRANSPORTATION

FLEET MANAGEMENT DIVISION

Equipment Life Cycle Prediction Tool

Administrator's Manual

5/22/2014

Table of Contents

Chapter 1

Importing Data

Preparing Data Files to Import Data

The first step to import data is to output the requisite files from SAP. There are four reports that must be run/exported as Microsoft Excel files:

1. Equipment
    - This file contains detailed information for each piece of equipment (Single Axle, Tandem Axle, Tri-Axle, Crew Cab, Loader, Excavator and Backhoe) that PennDOT currently owns
    - The fields included in this file are:
        1. Equipment
        2. AcquistnValue
        3. Start-up date
        4. Description
        5. TechIdentNo
        6. Model number
        7. District
        8. Functional Loc.
        9. Category
        10. Class
        11. Type
        12. Sub Type
        13. Capacity
        14. Transmission
        15. Power
        16. Mfr
        17. Model Year

      **Note: the fields MUST be in the exact order as listed*
    - To create this report in SAP, use Transaction IH08. Pull Variant: EQ_LIFECYL_EQU. Execute Transaction. Once the transaction is run:
        1. Select All.
        2. Go to top blue menu bar and Select Settings, choose Show/Hide Classification.
        3. A box will appear. Check the box for ECC Codes and click the Green Check.
        4. You can remove all columns after Model Year Column.
        5. Export to Excel.
    - The only Equipment ECC code prefixes that should be pulled into the database are:
        1. A15
        2. AA1
        3. AA4
        4. AK1
        5. AK2
        6. AK3
        7. A12
        8. A13
        9. E27
        10. E54
        11. E18
        12. EET

2. Equipment LTD Fuel Usage
    - This file contains the life-to-date fuel usage for each piece of equipment in the Equipment file
    - The fields included in this file are:
        1. Equipment
        2. Date
        3. Meas/TotCtrRdg

      **Note: the fields MUST be in the exact order as listed*

- To create this report in SAP, use Transaction IK17 in SAP. Pull Variant: EQ_LIFCYL_FUEL. Drop in the Equipment #s from Equipment Report (#1). Enter From Date Range (from____), (you can leave "TO" date range the standard 12/31/9999).

3. Equipment LTD Hours
   - This file contains the life-to-date hours charged to each piece of equipment in the Equipment file
   - The fields included in this file are:
     1. Equipment No. 2. LTD Usage Hours 3. Last Changed Date

     **Note: the fields MUST be in the exact order as listed*
   - To create this report in SAP, run SAP Equipment Not Meeting Standards Report (Y_DC1_320000857) Pull Variant: EQ_LIFCYL_HOUR. Put the Date Range in needed. Report can be run in the background.

4. Equipment Individual Maintenance Costs
   - Either of two reports can be used when importing maintenance cost data: Work Order Cost Report, or the IW38.
   - For each piece of equipment in the Equipment file, these files contains the information for each maintenance and repair (but not accident repair) record that has occurred since the last data import into the Prediction Tool
   - The fields included in the Work Order Cost Report file are:

1. Org.	8. Assembly Desc.	15. Tot. Equip.
2. Equipment	9. Mat. Desc.	16. Rented Equip.
3. ECC	10. Mat. Cost	17. Contractors
4. W O. #	11. Other Mat. Cost	18. Misc.
5. Date	**12. Tot. Mat.**	19. WOST
6. Date Cmp	**13. Tot. Labor**	
7. Assembly	14. Tot. Labor Hrs.	

     **Note: the fields needed for the import are in bold. These fields must be named exactly as shown above.*
   - The fields included in the IW38 are:

1. Order	**5. Basic fin. Date**	9. Entered by
2. Equipment	6. Bas. Start date	10. MaintPlant
3. Assembly	**7. Total act.costs**	11. Order Type
4. Description	8. Notification	12. System status

     **Note: the fields needed for the import are in bold. These fields must be named exactly as shown above.*
   - To create the Work Order Cost Report in SAP, run Equipment Cost Work Order Report (Y_DC6_14000072) using the Equipment Numbers from #1. Enter Fiscal Year in report criteria.
   - To create the IW38 in SAP, run transaction IW38. Get variant named EQ_LIFCYL_COST. Paste in the equipment numbers that you pulled from the first report. Run this report in the background. (Note: this variant runs from the beginning of the fiscal year to the current date; if you want a different date that will need to be changed when running the report)

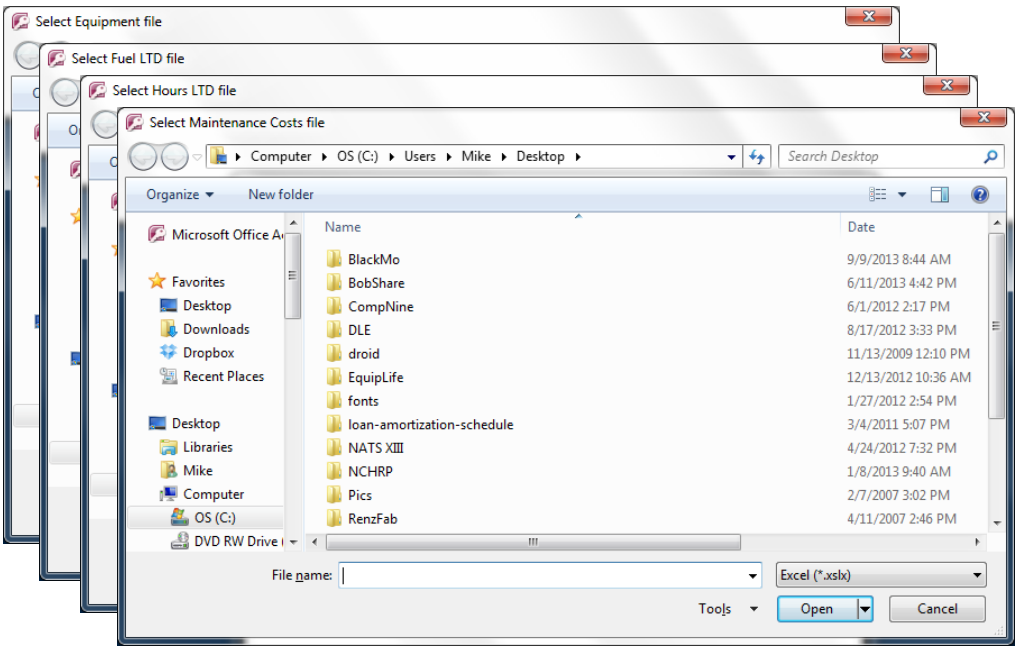
It is crucial that these files are created with EXACTLY these fields. The prediction tool is programmed to look in certain spots for certain data, so if a file is created with fields missing, or in a different order, the import could fail or import data improperly.

Import Data

Once each of the four data files has been created, the data import can commence. When getting ready to import the data, copy the Prediction Tool and the four data files to your local computer. It is best to not work with the "live" database. Also, the import process is very data intense and would take significantly longer if running over a network. Launch your local copy of the Prediction Tool.

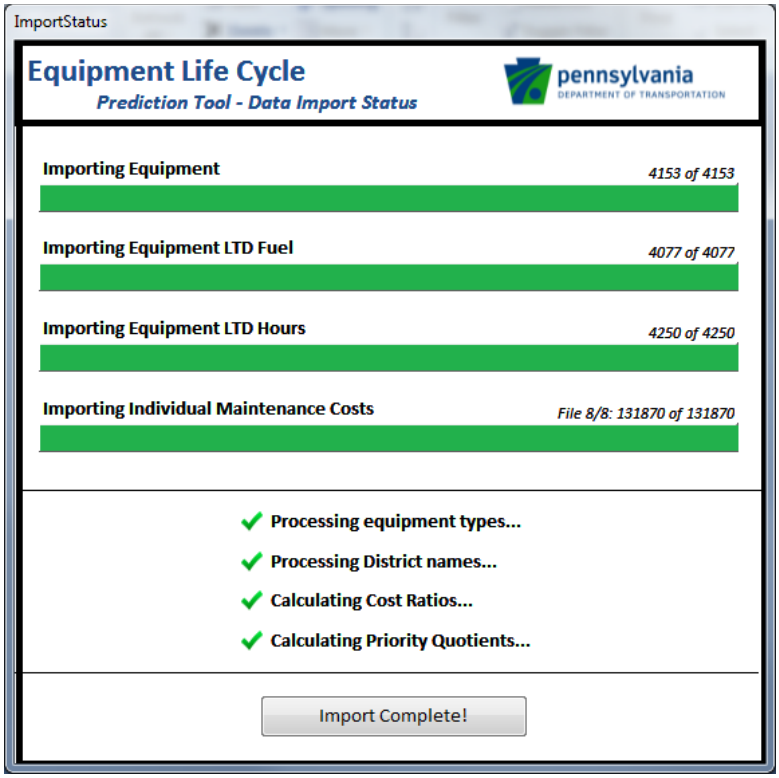
From the Main Menu of the Prediction Tool, click the `Import Data` button. You will be prompted to browse and select the four Excel data files that you created, in this order:

1. Equipment
2. Equipment LTD Fuel Usage
3. Equipment LTD Hours
4. Equipment Individual Maintenance Costs*



As you are prompted for these files, navigate to the directory you have stored them in, select the file, and click the Open button. Status bars for each file will keep you aware of the progress as the data gets imported.

*If the report used to create the Equipment Individual Maintenance Costs generates multiple output files, the Prediction tool can import the group of files for this portion of the import. To import multiple Equipment Individual Maintenance Costs files, you must select all of the files at once. To select multiple files at once, select the first file of the group by left-clicking once on it, and then hold down your control (CTRL) key on your keyboard and left-click once on each subsequent file in the group. Once all of the files that you want to import are highlighted, click the Open button to continue and import data from each of the files. As the import progresses through the Equipment Individual Maintenance Costs files, it will show you what file it is currently working on, and how many files are left to import.



After all four file types are imported, the Prediction Tool processes the data in four steps. These steps are:

- Processing equipment types
- Processing District names
- Calculating Cost Ratios
- Calculating Priority Quotients

These processing steps commence automatically after the Equipment Individual Maintenance Costs file has been imported. As each processing step completes, a green check mark will appear next to it.

Once all of the steps have been completed, the data import is complete. An 

button will appear, and clicking it will close the import status window, taking you back to the Main Menu.

The Prediction Tool will now be updated. Prediction Tool users should be notified that an update is available for download to their local computers. As a safeguard, place a back-up copy of the updated Prediction Tool on a computer that is not generally accessible to other users.