Next Generation Life-Cycle Cost Analysis Tool for Bridges in Iowa – Phase II

Final Report
September 2023

BRIDGE ENGINEERING CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
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Alice Alipour (orcid.org/0000-0001-6893-9602), Behrouz Shafei (orcid.org/0000-0001-5677-6324), and Maziar Kazemian (orcid.org/0000-0002-3067-4597)	InTrans Project 21-754
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16. Abstract

To meet the requirements of the Moving Ahead for Progress in the 21st Century (MAP-21) Act of 2012, a life-cycle cost analysis management (LCCAM) tool was developed to manage the maintenance actions of the portion of National Highway System (NHS) for the Iowa Department of Transportation (DOT).

The LCCAM software that was developed with the cooperation of the Iowa DOT and the Bridge Engineering Center at Iowa State University has successfully integrated risk into the decision-making process of determining the maintenance of bridge decks in Iowa. This Phase II project was aimed at upgrading the current version of the LCCAM tool and providing a suitable ground for future developments.

For this project, user cost calculations were added to the software. This was possible by following the roadmap published by Federal Highway Administration (FHWA). Three main parameters of user cost—travel delay time cost, vehicle operating cost, and crash cost—are calculated by the software based on data input from the user.

A comprehensive survey of maintenance activities was also carried out that included different national bridge elements and bridge management elements. This survey followed the nomenclature of the American Association of State Highway and Transportation Officials (AASHTO) and was aimed to create a consistent database of maintenance activities.

The user interface of the LCCAM software was updated to provide a more user-friendly experience for users. The updated graphical user interface provides a more aesthetic environment with the capability of saving the output of the software as well as incorporation of user cost calculations. The software also allows users to skip to the user cost calculations directly.

The upgraded software can be further improved by the addition of degradation curves for other bridge elements, which would make it more inclusive.

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Final Report
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Principal Investigator
Alice Alipour, Associate Professor
Bridge Engineering Center, Iowa State University

Co-Principal Investigator
Behrouz Shafei, Structure Engineer
Bridge Engineering Center, Iowa State University

Research Assistant
Maziar Kazemian

Authors
Alice Alipour, Behrouz Shafei, and Maziar Kazemian

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A report from
Bridge Engineering Center
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

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EXECUTIVE SUMMARY

Background

Roads and bridges play a pivotal role in the growth and prosperity of nations by enabling the transportation of people and goods. The quantity and quality of roads and bridges are key to economic development of countries around the world and, therefore, it is of utmost importance to construct new transportation infrastructure and maintain the structures in service.

Given that any country's sources of income are limited, the budget available for construction and maintenance of transportation infrastructure is, thus, restricted. Consequently, the available budget needs to be wisely distributed among the ongoing and potential projects. To this end, cost-benefit analysis can become very effective.

Once a cost-benefit analysis proves the efficiency of a certain project, life-cycle cost analysis (LCCA) can be performed to find the best maintenance method or the best construction option among different alternatives. This helps ensure that the chosen method has the lowest total cost during the service life of the structure.

As a requirement of the Moving Ahead for Progress in the 21st Century (MAP-21) Act, states are mandated to develop a transportation asset management tool for maintenance of their portion of the National Highway System (NHS). For this purpose, an LCCA management (LCCAM) tool was developed by a team from the Bridge Engineering Center at Iowa State University with the cooperation of Iowa Department of Transportation (DOT) Bridges and Structures personnel.

In its initial phase, the LCCAM tool aimed to incorporate the effects of uncertainties and risk into the life cycle of bridge decks. Therefore, more than 10 years of historical data were extracted from multiple sources ranging from Iowa DOT expert personnel in the field to Iowa's Structure Inventory and Inspection Management System and the National Bridge Inventory (NBI).

Using these data, the bridge deck degradation curve specific to Iowa bridges was developed based on the average age of each condition rating, which was calculated by probabilistic analysis. This degradation curve is key to maintenance management of bridge decks. Different bridge deck maintenance activities were integrated into the software and are based on the needs of the user. The best maintenance or chain of maintenance activities are then suggested by the software.

Problem Statement

To help the Iowa DOT build on the LCCAM software developed for Iowa, the tool needed to be made more user-friendly and to incorporate road user cost calculations.

Research Objectives

The first objective of this Phase II project was to upgrade the graphical user interface (GUI) to make the LCCAM tool more user-friendly and easier to surf. Secondly, this project aimed to integrate user cost calculations into the software without damaging the current procedure of maintenance management for bridge decks in Iowa.

Research Description

The roadmap for user cost calculations from the Federal Highway Administration (FHWA) was utilized to incorporate user cost calculations into the software. This roadmap allows for the calculation of six types of user costs. Three main user cost types are calculated and considered using the LCCAM tool, requiring a multitude of user inputs. A comprehensive example is provided in the report to help users with data entry.

A survey of maintenance activities was carried out to update the current state-of-the-practice and also provide a ground for future updates to the software, such as developing degradation curves for other bridge elements (i.e., superstructure, substructure, and culverts) as well as bridge management elements like drains and bearings. This survey will help with the incorporation of all bridge elements into the LCCAM software in the future.

Finally, the LCCAM software GUI underwent a complete revision to make it more user-friendly. The command window data input was removed, and all of the data entry and the procedure are now performed using a single window. The output data are more user-friendly, and they are shown in dedicated tables that allow the user to save the data in a text file in their directory of choice. Furthermore, the updated user interface allows the user to skip to the user cost calculations and deal with the user cost inputs directly.

Key Findings

- User cost calculations are integrated into the LCCAM software, which not only calculates the final user cost but also shows a breakdown of the user cost among its three main components: delay time cost, vehicle operation cost, and crash cost.

- The survey of maintenance activities that was developed based on American Association of Highway and Transportation Officials (AASHTO) nomenclature was helpful in making the maintenance actions more consistent with those of the rest of the nation and provides an appropriate ground for future developments in the LCCAM tool to make it more inclusive.

- The LCCAM tool has become more user-friendly with the upgrades to its GUI, making it easier for the user to navigate through the software's capabilities.

Recommendations for Future Research

- Future efforts need to be dedicated toward developing degradation curves for other bridge elements beyond the bridge deck (i.e., superstructure, substructure, and culverts) to make the tool more inclusive.

- The current LCCAM software uses delay time inputs from the user, which can be linked to a historical traffic database to automate this part of the calculations. Similar automations are possible upon linking the crash database of each road/county to the software. By doing so, the software could become more user-friendly and require less input from the user.

- A comprehensive investigation could be performed instead of a survey of maintenance activities to measure the cost and uncertainty of each maintenance activity to make these estimations more accurate.

1. INTRODUCTION

This chapter provides the background to understand the importance of this project.

1.1. Background

Our transportation infrastructure requires the construction of new infrastructure as well as the maintenance of the existing infrastructure in a safe and reliable condition. This highlights the importance of performing benefit-cost analysis to determine the desirability of a project among many other alternative projects (Harris 2009).

Due to the progress of civil engineering, once a project is selected, a multitude of scenarios are available to construct and/or maintain a structure, which can be challenging to the decision makers (Ehlen 2003). For a long time, a procedure (either construction of a new structure or choosing a maintenance activity) with the lowest initial cost was deemed suitable and was adopted for practice; however, upon the issuance of the 2012 Moving Ahead for Progress in the 21st Century (MAP-21) Act, states became obliged to develop transportation asset management plans (TAMPs), which require life-cycle cost (LCC) and risk management analysis (Alipour et al. 2020).

The LCC of a structure is measured either in present value or in uniform annualized value over a specified life cycle (which can be equal to the life cycle of the structure), and it is calculated using the summation of the initial cost and the cost of maintenance, repair, and renewal of the structure during the desired life cycle (Rahman and Vanier 2004).

The LCC analysis (LCCA) provides a ground for comparing the total discounted cost of different structure alternatives over the life cycle, including both user and agency costs. Given that structures are prone to deterioration, which is rooted in internal stressors (e.g., shrinkage and alkali-silica reaction) and external stressors (e.g., excessive loading and corrosion) that always accompany a structure, maintenance activities are inevitable to maintain the serviceability of a structure over time. The type and cost of maintenance activities depend on the type of structure, so the cost of maintenance is of utmost importance in considering and deciding to construct a structure.

According to Ryan et al. (2012) in the *Bridge Inspector's Reference Manual (BIRM)* for the Federal Highway Administration (FHWA), the importance of maintenance activities for bridges was first recognized at a national level after the collapse of the Silver Bridge, which killed 46 people, into the Ohio River in West Virginia on December 15, 1967. This tragic incident led to the Federal Highway Act of 1968, which mandated the Secretary of Transportation to initiate a national standard for inspection of bridges and to train bridge inspectors.

Following this mandate, the National Bridge Inspection Standards (NBIS) were developed in 1971 to provide guidance regarding the inspection procedure and frequency, as well as the report framework and details on required personnel qualifications and logging of the results into the National Bridge Inventory (NBI).

During the 1970s and 1980s, several manuals were published by AASHTO and the FHWA that contributed to the success and maturation of the NBIS. Benefiting from more than two decades of inspection and maintenance experience that resulted in gathering a notable amount of data, bridge management systems, such as Pontis and BRIDGIT, were developed into the 1990s.

Sponsored by the FHWA, Pontis was designed to provide maintenance management for state bridges while BRIDGIT was developed by the National Cooperative Highway Research Program (NCHRP) to help manage the maintenance of bridges on a smaller scale, such as local highway systems.

1.2. Bridge Condition Ratings

Based on the *AASHTO Guide for Commonly Recognized Structural Elements* (AASHTO 1997), bridge elements are divided into two main categories: national bridge elements (NBEs) and bridge management elements (BMEs). The *Manual for Bridge Element Inspection* (AASHTO 2019) states that “NBEs represent the primary structural components of bridges necessary to determine the overall condition and safety of the primary load carrying members.”

NBEs are broken down into four main components: deck, superstructure, substructure, and culverts. Two additional components are bridge rails and bearings (FHWA 2012). NBEs are designed to be consistent among all bridges in the US, which allows the compilation of a comprehensive and consistent database of bridge condition ratings and deterioration.

In the *Bridge Element Inspection Guide* issued by the Iowa Department of Transportation (DOT) (Iowa DOT 2014a), the deck is defined as a bridge component that is responsible for transferring the load from vehicles to the superstructure of the bridge, which transmits the loads to the substructure.

The bridge superstructure is composed of girders, trusses, arches, and floor systems in addition to cables, gusset plates, and pins or pin and hanger assemblies. Substructure elements are those used to transfer the load from the superstructure to the ground and include a range of elements such as piles, pile caps and footings, pile extensions, pier or bent caps, pier walls, and abutments. Culverts include a variety of steel, prestressed concrete, and reinforced concrete elements that are used to convey water from one side of the roadway to the other.

The other set of bridge elements are referred to as BMEs, which are defined as bridge components that are managed by agencies by employing bridge management systems (BMSs). BMEs generally include joints, wearing surfaces, protective coating systems, and deck or slab protection systems, but they are not limited to these components given agencies are advised to develop their own set of BMEs to help better manage information on the conditions of their bridges (AASHTO 2019).

The important parameters to consider before developing a new BME are element performance, deterioration rates, feasible actions, preservation costs, and training and inspection costs (AASHTO 2019).

The condition rating of a bridge is possible after all of the bridge components are determined. For this purpose, the NBIS condition rating has been used for a long time. With this rating system, each bridge component is rated between 0 and 9 with 0 being the failed condition while 9 represents excellent condition. Table 1.1 lists the descriptions for each rating.

Table 1.1. NBIS condition rating system

Condition Rating	Description
N	Not Applicable.
9	Excellent Condition.
8	Very Good Condition – No problems noted.
7	Good Condition – Some minor problems.
6	Satisfactory Condition – Structural elements show some minor deterioration.
5	Fair Condition – All primary structural elements are sound but may have minor section loss, cracking, spalling, or scour.
4	Poor Condition – Advanced section loss deterioration, spalling, or scour.
3	Serious Condition – Loss of section, deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical Condition – Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present, or scour may have removed substructure support. Unless closely monitored, it may be necessary to close the bridge until correction action is taken.
1	Imminent Failure Condition – Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic, but corrective action may put it back in light service.
0	Failed Condition – Out of service; beyond correction action.

Source: Iowa DOT 2015

Over years of utilizing the NBIS, officials have found some deficiencies in this system of bridge condition ratings, which incentivized AASHTO to develop a new condition rating system, as documented by Thompson and Shepard (2000), that rates components between 1 and 4 for severe, poor, fair, and good condition.

As the new condition rating system gains acceptance, the need to correlate the results of the old and new systems become more important along with the need for historical data for decision making. To address this issue, the Iowa DOT developed the definitions in Table 1.2.

Table 1.2. Comparison of condition rating systems

NBIS Condition Rating	AASHTO Descriptive Condition	Description
7, 8, 9	Good	Component defects are limited to only minor problems
5, 6	Fair	Structural capacity of the component is not affected by minor deterioration, section loss, spalling, cracking, or other deficiency
0, 1, 2, 3, 4	Poor and Severe	Structural capacity of the component is affected or jeopardized by significant deterioration, section loss, spalling, cracking, or other deficiency

Source: Iowa DOT 2014b

The AASHTO condition rating system is gaining more widespread use given it provides a more detailed inspection of bridge elements documenting element-level deterioration and conditions, simplified down to just four ratings. The second edition of the *Manual for Bridge Element Inspection* (AASHTO 2019) provides detailed guidance on how to rate the condition of each bridge element with corresponding images of deteriorated bridges.

1.3. Overview of Bridge Conditions in the US

A country's economy is highly dependent on the quality of its transportation system given it lays the groundwork for the mobility and accessibility of people, services, and goods (Jeong et al. 2018). The US is no exception, and that's the reason behind the extensive investment from government agencies in maintaining and developing the condition of transportation infrastructure.

As a case in point, the US government spends about $14.4 billion annually on only repair and rehabilitation of bridges (ASCE 2021). A transportation system is comprised of multiple sections including railways, highways, airports, and bridges. Bridges are essential parts of a transportation system in connecting two segments of a roadway or railroad. Therefore, it is imperative to monitor bridge conditions during regular conditions and during catastrophic events (Karlaftis et al. 2007, Shim et al. 2019, Zhou et al. 2019).

Performing optimized inspection and maintenance measures is necessary when it comes to reassuring the safety of travelers while minimizing the incurred cost to the organizations in charge of managing the bridges (Shepard 2005). According to estimates, about 80% of the cost of public infrastructure maintenance and construction in the US is funded by state and local governments (Bosworth and Milusheva 2011), which imposes a significant burden on not only state agencies but also the US government that already shoulders a total national deferred maintenance cost of about $1 trillion (Zhao et al. 2019).

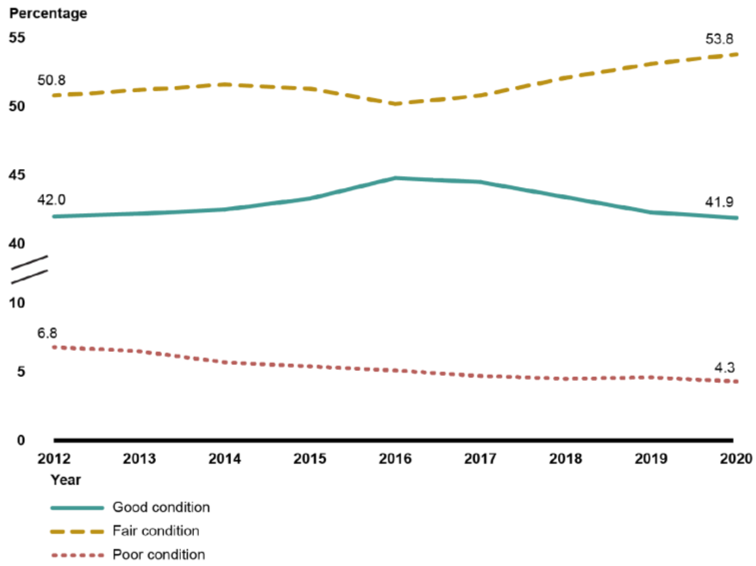
Even after considering all the funding, the American Society of Civil Engineers (ASCE) has reported that 9.1% of bridges in the US are structurally deficient (ASCE 2017). These bridges carry 188 million trips daily and were estimated to require $123 billion for repair and rehabilitation purposes, which has increased to $125 billion in the latest estimate—for 2021—even though the deck areas of structurally deficient bridges have decreased to 7.5% and undergo 178 million trips per day (ASCE 2021, GAO 2021).

The 2021 ASCE report card noted that, among 617,000 bridges in the US (at the time of publication), 42% of them were in service for at least 50 years. Given that most of the bridges are designed for a life span of 50 years, special speed and weight restrictions are imposed on these bridges to reduce the risk of failure; however, the measures increase user costs as well as drive time, especially for heavy vehicles, including ambulances and school buses. ASCE estimates that, with the current funding, the required repair and rehabilitation of bridges will be completed in 2071; however, the ongoing deterioration during this period will overwhelm the country's bridge network (ASCE 2021).

Between 2006 and 2015, a report from the U.S. Government Accountability Office (GAO) indicated that the percentage of structurally deficient bridges decreased from 9% to 7% and that the percentage of structurally deficient deck areas decreased from 13% to 10% (GAO 2016). The report mentioned that, although the average of the national-scale results show an overall descending trend in the number and deck area of structurally deficient bridges, the levels of the contribution to the percentages differ significantly between 42 states, Washington DC, and Puerto Rico, which showed a similar trend over the 10-year period with Rhode Island having the highest reduction rate (of almost 20% in a 10-year period), while the remaining states documented exacerbated bridge conditions with Delaware having the highest rate of increase in deficient bridges (of almost 4% in 10 years).

Although the FHWA oversees the federal funding of bridges in the US, it does not determine the target bridges for maintenance and/or construction; however, to motivate states to allocate a portion of their funding to repairing structurally deficient bridges, the MAP-21 Act issued a penalty provision for the states that report 10% or more of structurally deficient bridges (by deck area) on the National Highway System (NHS) for three consecutive years. Once the penalty provision is activated for a state, that state is obligated to spend equal to 50% of their 2009 fiscal year Highway Bridge Program funds on repairing their structurally deficient bridges.

The 2021 GAO Highway Bridges report (GAO 2021) specified corrosion as the main cause of bridge failures based on the 2019 element-level data as well as interview data acquired from multiple DOT sources. As shown in Figure 1.1, the report indicated that, although from 2012 to 2020, the deck area of the bridges in poor condition decreased from 6.8% to 4.3%, the deck area of bridges in good condition increased to 44.8% in 2016 from 42.0% in 2012, while this dropped to 41.9% in 2020.



GAO analysis of FHWA data (GAO 2021)

Figure 1.1. Changes in the condition of deck area for bridges in good, fair, and poor condition on the NHS, 2012 through 2020

The report also indicated that the deck area of bridges in fair condition increased from 50.2% to 53.8% and the average age of the bridges decreased from 47 years to 44 years from 2012 to 2020. The FHWA associated the reduction in bridge age to replacement of deficient bridges with new bridges (GAO 2021). However, upon reviewing these results, ASCE stated that the deterioration rate exceeds the repair rate. This was reflected in the overall bridge condition ratings in their 2017 and 2021 report cards, which degraded from the overall condition rating from C+ to C (ASCE 2017 and ASCE 2021).

ASCE has issued several recommendations to enhance the rating of bridge conditions, such as increasing the annual bridge repair fund from $14.4 billion to $22.7 billion, as well as allocating additional funding to research. Moreover, ASCE has suggested prioritizing the repair and rehabilitation of bridges so that they remain in fair condition given it requires much less funding than a fundamental rehabilitation, ultimately reducing the percentage of structurally deficient bridges to less than 5%.

Another strategy to enhance bridge conditions is to increase the highway trust fund by increasing the federal fuel tax. Furthermore, one of the most important and feasible methods to effectively improve bridge conditions is to employ an LCCA tool to help prioritize maintenance activities, leading to smarter decision making and optimized investments (ASCE 2021).

The 2017 ASCE *Infrastructure Report Card* (ASCE 2017) provided a state-by-state breakdown of structurally deficient bridges, as shown in Table 1.3.

Table 1.3. Best and worst five states with structurally deficient bridges by number and percentage within each state

Best five states					
By number	Washington DC 9	Nevada 31	Delaware 43	Hawaii 64	Utah 95
By percent	Nevada 1.6%	Texas 1.7%	Florida 2.1%	Arizona 2.6%	Utah 3.1%
Worst five states					
By number	Iowa 4,968	Pennsylvania 4,506	Oklahoma 3,460	Missouri 3,195	Nebraska 2,361
By percent	Rhode Island 24.9%	Iowa 20.5%	Pennsylvania 19.8%	South Dakota 19.6%	West Virginia 17.3%

Source: ASCE 2017

As shown, Nevada and Texas had the lowest percentage of deficient bridges (1.6% and 1.7%, respectively) within their states based on the total bridge deck area within each state. Rhode Island and Iowa had the highest percentage of structurally deficient bridges (24.9% and 20.5%, respectively) based on the total bridge deck area within each state.

The total number of deficient bridges was reported to be the highest in Iowa with 4,968 structurally deficient bridges. Given the statistics showing the high number and percentage of structurally deficient bridges in Iowa, the need to develop a reliable and up-to-date LCCA tool for bridges was given a high priority.

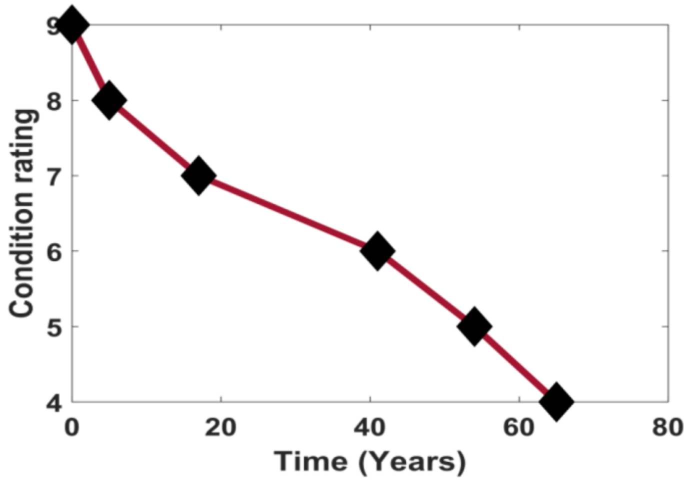
1.4. Developing an LCCA Tool for Iowa

To meet the requirements of the MAP-21 Act, the Iowa DOT, in conjunction with the Bridge Engineering Center at Iowa State University, first developed a MATLAB-based LCCA tool that employed a risk-integrated bridge deterioration model to specify required repair and maintenance activities for bridge decks. The detailed discussions of this tool can be found in Alipour et al. (2020).

The life-cycle cost analysis management (LCCAM) tool uses data from the NBI and Iowa's Structure Inventory and Inspection Management System database as well as from expert Iowa DOT sources. Given the abundance of data for bridge decks, the Phase II project development for the LCCAM software kept its focus on bridge decks, although the possibility of adding other bridge elements to the software is possible in the future.

The bridge deterioration model was developed based on the two-year inspection data for Iowa bridges to make it more accurate for use in Iowa and other states with similar climates. The acquired data were used to develop an LCCA methodology that predicts the ongoing costs (user and agency costs) related to the maintenance activities during the life cycles of bridges in Iowa.

The LCCA methodology uses more than 10 years of inspection data to determine the probability of transition of the bridge deck from one condition rating to the next over a specified duration of time. The acquired probability is then used to calculate the survival or failure probability distributions, which lead to determining the average age of each condition state for Iowa bridges. Based on the calculated average age for each condition rating, the deterioration curve for Iowa bridge decks is then derived, as shown in Figure 1.2, and used to predict the life cycle of a bridge deck.

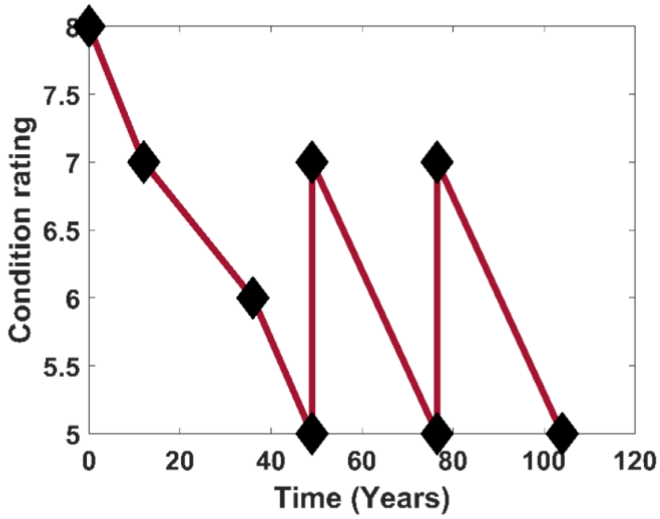


Alipour et al. 2020

Figure 1.2. Deterioration curve developed for Iowa bridge decks in LCCAM

Upon running the LCCAM software, Figure 1.2 helps provide insight into the life cycle for Iowa bridge decks. The software prompts the user to enter the current condition rating of the bridge deck as well as the intended condition rating. This leads to a menu of possible maintenance activities that allows users to select an activity or provide a comparison of several activities. Additionally, another option is embedded in the software that requires the additional years of service (the intended extension to the service life of the bridge) as input and provides a set of maintenance activities with their associated costs as the result.

The user can then select one of the sets of maintenance activities to increase the life cycle of the bridge deck for the intended number of years. If the selected set of maintenance activities result in an enhancement of the condition rating as well as an extension of the bridge service life, the software plots the new deterioration curve, as shown in Figure 1.3, for example, which indicates the deterioration curve of a bridge with two consecutive maintenance activities that lengthen the life cycle for the bridge.



Alipour et al. 2020

Figure 1.3. Sample deterioration curve for a bridge deck with two consecutive maintenance activities

The stochastic approach adopted to calculate the deterioration curve of Iowa's bridges provides the LCCAM software with an advantage over the previously practiced decision making that was solely dependent on a deterministic approach, where the necessity and scale of the project were the main parameters.

Currently, bridge maintenance funding is broken down by the Iowa DOT into the following categories: 70% assigned to replacement purposes, 23% to rehabilitation actions, and the remaining 7% allocated to repair activities (Alipour et al. 2020). Although this method of funding allocation has been practiced for a long time, allocation of the limited funds effectively needs to be enhanced. Therefore, employing a reliable, Iowa-based bridge maintenance management tool that incorporates risk into the management of bridges is of utmost importance to the state so that it may use its funds most efficiently.

1.5. Report Overview

The remainder of this report is divided into five additional chapters, as follows:

- **Chapter 2. Review of Existing LCCA Methods:** In this chapter, the available LCCA methods are summarized and compared together.

- **Chapter 3. User Cost Calculations:** This chapter is dedicated to calculation of user costs based on the recommendations of FHWA. Additionally, a comprehensive example is provided to help the user with the data entry.

- **Chapter 4. Survey of Maintenance Activities:** This chapter contains the survey results and its implication to the LCCAM.

- **Chapter 5. Updates to the Graphical User Interface:** This section highlights the improvements to the GUI of the LCCAM with representative examples.

- **Chapter 6. Summary, Future Recommendations, and Closing Thoughts:** This section summarizes the findings of the research by listing the recommendations and highlighting the future possible works.

2. REVIEW OF EXISTING LCCA METHODS

Due to the shortage of funding and the extensive need to construct new transportation structures as well as preserve existing infrastructure, LCCA tools have become an important asset to transportation agencies for decision making and management of their future projects (Alipour et al. 2012, Alipour 2010, Zhang et al. 2018). Although the LCCA concept has been around for more than 120 years, the widespread application of LCCA approaches in the US for bridges has a relatively short-lived duration of about 45 years (Hawk 2003). LCCA covers a wide range of applications and can be performed in various situations.

One of the proposed classifications of LCCA methods is by their level of management. Some of the LCCA tools are designed to help the decision makers select among a variety of projects while other LCCA tools have been developed to be more refined and to compare different alternatives for a single project. The former is called a system-level LCCA, whereas the latter is known as project-level LCCA.

Currently, four LCCA tools are widely used by different organizations to help manage their bridge transportation infrastructure: AASHTOWare Bridge Management (BrM), RealCost, BridgeLCC, and PEAT. The AASHTOWare BrM, which was previously known as Pontis, is probably the most-widely utilized. Pontis was first developed in 1989 and became an early bridge management system with financial support from the FHWA, which then transferred it to AASHTO for additional improvements (Alipour et al. 2020). In the 1990s, Pontis was initially encouraged to be used by states in the US. Then, it became mandatory for projects with at least $25 million of FHWA funding (Goh and Yang 2014).

The AASHTOWare BrM tool is capable of organizing structure information in an accurate database while providing the opportunity to update the data inventory with other external information. Additionally, this software allows for scheduling inspection routines, entering data from inspections, adding inspection data from external sources to the database, and producing NBI files, as well as Structure, Inventory, and Appraisal (SI&A) reports (AASHTO 2001).

Upon using the inspection data, which can be paired with historical data, the AASHTOWare BrM software is able to predict the future condition for the bridge and suggest repair and maintenance actions; however, the software is not capable of accounting for risk in the decision making (Khatami et al. 2016).

Another LCCA tool that is being used by state DOTs is called RealCost. RealCost was first released in 1998 by the FHWA to apply LCCA concepts to pavement design. This software was developed based on a Microsoft Excel macro function with a user-friendly graphical user interface (GUI) that allows for facilitated data input and tabular and graphical output. The software depends only on user input data and disregards historical data (Hawk 2003, Hatami and Morcous 2013).

RealCost is capable of comparing an indefinite number of alternatives. Given this capability, the input files need to be entered completely to allow the software to compute the life-cycle values for the agency and the user costs of repair and maintenance activities. Moreover, both deterministic and probabilistic modeling can be performed by the software, which is also equipped with deterministic sensitivity analysis and probabilistic risk analysis capabilities (FHWA 2004).

Currently, some state DOTs report utilizing RealCost for LCCA of bridge components in conjunction with that for pavements. Table 2.1 provides some details about the use of RealCost software in Wisconsin, California, Nebraska, and Minnesota.

Table 2.1. Application of RealCost software by some state DOTs

State	Wisconsin	California	Nebraska	Minnesota			
Component	**Asphalt overlay**	**Pavement**	**Deck overlay**	**Pavement**	**Bridge deck**	**Culvert**	**Sign**
Discount rate	5%	4%	3%	2.2%	2.2%	2.2%	2.2%
Life cycle (years)	45	20–55	60	70	200	200	100
Condition rating	–	0–4	NBI	0–4	NBE	NBE	NBE

The BridgeLCC software was designed and developed by National Institute of Standards and Technology (NIST) to provide a user-friendly environment for bridge designers and decision makers to calculate and compare the LCC of different bridge alternatives. This software enables the entry of agency costs and user costs as well as third-party costs, which are defined as the costs associated with the third party that are not directly using the structure but are impacted by the construction of the structure (Ehlen 2003).

Upon calculation of the costs and completion of the LCCA, which is performed in real-time by the software, multiple building scenarios can be compared, such as steel bridge or concrete bridge and rehabilitation of the existing bridge or building a new bridge. BridgeLCC also uses the commonly recognized (CoRe) bridge elements similar to those used by Pontis (Ehlen 2003).

BridgeLCC allows for both deterministic and probabilistic analysis. If deterministic analysis is selected, the software can perform a sensitivity analysis to highlight the level of impact for each variable on the LCCs of each alternative. This can be very important in instances where a high probability of change in one or multiple factors is possible. When probabilistic analysis is selected, the software performs a Monte Carlo simulation. This allows the user to provide the best-guess value as well as a variation range for each input, which results in a range of LCCs instead of a single value (which is the case with a deterministic analysis) (Ehlen 2003).

The Priority Economic Analysis Tool (PEAT) was developed by the Ministry of Transportation of Ontario (MTO) as an asset management tool using Microsoft Excel. This tool was designed to help MTO staff decide whether to start a project in the current fiscal period or later.

A benefit-to-cost ratio is calculated for the projects at hand, and the tool shows the decisions as Do It Now or Do It Later. This procedure can be applied to existing transportation infrastructure, a rehabilitated and repaired structure, and when a structure is going to be repaired. Additionally, the PEAT provides refined LCCA data that guides MTO staff in deciding between multiple alternatives for a single project.

Table 2.2 provides a summary of the capabilities of the various LCCA tools reviewed.

Table 2.2. Comparison of different LCCA tools

Item	AASHTOWare BrM	RealCost	BridgeLCC	PEAT	Iowa DOT
Level of management	System	Project	Project	Project	Project
Specialty area	Bridge	Bridge and Pavement	Bridge	Highway, Bridge, and Intersection	Bridge Deck
Application to new or existing structures?	Both	Both	New	Both	Existing
Considered costs:					
- Engineering cost	Yes	No	No	No	No
- Construction cost	Yes	Yes	Yes	Yes	No
- Routine maintenance	Yes	Yes	Yes	Yes	Yes
- Preventive maintenance	Yes	Yes	Yes	Yes	Yes
- Corrective maintenance	Yes	Yes	No	Yes	Yes
- Environmental cost	Yes	No	No	No	No
- Salvage cost	Yes	No	Yes	No	No
- User cost	Yes	Yes	Yes	Yes	Yes*
Analysis type?	D	Both	Both	D	P
Risk incorporated?	No	Yes	Yes	No	Yes
NBI or NBE condition rating	Both	Both	N/A	N/A	NBI
Type of cost analysis?	N/I	P	P	A	A

* Added in Phase II of this project
Analysis type? D = deterministic and P = probabilistic; N/A = not applicable; N/I = not identified; Type of cost analysis? P = present value and A = uniform annual value

The details of the newly-developed LCCA tool for the Iowa DOT are incorporated in Table 2.2 as the rightmost column to provide a comparison of this software with other available LCCA tools. The level of management, area of specialty, application for new or existing structures, type of considered costs, analysis type, condition rating type, and cost analysis type are compared.

3. USER COST CALCULATIONS

Two main types of costs are associated with any construction or maintenance actions: agency costs that are incurred by the managing organization and user costs that are incurred by users of the structure.

Based on the FHWA's manual for calculation of work zone road user costs (Mallela and Sadavisam 2011), monetary user costs can be divided into five categories: travel delay costs, vehicle operating costs (VOCs), crash costs, emission costs, and network or corridor impacts to nearby projects. Moreover, some non-monetary costs, such as noise level and business and local community impacts, are associated with user costs, although they were not considered in this study.

User cost calculation tools mostly account for travel delay costs, VOCs, and crash costs, given they represent most of the costs (Shrestha et al. 2021). Hence, this study calculated user costs by considering the travel delay costs, VOCs, and crash costs based on the FHWA report by Mallela and Sadavisam (2011), employing appropriate adjustment factors to calculate the costs for 2021.

3.1. Travel Delay Costs

The FHWA report states that "delay time is the attributed travel time necessary to traverse the work zone or to detour around it" (Mallela and Sadavisam 2011), and delay time is the summation of the extra travel time incurred by travelers due to speed changes, reduced speeds caused by forced flow, idling, or taking a detour.

The RealCost software can calculate delay time based on the traffic volume, road conditions, number of lanes, number of lane closures, and speed limits. Another method of delay time calculation uses dedicated spreadsheets developed by agencies, like that developed by the New Jersey DOT (NJDOT), which can be downloaded by clicking on "RUC Workbook Template – 2015 Edition" from https://www.state.nj.us/transportation/eng/documents/RUCM/.

Once the delay time is determined for a day of maintenance, travel time can be calculated using the following equation:

Travel Delay Costs = Delay Time × Unit Cost of Travel Time for Cars and Trucks × Number of Maintenance Days

3.1.1. Monetary Value of Travel Time

The monetary value of travel time includes the value of personal and business travel time for passenger cars as well as the value of travel time for trucks and the cost of time-related vehicle depreciation. The monetary value of time is calculated based on a percentage of the wages of the people. This percentage is 100% for business travel time of passenger cars and of travel time for trucks. However, the U.S. Department of Transportation Office of the Secretary (OST) indicates this is 50% and 70% for local personal travels of passenger vehicles and intercity travels of passenger vehicles, respectively.

3.1.1.1. Monetary Value of Travel Time for Passenger Vehicles

To calculate the hourly value of time for this study, the median annual income for Iowa households were extracted from 2020 U.S. Census results and divided by 2,080. An adjustment factor was then applied to adjust the 2020 household income to that for 2021. The adjustment factor was calculated using the 2020 and 2021 Employment Cost Index (ECI) factor based on the FHWA report (Mallela and Sadavisam 2011) suggestion.

Once the hourly value of time for a person is calculated, the hourly value of travel time for a vehicle can be estimated to account for vehicles with more than one traveler in them. This is possible by calculating the average vehicle occupancy (AVO) factor, as follows:

$$\text{AVO} = \text{Person-Miles of travel} \div \text{Vehicle-Miles of travel}$$

The national values for person-miles and vehicle-miles of travel for business and personal purposes can be extracted from the FHWA’s latest National Household Transportation Survey (NHTS) to calculate the AVO for business travel as well as personal travel.

Upon calculation of the AVO, the hourly value of travel time for a vehicle can be calculated for business and personal purposes using the following equation:

$$\text{hourly value of travel time for a vehicle} = \text{percentage of wage} \times (\text{annual wage} \div 2080) \times \text{AVO}$$

At this point, the total delay cost for passenger vehicles can be calculated using the weighted average value of travel time for business and personal purposes and multiplying this value by the number of maintenance days and the calculated daily delay time for passenger vehicles.

3.1.1.2. Monetary Value of Travel Time for Trucks

Similar steps are needed to calculate the total delay cost for trucks with the following adjustments. Note that the AVO for trucks was identified using the Highway Economic Requirements System State Version (HERS-ST), which recommends an AVO of 1.025 and 1.12 for single-unit and combination trucks, respectively.

The 2021 median hourly wages for light or delivery services and heavy and tractor – trailer were extracted from the Bureau of Labor Statistics to account for the wages of single-unit and combination trucks (as suggested by the FHWA in Mallela and Sadavisam 2011). Paired with the 2021 report from the Bureau of Transportation Statistics, the total compensation for truck drivers was calculated and used to determine the hourly monetary value of truck travel time.

To calculate the total travel delay cost for trucks, the weighted average of hourly cost of truck delay time is multiplied by the delay time for all vehicles and by the total number of maintenance days.

3.1.1.3. Monetary Value of Time-Related Vehicle Depreciation

The monetary value of time-related vehicle depreciation accounts for the time-related depreciation costs incurred by road users due to the travel delays. To calculate this portion of user costs, the HERS-ST estimation of time-related vehicle depreciation was used; however, this estimation was carried out in 1995, so, to account for the changes in the time-related depreciation, the FHWA recommends using an adjustment factor based on the Producer Price Index (PPI) growth over time. Table 3.1 indicates the HERS-ST estimations, adjusted estimation in 2010, and adjusted results for 2021.

Table 3.1. Adjusted HERS-ST time-related vehicle depreciation

Item Number	Vehicle Type	Time-Related Depreciation in 1995 ($/hr)	Time-Related Depreciation in 2010 ($/hr)	Time-Related Depreciation in 2021 ($/hr)
1	Small autos	1.09	1.05	1.107
2	Medium-sized to large autos	1.45	1.40	1.648
3	Four-tire, single-unit trucks	1.9	2.58	3.104
4	Six-tire trucks	2.65	3.60	4.331
5	3+ axle combination trucks	7.16	10.12	13.156
6	3 or 4 axles	6.41	9.06	12.48
7	5+ axles	6.16	8.70	11.31

Based on the recommendations from the FHWA (Mallela and Sadavisam 2011), the time-related vehicle depreciation for passenger vehicles, single-unit trucks, and combination unit trucks can be calculated by averaging the 2021 time-related depreciations for items 1 and 2, items 3 and 4, and items 5, 6, and 7, respectively.

Once the hourly time-related depreciation for each vehicle type is obtained, the total depreciation is equal to the summation of the product of hourly time-related depreciation for each vehicle type and the percent of each vehicle type and total delay time for all vehicles.

3.2. Vehicle Operating Costs

VOCs are defined by the FHWA (Mallela and Sadavisam 2011) as “the expenses incurred by road users as a result of vehicle use, which include the running costs that vary with the degree of vehicle use and are, thus, mileage dependent, and do not include fixed costs such as insurance, time-dependent depreciation, financing, and storage.”

To estimate the VOCs for each vehicle, the fuel and engine oil consumption, tire wear, repair and maintenance, and mileage-related depreciation are considered during the time of speed change, idling, and taking a detour. Multiple models have been suggested by the NCHRP, the Texas Research and Development Foundation, the HERS-ST, and the U.S. Environmental Protection Agency (EPA) to estimate the VOCs for each vehicle. This study used a simplified version of the HERS-ST model that considers two general cases: free flow in the work zone and forced flow in the work zone.

If the free flow condition is used, the VOCs are calculated based on the speed limit of the work zone. If forced flow is used, the software developed for this study asks for the estimated speed in the work zone and calculates the speed change by subtracting the estimated work zone speed from the speed limit of the roadway.

Once the VOC factor for each vehicle type is determined, the total VOC is calculated by multiplying the weighted VOC factor by the annual average daily traffic (AADT) and by the adjustment factor. The adjustment factor is calculated based on the Consumer Product Index (CPI) for 2021 and 2010, as suggested by the FHWA (Mallela and Sadavisam 2011).

3.3. Crash Costs

Crash costs are defined by the FHWA (Mallela and Sadavisam 2011) to be “a function of the expected change in the crash rates due to the presence of work zones.” To calculate the crash costs, therefore, the work zone crash rate should be first calculated for each crash severity level. To this end, the crash severity concept was addressed as follows.

In this study, the KABCO injury scale was used for analysis of crash severity. KABCO is used by law enforcement officers to document crash scenes and is approved by the National Highway Traffic Safety Administration (NHTSA). Table 3.2 shows the KABCO injury scale coding and descriptions.

Table 3.2. KABCO injury scale

Code	Severity	Description
K	Fatal	Any injury that results in death within 30 days of crash occurrence.
A	Incapacitating	Any injury other than a fatal injury that prevents the injured person from walking, driving, or normally continuing the activities that the person was capable of performing before the injury occurred (e.g., severe lacerations, broken limbs, damaged skull)
B	Injury evident	Any injury other than a fatal injury or an incapacitating injury that is evident to observers at the scene of the crash in which the injury occurred (e.g., abrasions, bruises, minor cuts)
C	Injury possible	Any injury reported that is not a fatal, incapacitating, or non-incapacitating evident injury (e.g., pain, nausea, hysteria)
O	Property damage only	Property damage to property that reduces the monetary value of that property

Source: Mallela and Sadavisam 2011

Injuries mentioned in Table 3.2 are associated with a human capital cost and a comprehensive cost. Human capital refers to the costs that are directly associated with the crash while comprehensive covers the intangible costs that are non-monetary, such as the risk of physical and mental suffering or the risk of loss of life.

In this study, both the human capital costs and comprehensive costs were considered, and the monetary value of crashes are shown in Table 3.3 based on the FHWA Highway Safety Benefit-Cost Analysis (BCA) tool and guide, as covered in the *Crash Costs for Highway Safety Analysis* report (Harmon et al. 2018), and then adjusted to 2021 by using an adjustment factor of ECI – total compensation.

Table 3.3. 2021 monetary crash cost based on the KABCO injury scale

Code	Severity	Monetary crash cost
K	Fatal	$13,272,095
A	Incapacitating	$769,625
B	Injury evident	$233,238
C	Injury possible	$147,580
O	Property damage only	$13,983

Based on this information, the crash rate for a work zone was calculated based on historical crash data. For this purpose, the following equation was used:

$$CR = \frac{A \times 10^6}{T \times L \times AADT \times 365}$$

Where *CR* stands for crash rate, *A* is equal to the number of injuries for each injury level, *T* is the analysis period, and *L* is the length of the road zone.

Once the crash rate was calculated, it was multiplied by the crash modification factor (CMF) and crash reduction factor (CRF) to apply the effect of the work zone in increasing the crash rate due to lane closures and other parameters and also in reducing the crash rate due to preventive measures such as using signs (Mallela and Sadasivam 2011). The CMF should be greater or equal to 1, while the CRF should be smaller than or equal to 1. According to Mallela and Sadasivam (2011), the CMF ranges mostly between 1.2 to 1.7. However, there are no statistically approved values for the CMF. The CMF clearinghouse website suggests that a CMF value of 1.77 can be used for all crash types and crash severities (Mallela and Sadasivam 2011). Moreover, the CRF value can be considered to be 1 to have a more conservative result.

The other parameter to calculate was the million vehicle-miles traveled over the duration of maintenance, which was calculated as follows.

Million Vehicle-Miles Traveled = (duration of maintenance × TAADT × length of the work zone) ÷ 10^6

Where TAADT is the summation of AADT over the crash analysis period for a total.

The total crash cost was then calculated using the summation of the crash costs for each injury level. The crash cost for each injury level was then equal to the product of the crash rate and the value of million vehicle-miles traveled and the associated monetary value of crash cost to each crash injury scale.

3.4. User Cost Calculation Example

The user cost calculation provided in the LCCAM software is based on the reviewed material in this chapter. The changes in the user interface to incorporate user costs are further discussed in Chapter 5. This section provides a complete example to review and summarize the user cost calculation by the software from this Phase II project work.

The LCCAM tool can calculate the user cost after completion of the maintenance suggestion process. However, users can skip the maintenance suggestion process to directly calculate the user cost, as indicated in Figure 3.1.

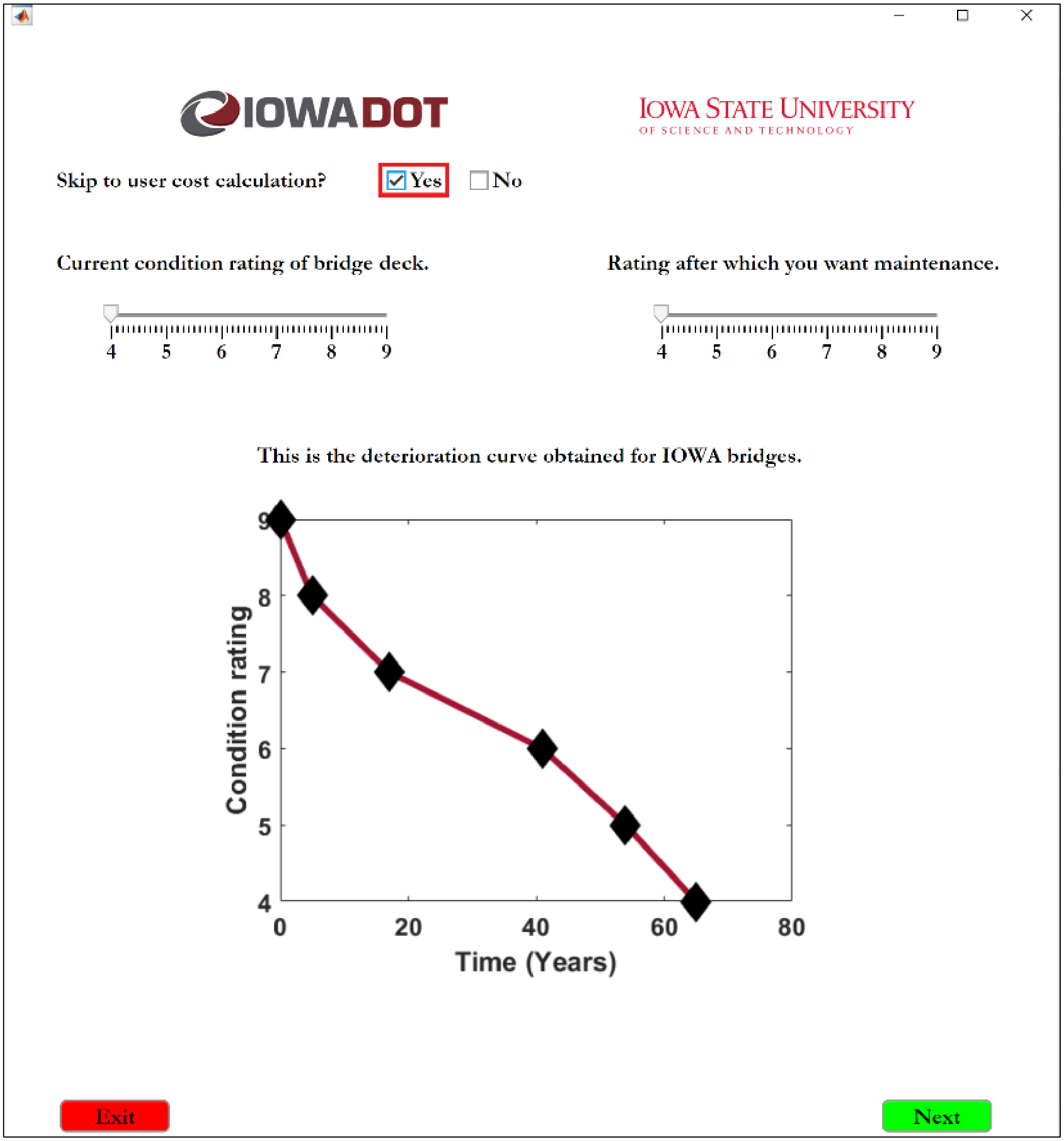


Figure 3.1. Selecting to skip to user cost calculation in the LCCAM tool

Once Yes is selected and the Next button is clicked, the LCCAM tool asks the user to input information regarding the maintenance duration and work-zone parameters as indicated in Figure 3.2.

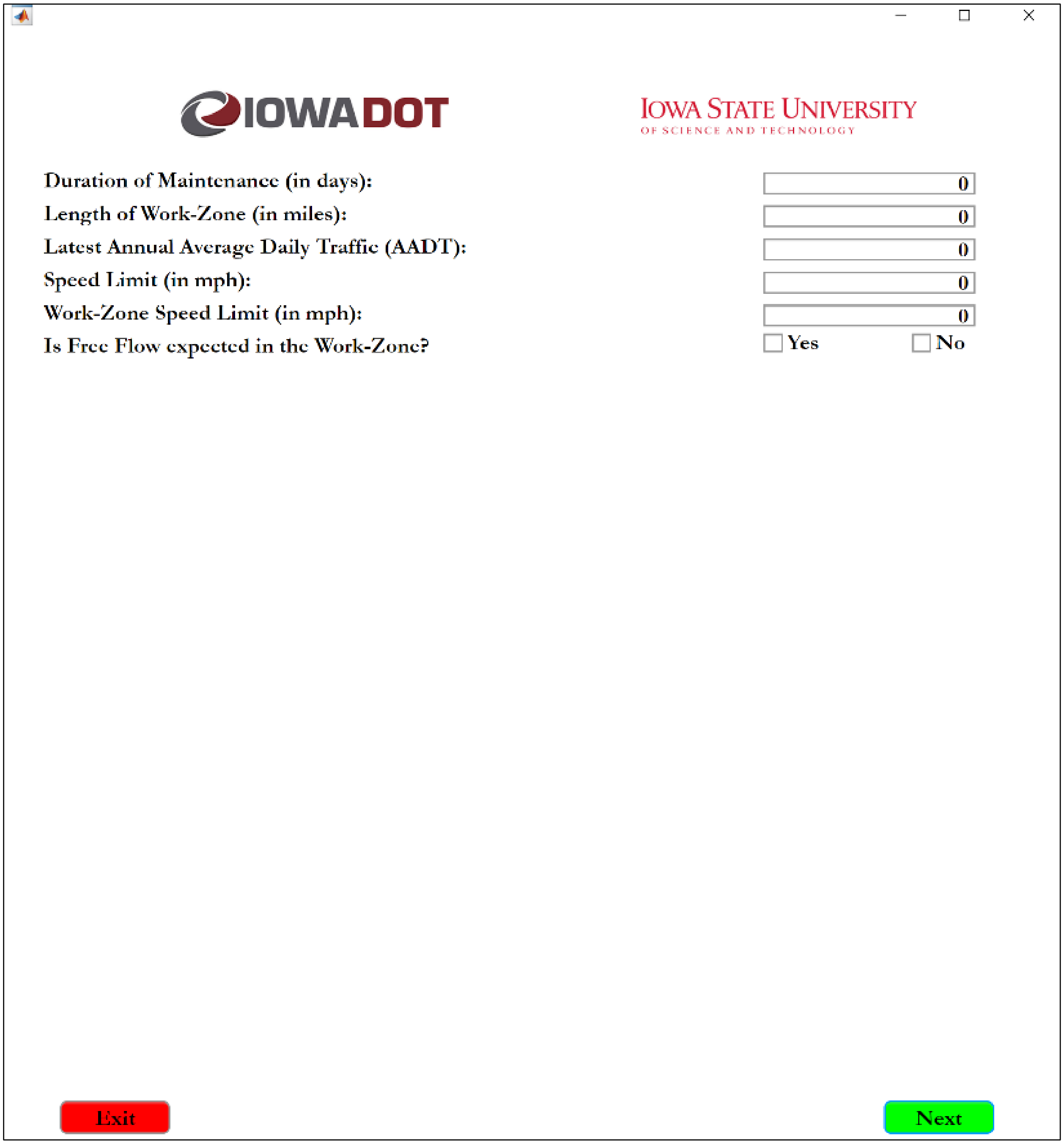


Figure 3.2. First page of data input for user cost calculation in the LCCAM tool

After entering the required data and selecting a state of flow in the work zone, clicking the Next button results in a prompt to enter additional data, as shown in Figure 3.3.

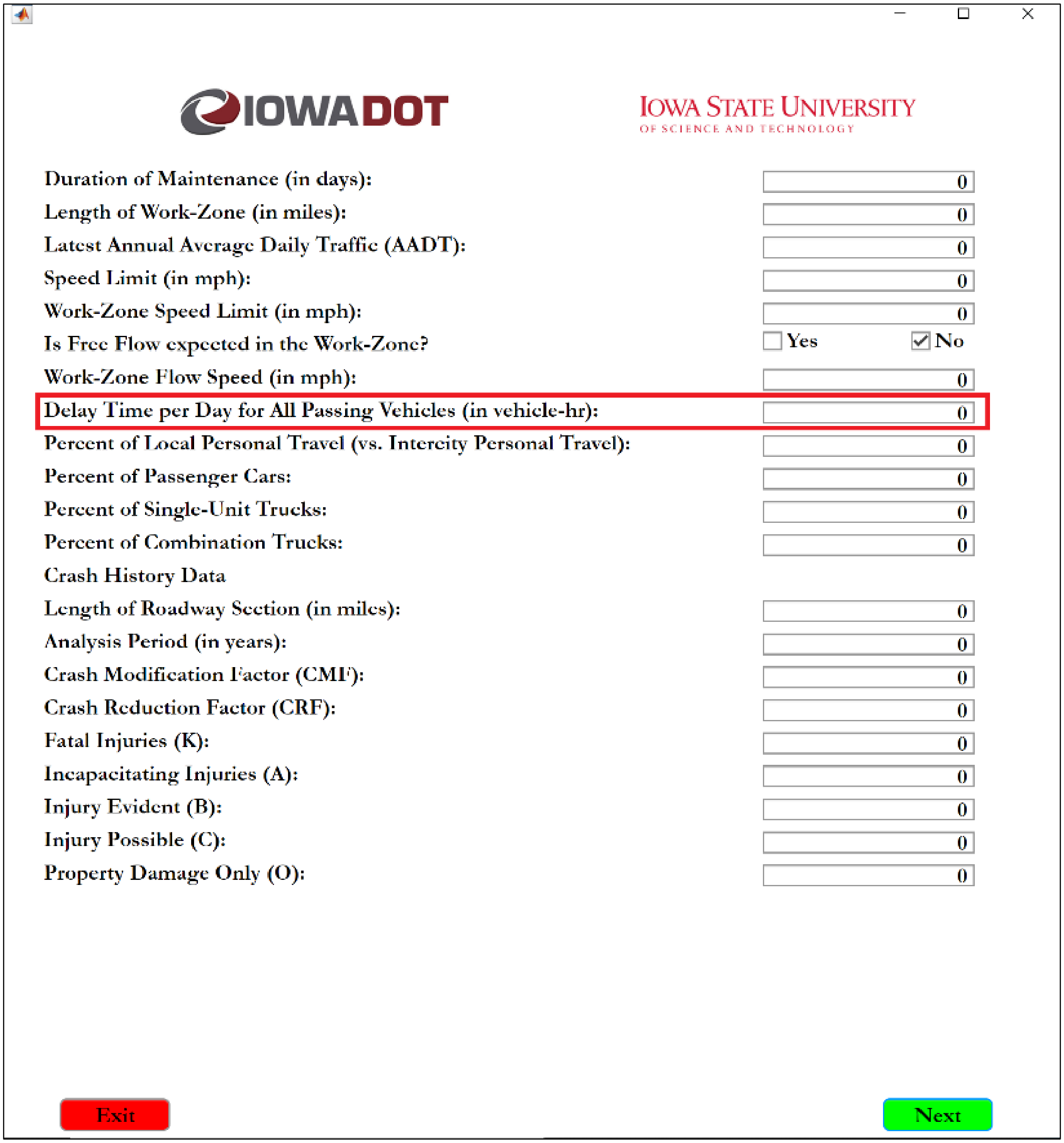


Figure 3.3. Second page of data input for user cost calculation in the LCCAM tool

All of the data required on this page are easily accessible except for the delay time, as indicated with a red rectangle around that row. To calculate the total delay time, a dedicated spreadsheet developed by the NJDOT is used, which can be found at the link below, has been changed to meet the requirements of this study and added to the LCCAM folder entitled DelayTimeCalculator.

https://www.state.nj.us/transportation/eng/documents/RUCM/

Using the DelayTimeCalculator worksheet, the user can come up with the entry for the LCCAM tool. In this worksheet, the pink cells, which are found on the first three spreadsheet tabs, are filled by the user. The white and lavender cells are automatically filled, leading to the calculation of the total delay time (shown later in this chapter on the fourth tab).

The first tab, shown in Figure 3.4, shows the four different tabs, Work Zone Analysis, Queue Delay, Work Zone Delays, and Delay Time, along the bottom and requires the user to input hourly traffic in a day as a percentage in addition to entering road parameters such as AADT, speed limit prior to work zone, breakdown of cars and trucks, normal and work zone capacity, and number of lanes.

Work Zone:	Lane Reduction				Normal Capacity:	6,000
Normal Speed (mph):	55	Percent Cars:	90		Work Zone Capacity:	3,000
Directional ADT:	50,000	Percent Truck:	10		Lanes Under Normal Operation:	3

Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM	0.7	350	2	3,000	-2,650	0	Y	350	0
1-2	0.5	250	2	3,000	-2,750	0	Y	250	0
2-3	0.4	200	2	3,000	-2,800	0	Y	200	0
3-4	0.6	300	2	3,000	-2,700	0	Y	300	0
4-5	1.8	900	2	3,000	-2,100	0	Y	900	0
5-6	4.4	2,200	2	3,000	-800	0	Y	2,200	0
6-7	6.2	3,100	2	3,000	100	100	Y	3,000	3,000
7-8	7.2	3,600	2	3,000	600	700	Y	3,000	3,000
8-9	5.6	2,800	2	3,000	-200	500	Y	3,000	3,000
9-10	5.0	2,500	2	3,000	-500	0	Y	3,000	3,000
10-11	4.8	2,400	2	3,000	-600	0	Y	2,400	0
11-12 PM	5.1	2,550	2	3,000	-450	0	Y	2,550	0
12-1	5.3	2,650	2	3,000	-350	0	Y	2,650	0
1-2	5.5	2,750	2	3,000	-250	0	Y	2,750	0
2-3	5.6	2,800	2	3,000	-200	0	Y	2,800	0
3-4	6.5	3,250	2	3,000	250	250	Y	3,000	3,000
4-5	6.9	3,450	2	3,000	450	700	Y	3,000	3,000
5-6	6.4	3,200	2	3,000	200	900	Y	3,000	3,000
6-7	5.9	2,950	2	3,000	-50	850	Y	3,000	3,000
7-8	4.9	2,450	2	3,000	-550	300	Y	3,000	3,000
8-9	4.0	2,000	2	3,000	-1,000	0	Y	2,300	900
9-10	3.0	1,500	2	3,000	-1,500	0	Y	1,500	0
10-11	2.1	1,050	2	3,000	-1,950	0	Y	1,050	0
11-12	1.6	800	2	3,000	-2,200	0	Y	800	0
TOTALS	100.0	50,000						50,000	27,900

1. Work Zone Analysis | 2. Queue Delay | 3. Work Zone Delays | 4. Delay Time

Figure 3.4. Work Zone Analysis tab on the DelayTimeCalculator worksheet

Upon providing the required information, the spreadsheet calculates the number of queued vehicles.

Figure 3.5 shows the second, Queue Delay, tab, which is used to calculate the queuing delay of the vehicles.

	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period	Queue Lanes (#)
1	6A-9A	3,000	6,000	0.50	10	55	700	3
2	3P-8P	3,000	6,000	0.50	10	55	900	3
3		3,000	6,000	0.50	10	55		3
4		3,000	6,000	0.50	10	55		3
5		3,000	6,000	0.50	10	55		3

	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1	38.4	0.85	0.015	0.085	0.070	12,000	840.000
2	38.4	1.09	0.020	0.109	0.089	15,900	1415.100
3	38.4						
4	38.4						
5	38.4						
			Totals			27,900	2255.100
			Added Time Weighted Average			0.081	hr/veh

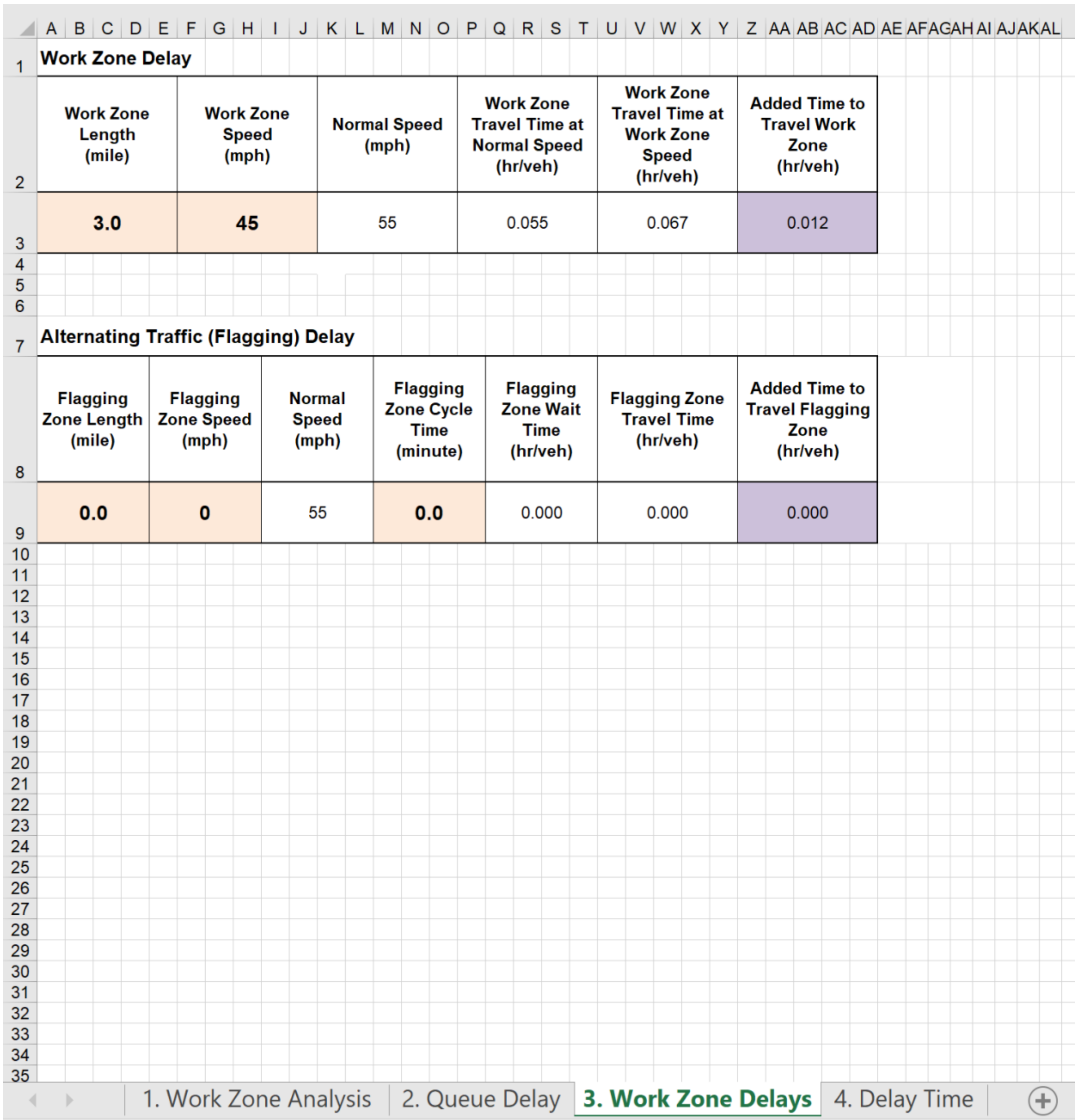
1. Work Zone Analysis | 2. Queue Delay | 3. Work Zone Delays | 4. Delay Time

Figure 3.5. Queue Delay tab on the DelayTimeCalculator worksheet

On this tab, the first table provides information on the queue periods. In the example shown, two queue periods are identified from the Work Zone Analysis tab: 6 to 9 a.m. and 3 to 8 p.m. For each period, then, the maximum number of queued vehicles is extracted from the first tab as 700 and 900, respectively.

The next step is to complete the second table on the Queue Delay tab. The total number of queued vehicles (located in the last column on the Work Zone Analysis tab) for each queue period is calculated and listed in the highlighted cells, which leads to the calculation of the queuing delay time per vehicle.

The third tab is dedicated to the calculation of work zone delays. As indicated in Figure 3.6, the work zone speed and length are entered in the highlighted cells and, if a flagging zone is used, the appropriate information is also entered.



Work Zone Delay

Work Zone Length (mile)	Work Zone Speed (mph)	Normal Speed (mph)	Work Zone Travel Time at Normal Speed (hr/veh)	Work Zone Travel Time at Work Zone Speed (hr/veh)	Added Time to Travel Work Zone (hr/veh)
3.0	45	55	0.055	0.067	0.012

Alternating Traffic (Flagging) Delay

Flagging Zone Length (mile)	Flagging Zone Speed (mph)	Normal Speed (mph)	Flagging Zone Cycle Time (minute)	Flagging Zone Wait Time (hr/veh)	Flagging Zone Travel Time (hr/veh)	Added Time to Travel Flagging Zone (hr/veh)
0.0	0	55	0.0	0.000	0.000	0.000

Figure 3.6. Work Zone Delays tab on the DelayTimeCalculator worksheet

At this point, all the input data are provided and the worksheet is able to calculate the delay time on the fourth, Delay Time, tab. The result for this example is shown in Figure 3.7.

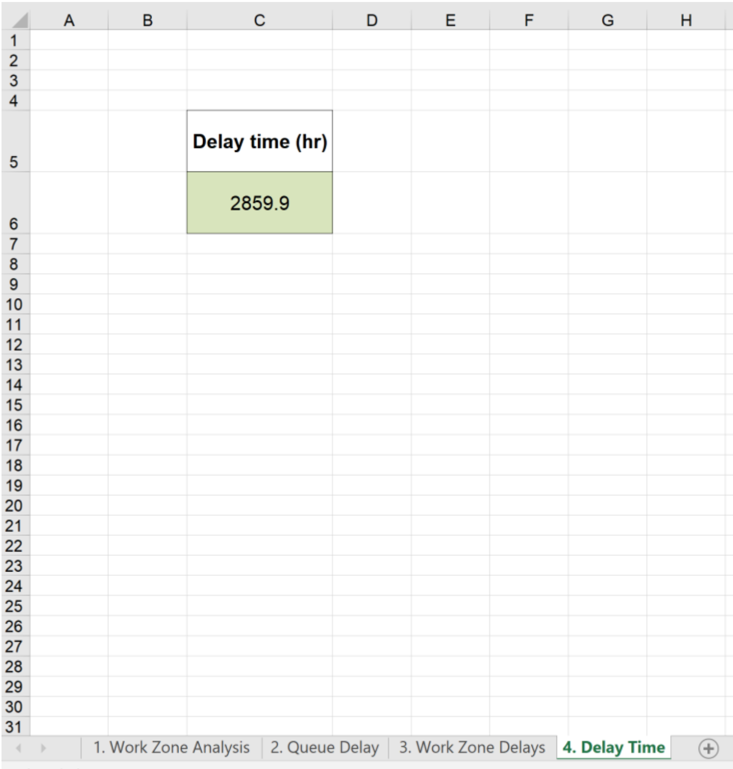


Figure 3.7. Delay Time tab on the DelayTimeCalculator worksheet

Now that the delay time is obtained, it is used for input to the LCCAM tool, as outlined with the red rectangle around that row in the previous Figure 3.3. After entering all the required data in the LCCAM tool and clicking Next, user costs are calculated. Figure 3.8 shows an example of the results of a user cost calculation for the data entered, as shown in Figure 3.9.

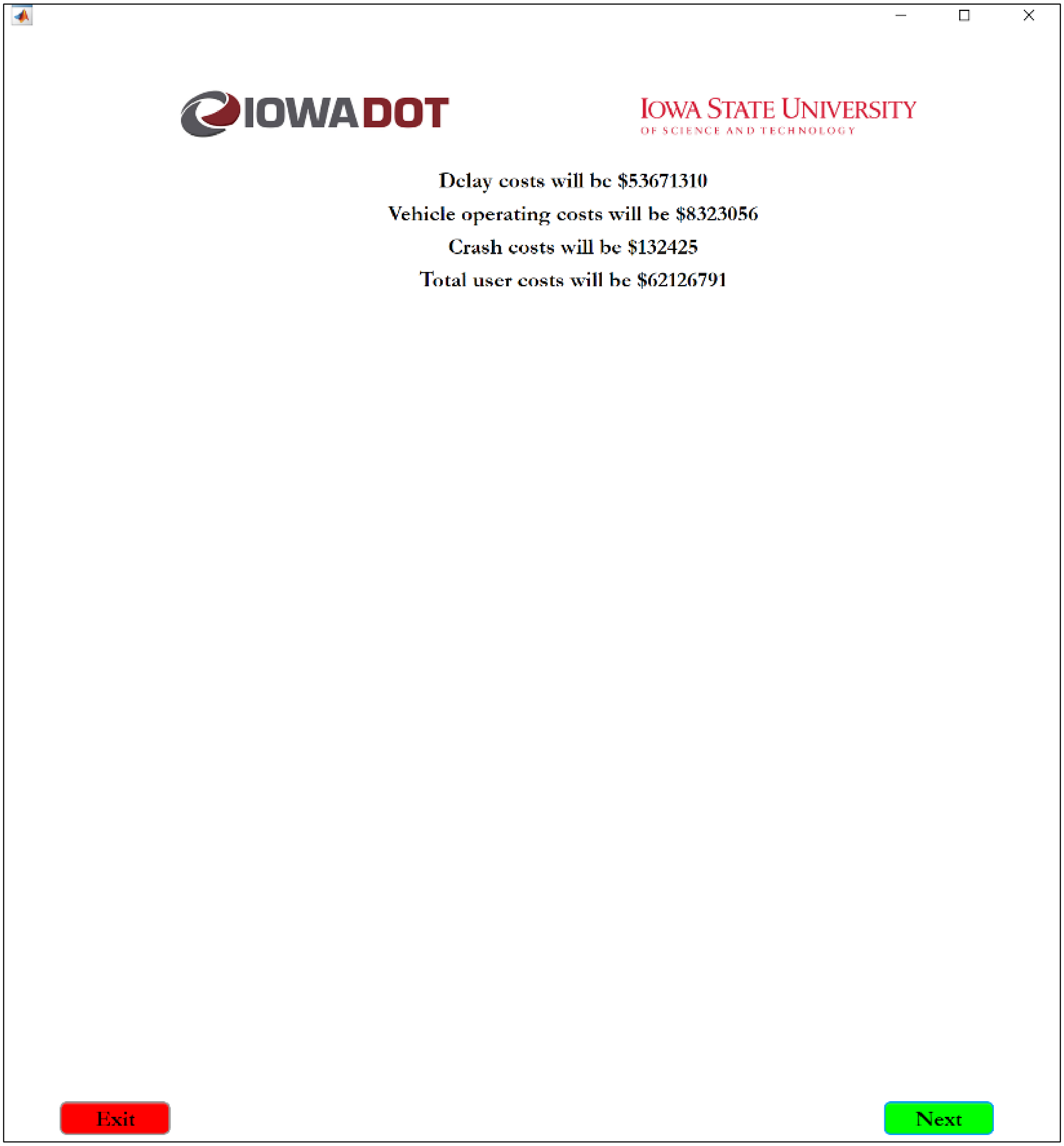


Figure 3.8. LCCAM output from user cost analysis

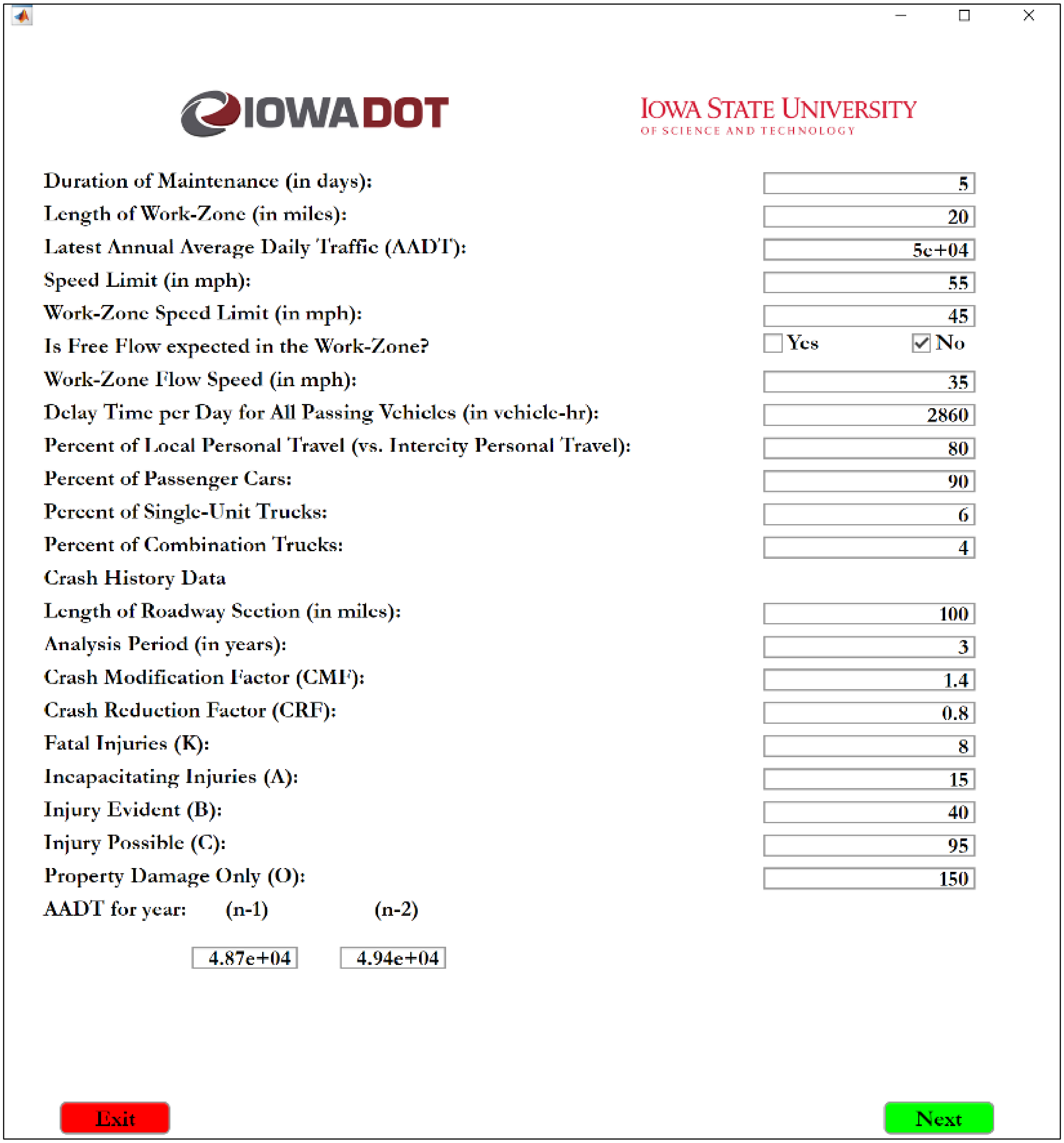


Figure 3.9. Example of LCCAM data entered for user cost calculations

4. SURVEY OF BRIDGE MAINTENANCE ACTIVITIES

An online survey of maintenance activities was developed with Iowa DOT maintenance personnel to serve three main purposes: make the LCCAM tool more consistent with the AASHTO (2021) bridge preservation actions wording, update the maintenance costs and frequencies, and provide a better base for further development of the LCCAM tool to include other bridge elements (i.e., substructure, superstructure) and bridge management elements (e.g., joint, drain, and bearing).

The survey was structured so that five recurring questions were asked about 30 different maintenance actions. The recurring five questions are summarized in Table 4.1, and the 30 maintenance actions are listed in Table 4.2.

Table 4.1. Recurring questions in the survey of maintenance actions

Number	Question
1	Is this activity being practiced in your district?
2	What is the frequency of this activity in your district?
3	Please indicate the condition of the component for this activity to take place.
4	What is the unit of measurement for this activity?
5	What is the estimated cost of maintenance per unit of measurement for this activity?

Table 4.2. Maintenance actions of interest

Number	Maintenance Action
1	Deck – Clean
2	Deck – Repair – Concrete Crack
3	Deck – Repair – Epoxy Injection
4	Deck – Repair – Concrete Crack, Healer/Sealer
5	Deck – Repair – Reinforced Concrete, Patch, Full-Depth
6	Deck – Repair – Reinforced Concrete, Patch, Partial-Depth Type 1 (Shallow)
7	Deck – Repair – Reinforced Concrete, Patch, Partial-Depth Type 2 (Deep)
8	Deck – Repair – Timber
9	Deck – Seal
10	Superstructure – Repair – Steel Girder
11	Superstructure – Repair – Prestressed Concrete
12	Superstructure – Repair – Concrete Girder
13	Substructure – Repair – Bridge Seat
14	Substructure – Repair – Pier Cap
15	Substructure – Repair – Column
16	Substructure – Repair – Shotcrete
17	Approach – Repair – Concrete Crack
18	Approach – Repair – Reseal Joints
19	Approach – Repair – Mud Jacking of Settled Panels
20	Approach – Repair – Install HMA Wedge on Settled Panels
21	Concrete Slope Protection – Repair – Reseal Joints
22	Concrete Slope Protection – Repair – Fill Voids Under Panels
23	Abutment – Clean – Bearing Seat
24	Rail – Repair – Shotcrete
25	Drain – Clean
26	Drain – Repair
27	Joint – Clean
28	Joint – Repair – All Types
29	Bearing – Clean
30	Bearing – Paint

The maintenance actions were finalized with the guidance of Iowa DOT Bridges and Structures personnel to remove the actions that are not practiced in the state and to include some that are practiced in the state but not reflected in the AASHTO 2021 *Guide to Bridge Preservation Actions*.

4.1. Survey Results

The survey of maintenance actions was distributed to seven Iowa DOT personnel from all six Iowa DOT districts, and seven responses were recorded for each question, which equals a response rate of 100%. This section summarizes the responses for each of the 30 maintenance actions.

4.1.1. Deck – Clean

The recorded survey results for the Deck – Clean activity are shown in Table 4.3.

Table 4.3. Survey results for Deck – Clean activity

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	1 year	Some shops try to get ahead of the problems before they get here and others as the problem shows	Not sure	Not sure
Yes	1 year	Good	Years	–
Yes	Not cyclic	The drain is plugged, joints need repair, drain pipes need replaced; most of the time it needs attention	2 ppl/day	$1,000
Yes	Not cyclic	Try to clean curb lines and bridge seats off every spring with power washers to remove salt residue	Each	$400 + equipment cost
Yes	1 year	Cyclic	Each	$750
Yes	2 years	Cyclic	Each	$750
Yes	4 years	Cyclic	–	$750

4.1.2. Deck – Repair – Concrete Crack

The recorded survey results for the Deck – Repair – Concrete crack activity are shown in Table 4.4.

Table 4.4. Survey results for Deck – Repair – Concrete crack

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	As cracks are found	Gallons	$60/hr
Yes	1 year	Large hollows	–	Depends
Yes	1 year	–	–	–
Yes	Not cyclic	–	–	–
Yes	Not cyclic	Fair	Lf	$4
Yes	> 4 years	Fair	Lf	$4
Yes	Not cyclic	Fair	Lf	$4

4.1.3. Deck – Repair – Epoxy Injection

The recorded survey results for the Deck – Repair – Epoxy injection activity are shown in Table 4.5.

Table 4.5. Survey results for Deck – Repair – Epoxy injection

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	1 year	Poor	Gal/day	$300/day
Yes	1 year	Large voids between the overlay and the deck surface	–	$3,000/kit
Yes	1 year	–	–	–
Yes	Not cyclic	Deck overlay to have separation from the old deck and usually has cracking and hollows	Hours, gallons	–
Yes	Not cyclic	Fair	Lf	$4
Yes	> 4 years	Condition based	Lf	$4
Yes	Not cyclic	Fair	Lf	$4

4.1.4. Deck – Repair – Concrete Crack, Healer/Sealer

Based on the recorded survey results for the Deck – Repair – Concrete crack, Healer/Sealer activity, this maintenance action is not practiced in Iowa.

4.1.5. Deck – Repair – Reinforced Concrete, Patch, Full-Depth

The recorded survey results for the Deck – Repair – Reinforced concrete, Patch, Full-depth activity are shown in Table 4.6.

Table 4.6. Survey results for Deck – Repair – Reinforced concrete, Patch, Full-depth

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Poor	Sy	$70
No	Not cyclic	–	–	–
Yes	1 year	–	–	–
No	–	–	–	–
Yes	Not cyclic	Poor	Sf	$300
Yes	Not cyclic	Poor	Sf	$300
Yes	Not cyclic	4	Sf	$300

4.1.6. Deck – Repair – Reinforced Concrete, Patch, Partial-Depth Type 1 (Shallow)

The recorded survey results for the Deck – Repair – Reinforced concrete, Patch, Partial-depth Type 1 (shallow) activity are shown in Table 4.7.

Table 4.7. Survey results for Deck – Repair – Reinforced concrete, Patch, Partial-depth Type 1 (shallow)

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	1 year	Fair	Sy	$60
Yes	1 year	Spalling on the deck	–	–
Yes	1 year	–	–	–
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150

4.1.7. Deck – Repair – Reinforced Concrete, Patch, Partial-Depth Type 2 (Deep)

The recorded survey results for the Deck – Repair – Reinforced concrete, Patch, Partial-depth Type 2 (deep) activity are shown in Table 4.8.

Table 4.8. Survey results for Deck – Repair – Reinforced concrete, Patch, Partial-depth Type 2 (deep)

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	1 year	Fair	Sy	$60
Yes	1 year	Spall on deck	Year	–
Yes	1 year	–	–	–
No	–	–	–	–
No	–	–	–	–
No	Not cyclic	–	–	–
No	Not cyclic	–	–	–

4.1.8. Deck – Repair – Timber

Based on the recorded survey results for the Deck – Repair – Timber activity, this maintenance action is not practiced in Iowa.

4.1.9. Deck – Seal

Based on the recorded survey results for the Deck – Seal activity, this maintenance action is not practiced in Iowa.

4.1.10. Superstructure – Repair – Steel Girder

Based on the recorded survey results for the Superstructure – Repair – Steel girder activity, this maintenance action is not practiced in Iowa.

4.1.11. Superstructure – Repair – Prestressed Girder

The recorded survey results for the Superstructure – Repair – Prestressed girder activity are shown in Table 4.9.

Table 4.9. Survey results for Superstructure – Repair – Prestressed girder

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Good	gallon	$300/day
No	1 year	–	–	–
Yes	1 year	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–

4.1.12. Superstructure – Repair – Concrete Girder

The recorded survey results for the Superstructure – Repair – Concrete girder activity are shown in Table 4.10.

Table 4.10. Survey results for Superstructure – Repair – Concrete girder

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Good	Sf	$100/hr
No	–	–	–	–
–	–	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–

4.1.13. Substructure – Repair – Bridge Seat

The recorded survey results for the Substructure – Repair – Bridge seat activity are shown in Table 4.11.

Table 4.11. Survey results for Substructure – Repair – Bridge seat

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Good	Sy	$70/hr
No	–	–	–	–
Yes	1 year	–	–	–
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
No	–	–	–	–

4.1.14. Substructure – Repair – Pier Cap

The recorded survey results for the Substructure – Repair – Pier cap activity are shown in Table 4.12.

Table 4.12. Survey results for Substructure – Repair – Pier cap

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Good	Contractor work	–
No	Not cyclic	–	–	–
No	–	–	–	–
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
No	–	–	–	–

4.1.15. Substructure – Repair – Column

The recorded survey results for the Substructure – Repair – Column activity are shown in Table 4.13.

Table 4.13. Survey results for Substructure – Repair – Column

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Good	Sy	$70/hr
No	Not cyclic	–	–	–
Yes	1 year	–	–	–
Yes	Not cyclic	Fair to poor	Per column	$150/sf
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
No	–	–	–	–

4.1.16. Substructure – Repair – Shotcrete

The recorded survey results for the Substructure – Repair – Shotcrete activity are shown in Table 4.14.

Table 4.14. Survey results for Substructure – Repair – Shotcrete

Practiced?	Frequency	Condition	Unit	Cost of maintenance
No	–	–	–	–
Yes	Not cyclic	Spalling	As needed	–
No	–	–	–	–
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	–	–	–

4.1.17. Approach – Repair – Concrete Crack

The recorded survey results for the Approach – Repair – Concrete crack activity are shown in Table 4.15.

Table 4.15. Survey results for Approach – Repair – Concrete crack

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Poor	Contractor	–
Yes	Not cyclic	Cracked or walking approach holes maintenance or contracted	As needed	Depends
Yes	1 year	–	–	–
Yes	Not cyclic	Fair to poor	Lf	$4
Yes	Not cyclic	Fair to poor	Lf	$4
No	–	–	–	–
No	–	–	–	–

4.1.18. Approach – Repair – Reseal Joints

Based on the recorded survey results for the Approach – Repair – Reseal joints activity, this maintenance action is not practiced in Iowa.

4.1.19. Approach – Repair – Mud Jacking of Settled Panels

The recorded survey results for the Approach – Repair – Mud jacking of settled panels activity are shown in Table 4.16.

Table 4.16. Survey results for Approach – Repair – Mud jacking of settled panels

Practiced?	Frequency	Condition	Unit	Cost of maintenance
No	–	–	–	–
Yes	> 4 years	If approach is to be overlaid, we pump it first to sideling of the approach	–	Depends
No	–	–	–	–
Yes	Not cyclic	Fair to poor	Ton	$800
Yes	Not cyclic	Fair to poor	Ton	$800
Yes	Not cyclic	Fair to poor	Ton	$800
Yes	Not cyclic	Fair to poor	ton	$800

4.1.20. Approach – Repair – Install HMA Wedge on Settled Panels

The recorded survey results for the Approach – Repair – Install HMA wedge on settled panels activity are shown in Table 4.17.

Table 4.17. Survey results for Approach – Repair – Install HMA wedge on settled panels

Practiced?	Frequency	Condition	Unit	Cost of maintenance
No	–	–	–	–
Yes	Not cyclic	–	–	–
No	–	–	–	–
Yes	Not cyclic	Fair to poor	Ton	$800
Yes	Not cyclic	Fair to poor	Ton	$800
Yes	Not cyclic	Fair to poor	Ton	$800
Yes	Not cyclic	–	Ton	$800

4.1.21. Concrete Slope Protection – Repair – Reseal Joints

The recorded survey results for the Concrete slope protection – Repair – Reseal joints activity are shown in Table 4.18.

Table 4.18. Survey results for Concrete slope protection – Repair – Reseal joints

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	1 year	Poor	Sy	$100,000*
Yes	> 4 years	As needed	–	Varies
Yes	2 years	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–

* Based on another set of interviews with the Iowa DOT personnel, this value seems to be higher than the average unit cost.

4.1.22. Concrete Slope Protection – Repair – Fill Voids Under Panels

The recorded survey results for the Concrete slope protection – Repair – Fill voids under panels activity are shown in Table 4.19.

Table 4.19. Survey results for Concrete slope protection – Repair – Fill voids under panels

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Poor	Sy	$1,000/day
Yes	Not cyclic	Voids detected	–	Varies
Yes	2 years	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–
No	–	–	–	–

4.1.23. Abutment – Clean – Bearing Seat

The recorded survey results for the Abutment – Clean – Bearing seat activity are shown in Table 4.20.

Table 4.20. Survey results for Abutment – Clean – Bearing seat

Practiced?	Frequency	Condition	Unit	Cost of maintenance
No	–	–	–	–
Yes	Not cyclic	When dirt and other material accumulate	As needed	–
Yes	> 4 years	–	–	–
Yes	1 year	Good	–	–
Yes	1 year	Cyclic	Each	$100
Yes	1 year	Cyclic	Each	$100
Yes	> 4 years	–	–	–

4.1.24. Rail – Repair – Shotcrete

The recorded survey results for the Rail – Repair – Shotcrete activity are shown in Table 4.21.

Table 4.21. Survey results for Rail – Repair – Shotcrete

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Good	Lf	$50/day
Yes	Not cyclic	When rebar or efference is present	As needed	–
Yes	2 years	–	–	–
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Fair to poor	Sf	$150
Yes	Not cyclic	Poor	Sf	$150

4.1.25. Drain – Clean

The recorded survey results for the Drain – Clean activity are shown in Table 4.22.

Table 4.22. Survey results for Drain – Clean

Practiced?	Frequency	Condition	Unit	Cost of maintenance
No	–	–	–	–
Yes	1 year	When needed	Three times a year	Labor at most
Yes	2 years	–	–	–
Yes	Not cyclic	Fair to poor	Each	$25
Yes	1 year	Cyclic	Each	$25
Yes	1 year	Cyclic	Each	$25
Yes	1 year	Cyclic	–	–

4.1.26. Drain – Repair

The recorded survey results for the Drain – Repair activity are shown in Table 4.23.

Table 4.23. Survey results for Drain – Repair

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Good	Lf	–
Yes	Not cyclic	If extension has failed, we replace	As needed	Varies
Yes	2 years	–	–	–
Yes	Not cyclic	Missing	Each	$25
Yes	Not cyclic	Fair to poor	Each	$25
Yes	Not cyclic	Missing	Sf	$25
Yes	Not cyclic	Missing	Each	$25

Based on another set of interviews with the Iowa DOT personnel, the acquired cost of maintenance was found to be lower than the actual maintenance cost, which is $100 each.

4.1.27. Joint – Clean

The recorded survey results for the Joint – Clean activity are shown in Table 4.24.

Table 4.24. Survey results for Joint – Clean

Practiced?	Frequency	Condition	Unit	Cost of maintenance
No	–	–	–	–
Yes	Not Cyclic	When it's full of material	As needed	–
Yes	> 4 years	–	–	–
Yes	1 year	Cyclic	Each	$25
Yes	1 year	Cyclic	Each	$25
Yes	1 year	Cyclic	Each	$25
Yes	1 year	Cyclic	Each	$25

Based on another set of interviews with the Iowa DOT personnel, the acquired cost of maintenance was found to be lower than the actual maintenance cost, which is $250 each.

4.1.28. Joint – Repair – All Types

The recorded survey results for the Joint – Repair – All types activity are shown in Table 4.25.

Table 4.25. Survey results for Joint – Repair – All types

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	Not cyclic	Poor	–	–
Yes	Not cyclic	When failure occurs	As needed	Varies
Yes	1 year	–	–	–
Yes	Not cyclic	Poor	Each	$600
Yes	Not cyclic	Poor	Each	$600
Yes	Not cyclic	Poor	Each	$600
Yes	Not cyclic	Poor	Each	$600

4.1.29. Bearing – Clean

The recorded survey results for the Bearing – Clean activity are shown in Table 4.26.

Table 4.26. Survey results for Bearing – Clean

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	1 year	Good	Lf	–
Yes	> 4 years	When time allows	–	–
Yes	Not cyclic	–	–	–
Yes	1 year	Cyclic	Each	$5
Yes	1 year	Cyclic	Each	$5
Yes	Not cyclic	Fair	Each	$5
Yes	1 year	Cyclic	Each	$5

4.1.30. Bearing – Paint

The recorded survey results for the Bearing – Paint activity are shown in Table 4.27.

Table 4.27. Survey results for Bearing – Paint

Practiced?	Frequency	Condition	Unit	Cost of maintenance
Yes	> 4 years	Good	Sf	–
Yes	Not cyclic	After washing and when rusting is noted	As needed	–
No	–	–	–	–
No	–	–	–	–
Yes	Not cyclic	Fair to poor	Each	$100
Yes	Not cyclic	Fair to poor	Each	$100
Yes	Not cyclic	Fair to poor	Each	$100

4.2. Comparison of Survey Results to the Phase I LCCAM Tool for Bridge Decks

Based on the survey results, five maintenance activities are performed around the state on bridge decks. Although the names of these five activities may differ some from those included in the LCCAM tool, the following comparisons summarize the differences and similarities of the survey results to the Phase I LCCAM tool.

4.2.1. Deck – Clean

Based on the survey results, deck cleaning is performed yearly and costs about $750 per bridge deck. The LCCAM tool offers two maintenance activities related to deck cleaning: Sweeping and Washing. Sweeping is a yearly activity that costs about $300 per bridge deck, while washing is a bi-yearly activity that costs about $4,000 per bridge deck. After consulting with the Iowa DOT, it was decided to update the cost of Sweeping to $750 per year.

4.2.2. Deck – Repair – Concrete Crack

It was indicated from survey results that this maintenance activity is condition-driven and requires $4 per linear foot of deck cracks. A similar maintenance activity was included in the LCCAM tool, entitled Epoxy Crack Chasing, which costs about $10 per linear foot of deck cracks. After consulting with the Iowa DOT, it was decided to update the cost of Epoxy Crack Chasing to $4 per linear foot of deck cracks.

4.2.3. Deck – Repair – Epoxy Injection

Similar to concrete crack repairs, epoxy injection was reported to be condition-driven and costs about $4 per linear foot of deck cracks. This activity is similar to the Epoxy Injection activity that is included in the LCCAM tool and costs about $8 per linear foot of deck cracks. After consulting with Iowa DOT personnel, it was decided to update the cost of Epoxy Injection to $4 per linear foot of deck cracks.

4.2.4. Deck – Repair – Reinforced Concrete – Patch, Full-Depth

The survey results indicated that full-depth patching of reinforced concrete for bridge decks is condition-driven and costs about $300 per square foot of patching. Although a Patching activity is included in the LCCAM tool, it has a different nature compared to that from AASHTO. In the Phase I LCCAM tool, the patching activity is divided into two categories: Asphalt Patching and Concrete Patching. Asphalt Patching costs about $10 per square foot, and Concrete Patching costs about $60 per square foot.

4.2.5. Deck – Repair – Reinforced Concrete – Patch, Partial-Depth Type 1 (Shallow)

According to the survey results, shallow partial-depth patching of reinforced concrete bridge decks costs about $150 per square foot of patching area. As indicated for full-depth patching in the previous section, a similar activity is present in the LCCAM tool. After consulting with Iowa DOT personnel, it was decided to update the cost of Concrete Patching to $150 per square foot of patching area.

5. UPDATES TO THE GRAPHICAL USER INTERFACE

The Phase I LCCAM tool provides a suitable ground for evaluating and comparing the maintenance costs for bridge decks over the lifetime of a bridge. To make the Phase I LCCAM tool more user-friendly, some changes were made to the GUI as described in this chapter.

The first major change was the MATLAB user interface figure (uifigure) that the entire GUI is built upon. On start-up, the code takes in the user's screen size and makes the uifigure take up the left half of their screen, as shown in Figure 5.1.

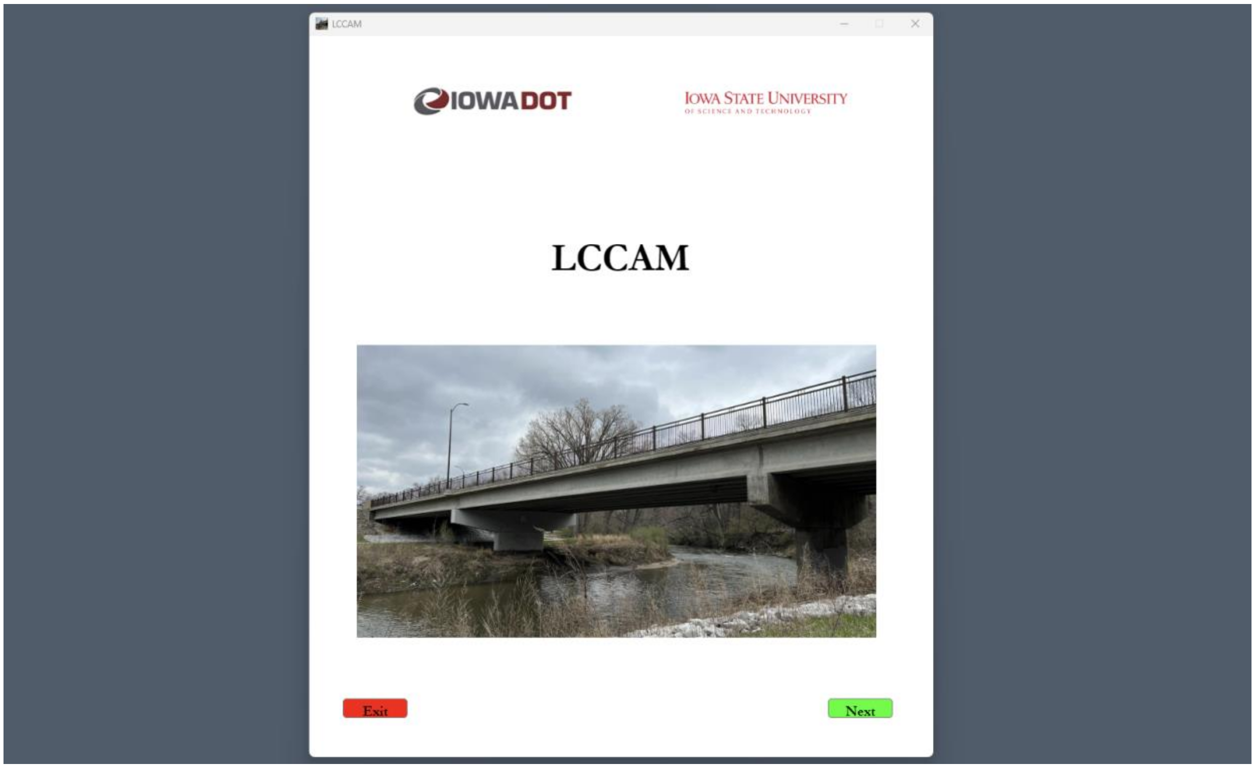


Figure 5.1. LCCAM start-up screen

All text, images, input buttons, etc. scale with the user's screen height and width. On start-up, the user is presented with the Title Screen, which contains the program name, the Iowa DOT logo, an image of a bridge in Iowa (taken by the authors), and the Next and Exit buttons.

After the user clicks on Next, the next screen to appear is the main input screen, which is shown in Figure 5.2.

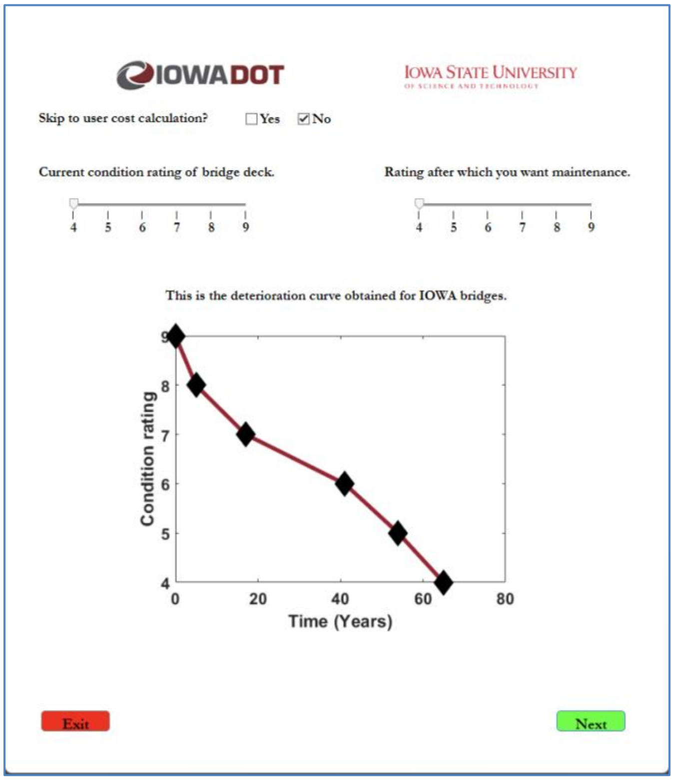


Figure 5.2. LCCAM main input screen

Here, the user can opt to skip to user cost calculations (previous section 3.4) or enter the current and service conditions ratings using sliders. The same window also presents the most current deterioration curve for Iowa bridge decks.

Depending on the service condition ratings, the maintenance options given to the user vary. Figure 5.3 provides an example for a current rating of 8 and a service rating of 4.

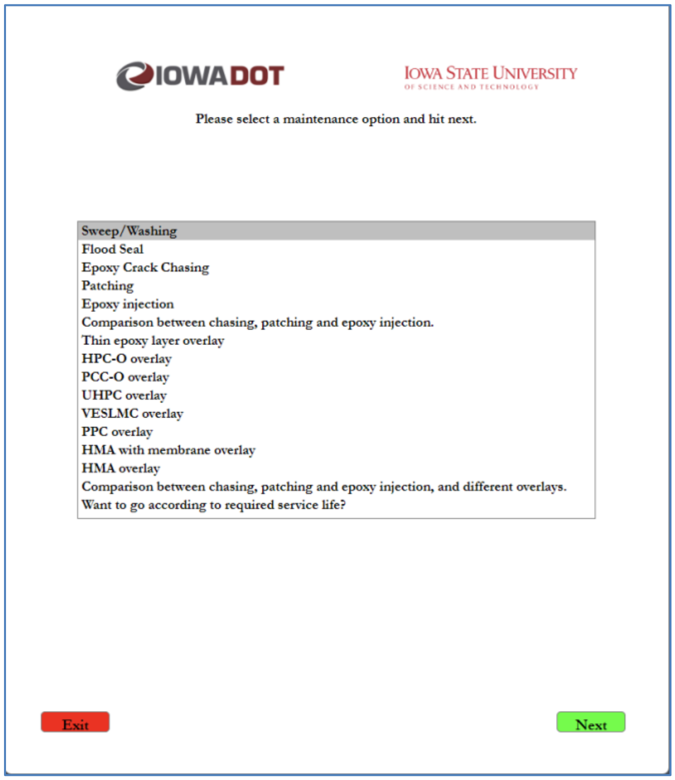


Figure 5.3. Suggested maintenance activities for a current condition rating of 8 and a maintenance condition rating of 4

Based on the selected variables, eight activities are suggested to the user: HPC-O, PCC-O, UHPC, VESLMC, PCC, HMA with membrane, or HMA overlay and suggest maintenance activities for a specified extension to the service life of the bridge deck (the latter of which is not shown in the Figure 5.3 screen capture).

After the user selects a maintenance action, the tool provides an estimated cost of maintenance with the capability of adjusting the maintenance cost, as shown in Figure 5.4. Upon clicking on the Next button, the page that appears shows the user the final maintenance cost and how the maintenance action affects the service life and condition rating of the bridge deck. The user can select to continue or go back and choose a different maintenance option.

Figure 5.4. Cost estimate of a maintenance activity

Upon selecting the maintenance option by clicking Next, the software asks for a variety of inputs needed to calculate the cost and condition and service life changes. Currently, the software asks for one cost calculation input per screen to reduce the complexity of the code. Once the software has recorded all necessary information entered by the user, it calculates the results and displays them. This may take the form of a written print-out (shown in Figure 5.5), a plot that is not connected to the uifigure to allow user manipulation and file saving, or a table.

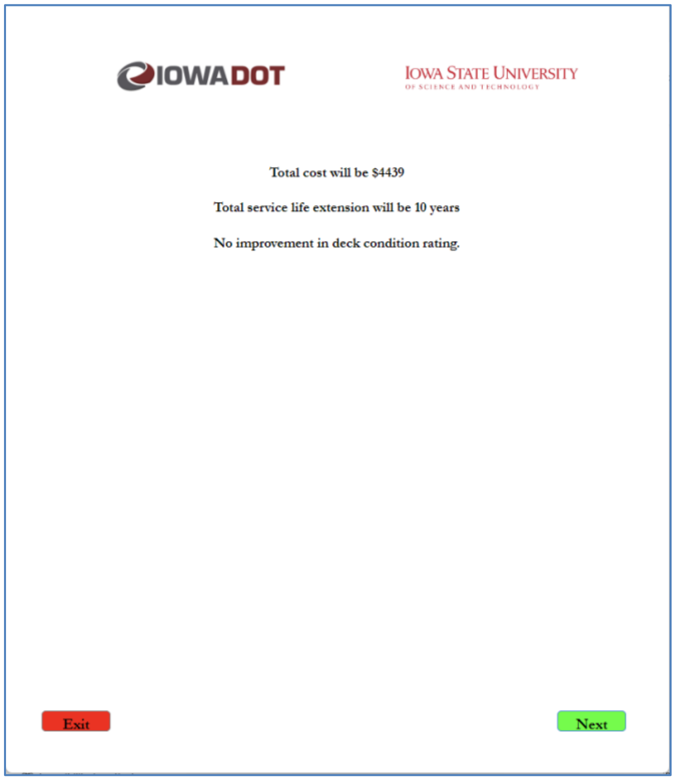


Figure 5.5. Printed output of maintenance activity results

The software then gives the user the option to export the results, as shown in Figure 5.6. If “Yes” is selected, then a window will open to allow the user to select a location for the results file.

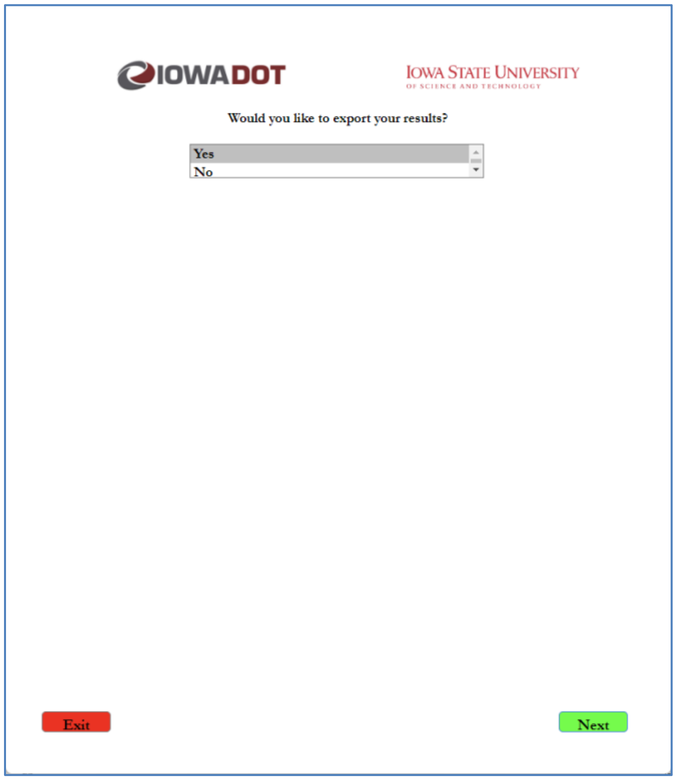


Figure 5.6. Option to save the output of a maintenance activity

Then, the software asks the user if they would like to calculate user costs, as shown in Figure 5.7.

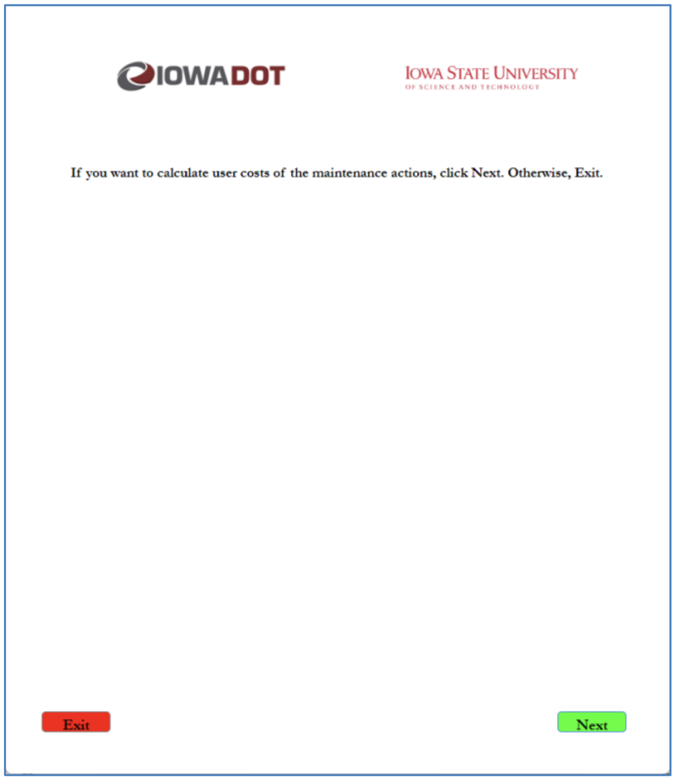


Figure 5.7. Prompt for user cost calculation

The same screen appears as the one when the user selects the option to skip to the user cost calculations on the main input screen. This screen prompts the user for all necessary inputs on one screen, as shown in Figure 5.8.

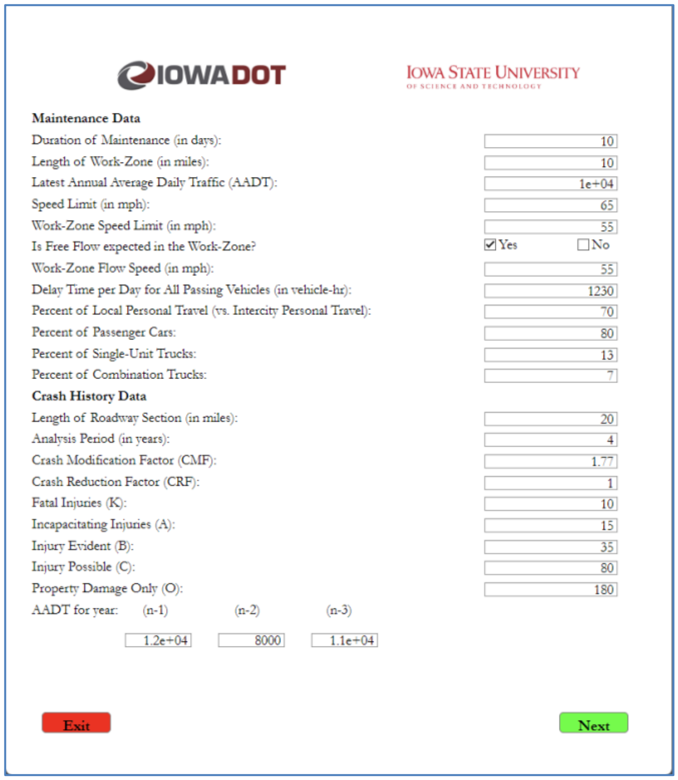


Figure 5.8. User cost calculation input

See Chapter 3 for details on user cost calculations and using the DelayTimeCalculator worksheet to complete the inputs on this screen. Note that some questions don’t appear until entry of certain input values, after the user clicks Next, given the software needs these to know which additional values to prompt the user for. Finally, the tool reports the results in text form, as shown in Figure 5.9.

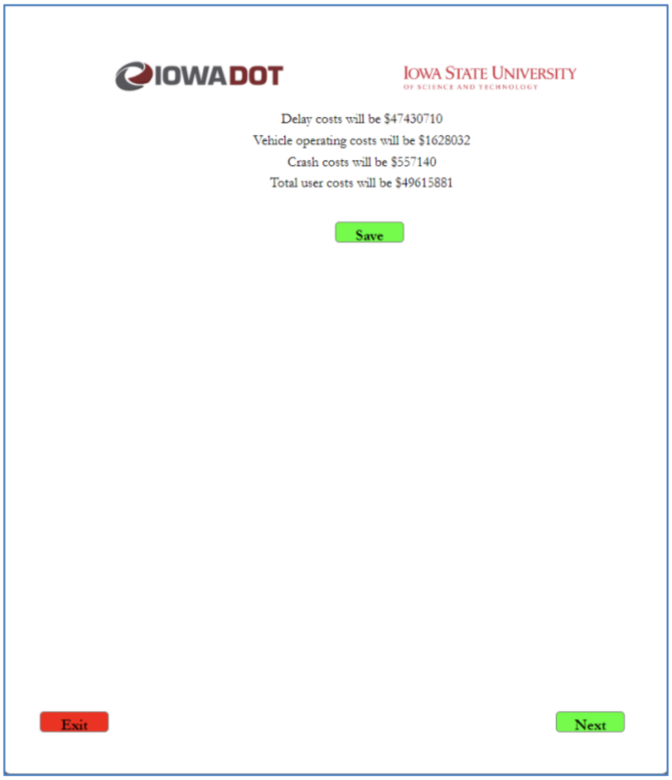


Figure 5.9. Final results of user cost calculations

The LCCAM prints a breakdown of user costs as well as the total user cost, which becomes helpful to better comprehend the major reason for user costs. As shown in Figure 5.9, the tool allows the user to save the user cost calculations.

6. SUMMARY, FUTURE RECOMMENDATIONS, AND CLOSING THOUGHTS

The aim of this Phase II project was to build on the LCCAM tool for continued use by the Iowa DOT. LCCAM was developed to meet the requirements of the MAP-21 Act, which requires states to adopt a TAMP for preservation of their portion of the NHS. To this end, the Iowa DOT used a deterministic approach, which considers fixed costs for maintenance activities without accounting for the variability of inputs and associated risks for each maintenance activity.

To overcome the drawbacks of this approach, the LCCAM tool was developed to incorporate risk into the decision-making process. A stochastic model was used to obtain the degradation curve for bridge decks based on the historical performance of Iowa bridges. This tool uses the current condition rating of the bridge and also asks for the condition rating that the maintenance activities to be started are aimed at.

Based on the input data, the software suggests a list of possible maintenance activities to the user. The software can compare the cost of multiple maintenance options and can also suggest a chain of maintenance activities to reach a predetermined extension to the lifetime of the bridge deck.

Upon the successful implementation of the LCCAM tool, this second phase of the project aimed to enable the calculation of user costs, improve the existing maintenance data as well as provide a base for developing the software to cover the maintenance of other bridge elements, and further enhance the GUI.

A major update to the software is the capability to utilize user cost calculations, which were developed by following the FHWA's roadmap. Three principal components of user cost are considered using the Phase II LCCAM tool: travel delay costs, VOCs, and crash costs.

The output of the user cost calculations provides a breakdown of the final costs between the three parameters, allowing decision-makers to adjust the maintenance requirements to acquire the lowest user costs.

A survey of maintenance activities throughout the six Iowa DOT districts was also developed based on AASHTO requirements. The survey aimed to update existing data and bring definitions of the activities closer to AASHTO classifications and terminology. The survey also aimed to provide a basis for developing the LCCAM tool to include the maintenance activities in the future for bridge components other than decks, which is possible upon developing degradation curves for the other bridge elements: superstructure, substructure, and culverts.

The applied improvements to the GUI provide a more user-friendly and aesthetically appealing environment for the user to work with the software. The changes to the tool are visible from the first page, where the input system is changed from a command window to a scroller. In the same page, some information is provided regarding the sponsor and developer of the software.

Compared to the Phase I version, the updated Phase II GUI facilitates surfing across the software by providing the ability to go back during each step and also by providing the ability to skip to the user cost analysis from the first page. Furthermore, the Phase II LCCAM tool allows the user to save the analysis in a text file in the location of the software.

Although the updated version of the LCCAM tool offers proper maintenance activities for bridge decks and is able to calculate user costs, it has not been implemented beyond the scope of bridge decks for other bridge elements (i.e., superstructure, substructure, and culverts). Future efforts need to be dedicated toward developing degradation curves for other bridge elements to make the tool more inclusive.

Additionally, the Phase II LCCAM software uses delay time inputs from the user, which can be linked to historical traffic databases to automate this part of the calculations. Similar automations are possible upon linking the crash database of each road/county to the software. By doing so, the software would become increasing more user-friendly and require less direct input from the user.

A comprehensive investigation could also be performed instead of a survey of maintenance activities to measure the cost and uncertainty of each maintenance activity to make the estimations more accurate.

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