CHAPTER 13
PAVEMENT TYPE SELECTION AND LIFE CYCLE COST ANALYSIS

13.1 Introduction

Some of the principal factors to be considered in choosing a pavement type are soil characteristics, traffic volume and types, climate, life cycle costs, and construction considerations. All of the above factors should be considered in any pavement design, whether it is for new construction or rehabilitation.

Life cycle cost comparisons must be made between properly designed structural sections that would be approved for construction. The various costs of the design alternatives over a selected analysis period are the major consideration in selecting the preferred alternative. A Life Cycle Cost Analysis (LCCA) includes costs of initial design and construction, future maintenance, rehabilitation, and user costs. The Colorado Department of Transportation (CDOT) uses the AASHTOWare™ DARWin™ M-E software program for designing flexible and rigid pavements. Federal Highway Administration (FHWA) RealCost software is to be used for probabilistic LCCA. It is imperative that careful attention be given to the calculations involved and the data used in the calculations to ensure the most realistic and factual comparison between pavement types and rehabilitation strategies.

Several design variations are possible within each rehabilitation strategy. A suggested flowchart illustrating the selection process for new pavement construction is shown in **Figure 13.1 Pavement Selection Process Flow Chart.**

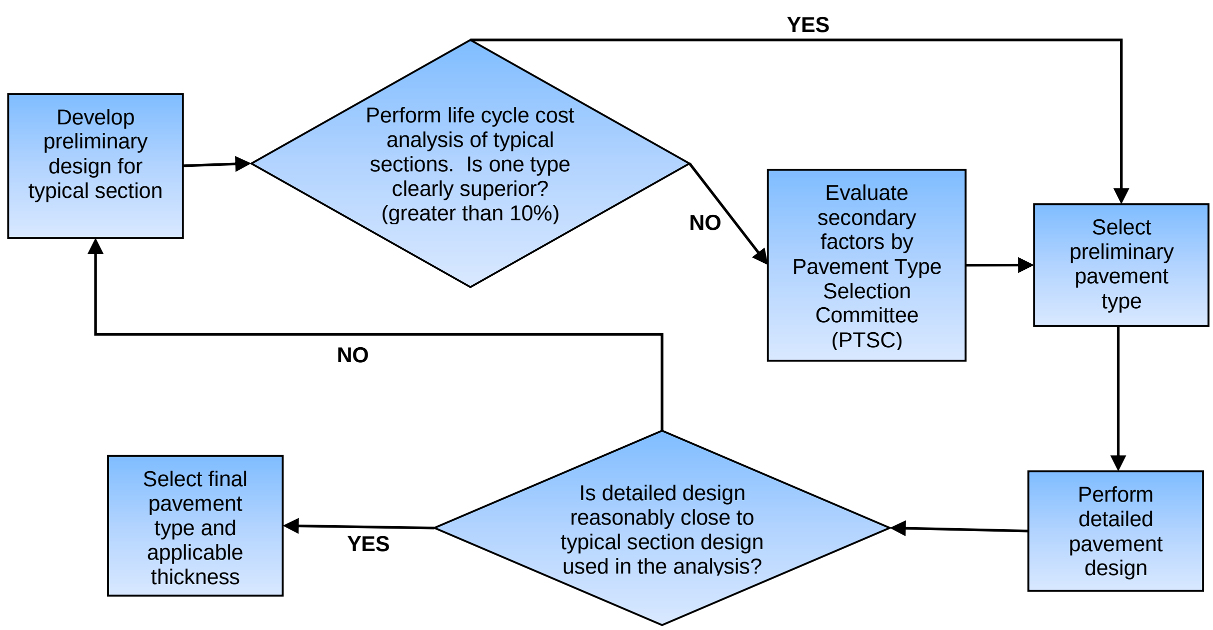

Figure 13.1 Pavement Selection Process Flow Chart

13.2 Implementation of a LCCA

A LCCA comparing concrete to asphalt pavements will be prepared for all new or reconstruction projects with more than $2,000,000 initial pavement material cost. This includes pavement and may include other pavement section elements such as base course material, geotextiles and geogrids, embankment, alternative base/subgrade treatments, etc. Pavement section elements other than pavement type should be included in the initial pavement material cost threshold if they differ by either type, quantity, etc. between the pavement types being compared. A LCCA comparing asphalt and concrete should also be prepared for all surface treatment projects with more than $2,000,000 initial pavement cost where both pavement types are considered feasible alternatives as determined by the RME. If the RME determines one pavement type is not a feasible alternative for a surface treatment project, they will include information supporting their decision in the Pavement Justification Report (PJR). Some examples of why alternatives may not be considered feasible are constructability, lane closure limitations set by regional traffic policies, geometric constraints, and minimum required pavement thicknesses. It may be helpful to discuss constructability concerns with industry to ensure that CDOT does not overlook recent innovations within the paving industry(s). For CDOT projects, the net present value economic analysis will be used. Refer to the references at the end of this chapter for documents published that explain a LCCA.

Examples of projects where a LCCA may not be necessary are:

- A concrete pavement, which is structurally sound and requires only resealing and/or minor rehabilitation work.
- A concrete or asphalt pavement, which is structurally sound but may need skid properties restored or ride improved .
- Minor safety improvements such as channelization, shoulder work, etc.
- Bridge replacement projects with minimal pavement work
- Locations where curb and gutter or barrier prohibit the use of alternative thicker treatments.

13.2.1 Analysis Period

The analysis period to be used is the period of time selected for making an LCCA of pavement costs. **CDOT will be using a 40-year period for their LCCAs**. All alternatives being considered should be evaluated over this same period. For example, If the service life of an alternative were 15 years, another rehabilitation project would have to be applied at year 30, and into the future, until the analysis period is covered.

13.2.2 Performance Life

Besides initial costs and discount rate, the performance life of the rehabilitation strategy is a major component of the LCCA. The total economic life of the alternative is used to compare initial designs along with the performance lives gained from the future rehabilitation of the pavement.

CDOT uses an assortment of rehabilitation strategies for pavements. Potential pavement alternatives include, but are not limited to mill and fill, hot or cold in-place recycling, overlay, rubblization, and concrete overlays. Every approach to rehabilitation will include a type of treatment and the life of that treatment. Planned rehabilitation is used in the pavement analysis to make engineering comparisons of candidate strategies and is not used for future funding eligibility determinations.

To select a future strategy, the pavement designer will review the data from the Pavement Management System to determine what was done in the past. Each section of pavement could have its own unique rate of deterioration and performance life. The decision of using the same tactic or modifying the treatment will be determined by analyzing past treatments and the lives of those methods.

The RealCost program takes into account the entire range of probable pavement service lives for both the initial design and future rehabilitation designs. Therefore, the designer should use the worst case scenario(s) of performance life when determining the number of rehabilitation strategies to be included in the software program to ensure the 40 year analysis period is satisfied.

13.2.3 Rehabilitation Selection Process

CDOT has developed a selection process that takes full advantage of available pavement management performance data. It is believed the following guide will provide recommendations that are more representative of actual pavement performance on Colorado highways. The selection of the appropriate treatment should be based on an engineering analysis for the project. The following precedence is recommended for selecting a rehabilitation strategy to be used in the LCCA:

- The pavement designer should use the historical treatments on the same roadway with the associated service life. Past strategies could be determined by coring the pavement, as well as, historical plan investigations. The coring program is outlined in **APPENDIX C**. Typically, discrepancies arise in the pavement management data and the thickness of cores.

- The pavement designer may have to categorize a lift thickness as being a structural or a functional (preventive maintenance) overlay.

    - The service life of a structural overlay is determined as the number of years between two structural overlays.

    - If a functional overlay was performed, a service life is not established and no adjustment is done on the expected service life. The cost of the functional treatment should be included as part of the maintenance cost and the cost shown in **Table 13.4 Annual Maintenance Costs** will need to be revaluated.

If the core and historical information is unknown, then refer to **Table 13.1 Default Input Values for Treatment Periods to be Used in a LCCA**. The performance lives shown in **Table 13.1**

Default Input Values for Treatment Periods to be Used in a LCCA are based on statewide average data. This information does not distinguish between traffic and environmental conditions. It only considers the historical timing of the rehabilitation treatments. Based on the current budgetary constraints, the optimal timing for these treatments may be different. Therefore, regional or local adjustments should be made using information from similar facilities with similar traffic levels if the data is available.

Table 13.1 Default Input Values for Treatment Periods to be Used in a LCCA

Type of Treatment (1)	Performance in Years		
	Minimum	Most Likely	Maximum
Cold Planing and Overlay (2)	6	12	21
2 to 4 Inch Overlay (2)	5	11	39
Stone Matrix Asphalt Overlay	5	9	17
Full Depth Reclamation and Overlay (2)	10	12	15
Heating and Remixing and Overlay (2)	4	7	14
Heating and Scarifying and Overlay (2)	6	9	23
Cold In-Place Recycling and Overlay (2)	3	8	16
Overall Weighted Statewide Average	**5**	**10**	**26**

Note:
(1) This table will not be used to select project-specific rehabilitation strategies. The performance years are not intended to be a comparative tool between different treatment types, they are default values to be entered into the probabilistic LCCA after the appropriate treatment has been selected based on project specific design criteria.
(2) **If polymer modified asphalt cement is used, add 1 year to the most likely value.**

13.3 Examples of the Rehabilitation Selection Process

13.3.1 Core Data Matches Historical Data

A reconstruction project is planned for year 2010 and unmodified HMA is anticipated. Cores taken from the roadway indicated the existing HMA thickness is 8.5 inches thick. The historical information from the Pavement Management System indicated the original construction project was built in 1976 with a total of 6 inches of unmodified HMA. In 1998, the second project milled 2 inches off the existing HMA and overlaid it with 4 inches of unmodified HMA. Since the core thickness is reasonably close to the historical data, the average service life of 17 years [(1998-1976) + (2010-1998)] / 2 should be used. The cash flow diagram is shown in **Figure 13.2 Unmodified HMA Cash Flow Diagram.**

Figure 13.2 Unmodified HMA Cash Flow Diagram

13.3.2 No Core Data and No Historical Data

A reconstruction project is planned for year 2010 and modified HMA is anticipated. Discernable lifts of HMA could not be found in the roadway cores and no historical information is available for this area. Since a curb and gutter will be constructed, future rehabilitation work will require cold planing and overlays. Based on **Table 13.1 Default Input Values for Treatment Periods to be Used in a LCCA,** the most likely life expectancy for this rehabilitation strategy is 13 years (12 + 1 year for modified HMA). The cash flow diagram is shown in **Figure 13.3 Cold Plaining and Overlay with Polymer Modified HMA Cash Flow Diagram.**

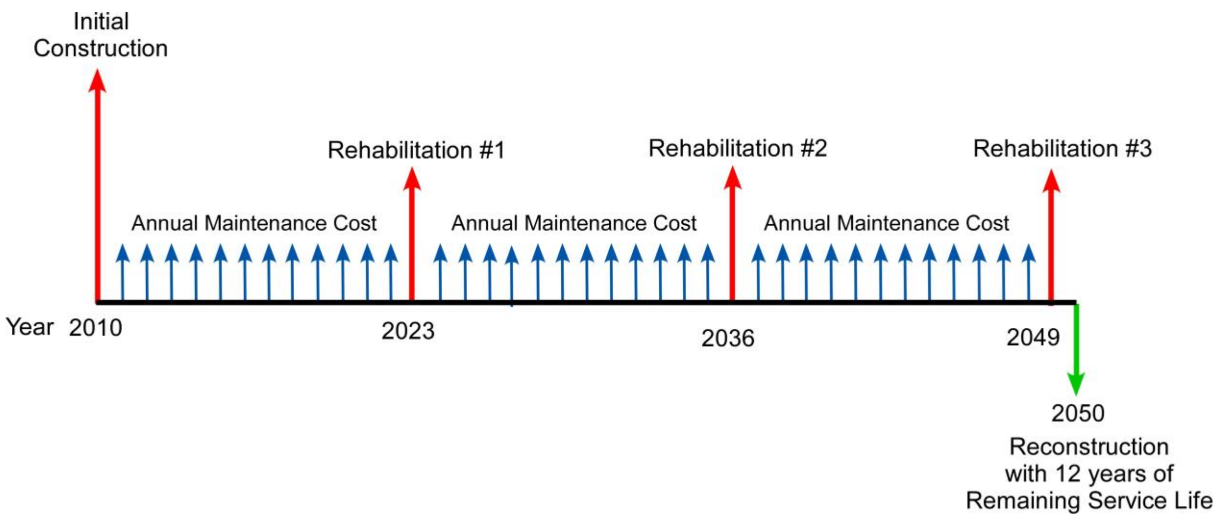

Figure 13.3 Cold Plaining and Overlay with Polymer Modified HMA Cash Flow Diagram

13.3.3 Portland Cement Concrete Pavement

The LCCA of a PCCP may be analyzed with either a 20 or 30-year initial design period and a 40 year analysis period. **Note**: **The designer should add ¼ inch to thickness for future diamond grinding.**

Rehabilitation: When available, the designer should use regional or local performance data of similar facilities and traffic levels. If no local data is available, the default **years to the first rehabilitation cycle for PCCP is a triangular distribution with a minimum value of 16 years the most likely value of 27 years and the maximum value of 40 years**. This information is based on statewide average data. It does not distinguish between traffic levels or environmental conditions, it only considers the historical timing. Due to budgetary constraint, the optimal timing may be different. Therefore, these values should only be used in the absence of any other information.

- PCCP with dowel and tie bars will require ½ percent slab replacement in the travel lanes, full width diamond grinding with longitudinal, and transverse joint resealing.

- PCCP without dowel or tie bars will require 1 percent slab replacement in the travel lanes, full width diamond grinding with longitudinal and transverse joint resealing.

Based on an $8 million project, the 40-year LCCA comparison between the 2-inch HMA overlay alternative at 20 and 30 years is about 5.5% more expensive than the PCCP rehabilitation at 27 years.

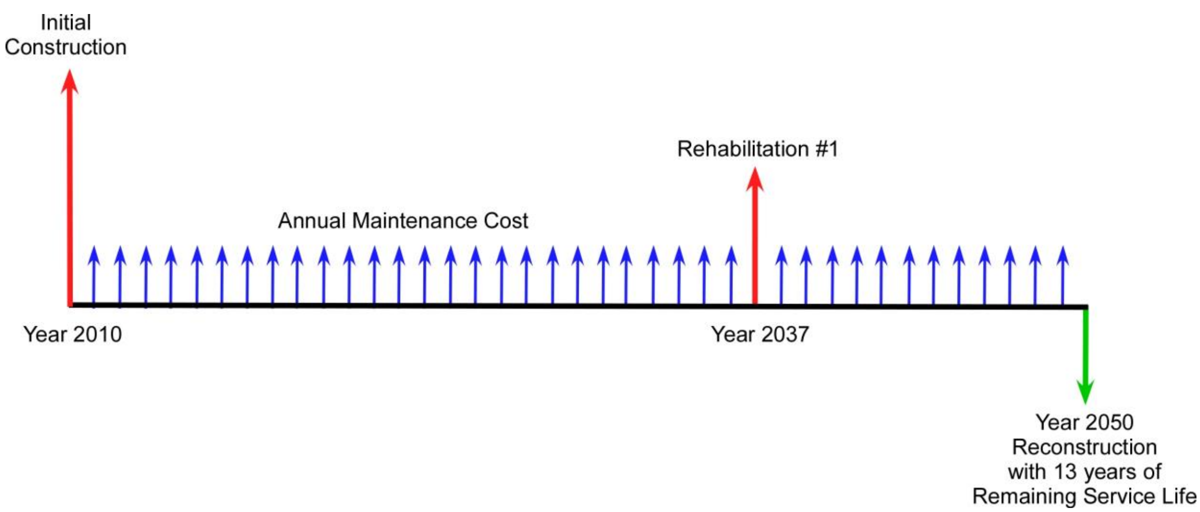

Figure 13.4 PCCP Cash Flow Diagram

13.3.4 Restoration, Rehabilitation, and Resurfacing Treatments

The economic cost of these surface treatments are performed with the following parameters of a 40 year analysis period and a 10, 20 and 30 year design period.

13.4 Discount Rate

All future costs are adjusted according to a discount rate prorated to a present worth. Costs incurred at any time into the future can be combined with initial construction costs to give a total cost over the life cycle. See **Table 13.2 Present Worth Factors for Discount Rates** for a uniform series of deposits, S_n. **The current discount rate is 2.22 percent with a standard deviation 0.38 percent** (6).

The discount rate and standard deviation will be calculated annually. If the new 10-year average discount rate varies by more than two standard deviations from the original discount rate used at the time of the design, in this case 0.75 percent resulting in a discount rate range of 1.47 to 2.97 percent, a new LCCA should be performed. Thus, all projects that have been shelved prior to 2011 and/or not been awarded should have a new LCCA performed. The designer is responsible for checking previous pavement designs to ensure an appropriate discount rate was used and the pavement choice is still valid.

The discounting factors are listed in **Table 13.3 Discount Factors for Discrete Compounding** in symbolic and formula form and a brief interpretation of the notation. Normally, it will not be necessary to calculate factors from these formulas. For intermediate values, computing the factors from the formulas may be necessary, or linear interpolation can be used as an approximation.

The single payment present worth $P = F(P/F, i_{\%}, n)$ notation is interpreted as, "Find P, given F, using an interest rate of $i_{\%}$ over n years". Thus, an annuity is a series of equal payments, A, made over a period of time. In the case of an annuity that starts at the end of the first year and continues for *n* years, the purchase price, P, would be $P = A \times (P/A, i_{\%}, n)$. See **Table 13.2 Present Worth Factors for Discount Rates.**

Table 13.2 Present Worth Factors for Discount Rates

n **(years)**	**Discount Rate**	
	2.22%	
	PWF_n	**S_n**
5	0.8960	4.6835
6	0.8766	5.5601
7	0.8575	6.4176
8	0.8389	7.2565
9	0.8207	8.0772
10	0.8029	8.8801
11	0.7854	9.6655
12	0.7684	10.4339
13	0.7517	11.1855
14	0.7354	11.9209
15	0.7194	12.6403
16	0.7038	13.3440
17	0.6885	14/0325
18	0.6735	14.7060
19	0.6589	15.3649
20	0.6446	16.0095
21	0.6306	16.6401
22	0.6169	17.2570
23	0.6035	17.8605
24	0.5904	18.4509
25	0.5776	19.0285
30	0.5175	21.7335
35	0.4637	25.1573
40	0.4155	26.3291
Note: PWF_n = present worth factor S_n = uniform series of deposits		

Table 13.3 Discount Factors for Discrete Compounding

Factor Name	Converts	Symbol	Formula	Interpretation of Notation
Single Payment Present Worth	F to P (future single payment to present worth)	(P/F, $i_{\%}$, *n*)	$(1+i)^{-n}$	Find P, given F, using an interest rate of $i_{\%}$ over *n* years
Uniform Series Present Worth	A to P (annual payment to present worth)	(P/A, $i_{\%}$, *n*)	$\frac{(1+i)^n-1}{i(1+i)^n}$	Find P, given A, using an interest rate of $i_{\%}$ over *n* years
Note: P = the single payment present worth; F = future single payment; i % = the interest rate percent, and *n* = number of years.				

13.5 Life Cycle Cost Factors

Cost factors are values associated with the LCCA which cover the full cycle from initial design to the end of the analysis period. Any item that impacts the initial cost should be analyzed, as well as, a determination made as to whether it should be included in the cost analysis. Such items would include shoulder construction, major utility considerations, mobilization, temporary access, traffic crossovers, etc. Some of the factors the designer should consider are described in the following sections.

13.5.1 Initial Construction Costs

Pavement construction costs are the expenses incurred to build a section of pavement in accordance with plans and specifications. The pavement construction cost is one of the most important factors in the LCCA and should be as accurate as possible. Initial cost of PCCP and HMA should be based on the best available information. The current version of CDOT's *Cost Data Manual* should be used unless up-to-date bid prices are available for similar work in the same general area. The designer should take into consideration project specific information, such as special mixes, fast track mixes, pavement constructability, special binders, construction phasing, project location, and other pertinent information. These project details may alter the unit costs shown in the figures. The designer should exercise good judgment in the application of the PCCP and HMA unit costs. If there is a wide range of prices for a certain item, it is best to run a sensitivity analysis to determine the effect of cost variation on the end result. Computing the initial cost of a design alternative involves not only the material quantity calculations, but also the other direct costs associated with the pavement alternative being considered. Difference in grading quantities required by different pavement alternatives should be considered where appropriate. For example, the comparison of a thick overlay alternative versus a removal and replacement alternative should include the required shoulder quantity for the overlay. If traffic control costs vary from one alternative to another, the cost should be estimated and included as an initial cost. The different construction techniques, curing time, and duration of lane closures associated with PCCP or HMA have a significant impact on the user costs. For example, a HMA overlay could involve the closure of one lane of traffic at a time, while a concrete pavement overlay might necessitate complete roadway closure and construction detours. This will impact traffic control and user costs. The designer should utilize the resources of the Engineering Estimates Unit as necessary to supplement information used in the calculation of the unit cost. The supporting information and any worksheets for the unit cost should be included in the Pavement Justification Report.

13.5.2 Asphalt Cement Adjustment

Included in the unit cost of HMA should be an adjustment for the Force Account Item. This item revises the Contactor's bid price of HMA found in the Cost Data book based on the price of crude oil at the time of construction. The data varies from year to year, Region to Region, and by the various binders used by CDOT. In 2009, the average was an increase of \$3.30 per ton of HMA. In 2013, the average was an increase of \$4.24. The weighted average of over 8.9 million tons of HMA is an increase of \$0.67 per ton. Therefore, we recommend a triangular distribution with the minimum value of -\$2.56, a most likely value of \$0.67 and a maximum value of \$4.24 per ton of mix. The unit cost modification is based on data from projects that were awarded from 01/01/2009 through 12/31/2015.

13.5.3 Maintenance Cost

The designer should exercise good judgment in the application of maintenance costs. Inappropriate selection can adversely influence the selection of alternatives to be constructed. Maintenance costs should be based on the best available information. The CDOT Maintenance Management System compiled data on state highway maintenance costs. The annual maintenance cost per lane mile is shown in **Table 13.4 Annual Maintenance Costs**. This data was collected from January 1, 2000 to December 31, 2014 and normalized to 2015 dollars. If actual cost cannot be provided, use the following default values:

Table 13.4 Annual Maintenance Costs

Type of Pavement	Average Annual Cost Per Lane Mile	Lane Miles Surveyed
HMA	\$1,027	392
PCCP	\$640	416

13.5.4 Design Cost

The expected Preliminary Engineering (PE) costs for designing a new or rehabilitated pavement including materials, site investigation, traffic analysis, pavement design, and preparing plans with specifications vary from Region to Region and are in the **range of 8 to 12 percent with the average being 10 percent of the total pavement construction cost**.

13.5.5 Pavement Construction Engineering Costs

Included in the pavement construction cost should be the Cost of Engineering (CE). The CE and indirect costs can be found at the Site Manager Construction website.

13.5.6 Traffic Control Costs

Traffic control costs is the cost to place and maintain signs, signals, and markings and devices placed on the roadway to regulate, warn, or guide traffic. Traffic control costs vary from Region to Region and from day to night. **The range is from 10 to 18 percent with the average being 15 percent of the total pavement construction cost**. In some designs, the construction traffic control costs may be the same for both alternatives and excluded from the LCCA.

13.5.7 Serviceable Life

The serviceable life represents the value of an investment alternative at the end of the analysis period. The method CDOT uses to account for serviceable life is prorated based on the cost of the final rehabilitation activity, design life of the rehabilitation strategy, and the time since the last rehabilitation. For example, over a 40-year analysis, Alternative A requires a 10-year design life rehabilitation to be placed at year 31. In this case, Alternative A will have 1 year of serviceable life remaining at the end of the analysis (40-31=9 years of design life consumed and 10-9=1 year of serviceable life). The serviceable life is 1/10 of the rehabilitation cost, as shown in equation **Eq. 13.1**.

$$\mathbf{SL = (1 - (L_A/L_E)) * C} \qquad \textbf{Eq. 13.1}$$

Where:

SL = serviceable life
L_A = the portion of the design life consumed
L_E = the design life of the rehabilitation
C = the cost of the rehabilitation

13.5.8 User Costs

These costs are considered to be indirect "soft" costs accumulated by the facility user in the work zone as they relate to roadway condition, maintenance activity, and rehabilitation work over the analysis period. These costs include user travel time, increased vehicle operating costs (VOC), and crashes. Though these "soft" costs are not part of the actual spending for CDOT, they are costs borne by the road user and should be included in the LCCA. Due to the lack of crash cost data for certain types of work zone activities, CDOT will not consider the costs due to crashes.

User Cost Program

13.5.8.1 Introduction

The User Cost website is a tool used to calculate the user cost associated with work zones for a LCCA. The program allows the engineer to start a new file or import a file from a previous edition of the program. Updates from the previous version include new cost data, pilot car operations, a larger number of types of work, cross over alternative, and printing capabilities.

13.5.8.2 Using the User Cost Software

Project Data

When entering the website, the designer will be looking at a fresh project page (see **Figure 13.5 User Cost Website**). Accessing the data cells may be done by pointing and clicking, or by using the tab key on the keyboard. The first step is to enter project specific data in the following fields (optional fields are not required for calculations):

- Project code: CDOT's 5 digit code
- Name of project
- Project start and end date (optional)
- Author and comments (optional)
- Length of closure
- Design speed
- Speed limit
- Work zone speed
- Percent grade

According to the Highway Capacity Manual, grades less than 2 percent will not need adjustments to the highway capacity (User Cost has a default value of 2 percent). Any grade less than 3% and longer than 1 mile, or any grade greater than 3% and longer than ½ mile should be analyzed separately. The average grade of the project may be used for analysis.

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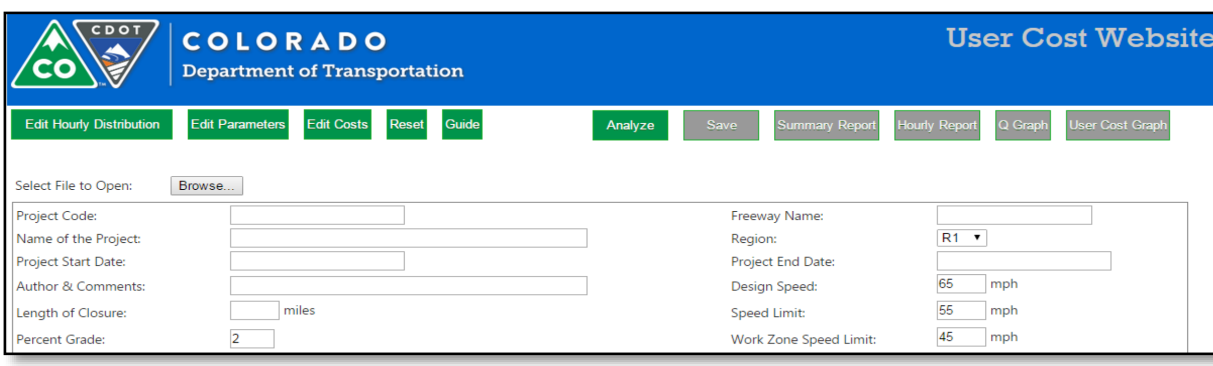


Figure 13.5 User Cost Website

Lane Closures

- **Single Lane Closure (SLC):** For a single lane closure, enter the total number of lanes in each direction, the number of open lanes, and the number of temporary lanes (see **Figure 13.6 Single Lane Closure Screenshot**). Temporary lanes are temporary detours in the work zone at the time of construction. If the project requires using the shoulder, the shoulder is considered a temporary lane. **Note: The sum of open and temporary lanes must be less than or equal to the total number of lanes in each direction.**

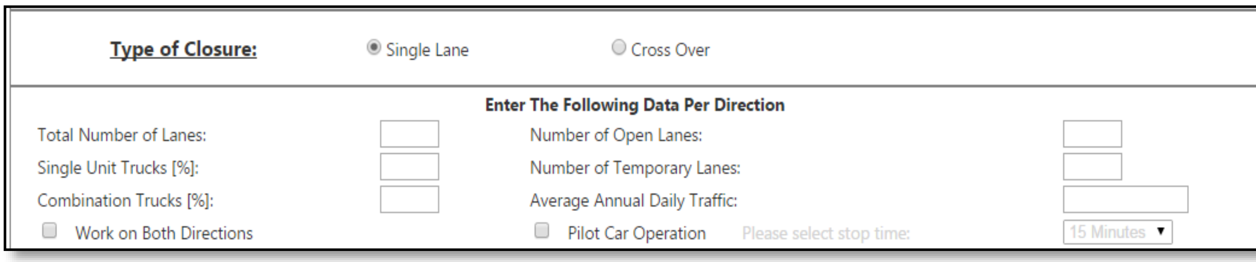


Figure 13.6 Single Lane Closure Screenshot

- **Traffic:** Next, enter the percent single and combination trucks along with the Average Annual Daily Traffic (AADT) for the direction you are working. Refer to **Section 3.1 CDOT Traffic** for obtaining traffic data. If the project requires working in both directions, check the '*Work on Both Directions*' box.

- **Pilot Car:** If a pilot car option is used, the program will calculate the pilot car as a separate '*Type of Work*' line item in the final report. The user can select a vehicle stop time of either 15 or 30 minutes. The program will calculate the pilot car cost based on the number of vehicles and trucks, 80% of the AADT, and stop time selected (see **Figure 13.7 Single Lane Closure Highlighting Pilot Car Operations).**

- **Cross Over:** In a cross over, the traffic volumes are the same as described in the single lane closure scenario.

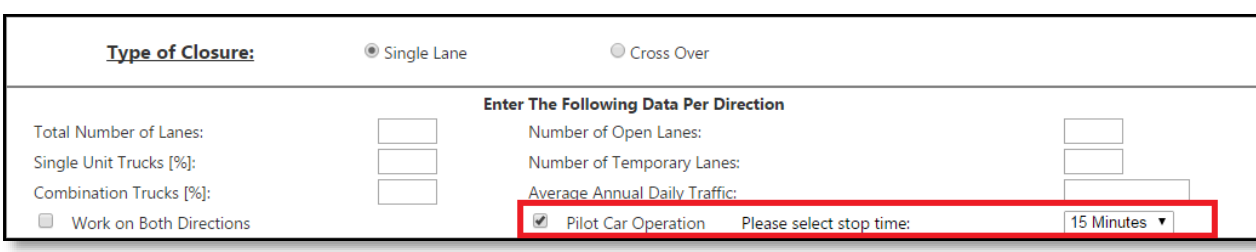


Figure 13.7 Single Lane Closure Highlighting Pilot Car Operations

- **<u>Example</u>:** I-70, a divided 4-lane interstate (2 primary lanes and 2 secondary lanes) will be reconstructed using a cross over. The phasing is such that the secondary direction is closed first (see **Figure 13.8 Example of Input for a Cross Over**). The input is as follows:
  - Secondary Direction Total Number of Lanes = 2
    - Number of Open Lanes = 1
    - Number of Temporary Lanes = 0
  - Primary Direction Total Number of Lanes = 2
    - Number of Open Lanes = 1
    - Number of Temporary Lanes = 0

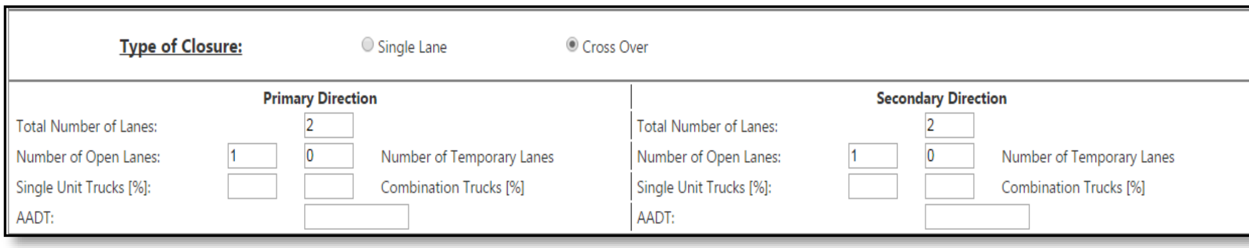


Figure 13.8 Example of Input for a Cross Over

Type of Work

The program has a list of 52 different types of work that may be selected for a project (see **Figure 13.9 Screenshot Showing Type of Work Menu**). To select a '*Type of Work'* from the list, point and single click on the item. To view additional items, use the arrows located on the right side of the menu to scroll down the list. Once you point and click on an item, the type of work moves into the '*Type of Selected Work'* area. To remove an item after it has been selected, single click on the red '*X'* to the right of the line item. It is suggested to pick the major item of the work to be constructed followed by minor work items and not to have more than five items selected. The program will allow one to select up to 25 types of work.

Once a '*Type of Work'* is selected, default values assigned to each item for calculating the duration of the work and the lane capacity will be used for calculations. If project specifics require a different duration or capacity, click the box for '*Duration, Depth,* or *Capacity'* and type a new value.

Note: The capacity adjustment factor has a set default value based on data from the *Highway Capacity Manual*, thus, if you have equipment in close proximity to the travelling public, you should input a value lower than the default value. **Table 13.5 Range of Capacity Values per Type of Work** shows the range in capacity that one may use to modify a particular type of construction or activity.

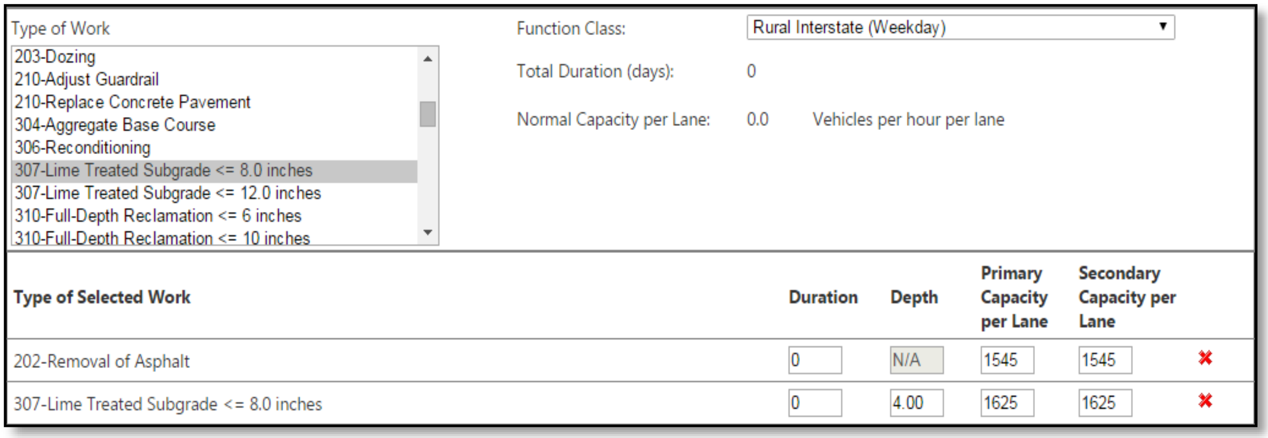


Figure 13.9 Screenshot Showing Type of Work Menu

Table 13.5 Range of Capacity Values per Type of Work

Item	Description	Int. Adj. Factor
202	Removal of concrete	-160 to +50
202	Removal of concrete (planing)	+120 to +160
202	Removal of asphalt	-160 to + 50
202	Removal of asphalt (planing)	+120 to +160
203	Unclassified excavation	-100 to +100
203	Unclassified excavation (C.I.P.)	-50 to + 100
203	Embankment material	-100 to +100
203	Embankment material (C.I.P.)	-50 to +100
203	Muck excavation	-50 to +50
203	Rolling	+100 to +160
203	Blading	+50 to +160
203	Dozing	-50 to +100
210	Adjust guardrail	-50 to +50
210	Replace concrete pavement	0 to +50
304	Aggregate base course	-50 to +50
306	Reconditioning	-50 to +160
310	Process asphalt material for base	-50 to +100

Item	Description	Int. Adj. Factor
403	HMA stone matrix asphalt	-100 to +160
403	HMA (patching)	0 to +160
403	HMA ≤ 1.0”	-100 to +160
403	HMA ≤ 2.0”	-100 to +160
403	HMA ≤ 3.0”	-100 to +160
405	Heating and scarifying	-50 to +100
406	Cold-in-place recycle	-50 to +100
408	Hot poured joint and crack sealant	-100 to +160
409	Microsurfacing	-100 to +160
412	Concrete pavement system	-160 to +160
412	Concrete pavement ≤ 6.0”	-160 to +160
412	Concrete pavement ≤ 10.0”	-160 to +160
412	Concrete pavement ≤ 14.0”	-160 to +160
412	Routing and sealing PCCP cracks	-100 to +160
412	Cross stitching	-100 to +100
412	Rubbilization of PCCP	-120 to –160
***	Miscellaneous Other roadway construction	-160 to +160

Function Class

The '*Function Class'* is a scroll down menu listing the different types of roadways (see **Figure 13.10 Screenshot of the Function Class Menu**). Items may be selected by pointing and single clicking on the item. Weekend and weekday options are provided for each functional class. In the case where lane closures span weekdays and weekends, both scenarios should be run and a weighted average user cost calculated.

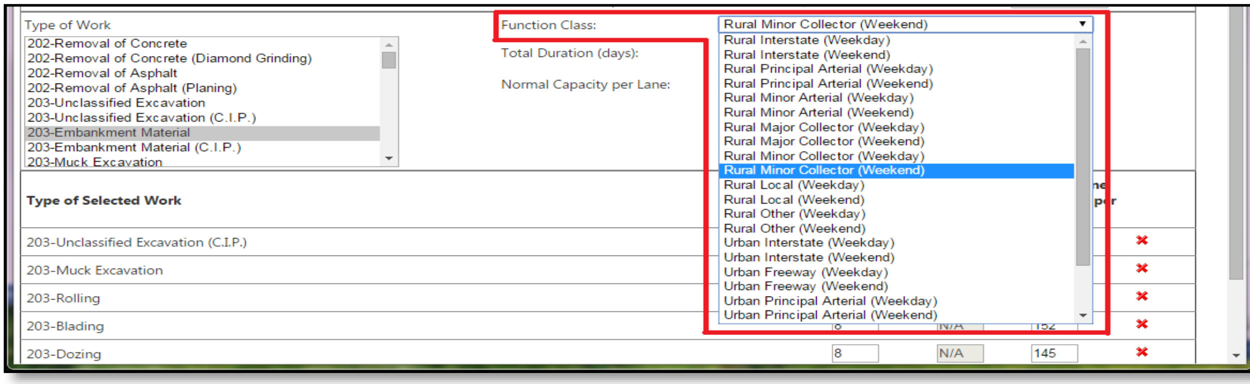


Figure 13.10 Screenshot of the Function Class Menu

Run the Program

When you click the '*Analyze'* button you will either get a successfully analyzed, or an error message. If the data entered is appropriate and within the advised set range, the '*Report'* button located at the top of the page will turn green (see **Figure 13.11 Successfully Analyzed Menu Bar**). At this point, all of the reports may be viewed by clicking the associated button. By clicking on a report button, a new page with the report will open in your browser. The reports may be printed by a right clicking and selecting '*Print'*.

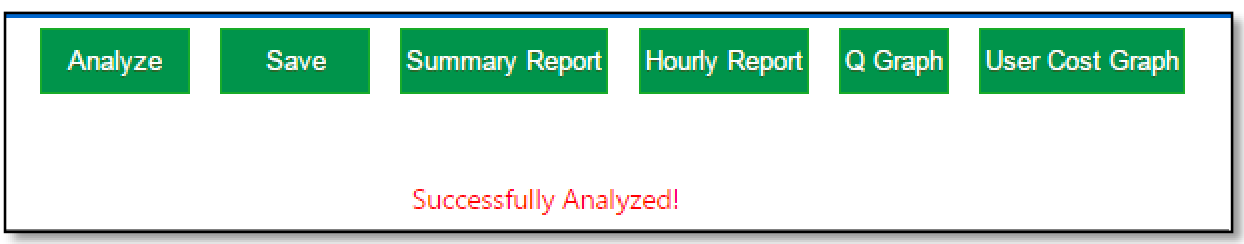


Figure 13.11 Successfully Analyzed Menu Bar

If an entry(s) is invalid, an error message will notify the user where the problem exists (see **Figure 13.12 Analysis Error Message)**. The user may go back to any portion of the program, fix the error, and re-analyze the data until all error messages are corrected and a successful run is made.

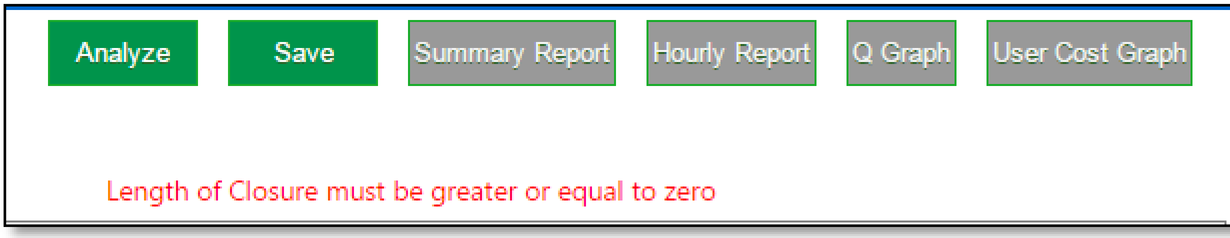


Figure 13.12 Analysis Error Message

Editing Default Inputs

Buttons that will allow you to customize construction information and parameters are available on the left side of the top row (see **Figure 13.13 Editing Input Buttons**). **Note:** If any information or parameters are changed, one must save them by selecting '*OK'* to close the edit; if you click on '*Cancel'* to close the box, it will not save any changes.

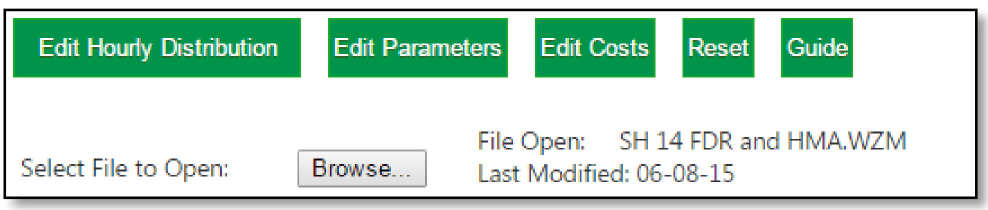


Figure 13.13 Editing Input Buttons

Edit Hourly Distribution

This screen allows you to change the hourly traffic distribution values for your project. Staff traffic has an internal web site (http://internal/App_DTD_DataAccess/index.cfm with a tab for traffic counts), however not all traffic data is available in all areas of the state at this time. The total sum of distribution factors cannot exceed 1.0 (see **Figure 13.14 Hourly Distribution Edit Scree**n). **Note**: A queue greater than 5 miles or a delay greater than ½ hour should not be allowed to form. The program calculates the user cost when a work zone is in place. For example, if the contractor only works from 9:00 a.m. to 5:00 p.m. on a single lane closure, then all the hourly traffic distribution values outside the working time should be changed to zero (0).

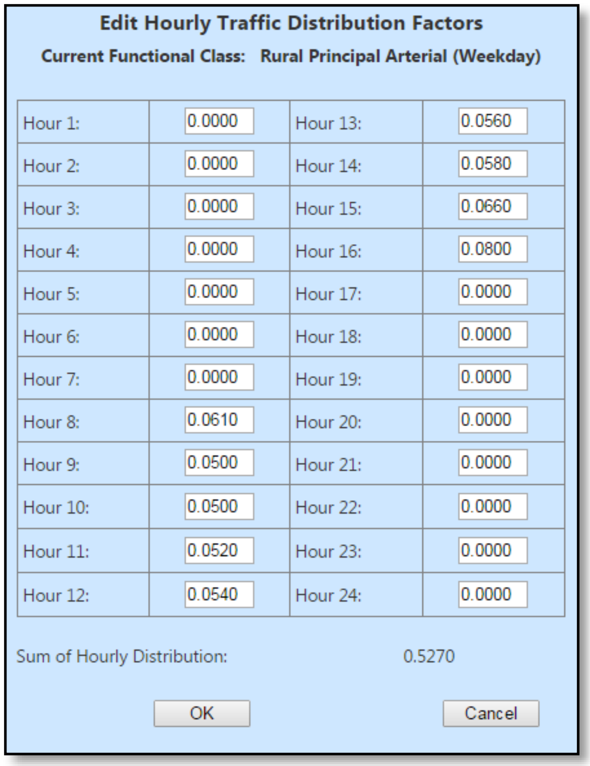


Figure 13.14 Hourly Distribution Edit Screen

Edit Parameters

Changing or editing a parameter in the User Cost software will effect one or more other variables. Below is a list of parameters and the effect they have on other variables (see **Figure 13.15 Edit Parameters Screen**).

- The intensity value (how close the contractor is working to the travelling public) is linked to lane capacity.
- Productivity changes the duration.
- The Present Serviceability Index (road quality) is linked to user cost due to wear and tear on the vehicles.
- The lane width factor affects the capacity.
- The width factor is affected by lane width, obstruction distance, freeway size, and whether an obstruction is on both sides.
- Ramps that are not metered will cause traffic to accelerate and slow down which affects the capacity in the work zone.
- CPI: Consumer Price Index may be found at the following website: http://www.bls.gov/news.release/cpi.t01.htm

Edit Costs

The '*Edit Costs*' button near the top left corner allows the user to change the '*Value of Time*' for cars, single unit trucks, and combine trucks. Once the costs are changed click on the '*OK*' button (see **Figure 13.16 Edit Costs Screen**).

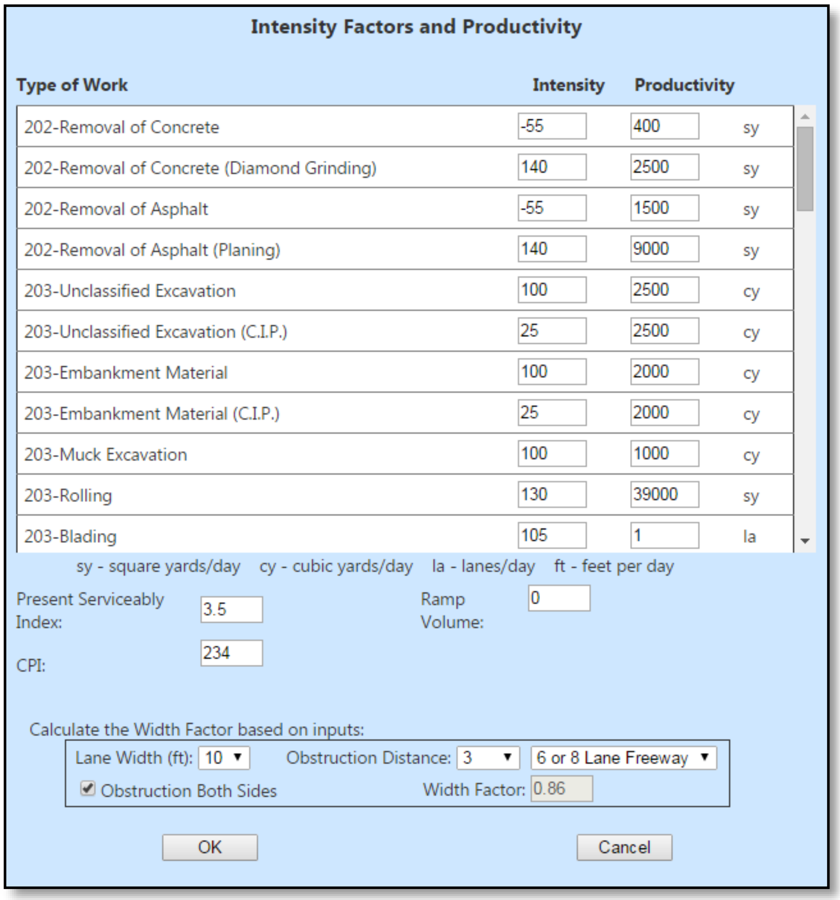


Figure 13.15 Edit Parameters Screen

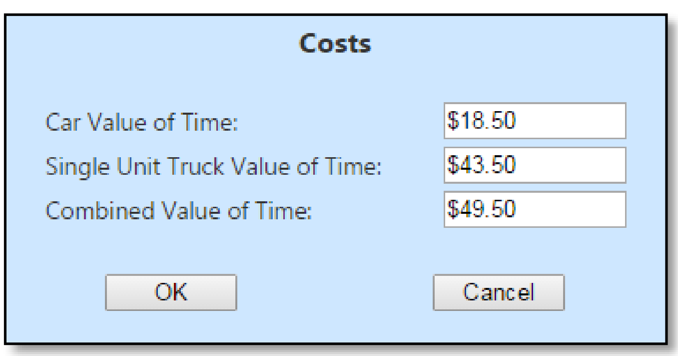


Figure 13.16 Edit Costs Screen

Saving Projects

The '*Save*' button is located near the center of the row of buttons. This button will save all inputs, including any changes to the hourly distribution, parameters, and costs, as well as, time stamp the file so the user will know when the file was last modified. After clicking '*Save'*, the file will appear in the bottom left of the web window (see **Figure 13.17 Saving a File**).

If the file does not appear at the bottom, it may be because your computer is blocking pop-ups. The user can allow the pop-ups only for this site by clicking the red '*X* 'on the top navigation bar of the web browser when the program tries to download the file. Next, click on the file and select '*Open'*. A text file will open. From the notebook text editor, select '*File'*, then '*Save'*, to save the file onto your computer. Next time the user opens the program, the file can be opened from the *'Browse'* button at the top of the screen.

Reset

The *'Reset'* button will clear the page and reset all the default values.

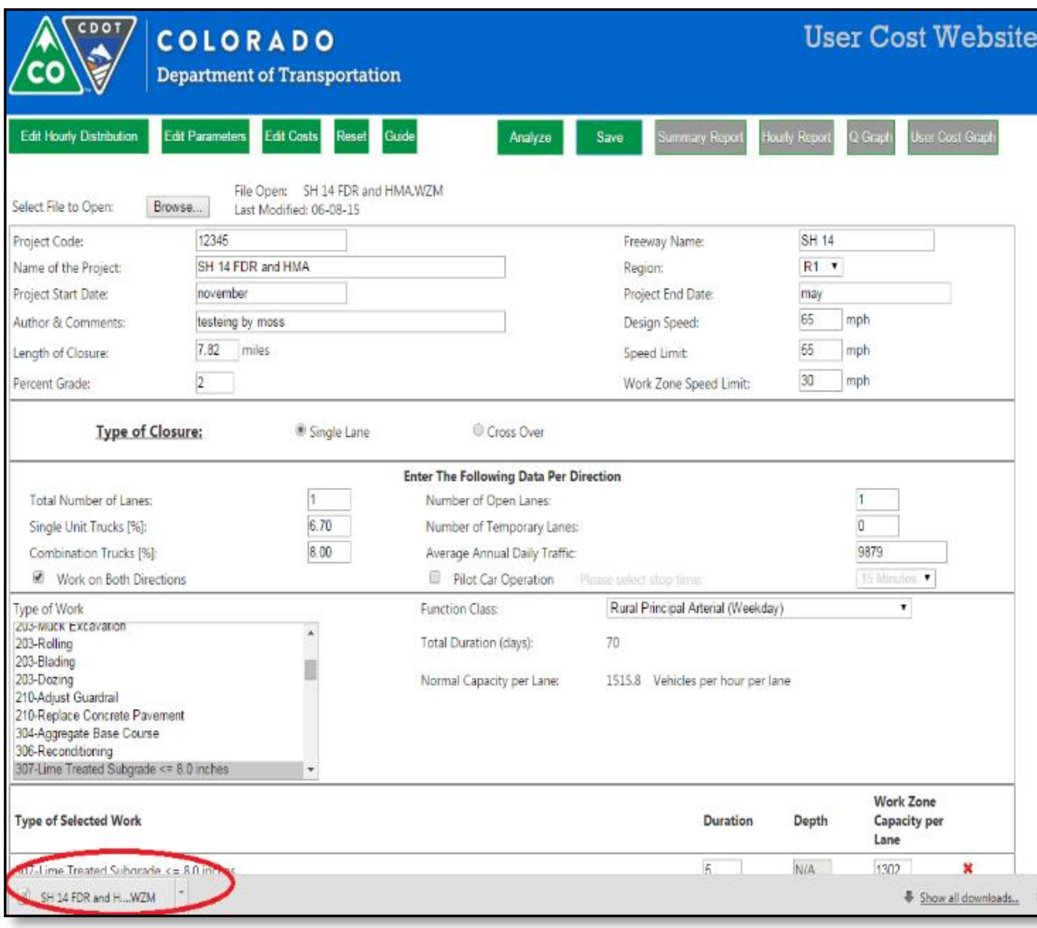


Figure 13.17 Saving a File

13.6 Probabilistic Life Cycle Cost Analysis

Two different computational approaches can be used in a LCCA; deterministic and probabilistic. The methods differ in the way they address the variability associated with the LCCA input values.

- **Deterministic:** In the deterministic approach, the analyst assigns each LCCA input variable a fixed, discrete value. The analyst determines the value most likely to occur for each parameter, usually basing the determination on historical evidence or professional judgment. Collectively, the input values are used to compute a single life-cycle cost estimate for the alternative under consideration. Traditionally, applications of a LCCA have been deterministic. A deterministic life-cycle cost computation is straightforward and can be conducted manually with a calculator or automatically with a spreadsheet. Sensitivity analyses may be conducted to test input assumptions by varying one input, holding other inputs constant, and determining the effect of the variation on the outputs. The deterministic approach, however, fails to address simultaneous variation in multiple inputs, and it fails to convey the degree of uncertainty associated with the life-cycle cost estimates.

- **Probabilistic:** Probabilistic LCCA inputs are described by probability functions that convey both the range of likely inputs and the likelihood of their occurrence. Probabilistic LCCA also allows for the simultaneous computation of differing assumptions for many different variables. Outputs and inputs express the likelihood a particular life-cycle cost will actually occur. Because of the dramatic increases in computer processing capabilities of the last two decades, the process of probabilistic analysis has become more practical. Simulating and accounting for simultaneous changes in LCCA input parameters can now be accomplished easily and quickly.

13.7 FHWA RealCost Software

The RealCost software was created with two distinct purposes. The first is to provide an instructional tool for pavement design decision-makers who want to learn about the LCCA. The software allows the student of LCCA to investigate the effects of cost, service life, and economic inputs on life-cycle cost. For this purpose, a Graphical User Interface (GUI) was designed to make the software easy to use. The second purpose is to provide an actual tool for pavement designers which they can use to incorporate life-cycle costs into their pavement investment decisions.

The RealCost software automates FHWA's LCCA methodology as it applies to pavements by calculating life-cycle values for both agency and user costs associated with construction and rehabilitation. The software can perform both deterministic sensitivity analyses and probabilistic risk analysis of pavement LCCA problems. Additionally, RealCost supports deterministic sensitivity and probabilistic risk analyses. RealCost compares two alternatives at a time and has been designed to give the pavement engineer the ability to compare an unlimited number of alternatives. By saving the input files of all alternatives being considered, the analyst can compare any number of alternatives. Furthermore, the software has been designed so an understanding of the LCCA process is sufficient to operate the software. Outputs are provided in tabular and graphic format.

The software automates FHWA's work zone user cost calculation method. This method for calculating user costs compares traffic demand to roadway capacity on an hour-by-hour basis, revealing the resulting traffic conditions. The method is computation intensive and ideally suited to a spreadsheet application. The software does not calculate agency costs or service lives for individual construction or rehabilitation activities. These values must be input by the analyst and should reflect the construction and rehabilitation practices of the agency. While RealCost compares the agency and user life-cycle costs of alternatives, its analysis outputs alone do not identify which alternative is the best choice for implementing a project. The lowest life-cycle cost option may not be implemented when other considerations such as risk, available budgets, and political and environmental concerns are taken into account. As with any economic tool, LCCA provides critical information to the overall decision-making process, but not the answer itself. FHWA's RealCost software may be obtained at:
http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm

13.7.1 Real Cost Switchboard

RealCost opens to the main menu form, called the *"Switchboard,"* a form superimposed on Microsoft Excel worksheet. The switchboard buttons, shown in **Figure 13.18 The RealCost Switchboard**, provide access to almost all of the functionality of the software including: data entry, analysis, reports, and utilities. The switchboard has five sections:

- **Project-Level Inputs:** Data that will be used for all alternatives. This data documents the project characteristics, define the common benefits that all alternatives will provide, and specifies the common values (i.e., discount rate) that will be applied with each alternative.

- **Alternative-Level Inputs:** Data that will be used for a specific design alternative. This data differentiate and alternatives from each other.

- **Input Warnings:** A list of missing or potentially erroneous data. The software identifies and displays the list.

- **Simulation and Output:** Forms used to view deterministic results, run Monte Carlo simulation of probabilistic inputs, view probabilistic results, and print reports.

- **Administrative Functions:** Forms used to save, clear, and retrieve data and to close the Switchboard or RealCost.

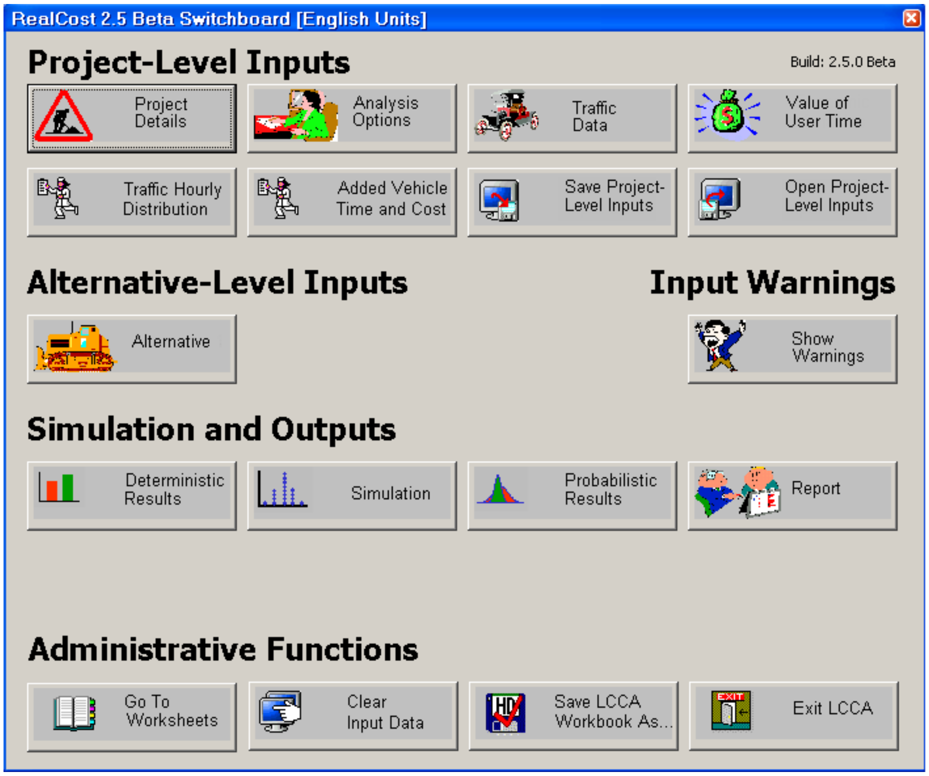


Figure 13.18 The Real Cost Switchboard

13.7.2 Real Word Example Using the RealCost Software

Compare 9 inches of HMA to 12 inches PCCP on a 4-lane section of I-70 (2-lanes per direction) near Bethune Colorado from MP 417 to MP 427, which is located in Region 1 (prior to 7/1/2013).

- **HMA (9 inches):** It is estimated the HMA alternative will take 54 construction days working from 8:00 a.m. to 5:00 p.m. with a single lane closure per direction. Each of HMA rehabilitation cycle will take approximately 20 construction days.

- **PCCP (12 inches):** The alternative will take 100 construction days per direction using a cross over. PCCP rehabilitation will take approximately 30 construction days (8:00 a.m. to 5:00 p.m.).

13.7.3 Project Details Options

The project details screen is used to identify and document the project, see **Figure 13.19 Project Details Input Screen**. The designer may enter project documentation details according to the field names (data entered into this form are not used in the analysis).

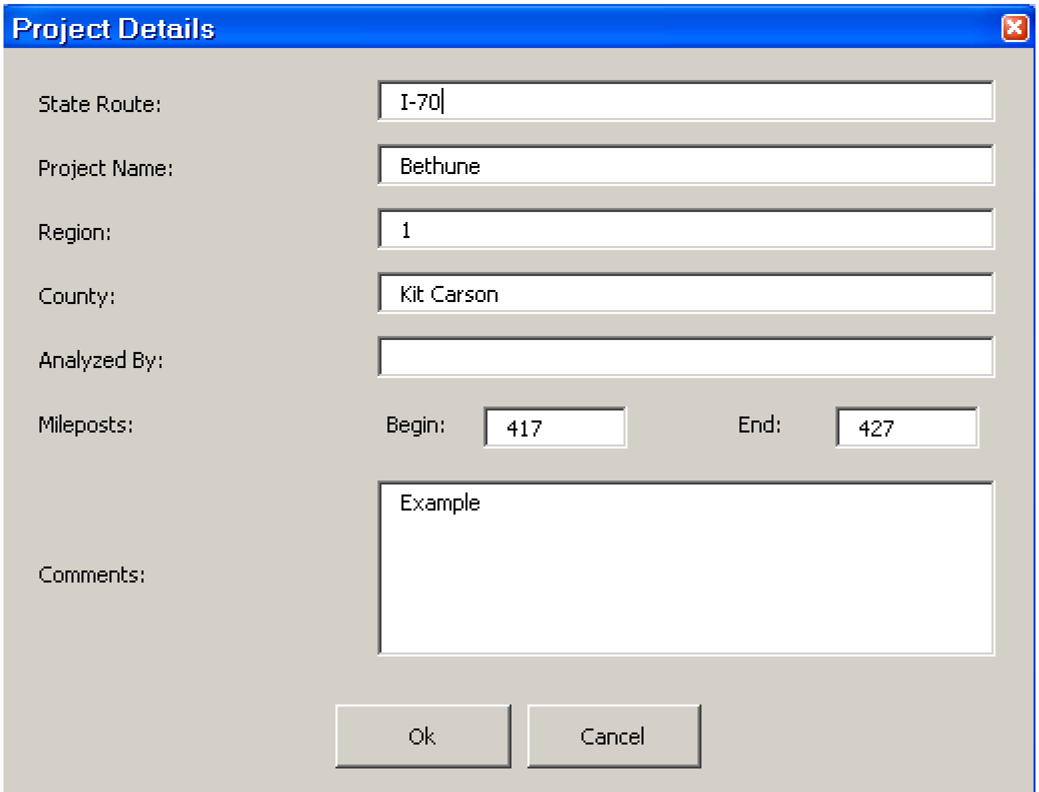


Figure 13.19 Project Details Input Screen

13.7.4 Analysis Options

Generally, analysis options are decided by agency policy rather than the pavement designer. Options defined in the Analysis Options form include the analysis period, discount rate, beginning year, inclusion of residual service life, and the treatment of user costs in the LCCA, see **Figure 13.20 Analysis Option Screen**. The data inputs and analysis options available on this form are discussed in **Table 13.6 Analysis Data Inputs and Analysis Options**, with CDOT and FHWA's recommendations. A checked box equals *"Yes,"* and unchecked box equals *"No"*.

Table 13.6 Analysis Data Inputs and Analysis Options

Variable Name	Probability Distribution (CDOT Default)	Value (CDOT Default)	Source
Analysis Units	Select option	English	CDOT
Analysis Period (Years)	User specified	40	**Sections 13.3.1, 13.3.2,** and **13.3.3**
Discount Rate (%)	Log normal	Mean and standard deviation	**Section 13.4** T-bill, inflation rate, and 10-year moving average
Beginning of Analysis Period	User specified	Date (year)	Project start date
Included Agency Cost Remaining Service Life Value	Select option	Yes	**Section 13.5** (serviceable life)
Include User Costs in Analysis	Select option	Yes	**Section 13.5.7**
User Cost Computation Method	Select option (specified/calculated)	Specified	**Section 13.5.7** Use user costs from CDOT WorkZone software*
Traffic Direction	Select option (both/inbound/outbound)	Both	Site specific
Include User Cost RSL	Select option	Yes	**Section 13.5.7**

Note: * When *"Specified"* is selected the manual calculated user cost from the WorkZone program will be used in the RealCost program.

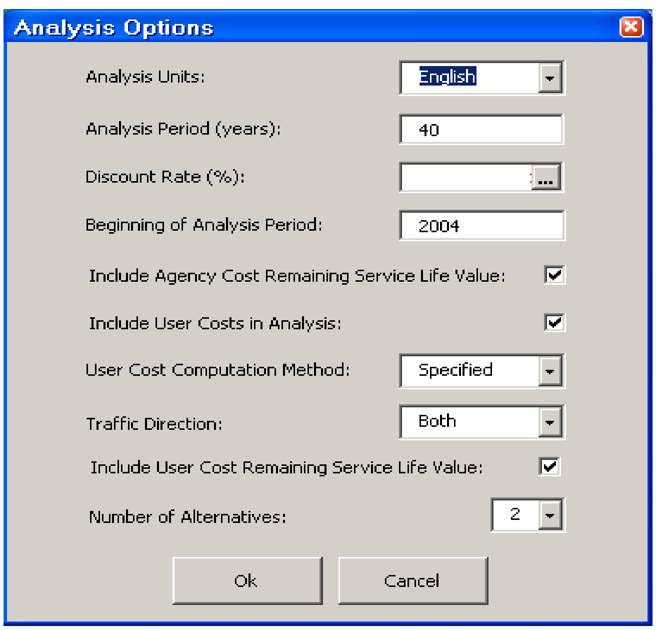


Figure 13.20 Analysis Option Screen

13.7.5 Traffic Data Options

Pavement engineers use traffic data to determine their design parameters. In RealCost traffic (see **Figure 13.21 Traffic Data Option Screen**) traffic data is used exclusively to calculate WorkZone.

Table 13.7 Traffic Data Options

Variable Name	Probability Distribution (CDOT Default)	Value (CDOT Default)	Source
AADT Construction Year (total for both directions)	Deterministic	User input	**Section 3.1.3**
Single Unit Trucks as Percentage of AADT (%)	Deterministic	User input	**Section 3.1.3**
Combination Trucks as Percentage of AADT (%)	Deterministic	User input	**Section 3.1.3**
Annual Growth Rate of Traffic (%)	Triangular	Minimum = 0.34 Most likely = 1.34 Maximum = 2.34	**Section 3.1.3**
Speed Limit Under Normal Operating Conditions (mph)	Deterministic	User input	Site specific
Lanes Open in Each Direction Under Normal Conditions	Deterministic	User input	Site specific
Free Flow Capacity (vphpl)	Deterministic	User input	CDOT WorkZone software (normal capacity per lane)
Queue Dissipation Capacity (vphpl)	Deterministic	User input	CDOT WorkZone software (work zone capacity per lane)
Maximum AADT (total for both directions)	Deterministic	User input	Site specific
Maximum Queue Length (miles)	Deterministic	5 miles	CDOT
Rural or Urban Hourly Traffic Distribution	Select option (urban/rural)	User input	CDOT WorkZone software (functional class)

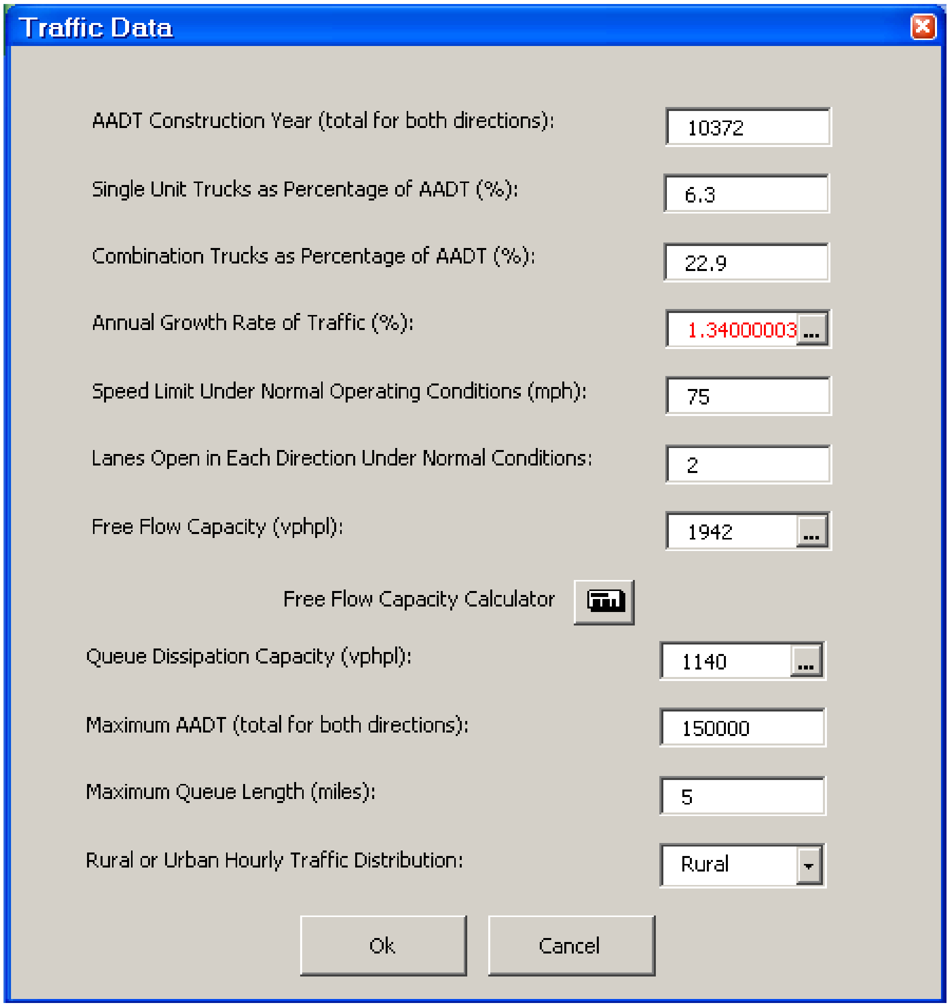


Figure 13.21 Traffic Data Option Screen

- **The Free Flow Capacity (FFC or vphpl):** Obtained from CDOT WorkZone software and is labeled *'Normal Capacity Per Lane'* on the input screen.

- **Queue Dissipation Capacity (QDC or vphpl):** Must be equal to or greater than the largest value of work zone capacity per lane under the alternatives input screen(s); otherwise an error is detected under the input error warnings check. The QDC is on a roadway when there is no work zone. The traffic comes to a either a complete or near complete stop and then starts and dissipates; similar vehicles at a traffic light or if an object is in the roadway. Thus, the QDC is how much traffic the roadway will carry under these conditions. This is different than free flow capacity and during a work zone's normal traffic flow where normal traffic slows down but does not come to a complete stop or near stop. Therefore, the QDC must be larger for the same roadway to be able to disperse more volume of traffic than a work zone condition.

Only a deterministic value is needed for the maximum AADT (both direction). The *Highway Capacity Manual* (2000) lists various volumes of freeways with 4, 6, and 8 lanes and a 4 lane arterial. It is fortunate that Denver, Colorado is listed in the tables and exhibits.

<u>Exhibit 8-13</u> – Reported maximum directional volumes on selected urban streets in the *Highway Capacity Manual* (2000) is shown as:

Colorado State Highway 2
6 Lanes: 3,435 vehicles/hour
Therefore: 3,435 vehicles/hour * 2 directions = 6,870 vehicles/hour both directions
6,870 vehicles/hour both directions * 24 hours = 164,880 maximum AADT both directions

<u>Exhibit 8-19</u> – Reported maximum hourly one-way volumes on selected freeways in the Highway Capacity Manual (2000) lists various volumes of freeways with 4, 6, and 8 lanes.

Colorado State Highway I-225
4-lane: 4,672 vehicles/hour
Therefore: 4,672 vehicles/hour * 2 directions = 9,344 vehicles/hour both directions
9,344 vehicles/hour both directions * 24 hours = 224,256 maximum AADT both directions
Colorado State Highway 6
6-lane: 7,378 vehicles/hour
Therefore: 7,378 vehicles/hour * 2 directions = 14,756 vehicles/hour both directions
14,756 vehicles/hour both directions * 24 hours = 354,144 maximum AADT both directions
Interstate Highway I-25
8-lane: 8,702 vehicles/hour
Therefore: 8,702 vehicles/hour * 2 directions = 17,404 vehicles/hour both directions
17,404 vehicles/hour both directions * 24 hours = 417,696 maximum AADT both directions

The pavement designer may select a reasonable maximum AADT. If need be, an interpolation may be in order to fit the project specifics. An alternate method is to use the Free Flow Capacity (vphpl) multiplied by the number of lanes, multiplied by the 2 directions, and multiplied by 24 hours.

13.7.6 Value of User Time

The '*Value of User Time'* form, shown in **Figure 13.22 Value of User Option Screen**, allows editing of the values applied to an hour of user time. The dollar value of user time is different for each vehicle type and used to calculate user costs associated with delay during work zone operations.

Table 13.8 Value of User Time Data Options

Variable Name	Probability Distribution (CDOT Default)	Value (CDOT Default)	Source
Value of Time for Passenger Cars ($/hour)	Deterministic	18.50	CDOT Work Zone software **Section 13.5.7**
Value of Time for Single Unit Trucks ($/hours)	Deterministic	43.50	CDOT Work Zone software **Section 13.5.7**
Value of Time for Combination Trucks ($/hour)	Deterministic	49.50	CDOT Work Zone software **Section 13.5.7**

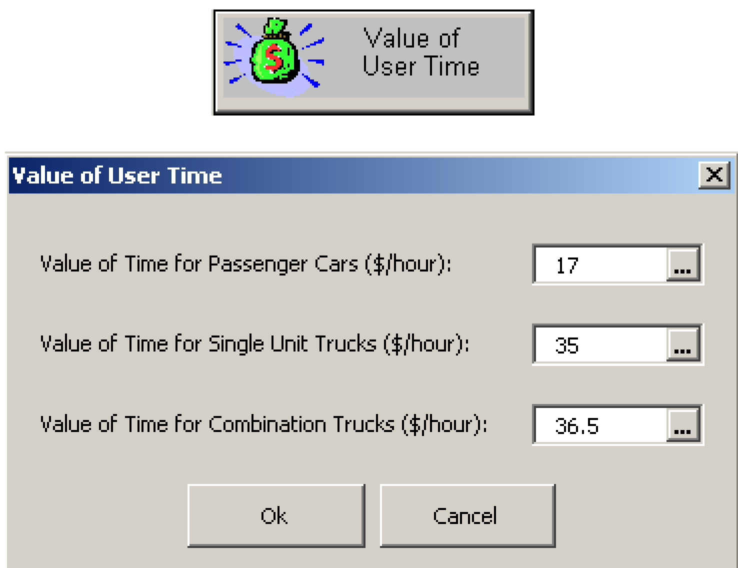


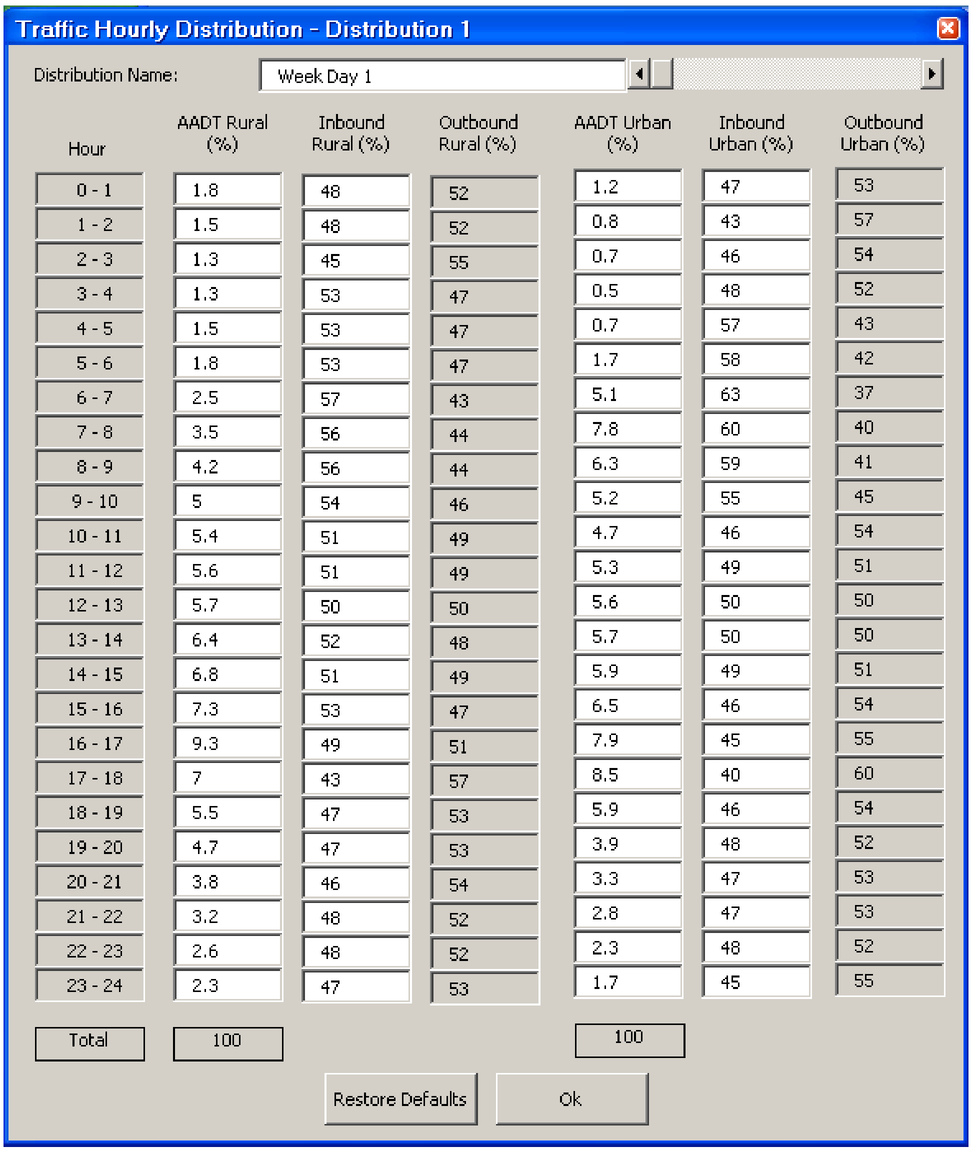
Figure 13.22 Value of User Option Screen

13.7.7 Traffic Hourly Distribution

To transform Annual Average Daily Traffic (AADT) to an hourly traffic distribution use the default Rural and Urban Traffic hourly distributions from MicroBENCOST provided with the RealCost software. The '*Traffic Hourly Distribution*' (see **Figure 13.23 Traffic Hourly Distribution Screen**) form is used to adjust (or restore) these settings. Distributions are required to sum to 100 percent.

Table 13.9 Traffic Hourly Distribution Data Options

Variable Name (percent)	Probability Distribution (CDOT Default)	Value (CDOT Default)	Source
AADT Rural	Real Cost default	Real Cost default	Real Cost software
Inbound Rural	Real Cost default	Real Cost default	Real Cost software
AADT Urban	Real Cost default	Real Cost default	Real Cost software
Inbound Urban	Real Cost default	Real Cost default	Real Cost software


Traffic Hourly Distribution - Distribution 1

Distribution Name: Week Day 1

Hour	AADT Rural (%)	Inbound Rural (%)	Outbound Rural (%)	AADT Urban (%)	Inbound Urban (%)	Outbound Urban (%)
0 - 1	1.8	48	52	1.2	47	53
1 - 2	1.5	48	52	0.8	43	57
2 - 3	1.3	45	55	0.7	46	54
3 - 4	1.3	53	47	0.5	48	52
4 - 5	1.5	53	47	0.7	57	43
5 - 6	1.8	53	47	1.7	58	42
6 - 7	2.5	57	43	5.1	63	37
7 - 8	3.5	56	44	7.8	60	40
8 - 9	4.2	56	44	6.3	59	41
9 - 10	5	54	46	5.2	55	45
10 - 11	5.4	51	49	4.7	46	54
11 - 12	5.6	51	49	5.3	49	51
12 - 13	5.7	50	50	5.6	50	50
13 - 14	6.4	52	48	5.7	50	50
14 - 15	6.8	51	49	5.9	49	51
15 - 16	7.3	53	47	6.5	46	54
16 - 17	9.3	49	51	7.9	45	55
17 - 18	7	43	57	8.5	40	60
18 - 19	5.5	47	53	5.9	46	54
19 - 20	4.7	47	53	3.9	48	52
20 - 21	3.8	46	54	3.3	47	53
21 - 22	3.2	48	52	2.8	47	53
22 - 23	2.6	48	52	2.3	48	52
23 - 24	2.3	47	53	1.7	45	55
Total	100			100		

Restore Defaults | Ok

Figure 13.23 Traffic Hourly Distribution Screen

13.7.8 Added Time and Vehicle Cost Options

- **Added Time per 1,000 Stops (Hours)** and **Added Cost per 1,000 Stops ($)**: These values are used to calculate user delay and vehicle costs due to speed changes that occur during work zone operations. This form (see **Figure 13.24 Added Time and Vehicle Stopping Costs Screen**) is used to adjust the default values for added time and added cost per 1,000 stops.

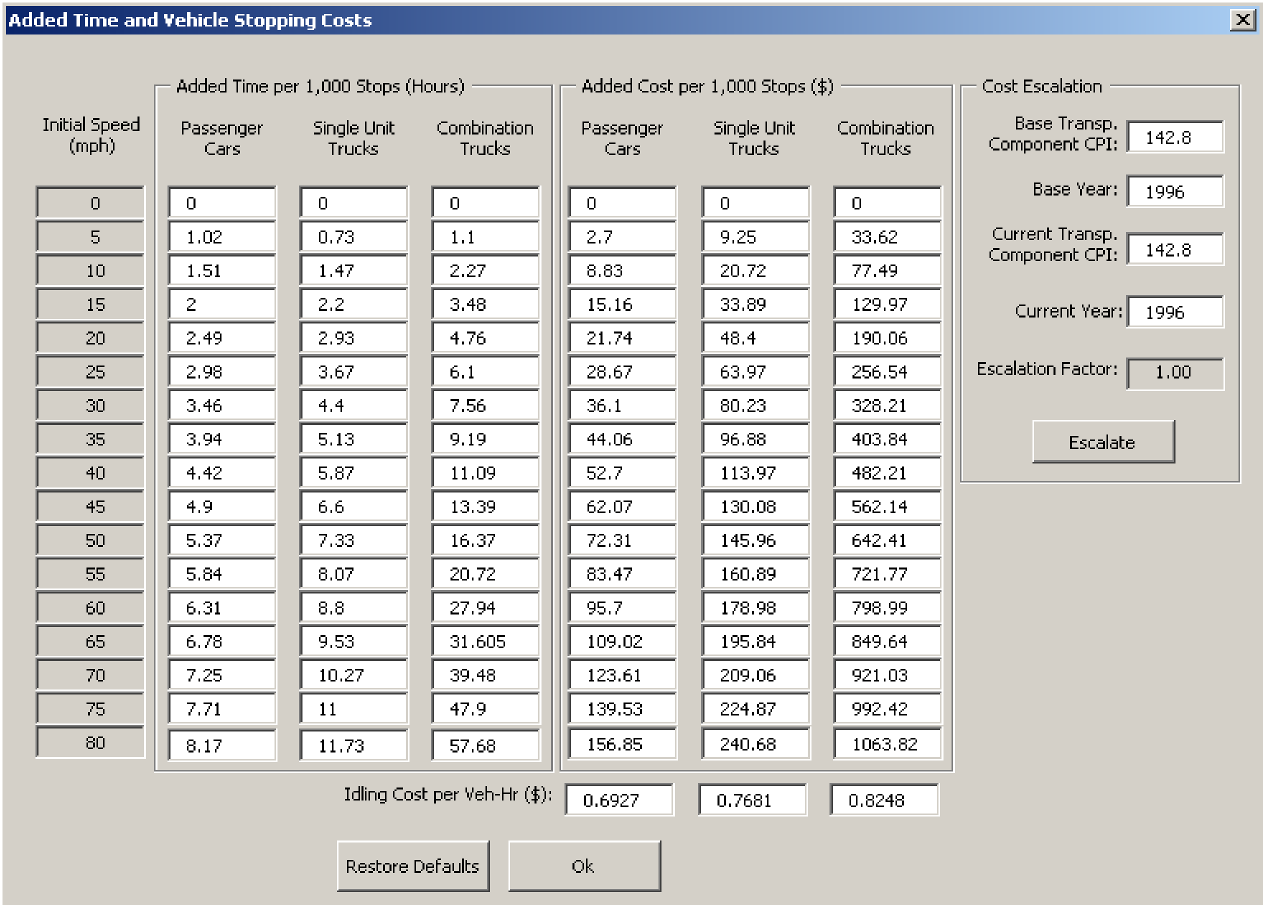
- **Idling Cost per Veh-Hr ($):** This value is used to calculate the additional vehicle operating costs resulting from traversing a traffic queue under stop and go conditions. The costs and times are different for each vehicle type.

- **Restore Defaults**: This button functions much the same as it does on the '*Traffic Hourly Distribution'* form. The default values are drawn from NCHRP Study 133, *Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects.*

- **Colorado Construction Cost Index**: May be obtained from the Agreements and Market Analysis Branch, Engineering Estimates and Market Analysis Unit. The unit publishes a quarterly report and is in Acrobat file format.

Table 13.10 Added Time and Vehicle Costs Data Options

Variable Name	Probability Distribution (CDOT Default)	Value (CDOT Default)	Source
Added Time Passenger Cars	Real Cost default	Real Cost default	Real Cost software
Added Time Single Unit Trucks	Real Cost default	Real Cost default	Real Cost software
Added Time Combination Trucks	Real Cost default	Real Cost default	Real Cost software
Added Cost Passenger Cars	Real Cost default	Real Cost default	Real Cost software
Added Cost Single Unit Trucks	Real Cost default	Real Cost default	Real Cost software
Added Cost Combination Trucks	Real Cost default	Real Cost default	Real Cost software
Base Transportation Component CPI	Deterministic	142.8	Real Cost software
Base Year	Deterministic	1996	Real Cost software
Current Transportation Component CPI	Deterministic	User input	CDOT
Current Year	Deterministic	User input	CDOT
Idling Cost Per Vehicle HR ($) Passenger Cars	Real Cost default	Real Cost default	Real Cost software
Idling Cost Per Vehicle HR ($) Single Unit Trucks	Real Cost default	Real Cost default	Real Cost software
Idling Cost Per Vehicle HR ($) Combination Trucks	Real Cost default	Real Cost default	Real Cost software



Initial Speed (mph)	Added Time: Passenger Cars	Added Time: Single Unit Trucks	Added Time: Combination Trucks	Added Cost: Passenger Cars	Added Cost: Single Unit Trucks	Added Cost: Combination Trucks
0	0	0	0	0	0	0
5	1.02	0.73	1.1	2.7	9.25	33.62
10	1.51	1.47	2.27	8.83	20.72	77.49
15	2	2.2	3.48	15.16	33.89	129.97
20	2.49	2.93	4.76	21.74	48.4	190.06
25	2.98	3.67	6.1	28.67	63.97	256.54
30	3.46	4.4	7.56	36.1	80.23	328.21
35	3.94	5.13	9.19	44.06	96.88	403.84
40	4.42	5.87	11.09	52.7	113.97	482.21
45	4.9	6.6	13.39	62.07	130.08	562.14
50	5.37	7.33	16.37	72.31	145.96	642.41
55	5.84	8.07	20.72	83.47	160.89	721.77
60	6.31	8.8	27.94	95.7	178.98	798.99
65	6.78	9.53	31.605	109.02	195.84	849.64
70	7.25	10.27	39.48	123.61	209.06	921.03
75	7.71	11	47.9	139.53	224.87	992.42
80	8.17	11.73	57.68	156.85	240.68	1063.82

Table 13.11 Added Time and Vehicle Stopping Costs Screen

13.7.9 Saving and Opening Project-Level Inputs

The last two buttons in the project level input section of the Switchboard (see **Figure 13.25 Saving and Opening Project Level Inputs**) are used to save and to retrieve (load) project-level inputs. Project-level inputs are saved in a small, comma-delimited file. This file may be named via ordinary Windows conventions and is automatically saved with the *.LCC extension. Changing the file extension will prevent RealCost from recognizing the file. **Note**: Alternative level inputs are saved separately from project-level inputs. The mechanism to save and open alternative level inputs is found on the '*Alternative 1'* and '*Alternative 2'* forms.

Warning: Opening an *.LCC file will overwrite data in the '*Project-Level Inputs'* section.

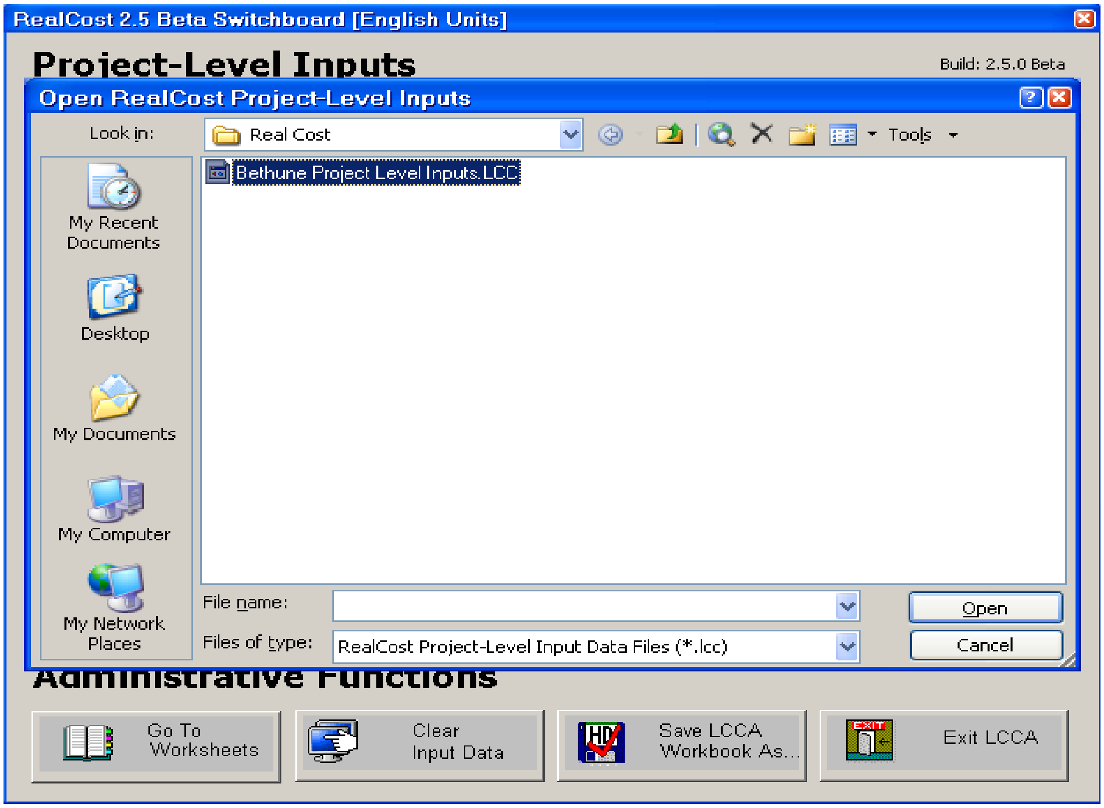


Table 13.12 Saving and Opening Project Level Inputs

Table 13.13 Number of Projects in the Study

Rehabilitation Technique	Components	Number of Projects
Heater Remixing	Process Mat	49
	Rejuvenating Agent	45
	Hydrating Lime	30
Heater Scarifying	Process Mat	19
	Rejuvenating Agent	17
Full Depth Reclamation (FDR)	-	54
Hot Mix Asphalt Overlay < 10,000 tons	All projects	84
	SX(100) PG 64-28	22
	SX(100) PG 64-22	34
	SX(100) PG 58-28	7
	SX(100) PG 76-28	7
	Furnish HMA	7
Hot Mix Asphalt Overlay > 10,000 tons	All projects	121
	SX(100) PG 64-22	36
	SX(100) PG 76-28	11
	SX(100) PG 58-28	11
	SX(100) PG 64-28	8
	SX(75)	21
Hot Mix Asphalt Mill and Fill < 10,000 tons	All projects	51
	SX(100) PG 64-22	15
	SX(100) PG 76-28	17
	SX(75) PG 58-28	7
Hot Mix Asphalt Mill and Fill > 10,000 tons	All projects	63
	SX(100) PG 64-22	10
	SX(75) PG 58-28	20
	SX(100) PG 64-28	5
	SX(100) PG 58-34	4
	SMA	13
Portland Cement Concrete Pavement < 10,000 square yards	All projects	184
Portland Cement Concrete Pavement > 10,000 square yards	All projects	67
Total		**692**

Table 13.14 Results of Heater Remixing

	Item	Amount
Process Mat	Number of Projects	49
	Total Square Yards	10,448,936
	Total Normalized Dollar Amount	$35,675,622
	Normalized Average per Square Yard	$3.41
Rejuvenating Agent	Number of Projects	45
	Total Gallons	698,230
	Total Normalized Dollar Amount	$1,243,166
	Normalized Average per Gallon	$45.45
Furnish HMA	Number of Projects	30
	Total Tons	115,302
	Total Normalized Dollar Amount	$5,330,720
	Normalized Average per Ton	$1.78

Table 13.15 Results of Heater Scarifying

	Item	Amount
Process Mat	Number of Projects	19
	Total Square Yards	3,676,832
	Total Normalized Dollar Amount	$3,785,756
	Normalized Average per Square Yard	$1.03
Rejuvenating Agent	Number of Projects	17
	Total Gallons	288,676
	Total Normalized Dollar Amount	$388,644
	Normalized Average per Gallon	$1.35

Table 13.16 Results of Full Depth Reclamation

Item	Amount
Number of Projects	22
Total Square Yards	2,033,398
Total Normalized Dollar Amount	$3,992,506
Normalized Average per Square Yard	$1.80

Table 13.17 Cold In-Place Recycling

	Item	Amount
All projects	Number of Projects	25
	Total Square Yards	4,809,986
	Total Normalized Dollar Amount	$3,785,756
	Normalized Average per Square Yard	$1.43
Rejuvenating Agent	Number of Projects	20
	Total Gallons	5,159,599
	Total Normalized Dollar Amount	$10,037,689
	Normalized Average per Gallon	$1.64
Hydrated Lime	Number of Projects	23
	Total Tons	15,876
	Total Normalized Dollar Amount	$1,594,706
	Normalized Average per Ton	$100.45

Table 13.18 PCCP Projects Less Than 10,000 Square Yards

	Item	Amount
All projects	Number of Projects	184
	Total Square Yards	383,088
	Total Normalized Dollar Amount	$24,650,614
	Normalized Average per Square Yard	$64.35
6 to 7 inches	Number of Projects	42
	Total Square Yards	31,569
	Total Normalized Dollar Amount	$1,161,058
	Normalized Average per Square Yard	$36.78
7 to 8 inches	Number of Projects	1
	Total Square Yards	5,917
	Total Normalized Dollar Amount	$172,757
	Normalized Average per Square Yard	$29.20
8 to 9 inches	Number of Projects	29
	Total Square Yards	55,627
	Total Normalized Dollar Amount	$3,206,541
	Normalized Average per Square Yard	$57.64
9 to 10 inches	Number of Projects	30
	Total Square Yards	81,124
	Total Normalized Dollar Amount	$5,771,991
	Normalized Average per Square Yard	$71.15
10 to 11 inches	Number of Projects	33
	Total Square Yards	84,032
	Total Normalized Dollar Amount	$6,172,580
	Normalized Average per Square Yard	$73,46

11 to 12 inches	Number of Projects	24
	Total Square Yards	58,018
	Total Normalized Dollar Amount	$4,330,870
	Normalized Average per Square Yard	$74.65
12 or greater inches	Number of Projects	19
	Total Square Yards	55,623
	Total Normalized Dollar Amount	2,895,314
	Normalized Average per Square Yard	$52.04

Table 13.19 PCCP Projects Greater Than 10,000 Square Yards

	Item	Amount
All projects	Number of Projects	67
	Total Square Yards	3,599,664
	Total Normalized Dollar Amount	$131,056,876
	Normalized Average per Square Yard	$36.41
4 to 7 inches	Number of Projects	3
	Total Square Yards	300,164
	Total Normalized Dollar Amount	$6,576,434
	Normalized Average per Square Yard	$21.91
8 to 9 inches	Number of Projects	10
	Total Square Yards	253,232
	Total Normalized Dollar Amount	$11,911,473
	Normalized Average per Square Yard	$47.04
9 to 10 inches	Number of Projects	17
	Total Square Yards	487,941
	Total Normalized Dollar Amount	$22,002,017
	Normalized Average per Square Yard	$45.09
10 to 11 inches	Number of Projects	10
	Total Square Yards	359,992
	Total Normalized Dollar Amount	$12,380,592
	Normalized Average per Square Yard	$34.39
11 to 12 inches	Number of Projects	7
	Total Square Yards	482,129
	Total Normalized Dollar Amount	$18,558,033
	Normalized Average per Square Yard	$38.49
12 or greater inches	Number of Projects	13
	Total Square Yards	978,159
	Total Normalized Dollar Amount	$37,517,776
	Normalized Average per Square Yard	$38.36

Table 13.20 HMA Overlay Projects Less Than 10,000 Tons

	Item	Amount
All projects	Number of Projects	84
	Total Tons	328,045
	Total Normalized Dollar Amount	$26,368,555
	Normalized Average per Ton	$79.79
SX(100) PG 64-28	Number of Projects	22
	Total Tons	65,638
	Total Normalized Dollar Amount	$5,736,291
	Normalized Average per Ton	$87.39
SX(100) PG 64-22	Number of Projects	34
	Total Tons	169,785
	Total Normalized Dollar Amount	$12,741,234
	Normalized Average per Ton	$82.66
SX(100) PG 58-28	Number of Projects	7
	Total Tons	37,083
	Total Normalized Dollar Amount	$2,477,618
	Normalized Average per Ton	$66.81
SX(100) PG 76-28	Number of Projects	7
	Total Tons	32,173
	Total Normalized Dollar Amount	$2,330,107
	Normalized Average per Ton	$72.42
Furnish HMA	Number of Projects	7
	Total Tons	23,435
	Total Normalized Dollar Amount	$1,496,769
	Normalized Average per Ton	$63.87

Table 13.21 HMA Overlay Projects Greater Than 10,000 Tons

	Item	Amount
All projects	Number of Projects	121
	Total Tons	4,282,222
	Total Normalized Dollar Amount	$248,255,441
	Normalized Average per Ton	$57.97
SX(100) PG 64-28	Number of Projects	9
	Total Tons	196,537
	Total Normalized Dollar Amount	$10,871,686
	Normalized Average per Ton	$55.32
SX(100) PG 64-22	Number of Projects	36
	Total Tons	1,210,798
	Total Normalized Dollar Amount	$68,523,424
	Normalized Average per Ton	$56.59

SX(100) PG 58-28	Number of Projects	11
	Total Tons	416,493
	Total Normalized Dollar Amount	$30,887,680
	Normalized Average per Ton	$74.16
SX(100) PG 76-28	Number of Projects	11
	Total Tons	416,493
	Total Normalized Dollar Amount	$30,887,680
	Normalized Average per Ton	$79.73
SX (75)	Number of Projects	21
	Total Tons	719,034
	Total Normalized Dollar Amount	$23,675,171
	Normalized Average per Ton	$32.93

Table 13.22 HMA Mill and Fill for Projects Greater Than 10,000 Tons

	Item	Amount
All projects	Number of Projects	51
	Total Tons	212,732
	Total Normalized Dollar Amount	$16,296,645
	Normalized Average per Ton	$76.61
SX(100) PG 64-22	Number of Projects	15
	Total Tons	28,333
	Total Normalized Dollar Amount	$2,418,438
	Normalized Average per Ton	$85.36
SX(100) PG 58-28	Number of Projects	7
	Total Tons	21,216
	Total Normalized Dollar Amount	2,730,082
	Normalized Average per Ton	$128.68
SX(100) PG 76-28	Number of Projects	17
	Total Tons	110,791
	Total Normalized Dollar Amount	$7,000,071
	Normalized Average per Ton	$63.18

Table 13.23 HMA Mill and Fill for Projects Greater Than 10,000 Tons

	Item	Amount
All projects	Number of Projects	63
	Total Tons	1,751,060
	Total Normalized Dollar Amount	$127,667,932
	Normalized Average per Ton	$72.56
SX(100) PG 58-34	Number of Projects	4
	Total Tons	95,697
	Total Normalized Dollar Amount	$8,251,056
	Normalized Average per Ton	$86.22
SX(100) PG 64-22	Number of Projects	5
	Total Tons	136,753
	Total Normalized Dollar Amount	$9,562,261
	Normalized Average per Ton	$69.92
SX(100) PG 58-28	Number of Projects	21
	Total Tons	688,657
	Total Normalized Dollar Amount	$48,738,394
	Normalized Average per Ton	$70.77
SX(100) PG 76-28	Number of Projects	10
	Total Tons	207,138
	Total Normalized Dollar Amount	$12,558,276
	Normalized Average per Ton	$60.63
SMA	Number of Projects	13
	Total Tons	345,467
	Total Normalized Dollar Amount	$30,229,383
	Normalized Average per Ton	$87.50

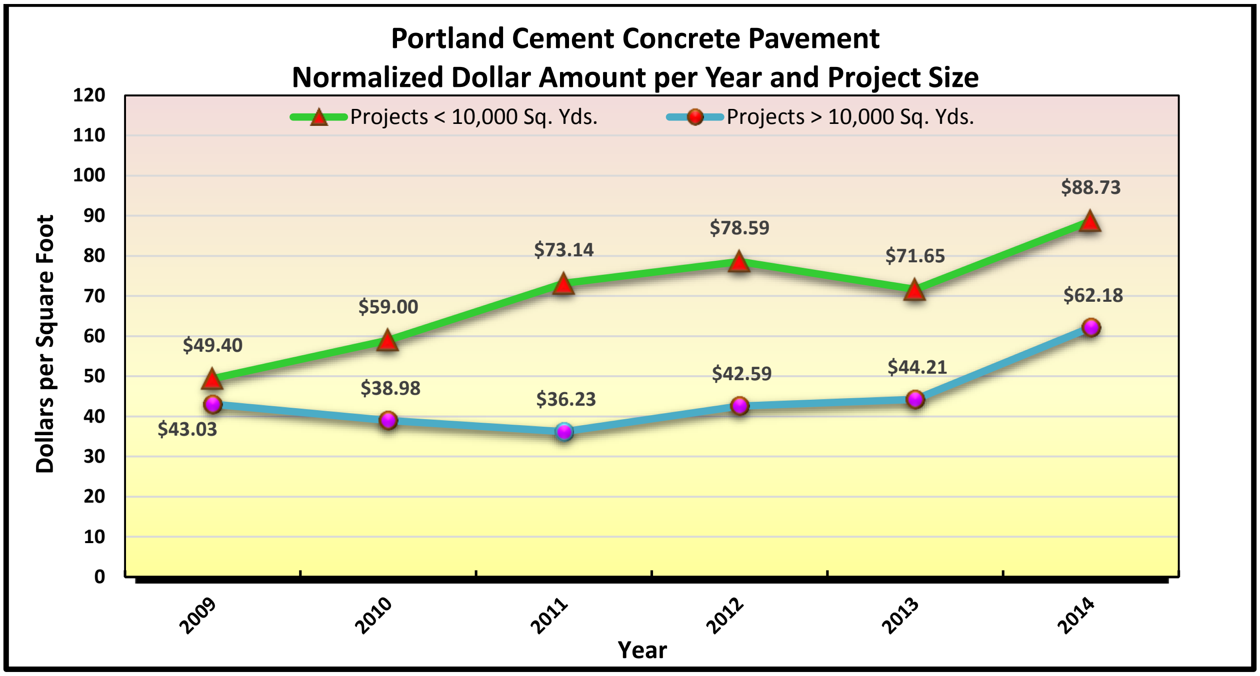


Figure 13.24 PCCP Normalized Dollar Amount per Year

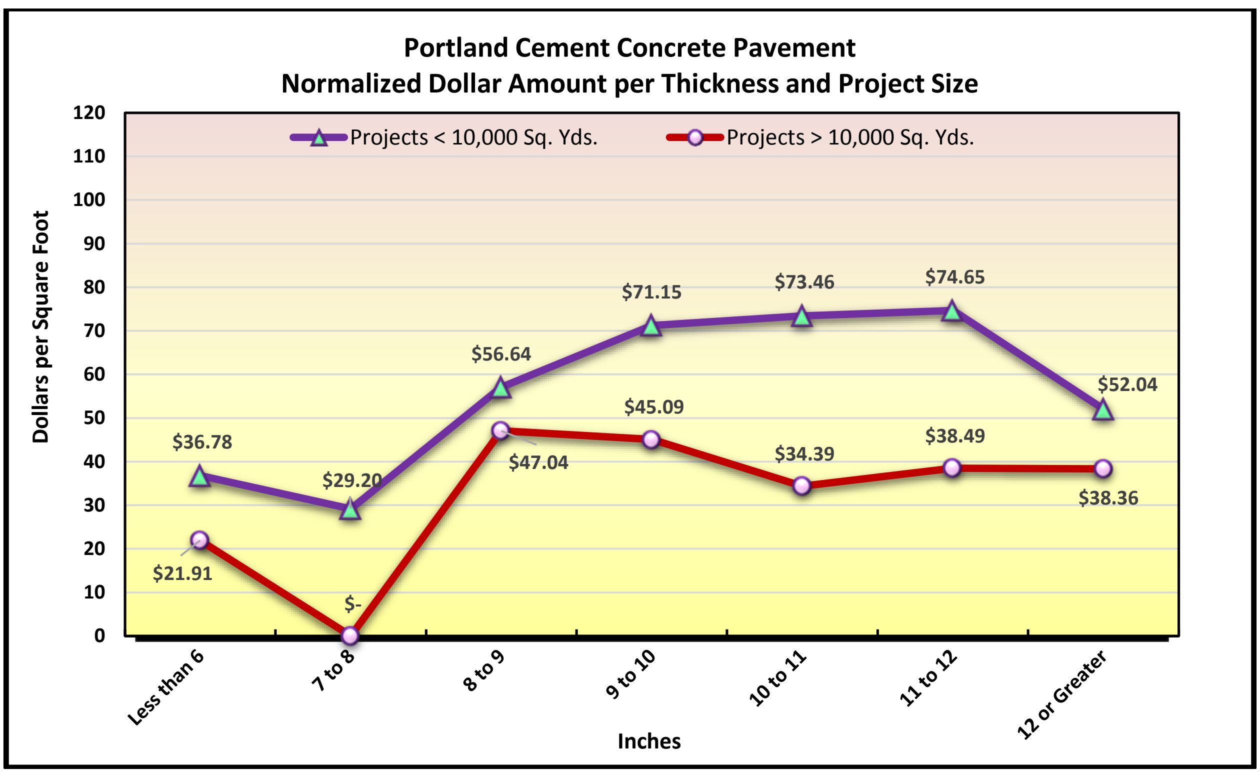


Figure 13.25 PCCP Normalized Dollar Amount per Thickness

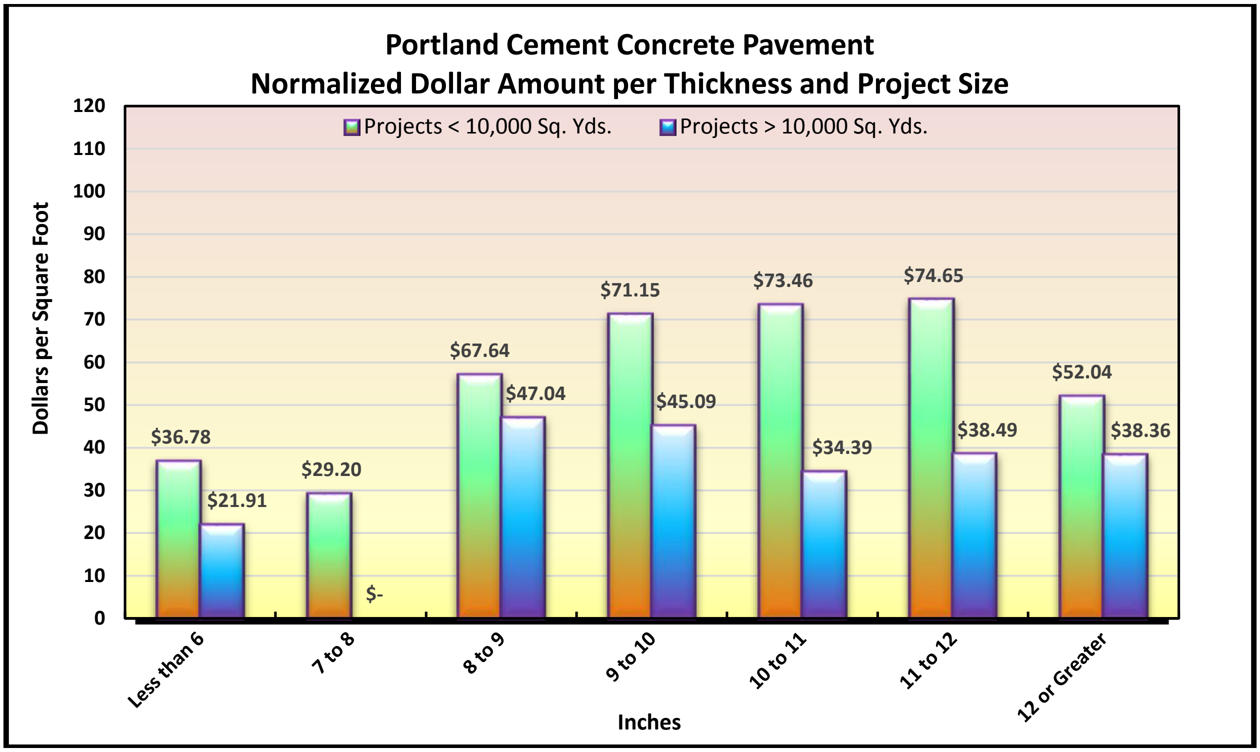


Figure 13.26 PCCP Normalized Dollar Amount per Thickness

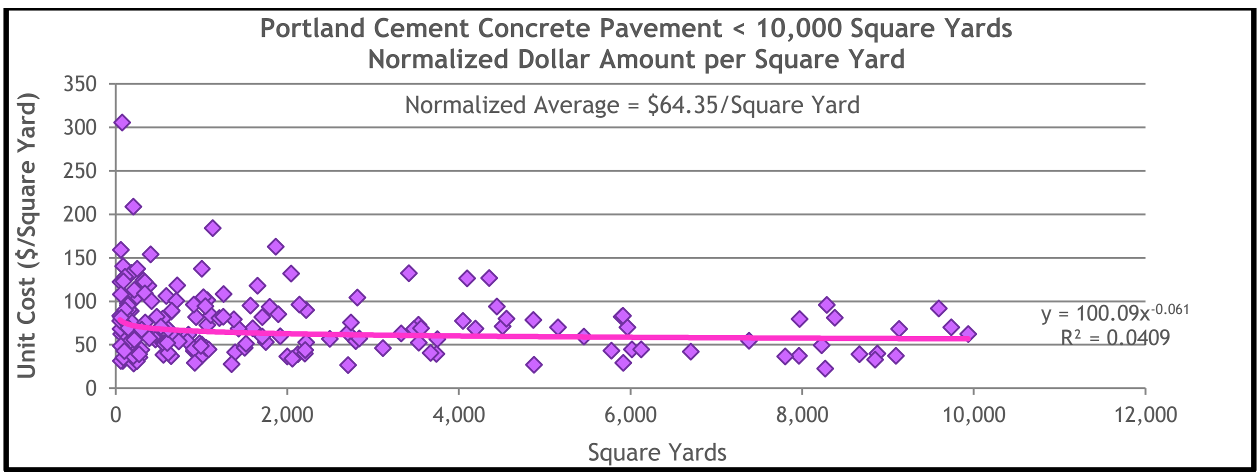


Figure 13.27 PCCP Normalized Dollar Amount per Total Square Yards for Projects Less Than 10,000 Square Yards

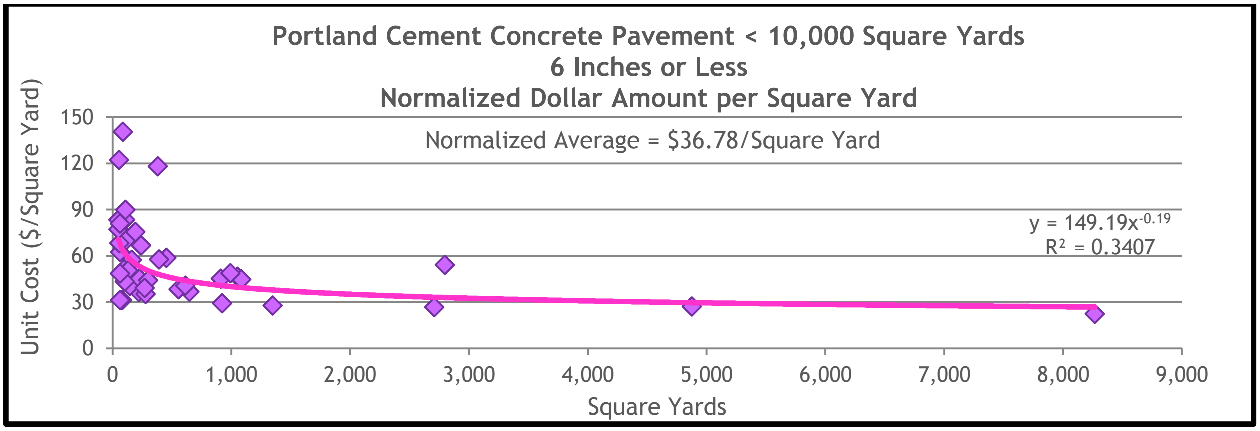


Figure 13.28 PCCP Normalized Dollar Amount for Projects of 6 Inches or Less in Thickness and Less Than 10,000 Square Yards in Size

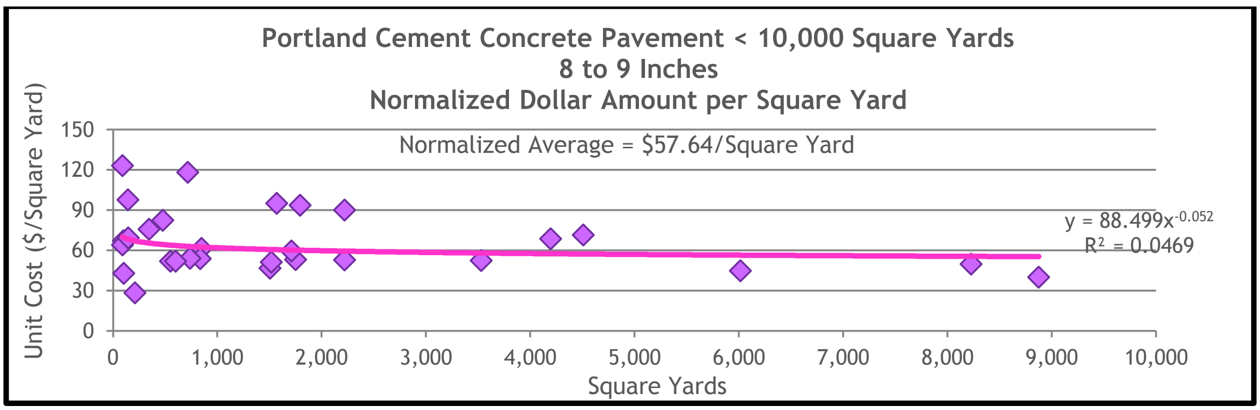


Figure 13.29 Normalized Dollar Amount for Projects of 8 to 9 Inches in Thickness and Less Than 10,000 Square Yards in Size

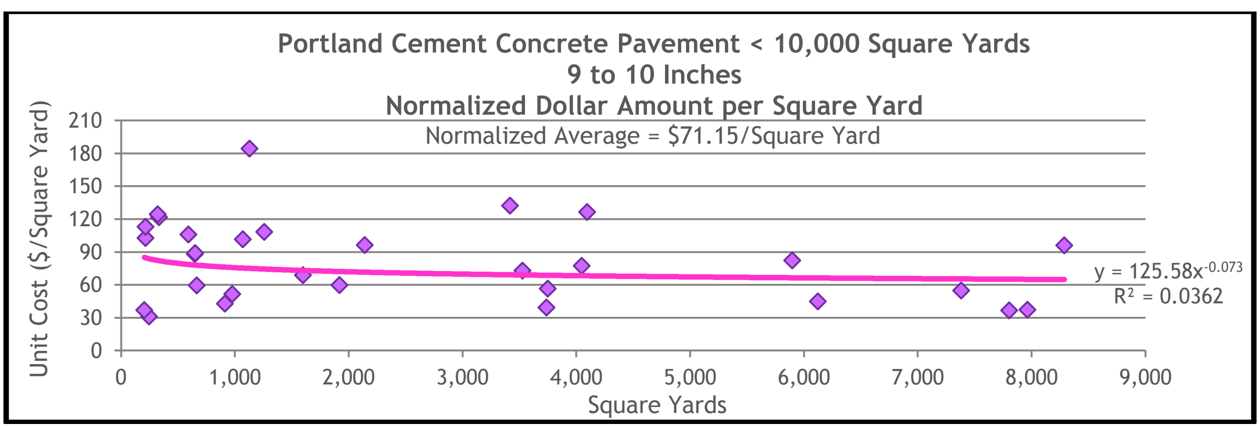


Figure 13.30 Normalized Dollar Amount for Projects of 9 to 10 Inches in Thickness and Less Than 10,000 Square Yards in Size

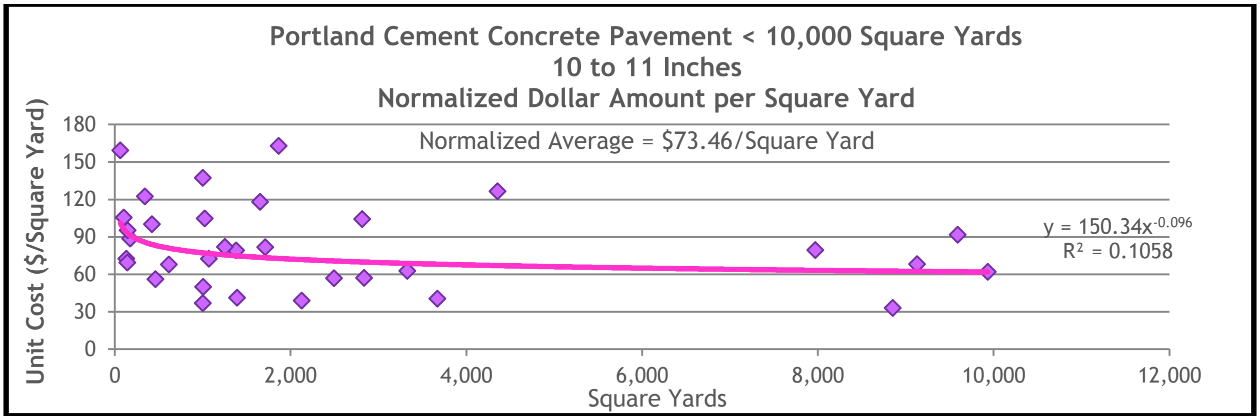


Figure 13.31 PCCP Normalized Dollar Amount for Projects of 10 to 11 Inches in Thickness and Less Than 10,000 Square Yards in Size

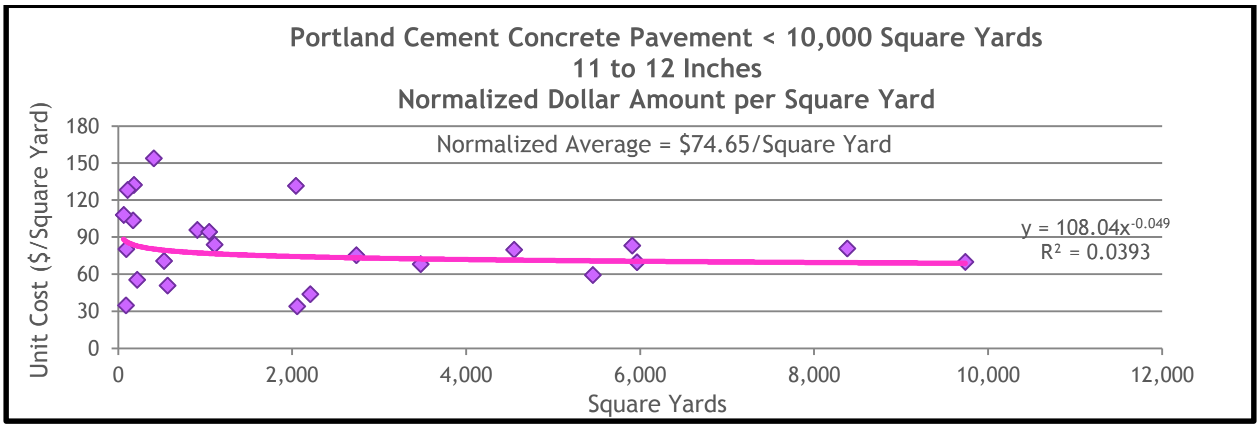


Figure 13.32 PCCP Normalized Dollar Amount for Projects of 11 to 12 Inches in Thickness and Less Than 10,000 Square Yards in Size

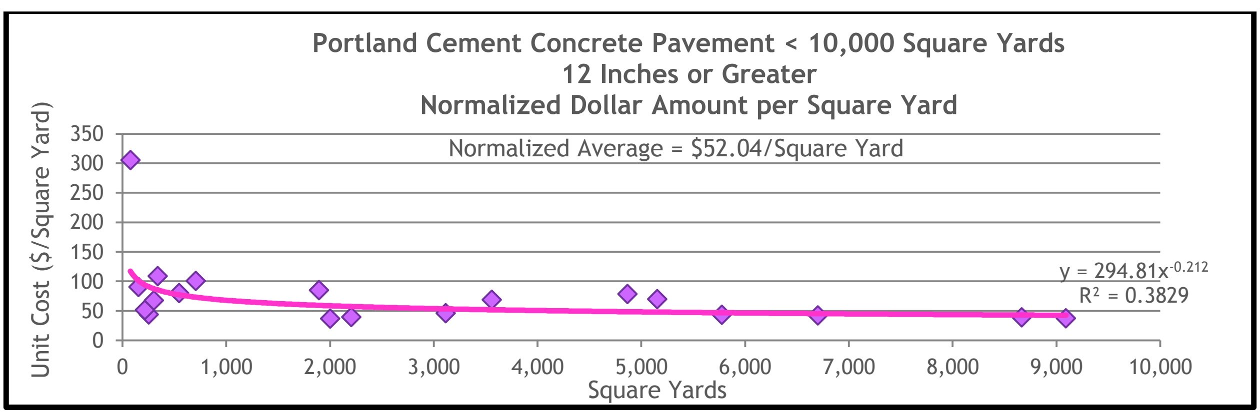


Figure 13.33 PCCP Normalized Dollar Amount for Projects of 12 Inches or Greater in Thickness and Less Than 10,000 Square Yards in Size

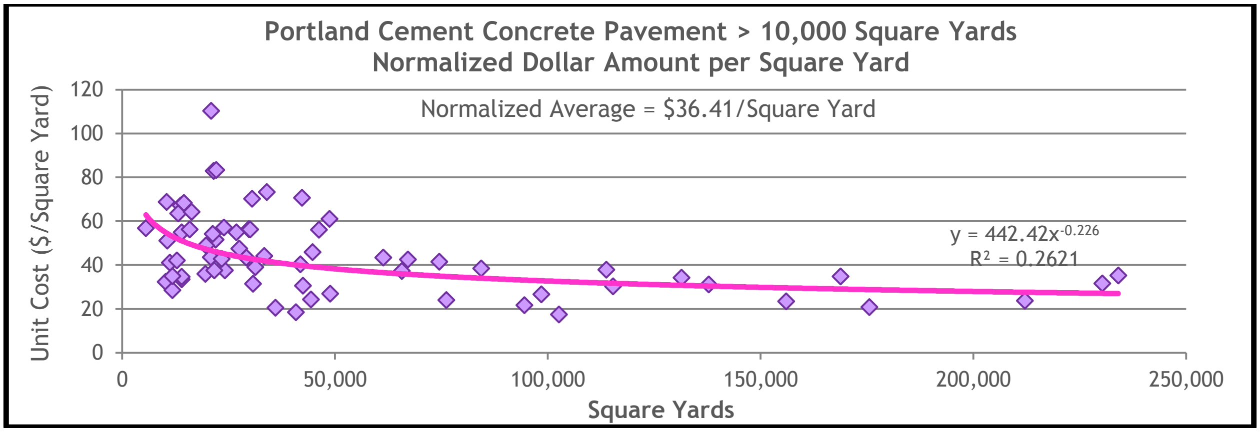


Figure 13.34 PCCP Normalized Dollar Amount per Total Square Yards for Projects Greater Than 10,000 Square Yards

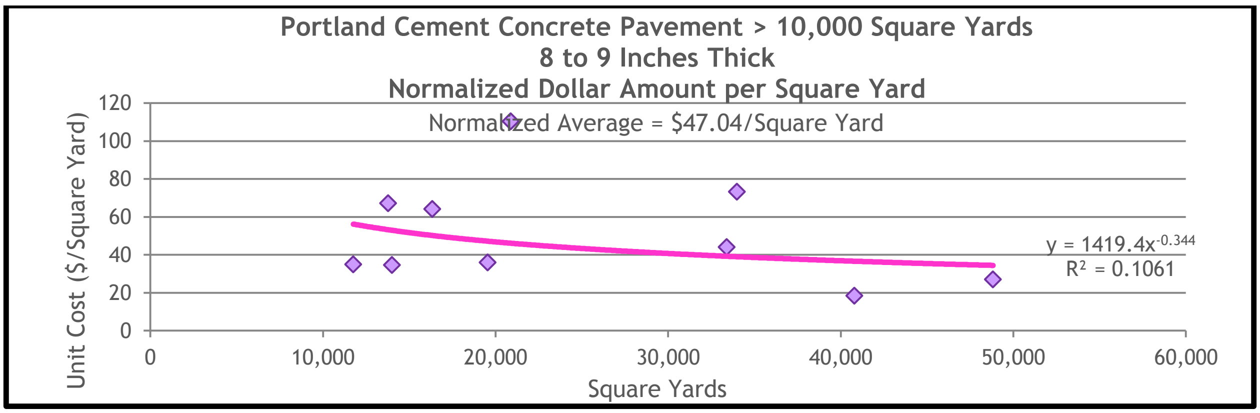


Figure 13.35 PCCP Normalized Dollar Amount for Projects of 8 to 9 Inches in Thickness and Greater Than 10,000 Square Yards in Size

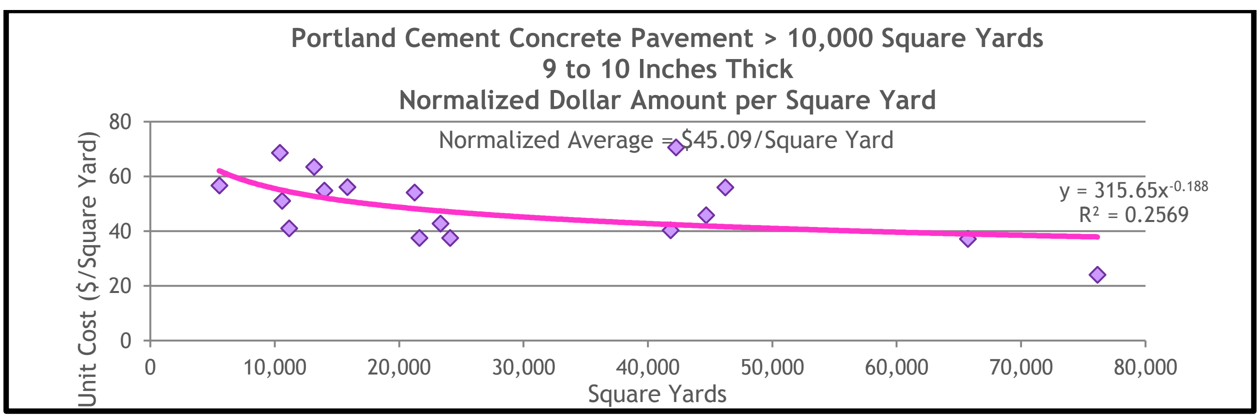


Figure 13.36 PCCP Normalized Dollar Amount for Projects of 9 to 10 Inches in Thickness and Greater Than 10,000 Square Yards in Size

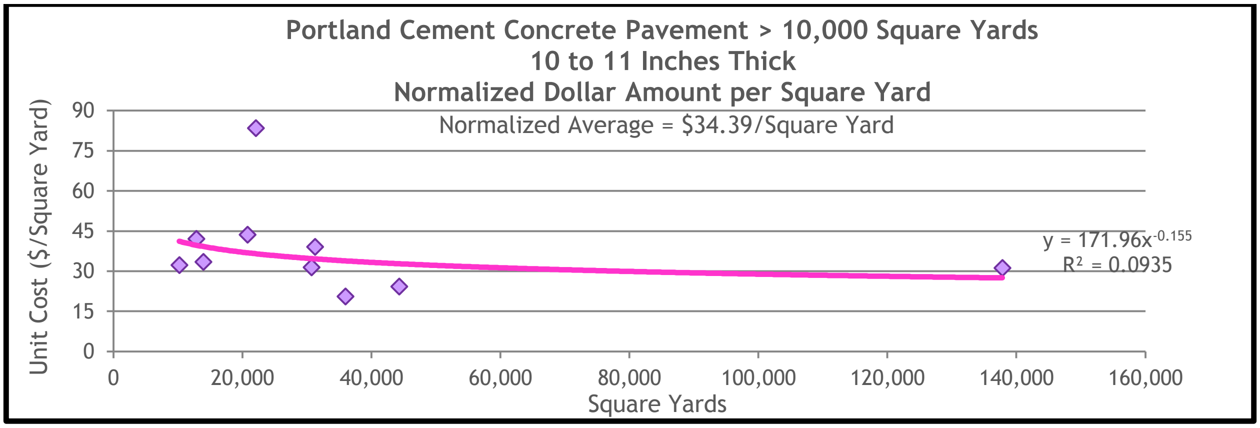


Figure 13.37 Normalized Dollar Amount for Projects of 10 to 11 Inches in Thickness and Greater Than 10,000 Square Yards in Size

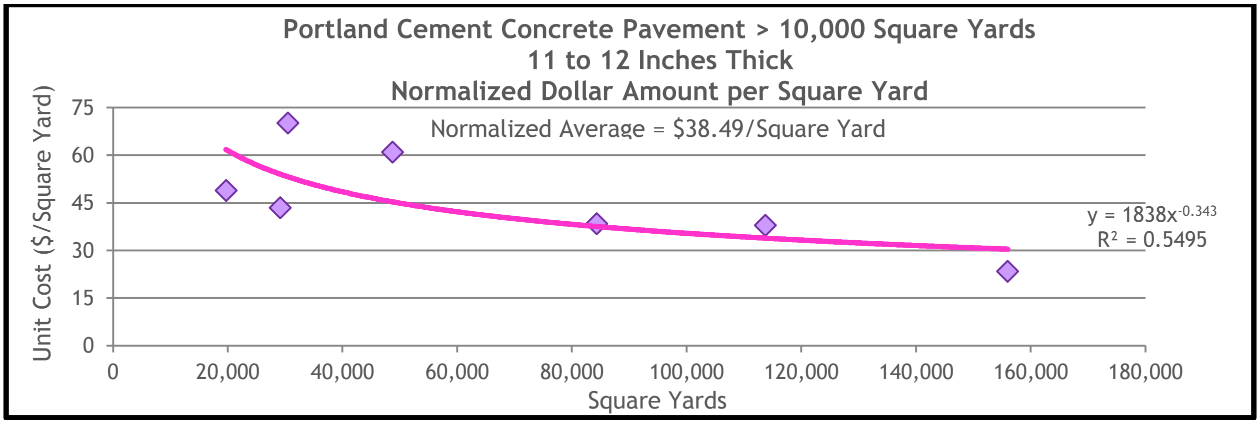


Figure 13.38 PCCP Normalized Dollar Amount for Projects of 11 to 12 Inches in Thickness and Greater Than 10,000 Square Yards in Size

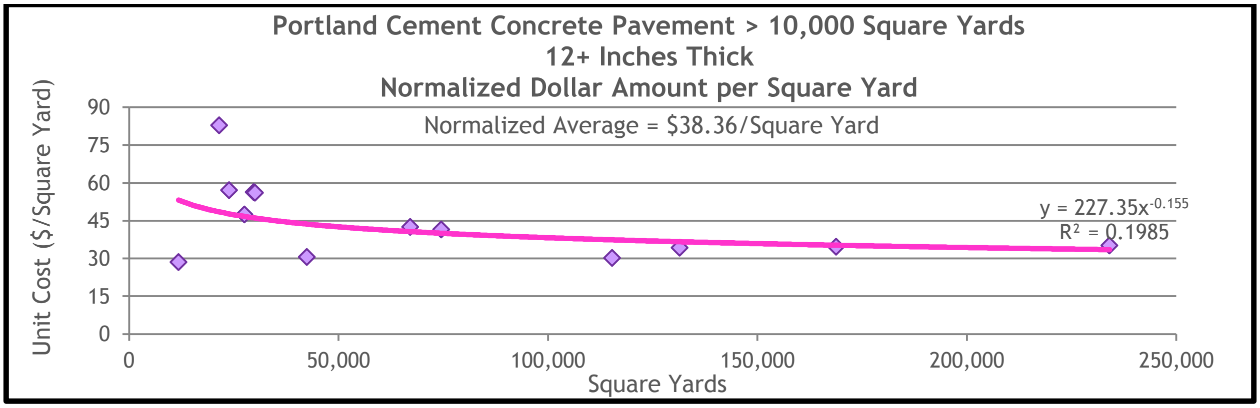


Figure 13.39 PCCP Normalized Dollar Amount for Projects of 12 Inches or Greater in Thickness and Greater Than 10,000 Square Yards in Size

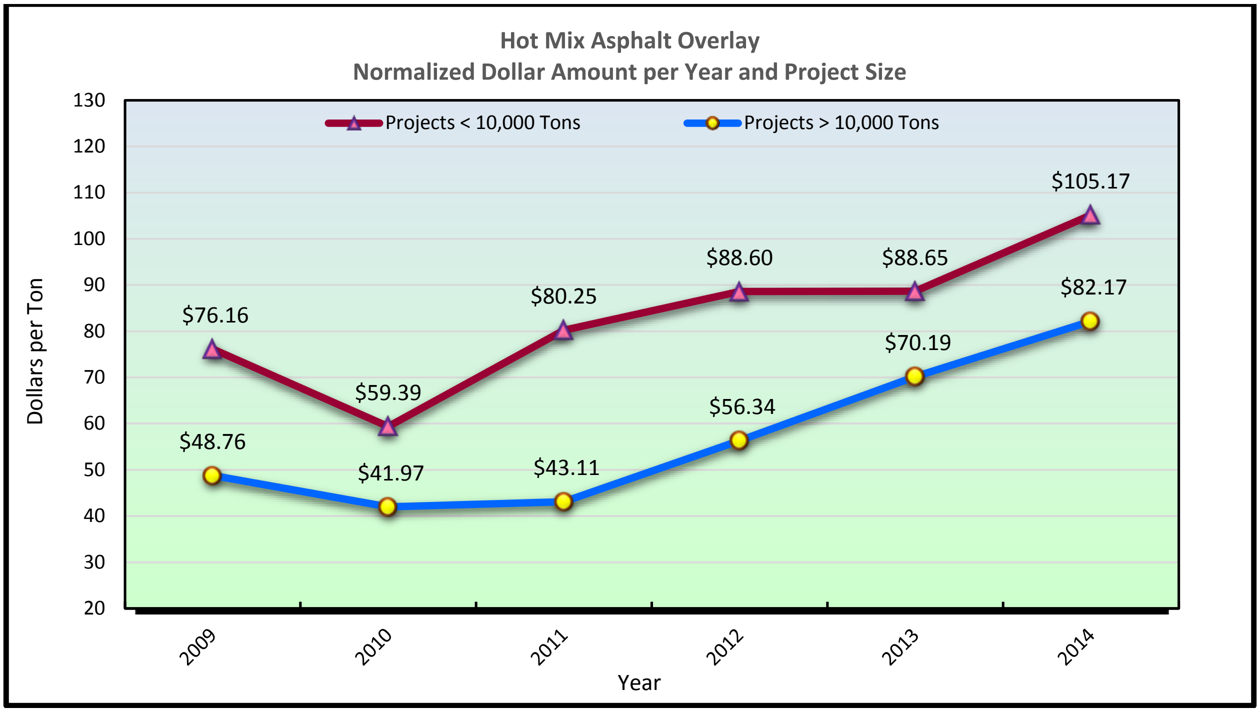


Figure 13.40 HMA Overlay Normalized Dollar per Year and Project Size

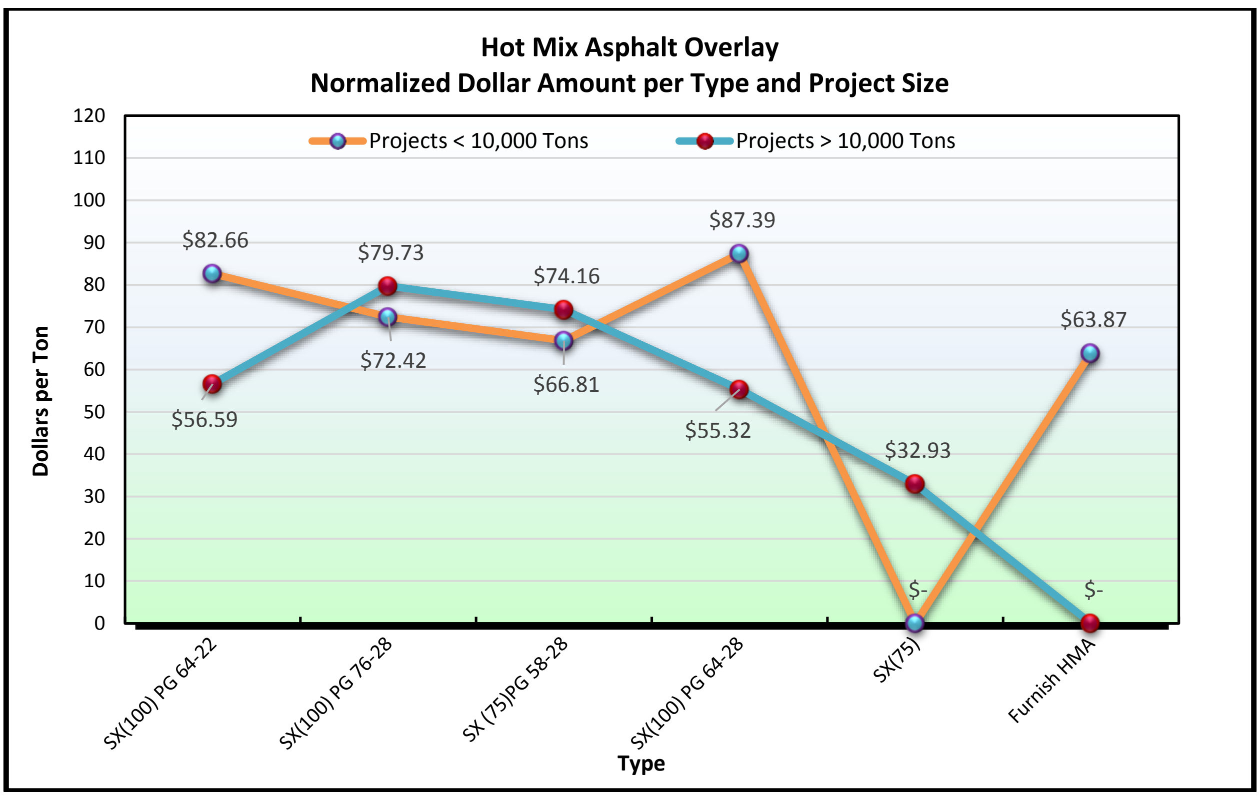


Figure 13.41 HMA Overlay Normalized Dollar per Product Type and Project Size

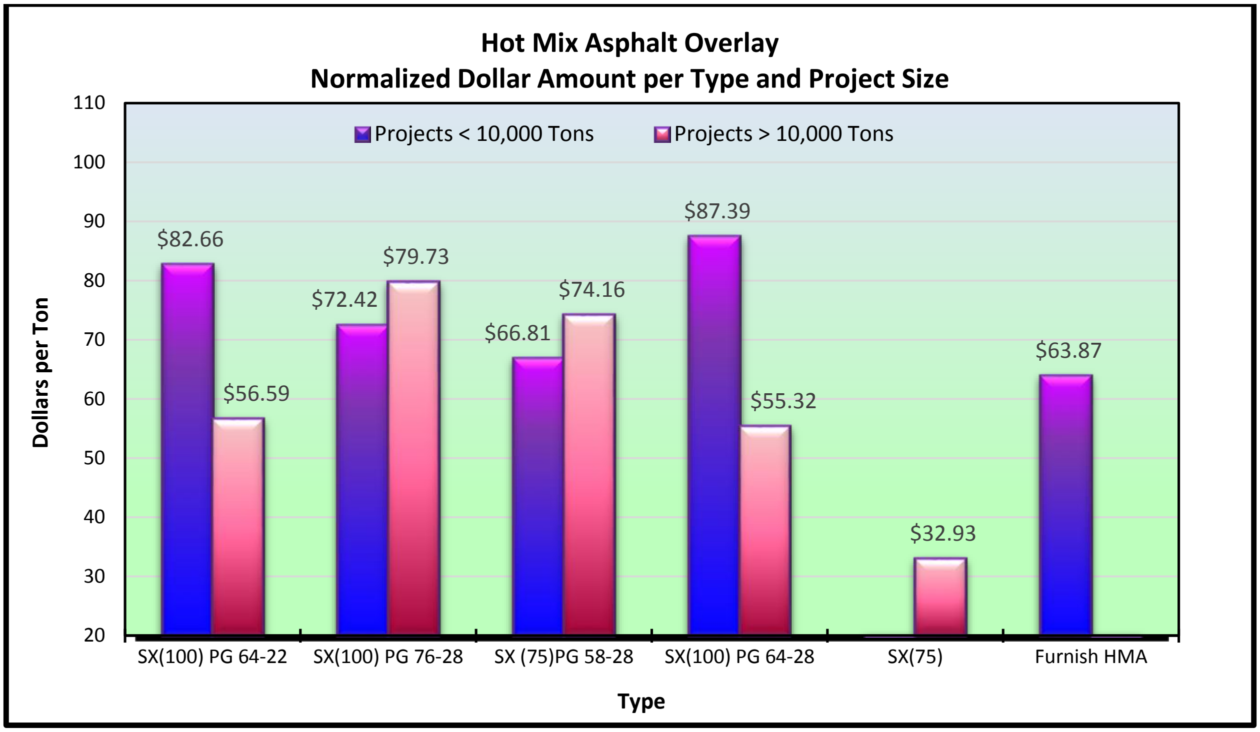


Figure 13.42 HMA Overlay Normalized Dollar per Product Type and Project Size

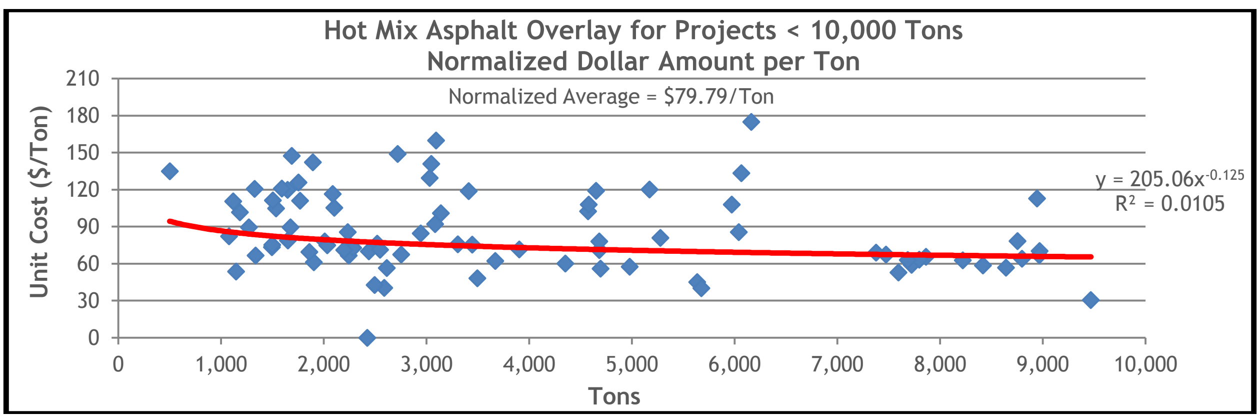


Figure 13.43 HMA Overlay Normalized Dollar Amount for Projects Less Than 10,000 Tons

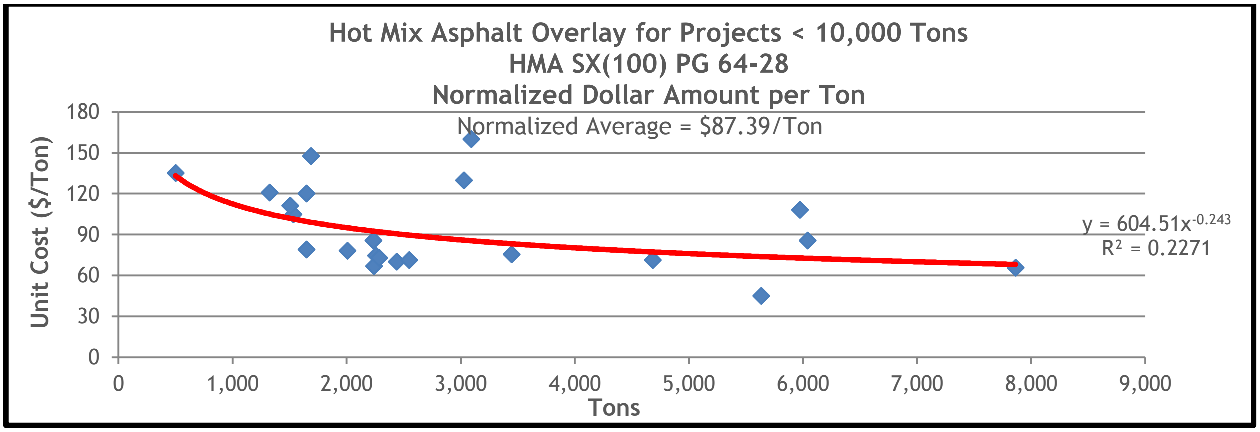


Figure 13.44 HMA Overlay Normalized Unit Costs for SX(100) PG 64-28 on Projects Less Than 10,000 Tons

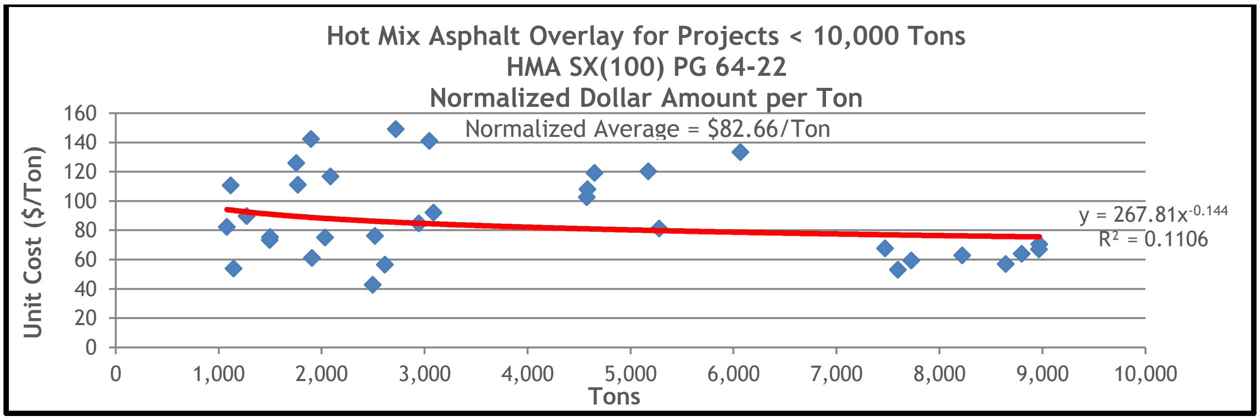


Figure 13.45 HMA Overlay Normalized Unit Costs for SX(100) PG 64-22 on Projects Less Than 10,000 Tons

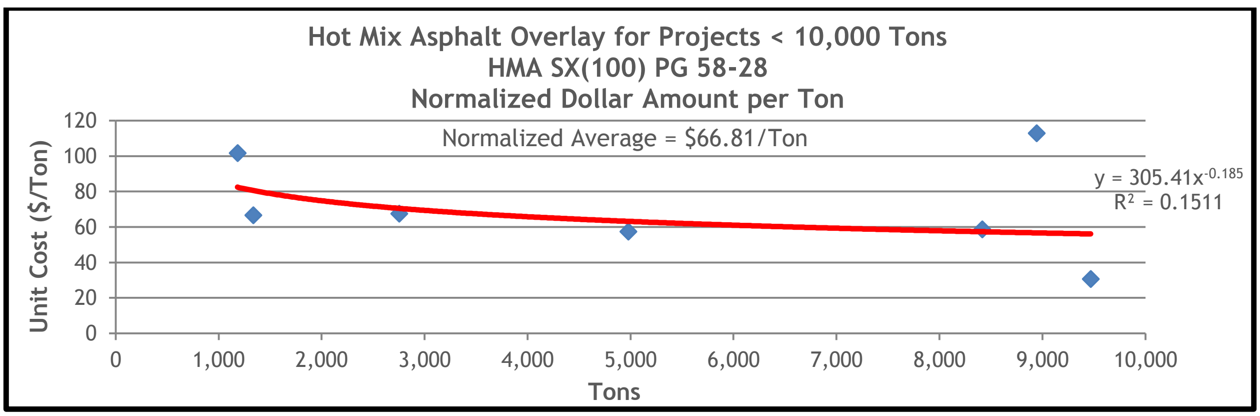


Figure 13.46 HMA Overlay Normalized Unit Costs for SX(100) PG 58-28 on Projects Less Than 10,000 Tons

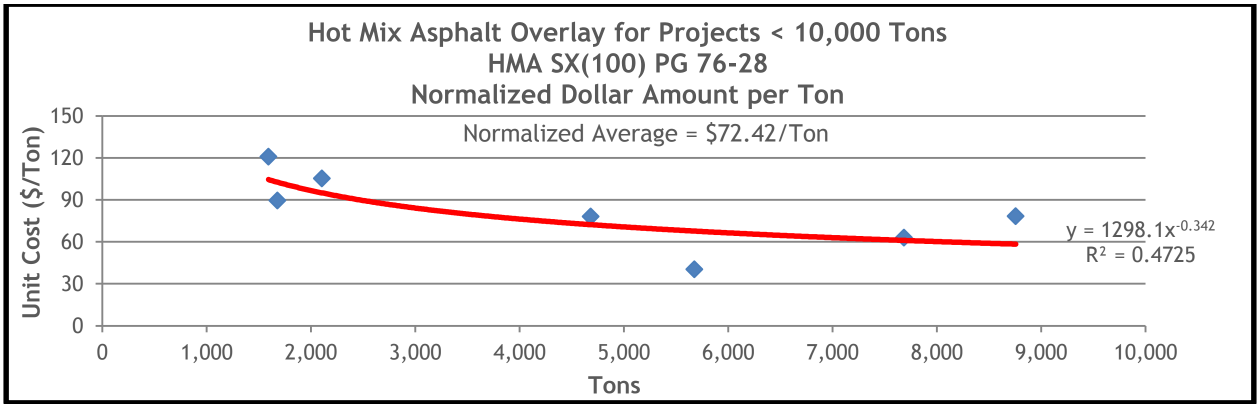


Figure 13.47 HMA Overlay Normalized Unit Costs for SX(100) PG 76-28 on Projects Less Than 10,000 Tons

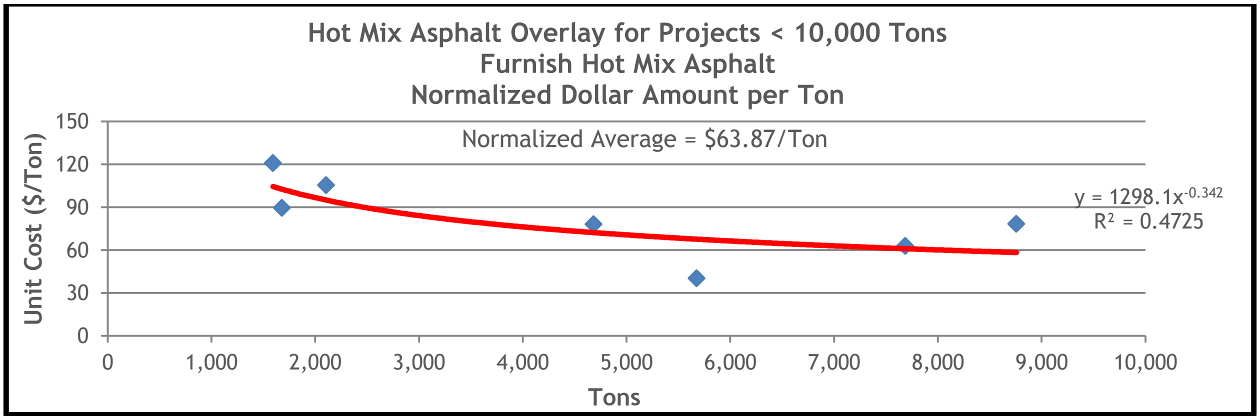


Figure 13.48 HMA Overlay Normalized Unit Costs for Furnish HMA on Projects Less Than 10,000 Tons

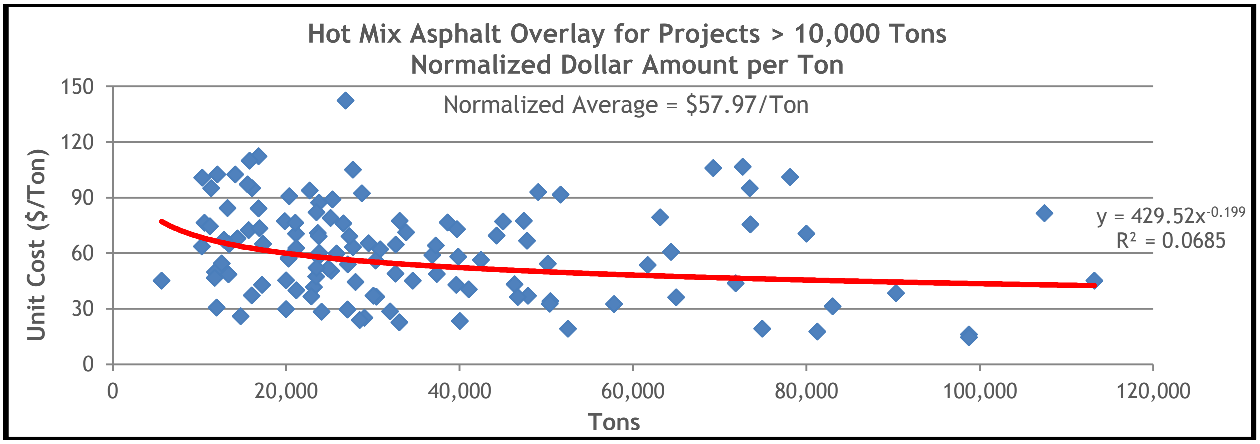


Figure 13.49 HMA Overlay Normalized Unit Costs for Projects with Greater Than 10,000 Tons

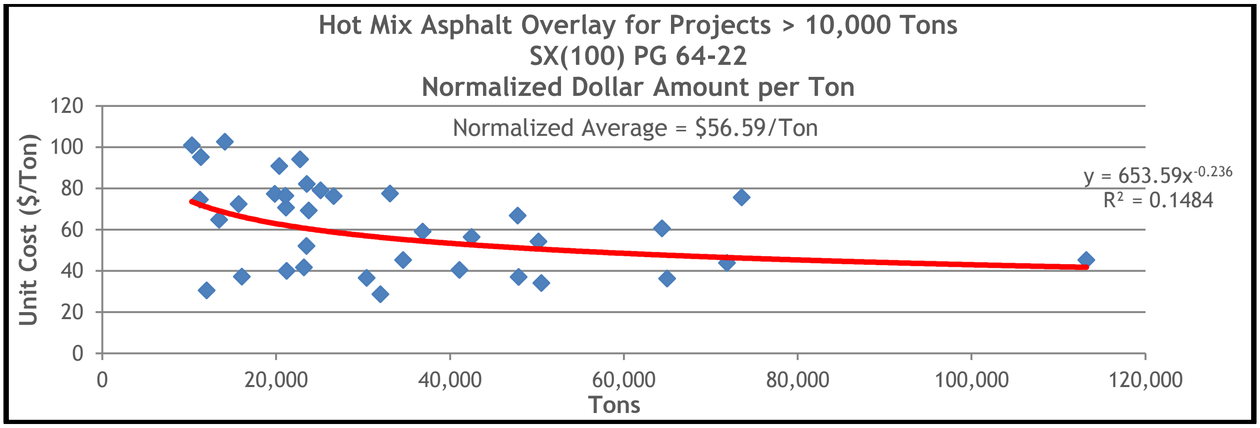


Figure 13.50 HMA Overlay Normalized Unit Costs for SX(100) PG 64-22 on Projects Greater Than 10,000 Tons

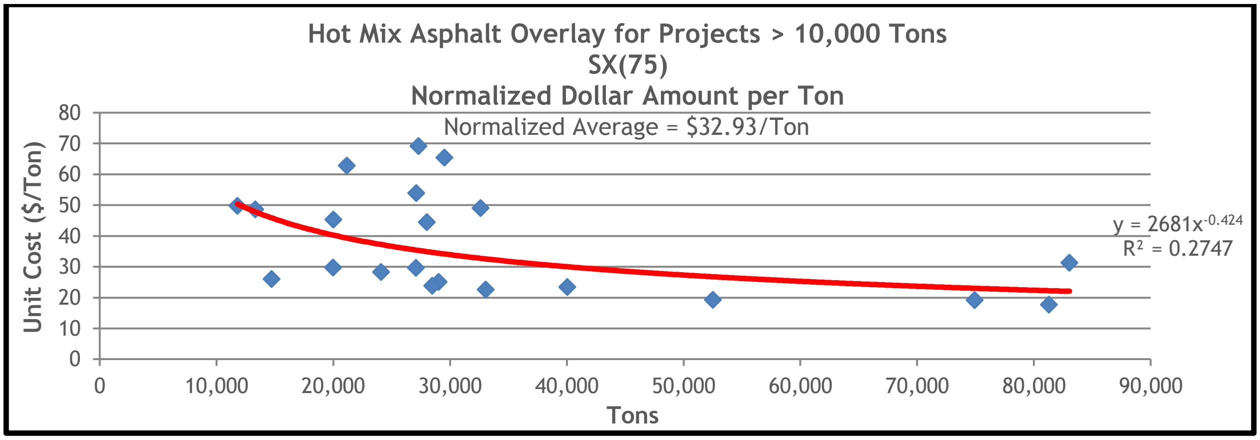


Figure 13.51 HMA Overlay Normalized Unit Costs for SX(75) on Projects Greater Than 10,000 Tons

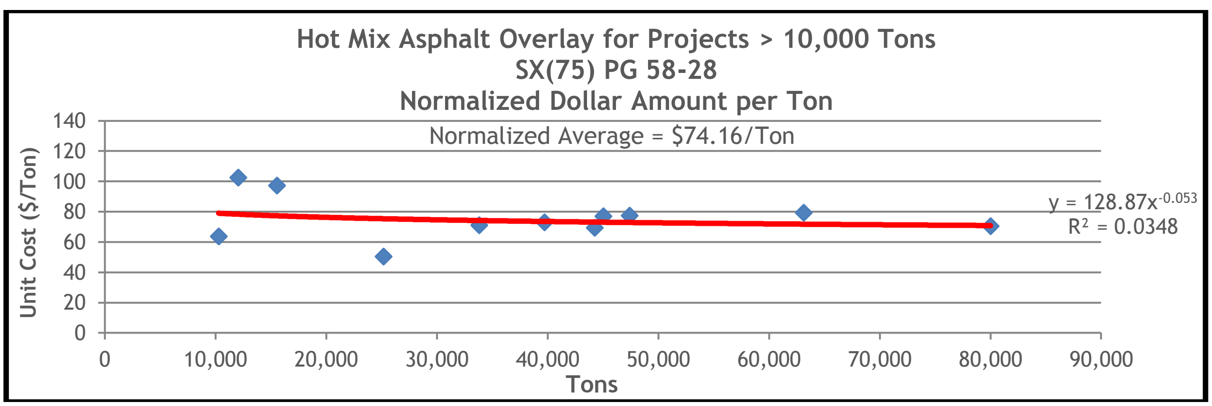


Figure 13.52 HMA Overlay Normalized Unit Costs for SX(100) PG 58-28 on Projects Greater Than 10,000 Tons

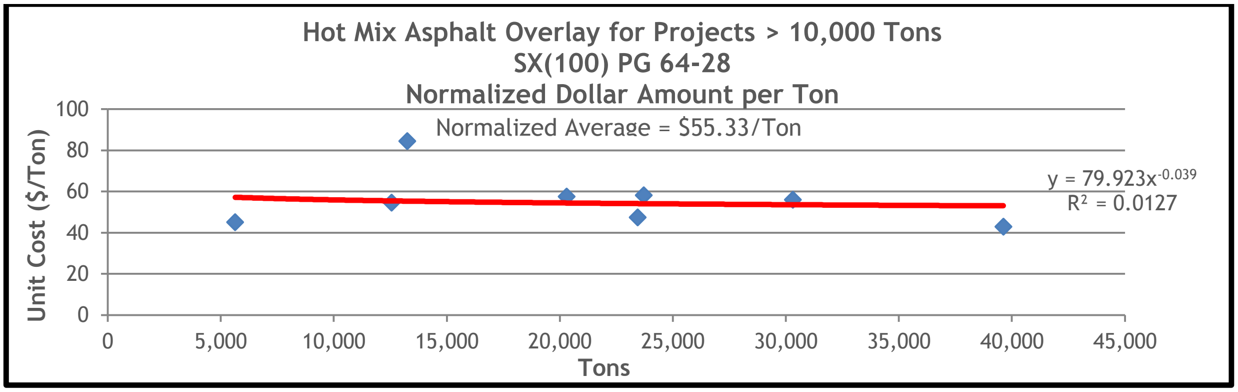


Figure 13.53 HMA Overlay Normalized Unit Costs for SX(100) PG 64-28 on Projects Greater Than 10,000 Tons

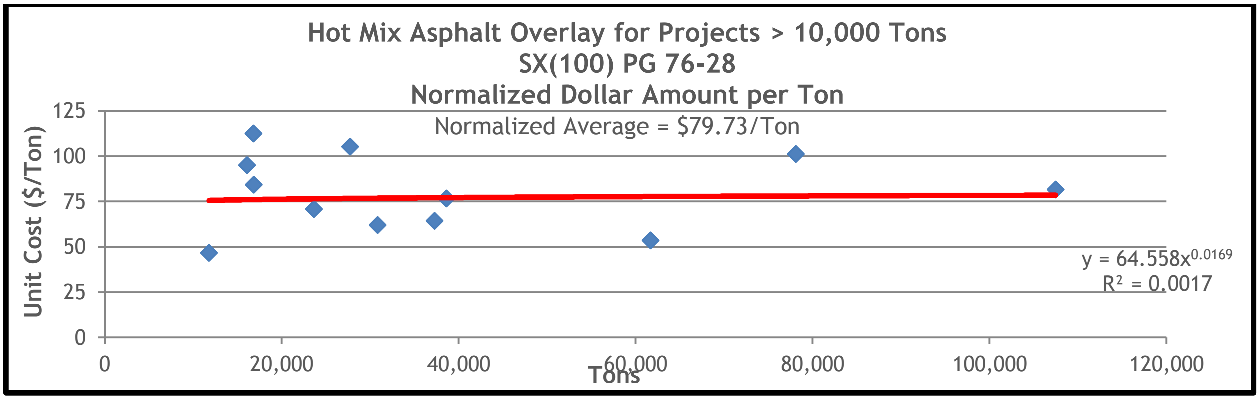


Figure 13.54 HMA Overlay Normalized Unit Costs for SX(100) PG 76-28 on Projects Greater Than 10,000 Tons

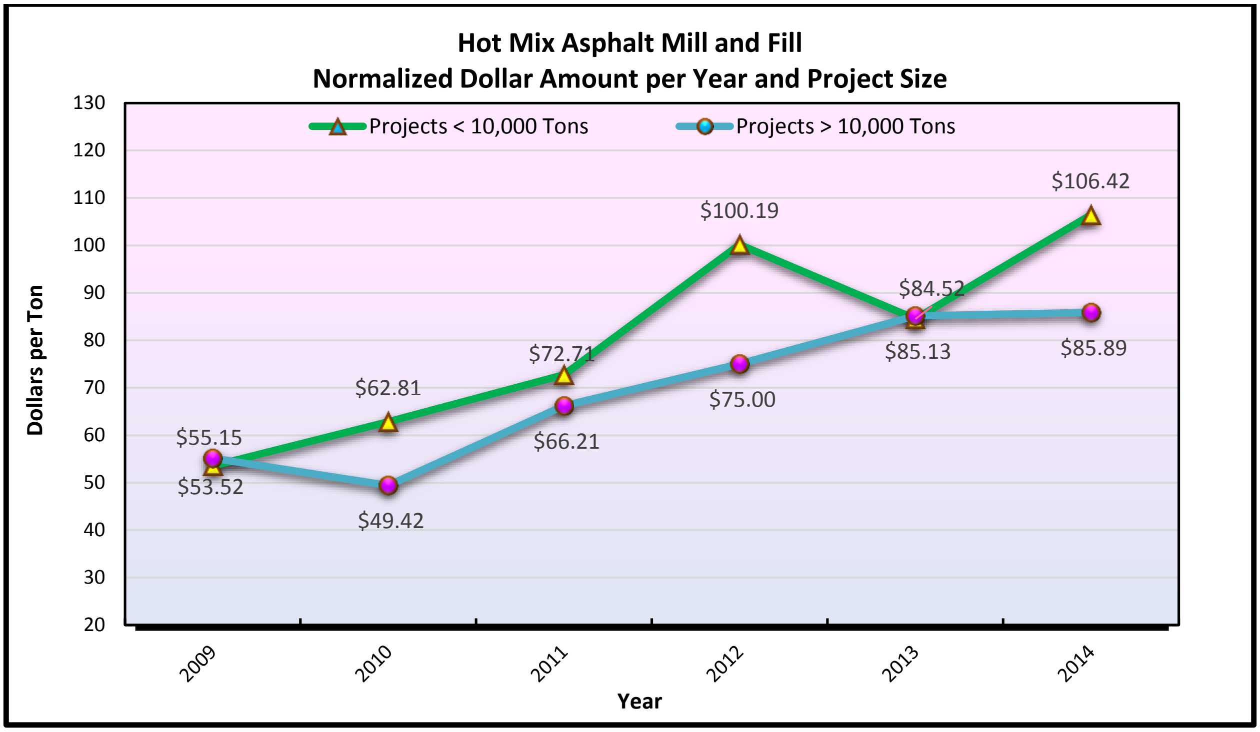


Figure 13.55 HMA Mill and Fill Normalized Dollar per Year and Project Size

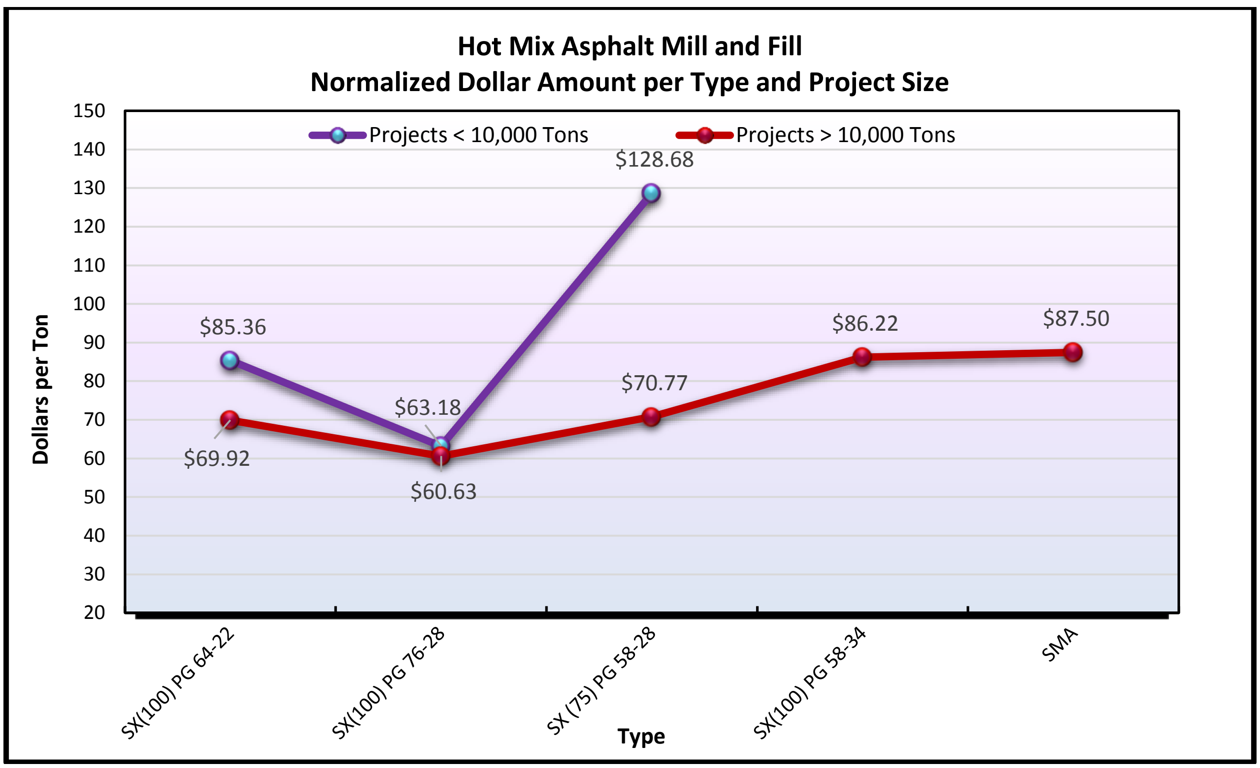


Figure 13.56 HMA Mill and Fill Normalized Dollar per Product Type

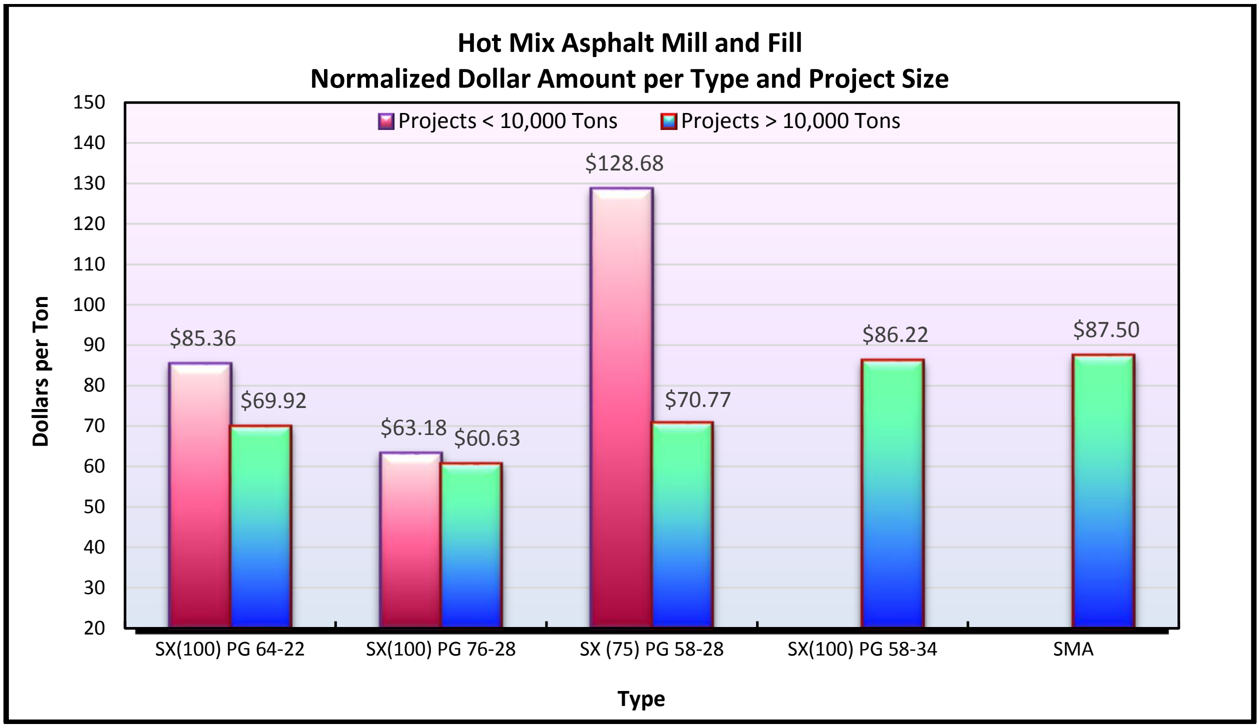


Figure 13.57 HMA Mill and Fill Normalized Dollar per Product Type

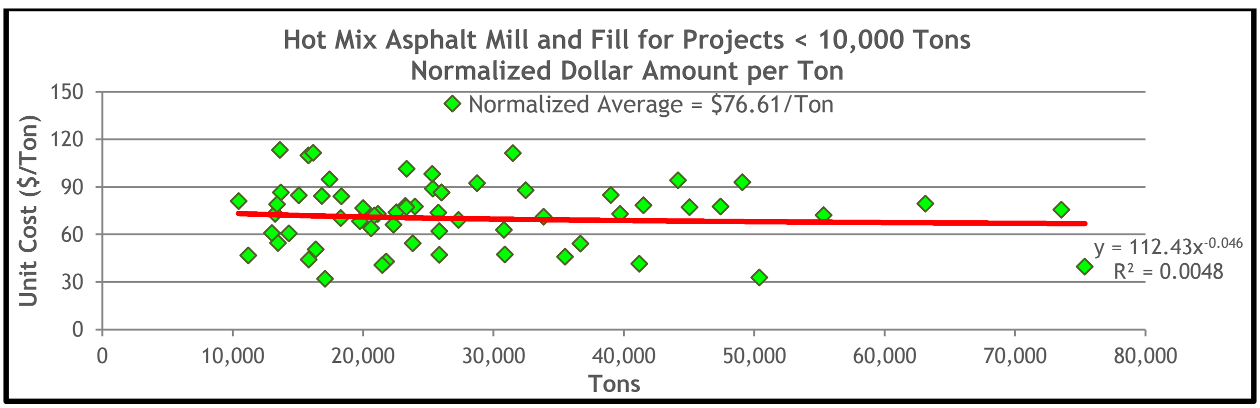


Figure 13.58 HMA Mill and Fill Normalized Unit Costs for Projects Less Than 10,000 Tons

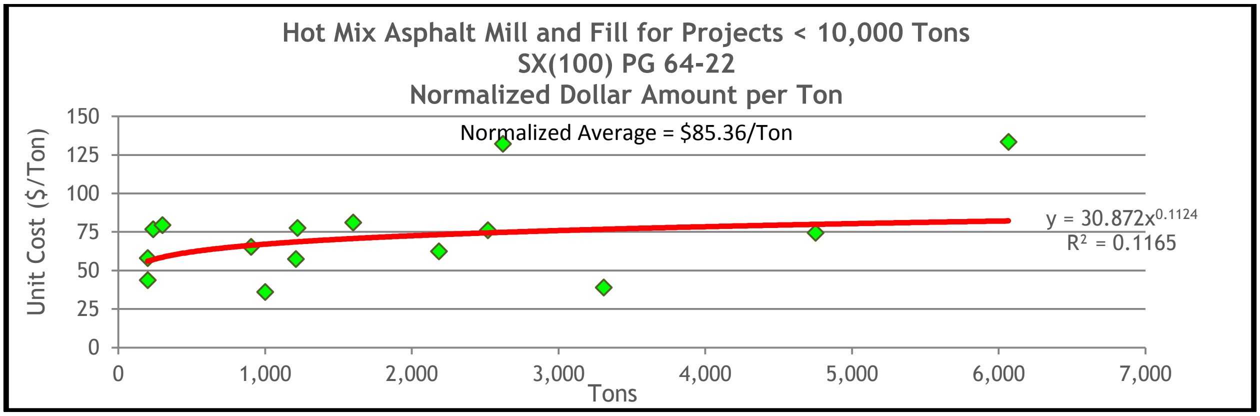


Figure 13.59 HMA Mill and Fill Normalized Unit Costs for SX(100) PG 64-22 on Projects Less Than 10,000 Tons

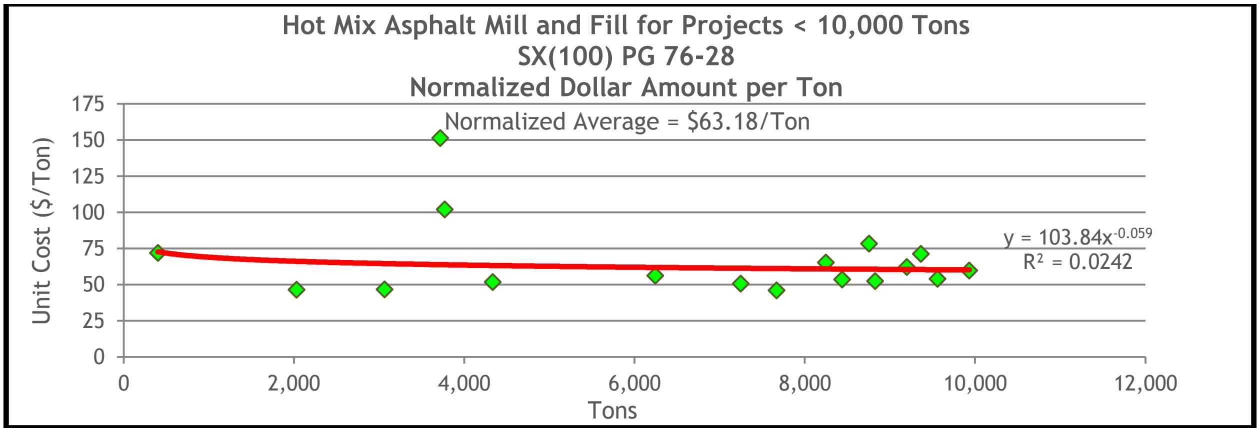


Figure 13.60 HMA Mill and Fill Normalized Unit Costs for SX(100) PG 76-28 on Projects Less Than 10,000 Tons

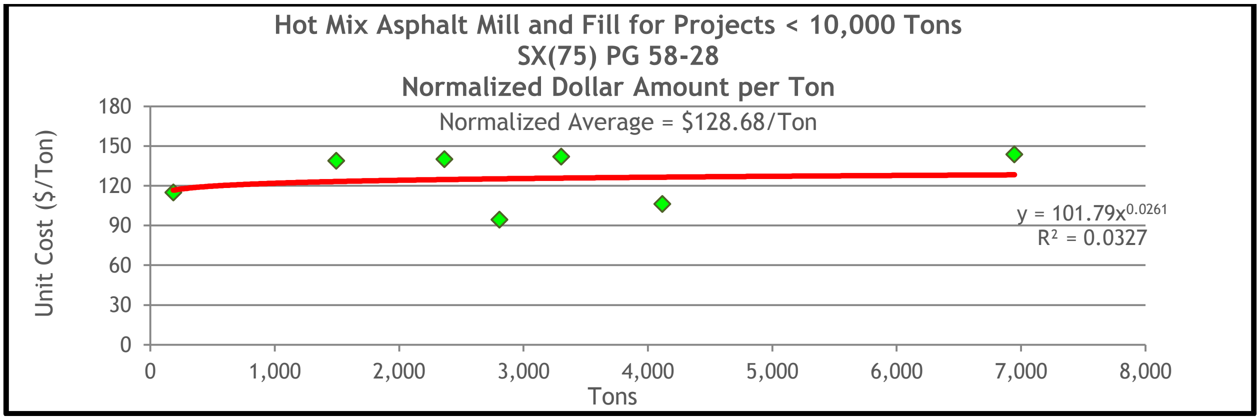


Figure 13.61 HMA Mill and Fill Normalized Unit Costs for SX(100) PG 58-28 on Projects Less Than 10,000 Tons

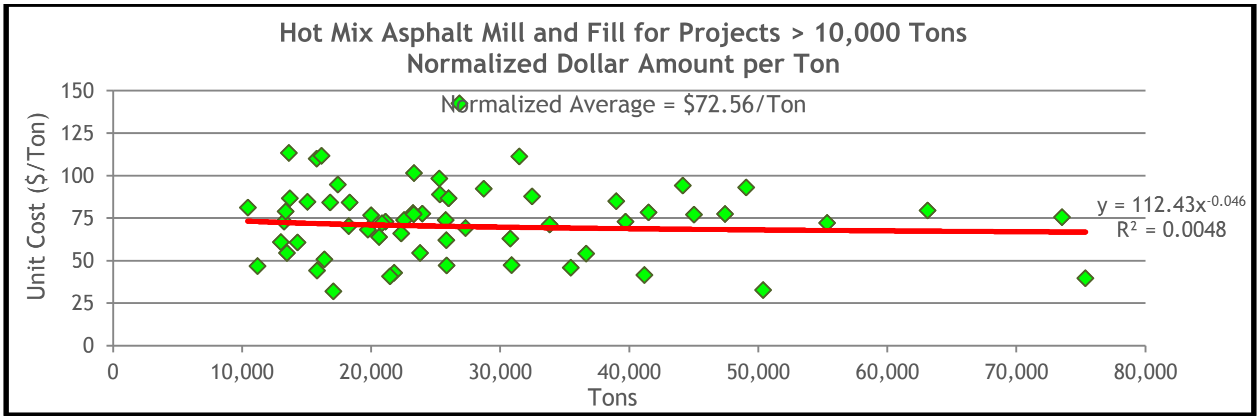


Figure 13.62 HMA Mill and Fill Normalized Unit Costs for Projects Greater Than 10,000 Tons

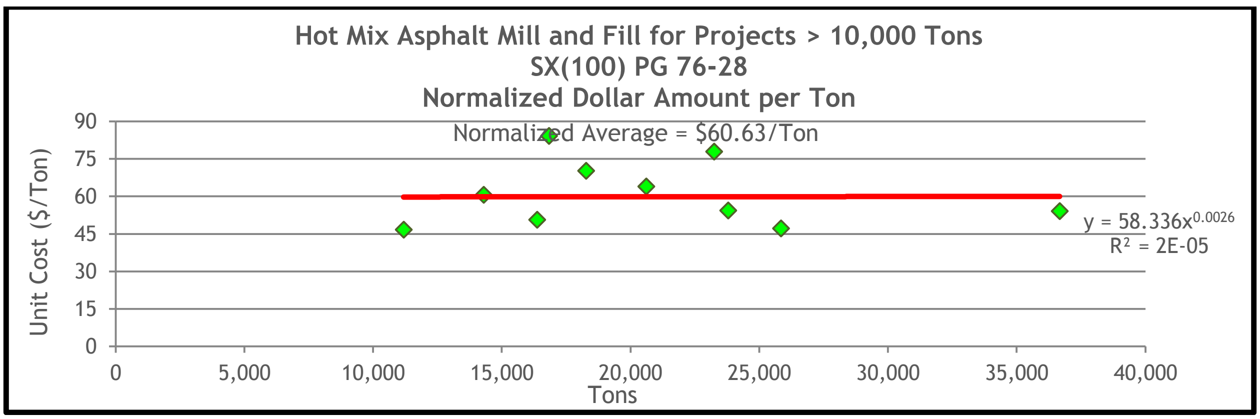


Figure 13.63 HMA Mill and Fill Normalized Unit Costs for SX(100) PG 76-28 on Projects Greater Than 10,000 Tons

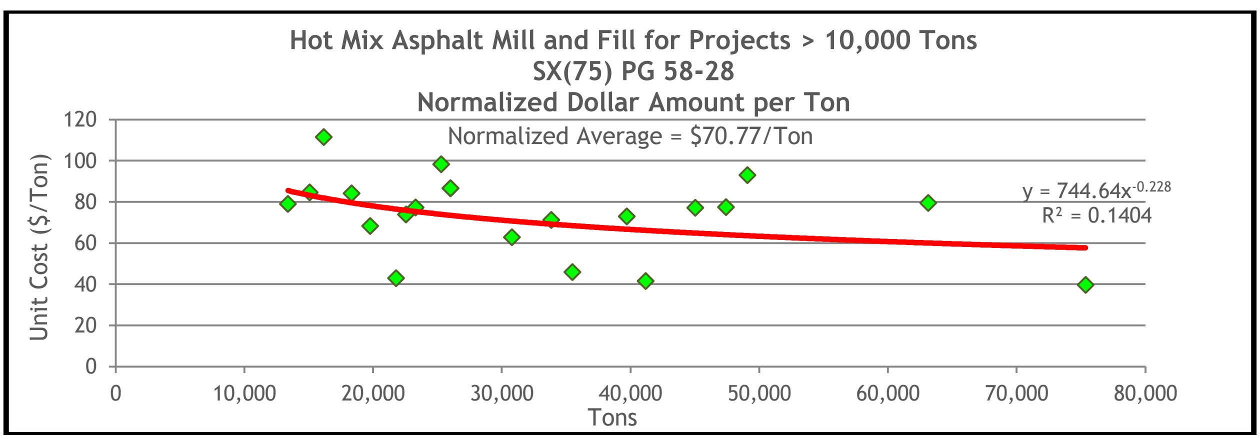


Figure 13.64 HMA Mill and Fill Normalized Unit Costs for SX(100) PG 64-22 on Projects Greater Than 10,000 Tons

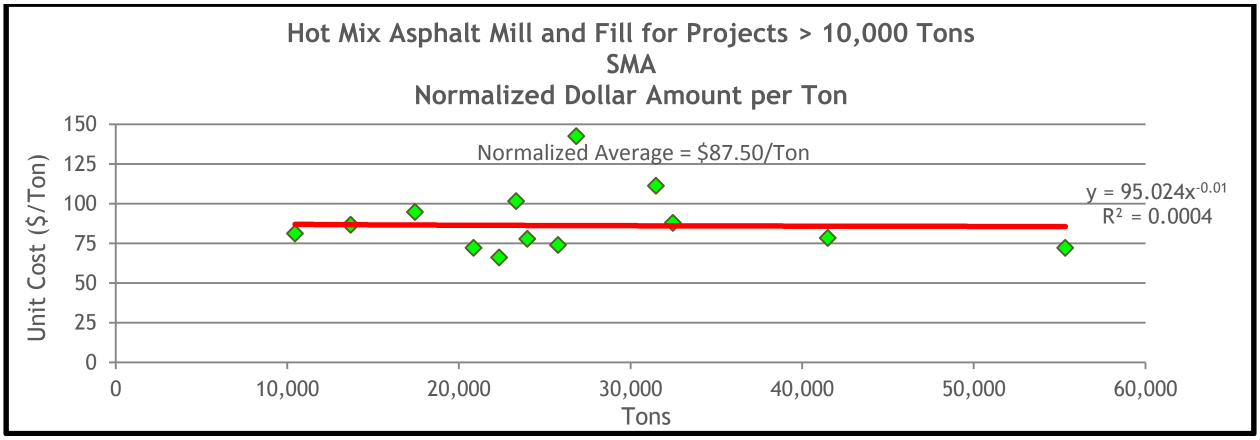


Figure 13.65 HMA Mill and Fill Normalized Unit Costs for SMA on Projects Greater Than 10,000 Tons

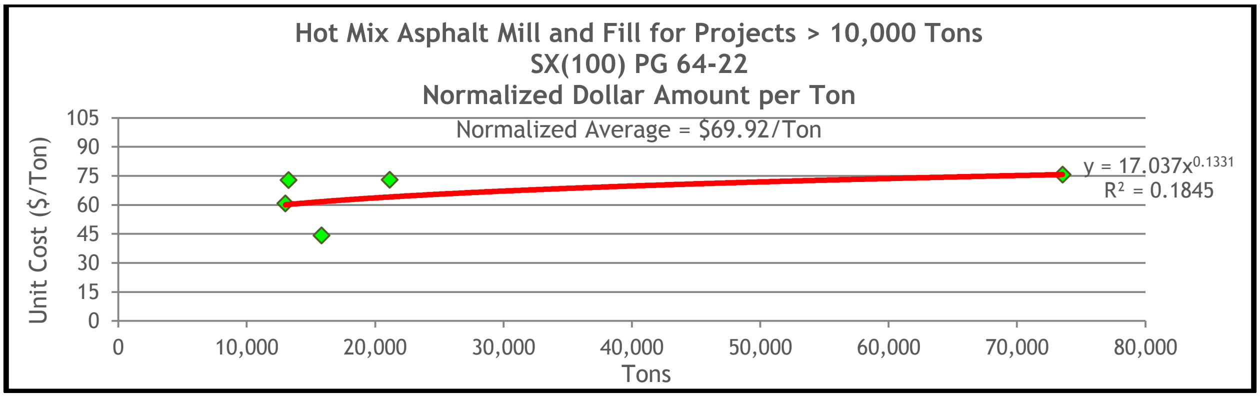


Figure 13.66 HMA Mill and Fill Normalized Unit Costs for SX(100) PG 64-22 on Projects Greater Than 10,000 Tons

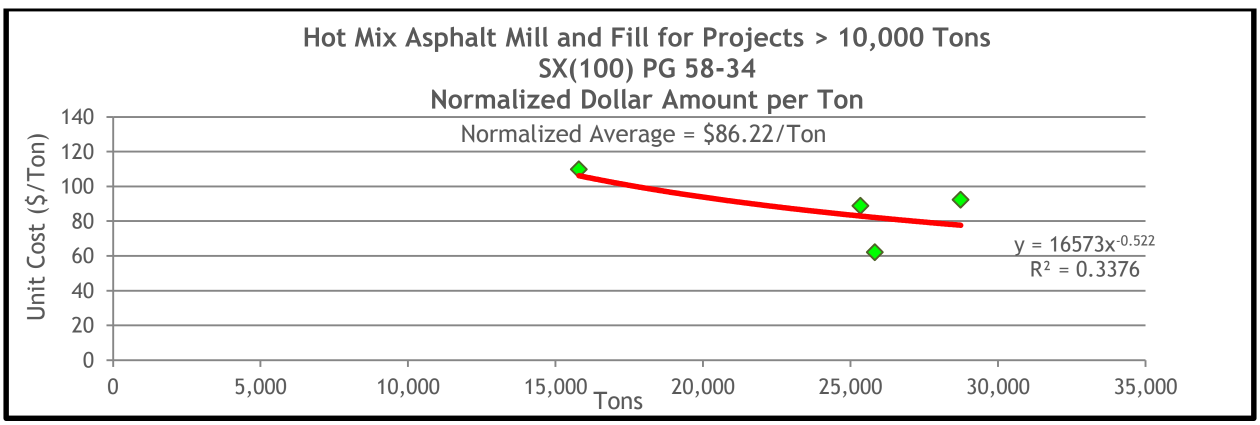


Figure 13.67 HMA Mill and Fill Normalized Unit Costs for SX(100) PG 58-34 on Projects Greater Than 10,000 Tons

13.7.10 Alternative Level Data Input Forms

- **Data that Define the Differences Between Alternatives:** These are specifics for component activities of each project alternative (the agency costs and work zone) and are considered alternative level inputs. Each project alternative is composed of up to seven activities and are performed in sequence. For example, Initial Construction precedes Rehabilitation 1, and Rehabilitation 3 precedes Rehabilitation 4. Data describing these activities are entered for each of the two project alternatives being compared. Refer to **Figure 13.70 Alternative 1 (HMA) Screen** and **Figure 13.71 Alternative 2 (PCCP) Screen** for a graphical representation.

- **ALTERNATIVE 1 and ALTERNATIVE 2 Inputs**: CDOT has created a Microsoft Excel worksheet for both pavement types to assist the designer in selecting the appropriate costs for initial and rehabilitation costs and a graphical representation. The user can select the cost of the pavement given the quantity. The forms for Alternative 1 and Alternative 2 are identical; at the top is a series of tabs which access different project alternative activities (see **Figure 13.72 Probabilistic Results Screen** and **Figure 13.73 Agency Cost Results Screen**). Data in this form are used to calculate agency and user costs.

  - The construction and maintenance data are agency cost inputs.
  - The service life data affect both agency and user costs (by determining when work zones will be in place). The work-zone-specific data affects user costs.
  - Each of the data inputs on this form is discussed in **Table 13.22 Alternative Level Data Options.**

Table 13.24 Alternative Level Data Options

Variable Name	Probability Distribution (CDOT Default)	HMA Value (CDOT Default)	PCC Value (CDOT Default)	Source
Alternative Description	User input	User input	User input	Site specific
Activity Description	User input	User input	User input	Site specific
Agency Construction Cost ($1,000)	Triangular	User input	User input	**Figure 13.26** to **Figure 13.69** or site specific
Activity Service Life (years)	Triangular	User input	User input	**Section 13.2.3** or **Section 13.3**
User Work Zone Costs ($1,000)	Deterministic	User input	User input	CDOT Work Zone software **Section 13.5.7**
Maintenance Frequency (years)	Deterministic	1 year	1 year	CDOT[1]

Agency Maintenance Cost ($1,000)	Deterministic	$1.027/lane mile[1]	$ 0.640/lane mile[1]	CDOT[1]
Work Zone Length (miles)	Deterministic	User input	User input	Site specific
Work Zone Capacity (vphpl)	Deterministic	User input	User input	CDOT Work Zone software **Section 13.5.7**
No of Lanes Open in Each Direction During Work Zone	Deterministic	User input	User input	Site specific
Work Zone Duration (days)	Deterministic	User input	User input	CDOT Work Zone software **Section 13.5.7**
Work Zone Speed Limit (mph)	User input	User input	User input	Site specific

Note:
[1] Use site specific or latest data. Recalculate yearly cost to account for the number of lanes and project length.

- **Work Zone Capacity** is equal to the WorkZone software's work zone capacity (inbound/outbound capacity) for the type of selected work. If two or more types of work are listed, use the lesser capacity value.

- **Work Zone Duration (days)** must be reasonable. For a PCC value, the WorkZone program may give a value of 5 days for the actual paving operation, thus, it is likely the designer will need to increase the days to a reasonable amount. The program is designed so the work zone will be in place for the paving operation and curing time.

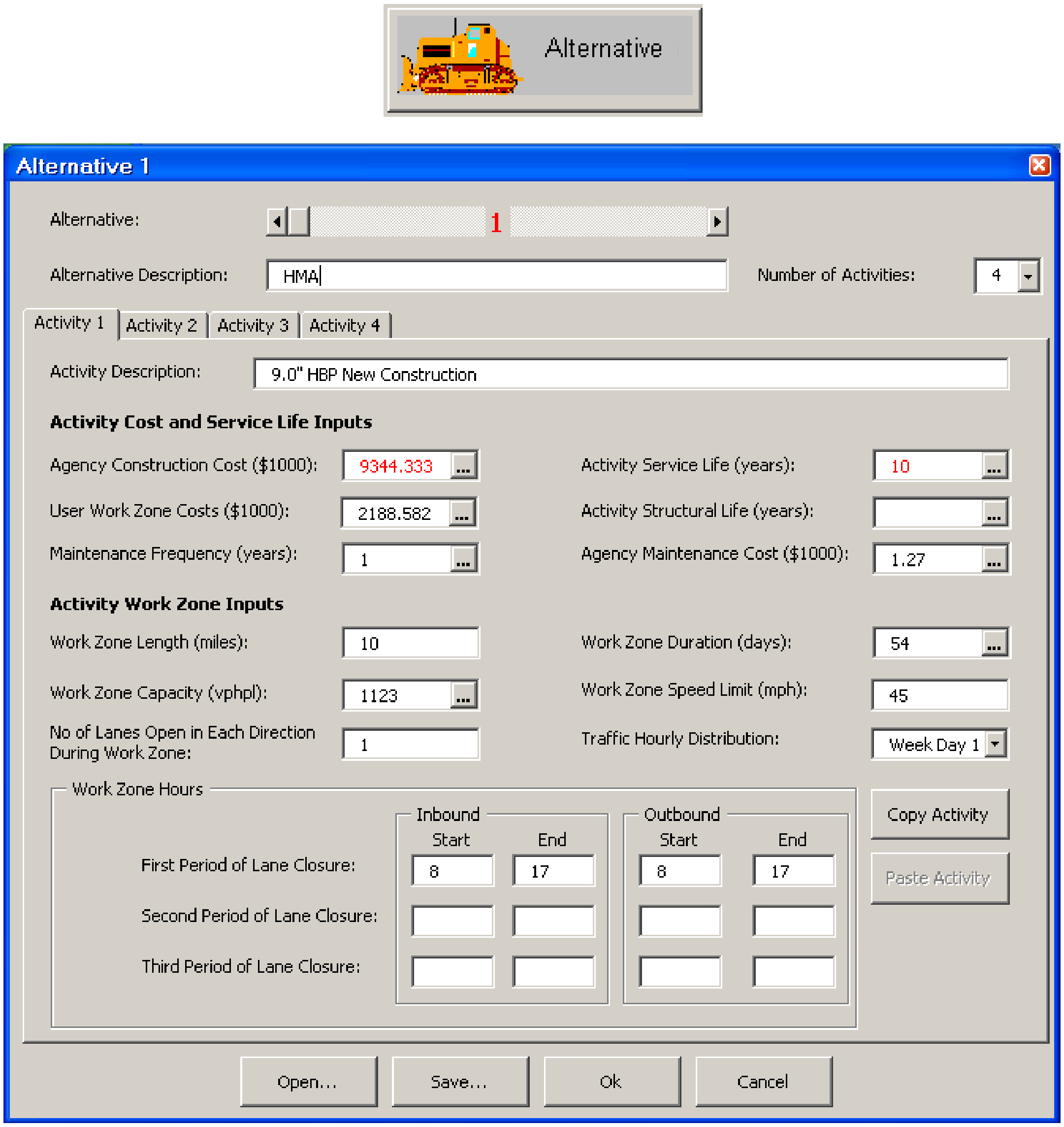


Figure 13.68 Alternative 1 (HMA) Screen

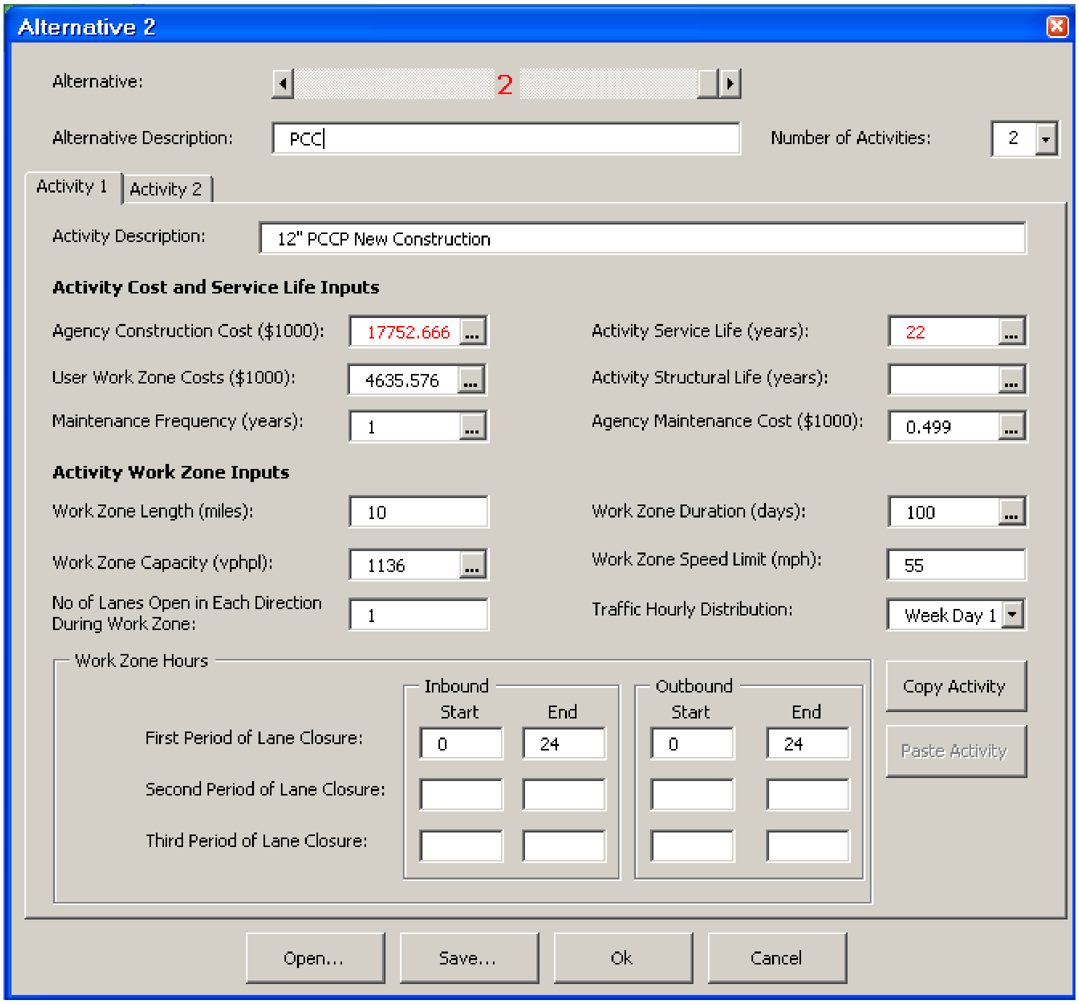


Figure 13.69 Alternative 2 (PCCP) Screen

13.7.11 Executing the Simulation

Running a simulation is a necessary step toward performing a probabilistic analysis. To conduct a probabilistic analysis, RealCost uses a Monte Carlo simulation which allows modeling of uncertain quantities with probabilistic inputs. The simulation procedure samples these inputs and produces outputs that are described by a range of potential values and likelihood of occurrence of specific outputs. The simulation produces the probabilistic outputs. The simulation screen is shown in **Figure 13.69 Simulation Screen.**

- **Sampling Scheme:** This section of the form determines where the software will draw its simulation numbers. Choosing *Random Results* causes the simulation seed value (where the simulation starts) to come from the computer's internal clock. While not truly random, this seed value cannot be influenced by the software user, and it produces different values with each simulation.

Table 13.25 Simulation Data Options

Variable Name	Probability Distribution (CDOT Default)	Value (CDOT Default)	Source
Random Results	De-select	no	RealCost Manual
Reproducible Results	Select	yes	RealCost Manual
Seed Value	Deterministic	2,000	RealCost Manual
Number of Iterations	Deterministic	2,000	RealCost Manual
Monitor Convergence	Select	yes	RealCost Manual
Monitoring Frequency (Number of Iterations)	Deterministic	50	RealCost Manual
Convergence Tolerance (%)	Deterministic	2.5	RealCost Manual
Tail Analysis Percentiles		See below	RealCost Manual
Percentile 1	Deterministic	5	RealCost Manual
Percentile 2	Deterministic	10	RealCost Manual
Percentile 3	Deterministic	75	CDOT
Percentile 4	Deterministic	95	RealCost Manual

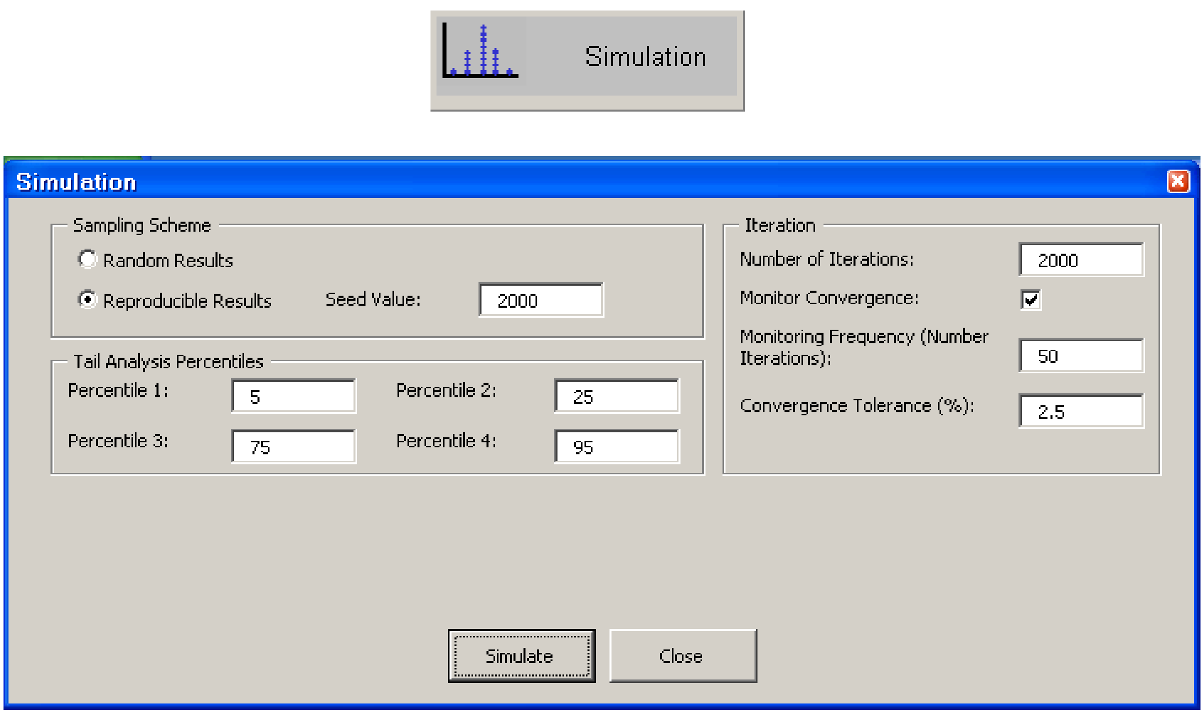
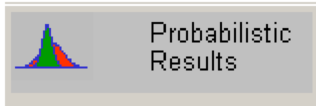
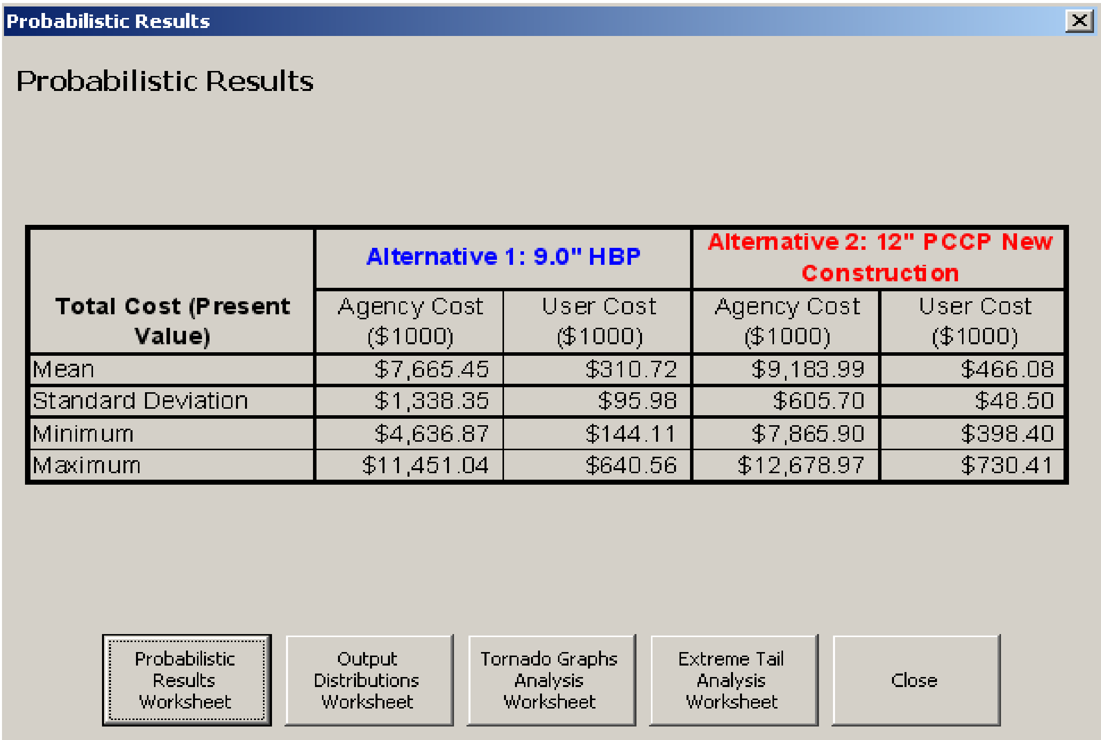


Figure 13.70 Simulation Screen

13.7.12 Analyzing Probabilistic Results

After a simulation run, probabilistic results are available for analysis. A simulation must be run prior to viewing probabilistic results. **Figure 13.72 Probabilistic Results Screen** shows the results of a probabilistic simulation.





Total Cost (Present Value)	Alternative 1: 9.0" HBP		Alternative 2: 12" PCCP New Construction	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	$7,665.45	$310.72	$9,183.99	$466.08
Standard Deviation	$1,338.35	$95.98	$605.70	$48.50
Minimum	$4,636.87	$144.11	$7,865.90	$398.40
Maximum	$11,451.04	$640.56	$12,678.97	$730.41

Figure 13.71 Probabilistic Results Screen

13.7.13 Analyzing Probabilistic Agency Costs

Agency Costs are critical to an insightful LCCA and are good estimates of the various agency cost items associated with initial construction, periodic maintenance and rehabilitation activities. Construction costs pertain to putting the asset into initial service. Data on construction costs are obtained from historical records, current bids, and engineering judgment (particularly when new materials and techniques are employed). Refer to **Figure 13.73 Agency Cost Results Screen** for a graphical representation of agency costs. Similarly, costs must be attached to the maintenance and rehabilitation activities identified in the previous steps to maintain the asset above predetermined conditions, performance, and safety levels. These costs include preventive activities planned to extend the life of the asset, day-to-day routine maintenance intended to address safety and operational concerns, and rehabilitation or restoration activities. Another consideration affecting the total agency cost is the value of the alternative at the end of the analysis period. One type of terminal value is called 'salvage value,' usually the net value from the recycling of materials at the end of a project's life. A second type of terminal value is the 'Remaining Service Life' (RSL) value of an alternative (the residual value of an improvement when its service life extends beyond the end of the analysis period). The RSL value may vary significantly among different alternatives, and should be included in the LCCA.

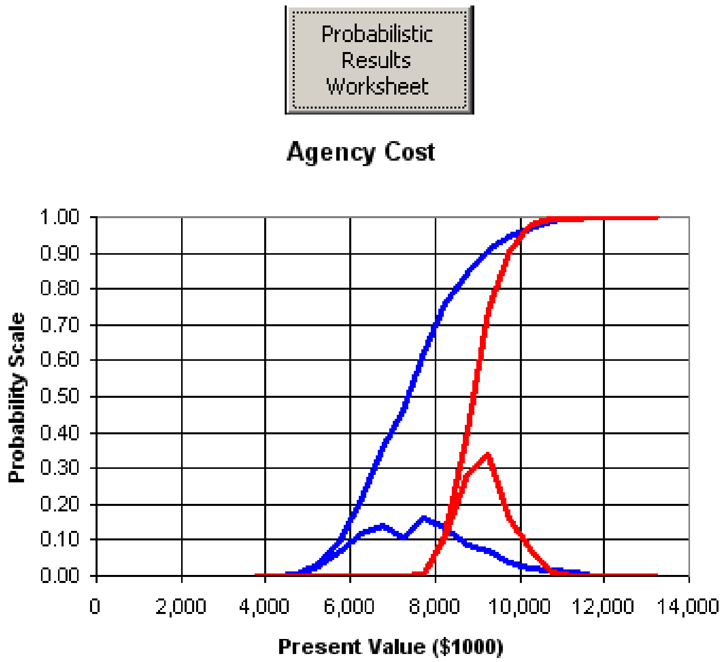
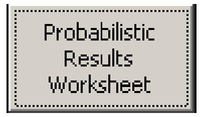


Figure 13.72 Agency Cost Results Screen

13.7.14 Analyzing Probabilistic User Cost

Best-practice LCCA calls for including the costs accruing to the transportation agency as described above and costs incurred by the traveling public. In the LCCA, user costs of primary interest include vehicle operating costs, travel time, and crashes. Such user costs typically arise from the timing, duration, scope, and number of construction and rehabilitation work zones characterizing each project alternative. Because work zones typically restrict the normal capacity of the facility and reduce traffic flow, work zone user costs are caused by speed changes, stops, delays, detours, and incidents. While user costs do occur during normal operations, these costs are often similar between alternatives and may be removed from most analyses. Incorporating user costs into the LCCA enhances the validity of the results, but at the same time is a challenging task. User costs can also be defined as the cost of travel that is borne by individual users. Highway user costs are the sum of motor vehicle running cost, the value of travel time, and traffic accident cost. Bus transit user costs on a particular highway segment are the fares, the value of travel time, and traffic accident costs; **Figure 13.74 User Cost Results Screen**.



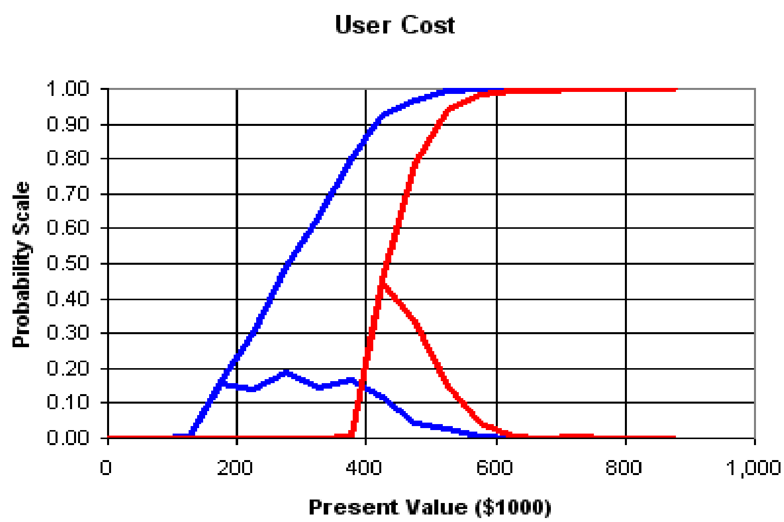


Figure 13.73 User Cost Results Screen

13.8 Comparing Probabilistic Results

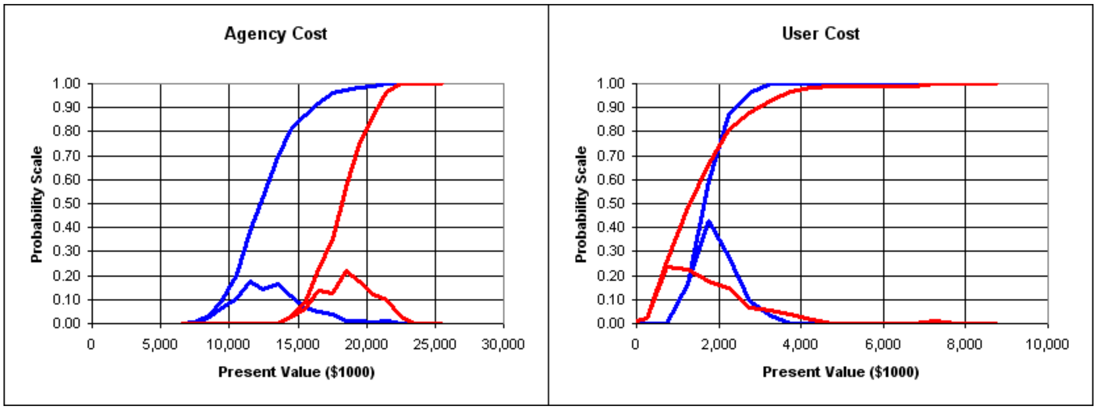
To calculate agency and user cost, the designer must select values that cross both agency and user cost lines at the 75 percent probability scale. Once the designer has determined both values, a total of both probabilistic values can be calculated. For example:

Agency Cost
Blue: PCCP Lines 75% PV $13,000,000
Red: HMA Lines 75% PV $18,000,000

User Cost
Blue: PCCP Lines 75% PV $2,000,000
Red: HMA Lines 75% PV $2,000,000

Therefore:
PCCP Present Value at 75% Probability = $13,000,000 + $2,000,000 = $15,000,000
HMA Present Value at 75% Probability = $18,000,000 + $2,000,000 = $20,000.000

Refer to **Figure 13.75 Agency-User Cost Results Screens** for a graphical representation of the probability versus agency and user costs.



Equivalent Designs are considered equal if the equation below is 10 percent or less:

(large NPV value – small NPV value) x 100 / **(small NPV value)** **Eq. 13.2**

Comparing the two alternatives yields:

($20,000,000 - $15,000,000) x 100 / $15,000,000 = 33.3%

A comparison that yields results within 10 percent may be considered to have equivalent designs. A comparison that yields results within 5 percent would certainly be considered to have equivalent designs. Refer to **Section 13.9 Pavement Type Selection Committee (PTSC)** when the alternatives are within 10 percent. Other secondary factors can and should be used to help in the pavement selection. For more information, contact the Pavement Design Program Manager at 303-398-6561.

13.9 Pavement Type Selection Committee (PTSC)

Whenever the cost analysis does not show a clear LCCA within 10 percent advantage for one of the feasible alternatives, other secondary factors can be used to help in the selection process. Most of these factors are very difficult to quantify in monetary units. Decision factors considered important in selecting the preferred alternatives are chosen and ranked withsome decision factors having a greater influence on the final decision than others. The PTSC members could complete the rating sheet independently or collectively so that the final results represent a group decision and not just one individual. Other important factors can be considered to help select the best alternative when the life cycle costs comparison yields results within 10 percent. These secondary factors may include initial construction cost, future maintenance requirements, performance of similar pavements in the area, adjacent existing pavements, traffic control during construction (safety and congestion), user costs, conservation of materials and energy (recycling), environmental factors, availability of local materials and contractor capabilities, incorporation of experimental features, stimulation of competition, and local municipal factors. The procedure for selecting the best alternative among these secondary factors is given below.

13.9.1 Purpose

The purpose of the Committee will be to:

- Ensure the decision for the pavement type is in alignment with the unique goals of the project and statewide consistency of decision making.
- Provide industry with the opportunity to review the life cycle cost analysis (LCCA) document.
- Formalize the decision process of the Region's pavement type selection.
- Create accountability of the decision of pavement type at the level of Chief Engineer.
- Improve credibility of the decision by following a documented process and clearly communicating the reasons for the decision.

13.9.2 Scope

Reconstruction or new construction of corridor projects with large quantities of pavement where the initial life cycle cost analysis (LCCA) results indicate the pavement types are within 10 percent of each other, the percentage difference will be calculated in such a manner that the alternative with lower the LCCA will be the basis, and therefore will be the LCCA value in the denominator.

13.9.3 Membership

The membership in the PTSC should include all of the following individuals:

- Region Materials Engineer and Resident Engineer
- Headquarters Pavement Design Program Manager
- Region Program Engineer(s) and Transportation Director
- Region Maintenance Superintendent
- Headquarters Materials and Geotechnical Branch Manager
- Headquarters Project Development Branch Manager
- Federal Highway Administration's Pavement and Materials Engineer

13.9.4 Roles of Membership

The following outlines the individual's roles in the PTSC:

- The Region Materials Engineer, Resident Engineer, Region Maintenance Superintendent and Headquarters Pavement Design Manager and Program Engineer will be responsible for the technical details including pavement design, costs, truck traffic, construction timing and sequencing, and the LCCA.
- The Program Engineer and Transportation Director will be responsible for identifying the project goals and the corresponding importance of the elements within the LCCA to match the project goals.
- The Branch Managers will ensure the statewide uniformity of the process and prepare the documentation of the recommendation that will be forwarded to the Chief Engineer.

- The Chief Engineer will make the final decision on the pavement type.

The PTSC will:

- Conduct a critical and independent review of the LCCA.
- Allow industry a period of 2 weeks to review the committee supported LCCA and provide written comments regarding the input assumptions.
- Review written comments from industry to ensure that they are adequately addressed.
- Adjust the LCCA as appropriate. Proceed to the next step if the revised LCCA indicates the pavement alternatives are within 10 percent.
- Create a list of elements that correlate to the corridor project goals. The following possible elements along with a brief description are shown in **Table 13.24 Possible Elements for Pavement Type Selection Process.**
- Apply a rating scale, from the most to least important for each element to match the project goals.
- Determine the alternative that the element favors.
- Sum the most important elements for each alternative to establish if there is a clear advantage. If the alternatives have an equal amount of most important goals, run this step again for the secondary goals, then for the least important if necessary.
- Make a recommendation for pavement type to the Chief Engineer.

Table 13.26 Possible Elements for Pavement Type Selection Process

Element	Description
Total LCCA	Overall cost of the alternative
Initial cost	Availability of current funds to construct the corridor project
User cost during construction	Adverse effects to the traveling public during the construction phase
User cost during maintenance	Future traffic volume may adversely affect the traveling public
Future rehabilitation efforts	Feasibility of maintenance funds required for future work
Conservation of materials	Recycling the existing materials into the corridor project
Impact to local businesses	Access to stores may affect the revenue of the business
Constructability	Required construction techniques
Intersections	Design issues to ensure structural adequacy
Warranty	Benefit of the experimental feature
Evaluation of new technology	Advances in technologies may benefit CDOT or the public
Traffic control	If multiple phases are anticipated or the closure of one lane versus a detour

The above process should be completed by the time of the field inspection review meeting.

After the Chief Engineer has concurred with the preferred alternative for the corridor, no changes to the pavement type will be made unless directed by the Chief Engineer.

References

1. Goldbaum, Jay, *Life Cycle Cost Analysis State-of-the-Practice*, Final Report, Report No. CDOT-R1-R-00-3, Colorado Department of Transportation, March 2000.

2. Demos, George Paul, *Life Cycle Cost Analysis and Discount Rate on Pavements for the Colorado Department of Transportation*, Final Report, Report No. CDOT-2006-17, Colorado Department of Transportation, October 2006.

3. *Life-Cycle Cost Analysis Primer*, Report FHWA IF-02-047, Office of Asset Management, U.S. Department of Transportation, Federal Highway Administration, 400 7th Street, SW, Room 3211, Washington, DC 20590, August 2002.

4. *Life-Cycle Cost Analysis in Pavement Design - In Search of Better Investment Decisions*, Pavement Division Interim Technical Bulletin, Publication No. FHWA-SA-98-079, U.S. Department of Transportation, Federal Highway Administration, 400 7th Street, SW, Washington, DC 20590, September 1998.

5. *Economic Analysis Primer*, Publication No. FHWA IF-03-032, U.S. Department of Transportation, Federal Highway Administration, Office of Asset Management, 400 7th Street, SW, Room 3211, Washington, DC 20590, August 2002.

6. Harris, Scott, *Colorado Department for Transportation's Current Procedure for Life Cycle Cost Analysis and Discount Rate Calculations*, Final Report, Report No. CDOT-2009-2, Colorado Department of Transportation, January 2009.

7. Shuler, Scott and Schmidt, Christopher, *Performance Evaluation of Various HMA Rehabilitation Strategies, Final Report*, Report No. CDOT-2008-9, Colorado Department of Transportation, December 2008.