Equipment Life-Cycle Cost Analysis Tool (E-L-T) for Iowa Counties

User Manual
October 2019

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

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

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

A spreadsheet-based tool was also developed to capture equipment data and provide cost estimation and optimal replacement time. The tool has two modules: (1) deterministic analysis that captures single values as inputs and provides one-point estimation and (2) stochastic analysis, in which a range of values is captured and Monte Carlo simulation is used to provide a range of values as results. The stochastic analysis provides insights about the effect of uncertainties associated with variables to more realistically reflect actual practice. The tool considers both purchasing and leasing options to be applicable for counties that use each method of equipment acquisition. This manual provides instructions on how to use the tool, which is available for download at https://cmat.intrans.iastate.edu/research/completed/optimizing-maintenance-equipment-life-cycle-for-local-agencies/.

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EQUIPMENT LIFE-CYCLE COST ANALYSIS TOOL (E-L-T) FOR IOWA COUNTIES

User Manual
October 2019

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INTRODUCTION

This document provides instructions on how to use the Equipment Life-Cycle Cost Analysis Tool (E-L-T) developed for Iowa counties. It describes different aspects of the tool and offers a user's guide. Figure 1 graphically depicts use of the tool.

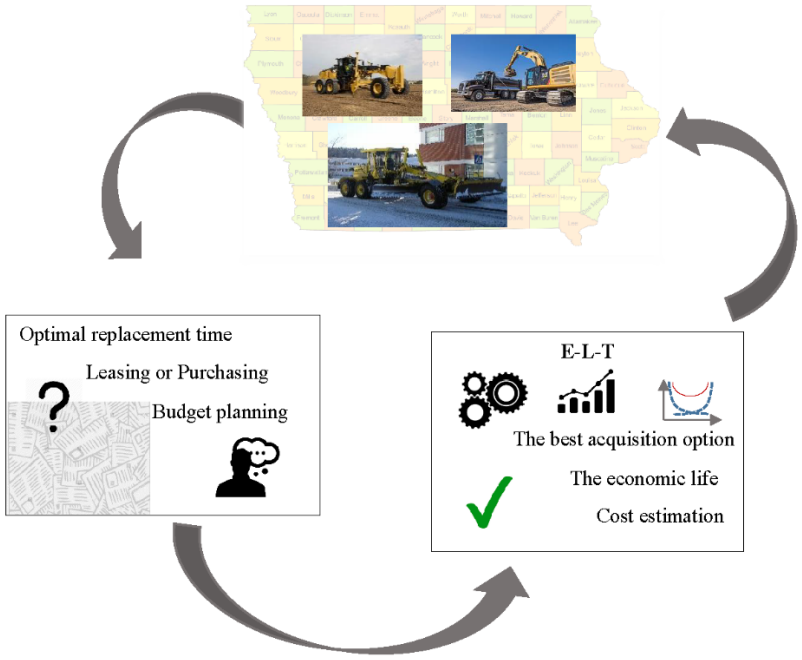


Figure 1. Use of the E-L-T for Iowa counties

An example of a case analysis is also presented to better guide the user in using the tool. A life-cycle cost analysis (LCCA) approach is adopted for estimating the future costs of equipment and determining the economic life and optimal replacement time to support agencies in making the most economic decisions on equipment procurement and replacement.

The tool takes as its inputs general economic information and basic equipment information considering both purchasing and leasing acquisition options. The tool captures information such as equipment usage, ownership and operating costs, and inflation rate. It then analyzes the information and estimates future costs using cost forecasting models derived from historical data analysis to determine the optimal economic life of the equipment. The tool is applicable for the two most common types of equipment in counties, motor graders and trucks.

The tool has two modules: (1) deterministic analysis and (2) stochastic analysis. The deterministic analysis captures constant input variables and provides one-point estimations. However, due to the randomness in real equipment operations, stochastic analysis is applied to consider uncertainties associated with input variables and provide a range of values and confidence intervals for results. The output of the tool can support equipment decision making for Iowa counties. For further explanation of the LCCA concept, equipment costs, equipment management decisions, Iowa counties' current practice, and data collection and analysis, refer to

the final report for this research project: Optimizing Maintenance Equipment Life-Cycle for Local Agencies.

Tool Overview

The tool was developed in Microsoft Excel software. It uses Visual Basic for Applications (VBA) for automatic calculations and analysis. The tool consists of three main worksheets. They are (1) the home page, (2) deterministic analysis, and (3) stochastic analysis. The tool is designed to receive input variables from the user who either enters inputs directly into the deterministic or stochastic worksheets to receive a one-point estimation of results in deterministic analysis or probabilistic results from the stochastic analysis. Also, a user-interface is designed in the home page to capture data more user-friendly to provide both deterministic and stochastic results.

The main results of the tool are provided as graphs and tables in the two sheets of deterministic and stochastic analysis. The following sections explain how to use the tool to create deterministic and stochastic sheets and also how to work with the user interface from the home page.

EXCEL SHEETS DESCRIPTION

Home Page

The home page's Excel sheet includes general guidelines for the tool. The user interface is launched from this page by clicking on the "Start with user interface" button, and the tool is fully explained by clicking on the help button that looks like a question mark on the sheet. The user interface permits the user to enter input data more easily. However, the user can also go to either the deterministic or stochastic sheets to insert data directly.

Deterministic Analysis Sheet

Figure 2 shows a screenshot of the deterministic analysis sheet.

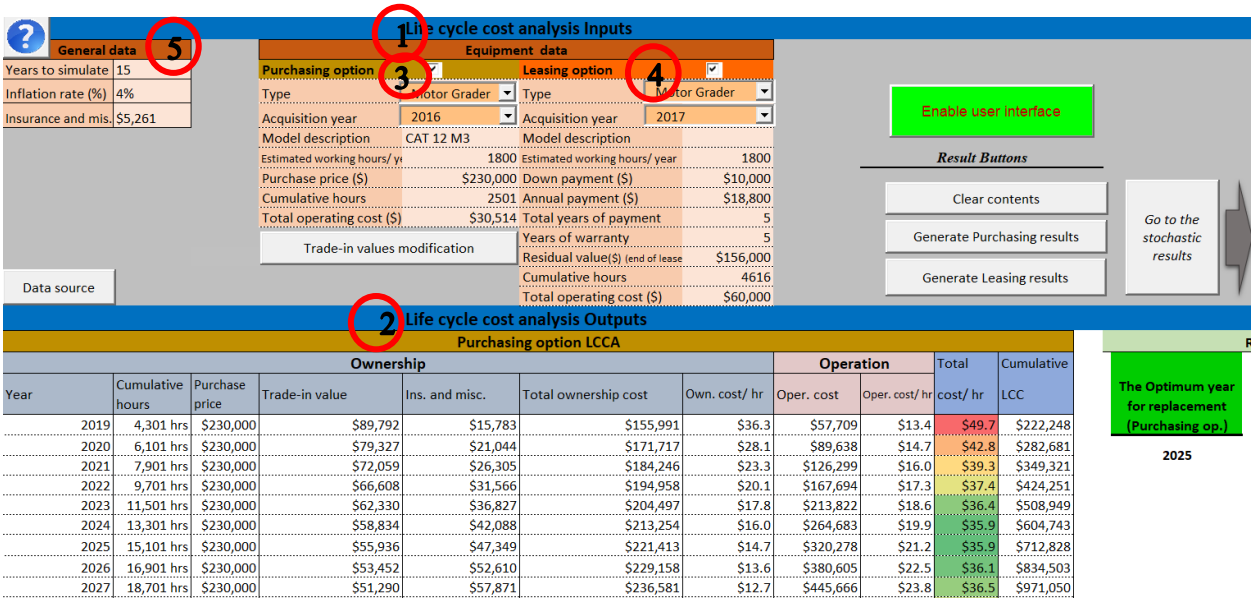


Figure 2. Deterministic analysis sheet

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

Life-Cycle Cost Analysis Inputs

General Data Inputs

The area labeled 5 in Figure 2 shows three input variables.

Years to simulate: This cell is the time interval to run the LCCA. For example, if the current year is 2019 and the user decides to run the tool from 2019 to 2025, the number entered into the cell would be 6.

Inflation rate: Equipment costs are affected by the economy. Inflation rate indicates the yearly percentage of increase in costs and reflects the increase in ownership and operation costs in the future, which is required to be estimated by the user. The default rate is 4% based on the survey's results of this research project and similar equipment LCCA studies by the Iowa Department of Transportation. The user can change the rate to reflect the actual county's practice.

Insurance and miscellaneous costs: Insurance costs represent the payment to an insurance company to cover the incurred costs of fire, theft, and accident, and also includes liability insurance. Some local agencies do not pay for insurance but rather use a self-insurance policy in which the agencies insure their equipment themselves and take financial risks. Miscellaneous costs include some uncategorized expenses of the equipment that are necessary to keep the equipment operating. For example, Iowa county engineers record these as "sundry costs" in their accounting reports and include the expenses of cleaning, regular inspections, shop utilities, fire extinguishers, light bulbs, first aid supplies, labor for upkeep on equipment, and work for minor tasks such as painting, mowing, and minor repairs. The final report provides further explanation on miscellaneous costs.

Equipment Data Inputs

Type: The type of equipment can be selected as "motor grader" or different types of "trucks" via the drop down menu. They are the two most common types of equipment used in Iowa counties.

Acquisition year: This cell is the year at which the equipment was purchased or leased.

Model description: This cell is a unique attribute for each piece of equipment indicating the model. For example, a 2016 CAT 12 M3 is a common motor grader used by counties.

Estimated working hours/year (or mileage/year): This cell indicates the amount of equipment usage per year during the specified time interval throughout the "years to simulate." According to current equipment record keeping in counties, working hours is recorded for graders and mileage is considered for trucks.

Purchase price: This cell is the price when the equipment was purchased.

Cumulative hours (or mileage): This cell is the total cumulative working hours or mileage of the equipment to date.

Total operating cost: This cell is the cumulative total operating cost of the equipment to date. Users should include all maintenance, parts, blades, tires, filters, labor, fuel, and oil costs for the equipment to date.

Down payment: This cell should be used in the leasing option to indicate the initial payment when the equipment was leased on credit.

Annual payment: This cell is the annual installment specified in the lease contract.

Total years of payment: This cell includes the total lease term.

Years of warranty: This cell is the period during which the leasing company covered all or a part of the operating costs.

Residual value: This cell is the remaining value of the equipment at the end of the leasing term specified in the lease contract.

Buttons

Trade-in values modification: This button guides the user to another page to modify the trade-in values. The default values were obtained from a research study that analyzed trade-in values of 1,500 graders and 3,000 trucks in 2003. However, adjusting the default values according to the current practice of agencies can result in more accurate estimations.

Clear contents: This button clears all the input values as well as all the graphs and charts in the output section. The user can click this button to start a new analysis and clear all contents in the output section.

Generate results: These buttons calculate the LCCA results for the purchasing and leasing options to display the results in the output section.

Enable user interface: This button enables the user interface to capture input variables via a user form.

Data source: This button shows the databases for graders and trucks obtained from counties.

Help: This button, which features a question mark, guides the user to the tool's manual.

Examples: At the very right side of the page, four real cases are demonstrated to generate input variables and provide real examples of using the tool.

Life-Cycle Cost Analysis Outputs

Figure 3 shows the outputs section for a real case of a grader from Henry County (input variables are shown in Figure 2) that runs the tool for 15 years.

Life cycle cost analysis Outputs

Purchasing option LCCA

	Ownership						Operation		Total	Cumulative
Year	Cumulative hours	Purchase price	Trade-in value	Ins. and misc.	Total ownership cost	Own. cost/ hr	Oper. cost	Oper. cost/ hr	cost/ hr	LCC
2019	4,301 hrs	$230,000	$89,792	$15,783	$155,991	$36.3	$57,709	$13.4	$49.7	$222,248
2020	6,101 hrs	$230,000	$79,327	$21,044	$171,717	$28.1	$89,638	$14.7	$42.8	$282,681
2021	7,901 hrs	$230,000	$72,059	$26,305	$184,246	$23.3	$126,299	$16.0	$39.3	$349,321
2022	9,701 hrs	$230,000	$66,608	$31,566	$194,958	$20.1	$167,694	$17.3	$37.4	$424,251
2023	11,501 hrs	$230,000	$62,330	$36,827	$204,497	$17.8	$213,822	$18.6	$36.4	$508,949
2024	13,301 hrs	$230,000	$58,834	$42,088	$213,254	$16.0	$264,683	$19.9	$35.9	$604,743
2025	15,101 hrs	$230,000	$55,936	$47,349	$221,413	$14.7	$320,278	$21.2	$35.9	$712,828
2026	16,901 hrs	$230,000	$53,452	$52,610	$229,158	$13.6	$380,605	$22.5	$36.1	$834,503
2027	18,701 hrs	$230,000	$51,290	$57,871	$236,581	$12.7	$445,666	$23.8	$36.5	$971,050
2028	20,501 hrs	$230,000	$49,404	$63,132	$243,728	$11.9	$515,460	$25.1	$37.0	$1,123,784
2029	22,301 hrs	$230,000	$47,725	$68,393	$250,668	$11.2	$589,988	$26.5	$37.7	$1,294,151
2030	24,101 hrs	$230,000	$46,230	$73,654	$257,424	$10.7	$669,248	$27.8	$38.4	$1,483,632
2031	25,901 hrs	$230,000	$44,873	$78,915	$264,042	$10.2	$753,242	$29.1	$39.3	$1,693,852
2032	27,701 hrs	$230,000	$43,654	$84,176	$270,522	$9.8	$841,969	$30.4	$40.2	$1,926,474
2033	29,501 hrs	$230,000	$42,527	$89,437	$276,910	$9.4	$935,429	$31.7	$41.1	$2,183,354

Results and graphs

The Optimum year for replacement (Purchasing op.)

2025

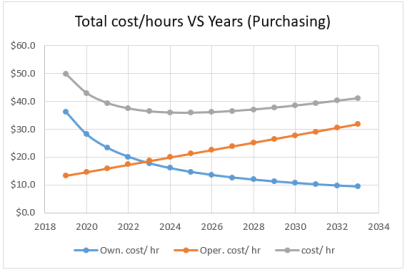


Figure 3. Output from a purchased motor grader analysis

In this section, future costs and other components are calculated using the embedded VBA coding. The operating cost was estimated based on historical equipment operating cost data obtained from counties. The total cost/hour is the total operating cost plus the total ownership cost divided by cumulative hours. Typically, the total cost per hour reduces to reach its minimum level before increasing again. The color coding in the column indicates this variation, such that as the color changes from green to yellow to red, the cost rate gets higher. It is recommended to replace the equipment at the lower cost rates. The lowest total cost per hour is the optimal replacement year (the greenest cell).

The graph in the outputs section shows how the ownership cost per hour decreases (mostly due to the decline in salvage value), the operating cost per hour increases (due to the increase in maintenance costs), and the total cost per hour decreases at first before starting to increase again. Cumulative LCC is the cumulative cost of the equipment considering the impact of inflation rate and can be used for budget planning.

Figure 4 shows the output for a real case of a leased motor grader (the input variables are shown in Figure 3).

Leasing option LCCA

	Ownership							Operation		Total	Cumulative
Year	Cumulative hours	Residual or Salvage value	Total payments	Ins. and misc.	Total ownership cost	Own. cost/ hr		Oper. cost	Oper. cost/ hr	cost/ hr	LCC
2019	6,416 hrs	$156,000	$47,600	$10,522	$58,122	$9.1		$60,000	$9.4	$18.4	$122,847
2020	8,216 hrs	$156,000	$66,400	$15,783	$82,183	$10.0		$60,000	$7.3	$17.3	$153,785
2021	10,016 hrs	$156,000	$85,200	$21,044	$106,244	$10.6		$60,000	$6.0	$16.6	$187,002
2022	11,816 hrs	$237,458	$260,000	$26,305	$204,847	$17.3		$240,221	$20.3	$37.7	$520,666
2023	13,616 hrs	$231,296	$260,000	$31,566	$216,270	$15.9		$298,652	$21.9	$37.8	$626,482
2024	15,416 hrs	$226,460	$260,000	$36,827	$226,367	$14.7		$362,435	$23.5	$38.2	$745,022
2025	17,216 hrs	$222,508	$260,000	$42,088	$235,580	$13.7		$431,568	$25.1	$38.8	$877,921
2026	19,016 hrs	$219,232	$260,000	$47,349	$244,117	$12.8		$506,051	$26.6	$39.5	$1,026,657
2027	20,816 hrs	$216,424	$260,000	$52,610	$252,186	$12.1		$585,885	$28.1	$40.3	$1,192,836
2028	22,616 hrs	$213,980	$260,000	$57,871	$259,891	$11.5		$671,070	$29.7	$41.2	$1,378,049
2029	24,416 hrs	$211,848	$260,000	$63,132	$267,284	$10.9		$761,605	$31.2	$42.1	$1,583,927
2030	26,216 hrs	$209,950	$260,000	$68,393	$274,443	$10.5		$857,491	$32.7	$43.2	$1,812,262
2031	28,016 hrs	$208,260	$260,000	$73,654	$281,394	$10.0		$958,727	$34.2	$44.3	$2,064,893
2032	29,816 hrs	$206,726	$260,000	$78,915	$288,189	$9.7		$1,065,314	$35.7	$45.4	$2,343,829
2033	31,616 hrs	$205,348	$260,000	$84,176	$294,828	$9.3		$1,177,252	$37.2	$46.6	$2,651,132

The Optimum year for replacement (Leasing op.)

2021

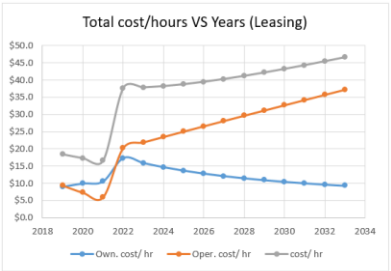


Figure 4. Output from a leased motor grader analysis

The ownership cost includes the down payment and annual payments. It is assumed that after the end of the leasing term, the user pays the residual value and owns the equipment. Therefore, the ownership cost per hour suddenly increases at the end of the leasing term. The operating cost per

hour decreases at first because the leasing company covers all the operating expenses during the warranty period, keeping the cumulative operating costs steady while the cumulative working hours is increasing. It increases suddenly after the warranty period because the user is responsible for all the operating expenses after that. The total cost per hour decreases at first and reaches its minimum at the end of the leasing period; then, during the owing stage, the operating cost increases and the ownership cost decreases. The tool recommends the end of the leasing period as the replacement year.

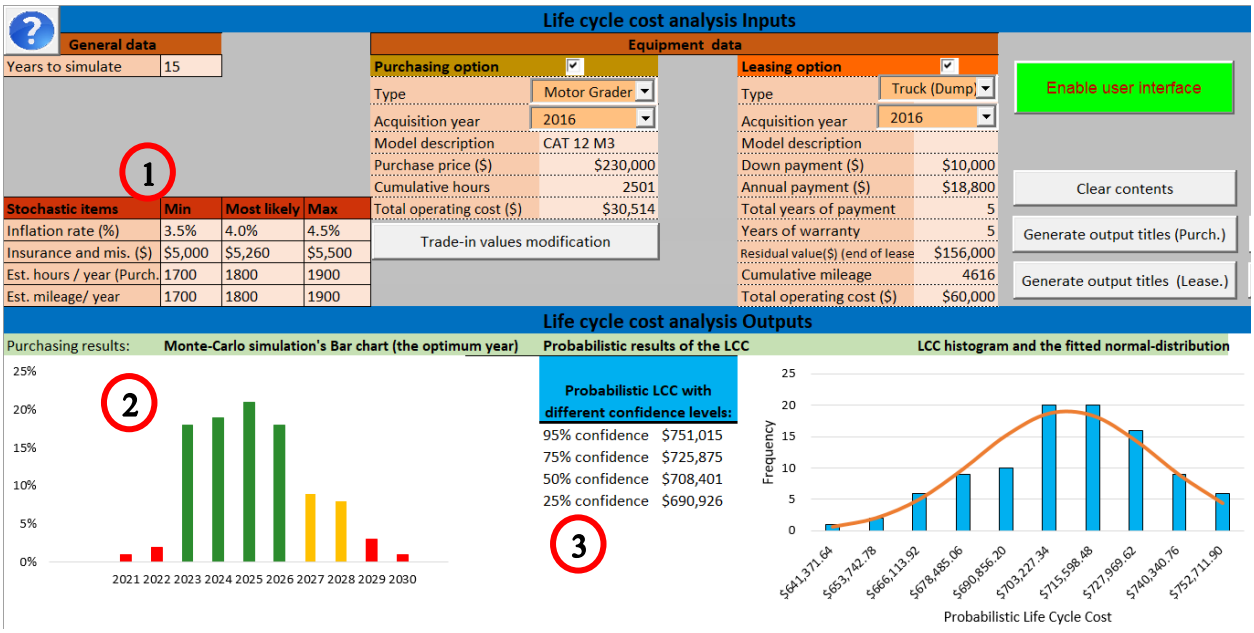
The user can compare the output from the leasing option with the purchasing option when two similar acquisition options are available for the same piece of equipment. Typically, the leasing option is recommended when the user requires short-term access to the equipment, while the purchasing option is suitable in case the user intends to keep the equipment for a longer term and has expertise in maintenance activities.

Stochastic Analysis Sheet

The stochastic analysis allows the user to consider uncertainties associated with input variables. This sheet is divided into two sections, input and output, similar to the deterministic analysis sheet, and it receives the inputs similar to the deterministic sheet. This sheet captures three probabilistic input variables in which a minimum, most likely, and maximum value are considered for these variables. The tool runs the Monte Carlo simulation to consider the probability distribution of defined variables and calculates results over and over, each time using different randomly selected values from the probability functions of input variables to provide a range of values as results.

Life-Cycle Cost Analysis Inputs

The inputs are filled out similar to the deterministic sheet. However, a range of values is required for three input variables: inflation rate, insurance and miscellaneous costs, and estimated working hours (or mileage), shown in Figure 5 by the label 1. Input variables are entered using real cases of equipment from counties, and results are obtained as shown in Figure 4.



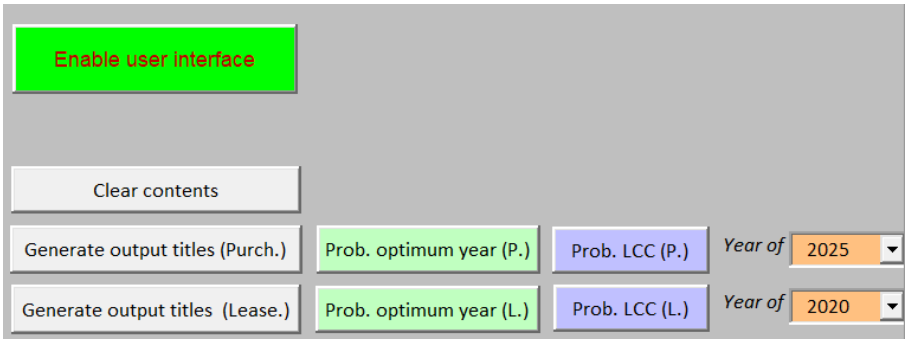


Figure 5. Stochastic analysis sheet

Buttons

The buttons are the same as the deterministic sheet, work in the same way (see the deterministic sheet section for their functions). However, the stochastic sheet has additional buttons.

Generate output titles: These buttons generate titles for the output section to provide a categorized section for output charts and graphs.

Probabilistic optimum replacement year: These buttons use the Monte Carlo simulation to generate probabilistic results for the optimum replacement year (labeled 2 in Figure 5).

Probabilistic LCC: These buttons run the Monte Carlo simulation to provide the total life-cycle cost (LCC) of the equipment in the specified year (from the respective drop down menu) with different levels of uncertainties (labeled3 in Figure 5).

Life-Cycle Cost Analysis Outputs

The area labeled 2 in Figure 4 shows the probabilistic result of the optimum year. The columns indicate how often the respective year is obtained as the best replacement year by changing the input variables within their defined ranges. The taller columns indicate better replacement years. Green columns indicate the recommended years for replacement decisions, while yellow columns are medium and the red columns are not recommended for replacement year.

The area labeled 3 in Figure 5 illustrates a histogram of probable total cumulative LCC in the specified year (2025 is shown in the example) and a fitted normal curve. The table indicates probable total cumulative LCC with different levels of confidence in the specified year providing better insights for budget planning.

User Interface

The user interface is run by clicking on the "Start with user interface" button on the home page. A form pops up to enter inputs that provide outputs after five steps. As Figure 6 shows, the first step is selecting the acquisition option.

Figure 6. Step 1 of the user interface

After entering information in each step (or tab), the "next" button (as shown by ) should be clicked to save the entered data and go to the next step. The green "Hide the form" button hides the form and enables the user to work through other sheets; the form can be shown again by clicking on the "Enable user interface" button in either the deterministic or stochastic sheet.

Based on the user's choice in Step 1, Step 2 includes input data of either the purchasing or leasing option shown in Figure 7.

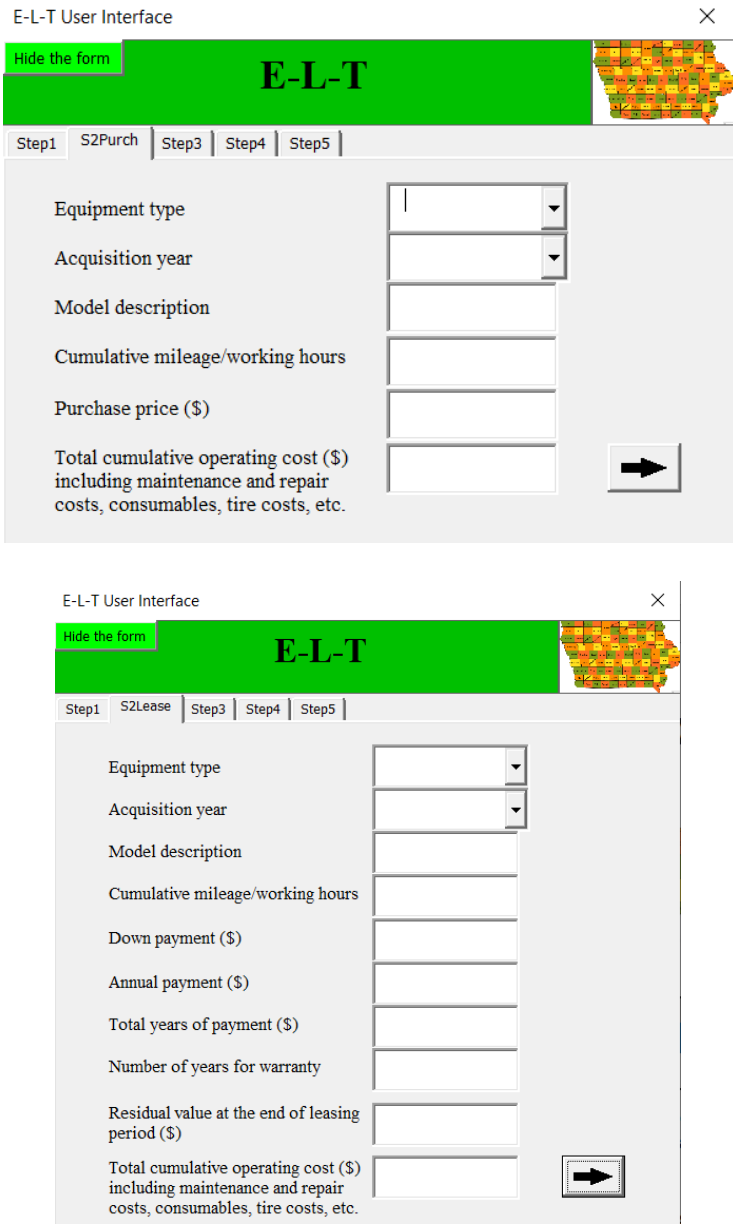


Figure 7. Step 2 of the user interface

The input variables are explained in earlier sections in this document.

Step 3 receives input data specific to running the deterministic analysis, as shown in Figure 8.

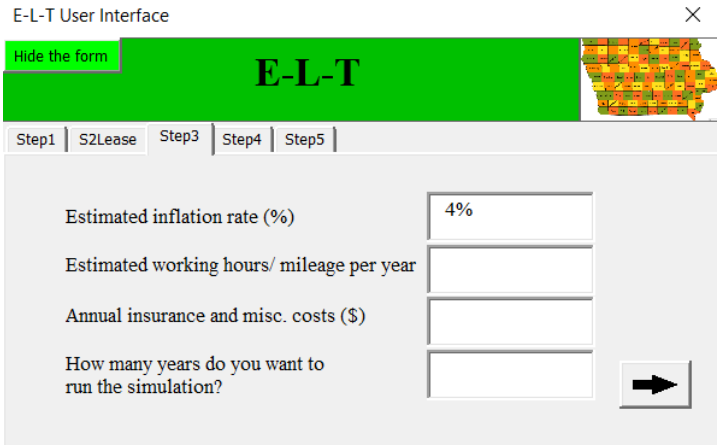


Figure 8. Step 3 of the user interface

Step 4 deals with trade-in values (Figure 9).

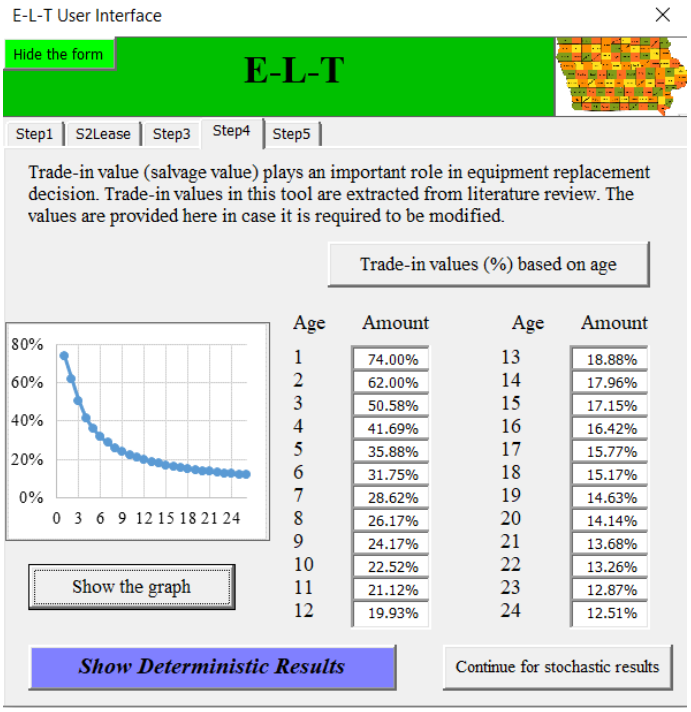


Figure 9. Step 4 of the user interface

By clicking on the "trade-in values" button, default values are shown in the cells, and the respective graph is shown by clicking on the "show the graph" button. The user can modify each cell according to more realistic and updated trade-in values and see the output graphs. By clicking the "Show Deterministic Results" button, the output of the deterministic analysis is shown the same as Figure 3 and 4. The user can hide the form and go through the results. The user can also run stochastic analysis in Step 5 by entering a range of values for some inputs (Figure 10).

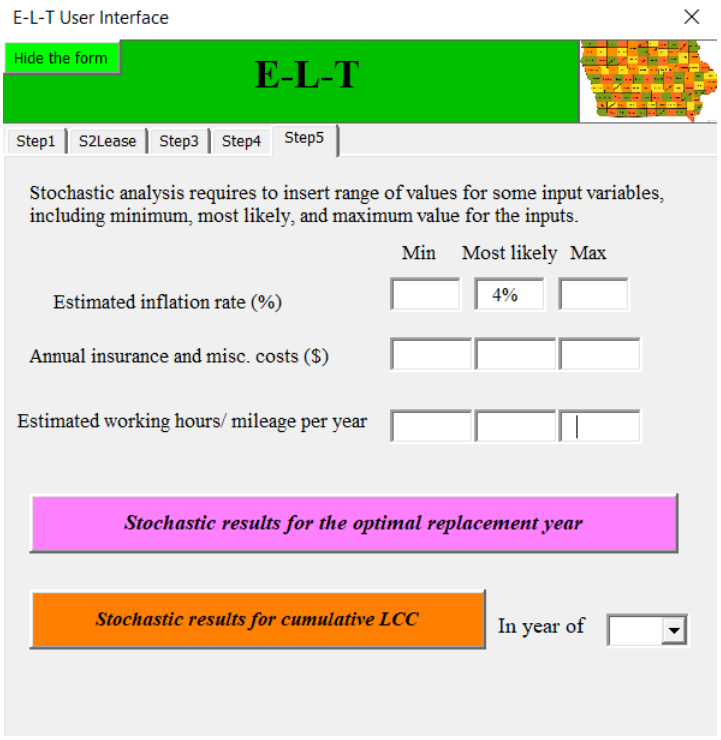


Figure 10. Step 5 of the user interface

In this step, the probabilistic results of the optimum year and total LCC (the same as Figure 5) is provided.

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