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COST-EFFECTIVENESS AND PERFORMANCE OF OVERLAY SYSTEMS IN ILLINOIS

VOLUME 2: GUIDELINES FOR INTERLAYER SYSTEM SELECTION DECISION WHEN USED IN HMA OVERLAYS

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16. Abstract

In an effort to control reflective cracking in hot-mix asphalt (HMA) overlays placed over Portland Cement Concrete (PCC) pavements, several reflective crack control (RCC) systems, including interlayer systems, have been used. However, the cost-effectiveness of interlayer systems is still in doubt due their performance and additional costs. In this project, a decision making procedure to aid in the selection of cost-effective interlayer systems was developed. As a core step in evaluating the benefit-cost ratio (B/C) of interlayer systems, a user-friendly life-cycle cost analysis (LCCA) program, CIND (**C**ost-effective **IN**terlayer system **D**ecision program) was developed. Based on sensitivity analysis, a B/C prediction model was proposed, which takes into account a performance benefit ratio (PBR) parameter, a material cost ratio (MCR), and a construction time ratio (CTR). Using the B/C model, a table was developed which allows the user to determine the most cost-effective interlayer system in a rehabilitation project for a given equivalent single-axle load (ESAL) level, representative low temperature (T_L), and existing concrete pavement joint spacing (JS). Finally, a decision making tree was constructed to simplify the process of determining the most cost-effective and compatible interlayer system for a given project. Depending on project significance and/or information availability, pavement engineers can select from one of three newly developed B/C evaluation tools (in order of sophistication): application tables, B/C prediction model, and the CIND computer program. Using these tools, it was found that B/C increases as PBR increases or MCR and CTR decrease. In general, System D is cost-effective in a wide range of ESALs and T_L values; especially in a cold region with lower traffic volume. The application range is reduced with the increase of JS, however. System E is relatively cost-effective only in warm regions having higher traffic volume.

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EXECUTIVE SUMMARY

In an effort to abate reflective cracking in hot-mix asphalt (HMA) overlays in Illinois, several reflective crack control (RCC) systems, including five types of interlayer systems, have been used. According to research conducted in 2008, only three interlayer systems ("area-wide" System A, System D, and System E) were proven effective in reducing the severity and/or extent of reflective cracking. System A consists of nonwoven polypropylene geotextile fabric; System D is an interlayer stress-absorbing composite (ISAC); and System E is a mixture-type interlayer with small-sized aggregates and a highly polymer-modified binder. In general, the interlayer systems reduced reflective cracking but their performance depends on traffic and climate conditions. However, because of the high cost of most interlayer systems, their efficiency, i.e., engineering value or cost effectiveness, is still in doubt.

This project developed a decision-making procedure for the selection of cost-effective interlayer systems that employs a user-friendly, life-cycle cost analysis (LCCA) program (CIND - **C**ost-effective **IN**terlayer system **D**ecision program). In LCCA, agency and user costs are computed for HMA overlays and interlayer systems in terms of initial and discounted future costs. To evaluate the cost effectiveness of the interlayer systems, a benefit-cost ratio (B/C)—a ratio of life-cycle cost (LCC) associated with savings resulting from the use of interlayer systems to total LCC of the interlayer systems— was obtained. The B/C of an interlayer system will depend on its performance, its initial cost, the construction procedure used, and the thickness of the HMA overlay used in conjunction with the interlayer. A B/C prediction model for an evaluation period of 30 years was proposed, in terms of performance-benefit ratio (PBR), material cost ratio (MCR), and construction time ratio (CTR). Since the main variable, PBR, is significantly related to traffic volume and climate, the B/C of interlayer systems can be determined from equivalent single-axle loads (ESALs) and representative low temperature (T_L). In addition, joint spacing plays an important role in the B/C of strip-type interlayer systems, such as System D. By comparing the B/C of various interlayer systems used in Illinois, the most cost-effective interlayer system could be determined for a given set of conditions. Several tables were developed that list the appropriate application regions for each interlayer system with respect to ESALs, T_L, and joint spacing (JS).

Finally, a decision-making tree was constructed to aid the designer in selecting the most cost-effective, as well as the most compatible interlayer system for a particular set of conditions. Using the decision tree, the most cost-effective interlayer system can be selected, based on HMA overlay design, traffic volume, and climate condition. Depending on project significance and/or information availability, pavement engineers can select from one of three newly developed B/C evaluation tools, which are, in order of sophistication: application tables, a B/C prediction model, and the CIND computer program.

Based on a variety of 25 interlayer systems evaluated, a B/C ranged from -29.4% to 16.0% for area-type System A, 3.4% to 28.5% for System D, and 4.0% to 59.8% for System E. The strip-type Systems A and B were found to have negative B/C due to their poor performance (PBR < 1.0). B/C increases linearly as PBR increases, but decreases linearly as MCR and CTR increase. System D has wider application ranges in terms of ESALs and T_L, especially in cold regions in Illinois; System E is cost-effective in warm regions of Illinois. As joint spacing increases, the application range of System D is extended up to 30 ft and is diminished after 30 ft.

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1. INTRODUCTION

1.1 BACKGROUND

Hot-mix asphalt (HMA) overlays are a pavement rehabilitation commonly used for the renewal of structurally or functionally deteriorated pavements. The new AASHTO mechanistic–empirical pavement design guide proposes three HMA overlay design approaches, depending on whether the existing pavement type is HMA, fractured concrete, or an intact concrete pavement—including composite pavement (NCHRP, 2003). For each of these, pre-overlay repairs are typically conducted prior in order to enhance the performance of the HMA overlay which follows. For example, cracking and seating, breaking and seating, rubblization, patching, slab jacking, and dowel bar retrofitting can be applied to concrete pavements, while milling, patching, and crack sealing are treatments usually used to repair flexible pavements prior to the placement of an overlay. Several methods are also sometimes used to control reflective cracking, such as the use of a thicker HMA overlay, sawing and sealing of joints in the new overlay, the placement of synthetic fabrics or steel netting below or between paving lifts in the overlay, or the application of a crack relief layer. Among these methods, interlayer systems have generally been found to be among the most cost efficient for controlling reflective cracking. However, interlayer systems can sometimes be costly, depending on the nature of the system used, in terms of both material and construction costs. Thus, cost effectiveness should be considered as part of overlay system design.

1.2 REFLECTIVE CRACK CONTROL IN ILLINOIS

HMA overlays are designed based on existing pavement, traffic, and climate conditions (see Figure 1). After deciding overlay thickness, a suitable reflective crack control (RCC) system can be selected. The RCC system, however, does not affect the HMA overlay thickness, since it has no structural function. The RCC system is selected on the basis of how effectively it can reduce the occurrence of reflective cracking. The effectiveness of the RCC system depends not only on its performance, but also its cost efficiency. For example, if the cost of controlling reflective cracking and increasing the HMA overlay service life is relatively high compared to the cost of untreated overlay when considering the life-cycle cost analysis, then the approach is inefficient and the cost benefit could be high.

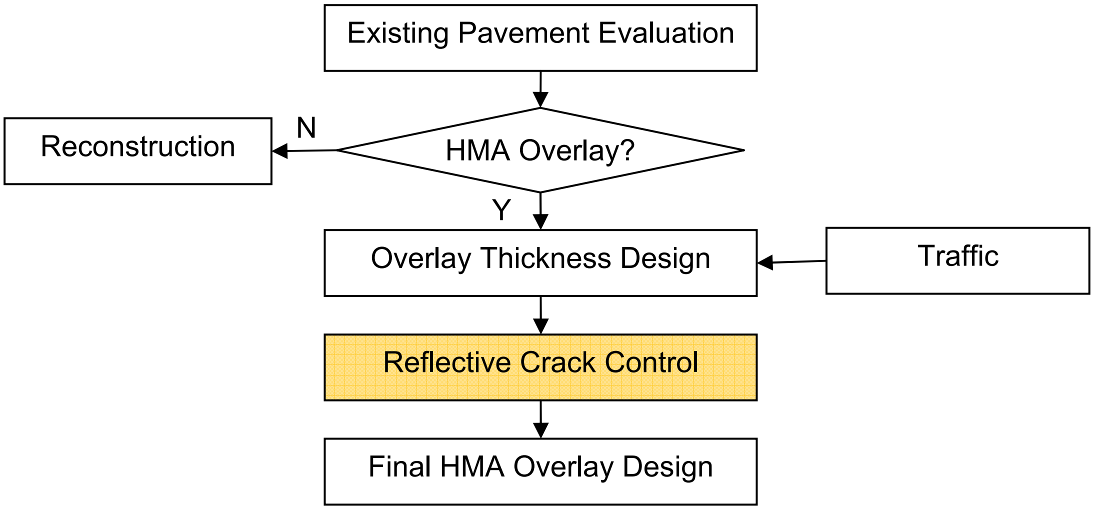


Figure 1. HMA overlay design procedure.

According to pavement rehabilitation policy in Illinois (IDOT, 2002), several RCC systems such as fabric interlayers, crack relief layers, and rubblization can be used in conjunction with an HMA overlay. Reflective crack control Systems A, B, and C which are used in Illinois are relatively thin geosynthetic fabrics that are placed beneath or within the HMA overlay. System A uses a non-woven reinforcing fabric and is typically adhered to a prepared pavement surface with a hot-applied asphalt binder tack coat. System B combines woven or non-woven reinforcing fabric and a waterproofing membrane which are embedded in self-adhesive bitumen ("peel and stick"); following placement, a light roller compactor is usually used. System C is a nonproprietary asphalt–rubber waterproofing membrane interlayer used in conjunction with cover aggregate. In addition, interlayer stress-absorbing composite (ISAC) and "sand mix" interlayers have been recently used as RCC systems (Buttlar et al., 1999; Vespa, 2005). They are designated as Systems D and E, respectively. ISAC is a sandwich-like structure which consists of two geotextile and rubber asphalt layers. The top layer is composed of a high-strength, woven geotextile designed to withstand high tensile stress, while the bottom layer is a low-stiffness, nonwoven geotextile with high strain tolerance and good adhesion characteristics. The middle layer—a highly rubberized asphalt—functions to dissipate strain energy. ISAC is only used as a strip-reflective crack control treatment. The sand mix interlayer system is designed to resist fracture. It is a mix of fine aggregate with highly polymer-modified asphalt binder, and is prepared using a high asphalt content at low void content. Sand antifracture (SAF), Strata, and IL 4.75-mm can be classified the same as System E. However, it should be recognized that they differ in design methodology. Furthermore, the nature of the polymer-modified binder used can be significantly different from one system to another. For obvious reasons, System E is predominantly applied as an area-wide treatment.

1.3 LIFE-CYCLE COST ANALYSIS

The Federal Highway Administration (FHWA) describes LCCA as "well-founded principles of economic analysis to evaluate the overall-term economic efficiency between competing alternative investment options" (FHWA, 1998). Life-cycle cost analysis (LCCA) integrates agency and user costs for initial and discounted future costs to account for all investments over a service life. The purpose of LCCA is to identify the lowest and/or the best value for the investment outlays; and it can be used to compare candidate designs and/or materials for pavement design and rehabilitation. The use of LCCA is mandated by federal legislation such as the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the National Highway System (NHS) Designation Act of 1995.

Three approaches have been used to evaluate cost effectiveness: maximum benefit, least cost, and a combination of the two (Lamptey et al., 2005). The maximum benefit approach is applicable for some activities such as capital investment for which the exact benefit is difficult to assess from alternatives due to uncertainty. In the least cost approach, when the same benefit can be achieved from each alternative, the least cost is regarded as the best. The third approach is the combination of benefit and cost analysis which was recommended by NCHRP Synthesis 223 (Geoffrey, 1996). This method is only applicable when both benefit and cost can be quantified in monetary terms.

In this study, the performance and cost benefit combination approach is used to evaluate the effectiveness of interlayer systems. The benefit of an interlayer system that results from the extension of service life of an HMA overlay can be assessed using field crack survey data. Cost benefit can then be quantified using LCCA, considering material costs, user delay costs, and overlay life (time to next rehabilitation). Subcategorization can also be considered, so that factors such as traffic level, climate, and PCC joint spacing on subsequent overlay deterioration rate can be considered in the LCCA.

1.4 DECISION-MAKING PROCEDURE IN PAVEMENT DESIGN

To determine the optimal design from alternatives under consideration, a decision-making procedure was required. Pavement evaluation considering performance and cost effectiveness is the most important step in this regard (Beg et al., 2000; Wei and Tighe, 2004; Lamptey et al., 2005). In Beg et al. (2000), three main components were used to evaluate pavement types: agency costs, user delay costs, and performance levels. In their study, the pavement performance levels were quantified from a pavement performance curve using a present serviceability index (PSI). Then, a cost-effectiveness index was developed using PSI, equivalent uniform annual cost (EUAC), performance period, and minimum tolerable PSI. In addition, other nonmonetary factors such as available materials and agency policy were included in the decision tree developed from their research. After combining the cost-effectiveness index and supplementary factors, the optimal pavement strategy could be selected.

For Wei and Tighe (2004), cost effectiveness (CE) was an essential parameter for selecting each treatment or strategy. The CE of each treatment was calculated based on performance effectiveness and corresponding life-cycle cost (LCC). Performance effectiveness was computed from the area under a performance curve for a treatment; LCC included agency and user costs for the treatment. Based on the CE analysis, the most cost-effective method was determined, and the best timing of the treatment was also decided. Finally, using the CE, strategy levels, and proper timing, a decision tree was developed to select the most appropriate treatment for a specific location and conditions.

In their study, Lamptey et al. (2005) developed a decision tree based on the cost effectiveness as well as the applicability of alternative designs. Figure 2 shows this decision tree for selecting an optimal pavement rehabilitation and maintenance (R&M) strategy simplified for Indiana pavement design procedures. In this procedure, the core part of the strategy is the LCCA evaluation of the R&M strategies.

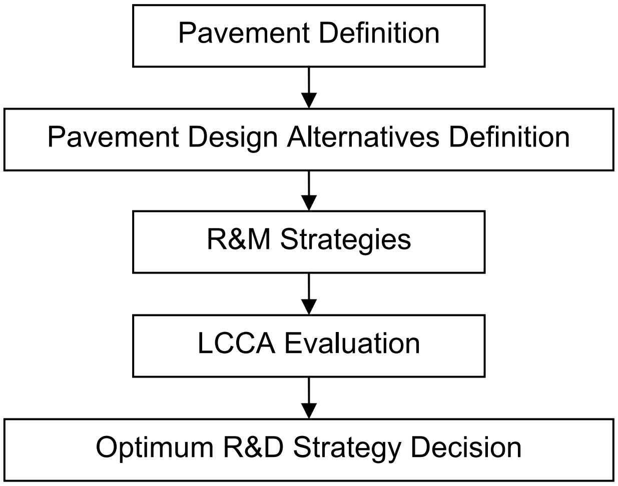


Figure 2. Typical decision tree to select a pavement alternative (Lamptey et al., 2005).

2. INTERLAYER SYSTEM DECISION PROCEDURE

2.1 GENERAL PROCEDURE

The procedure for selecting cost-effective interlayer systems consists of two main parts: performance and cost-benefit analysis. Figure 3 shows an entire but simplified framework for decision making related to cost-effective interlayer systems. In the first step, the five types of interlayer systems previously mentioned are incorporated as HMA overlay alternatives. Then, the relative benefits of the alternatives are obtained and compared with an untreated HMA overlay. In the performance-benefit analysis, the performance-benefit ratio is obtained to represent the reflective cracking delay rate for each interlayer system, and consequently, how long the service life of the HMA overlay is extended. In the second step, LCCA is used to evaluate the cost effectiveness achieved by the interlayer system. Then, using a decision tree, an optimal interlayer can be selected for a given HMA overlay design based on the cost-benefit analysis, as well as compatibility with the HMA overlay design.

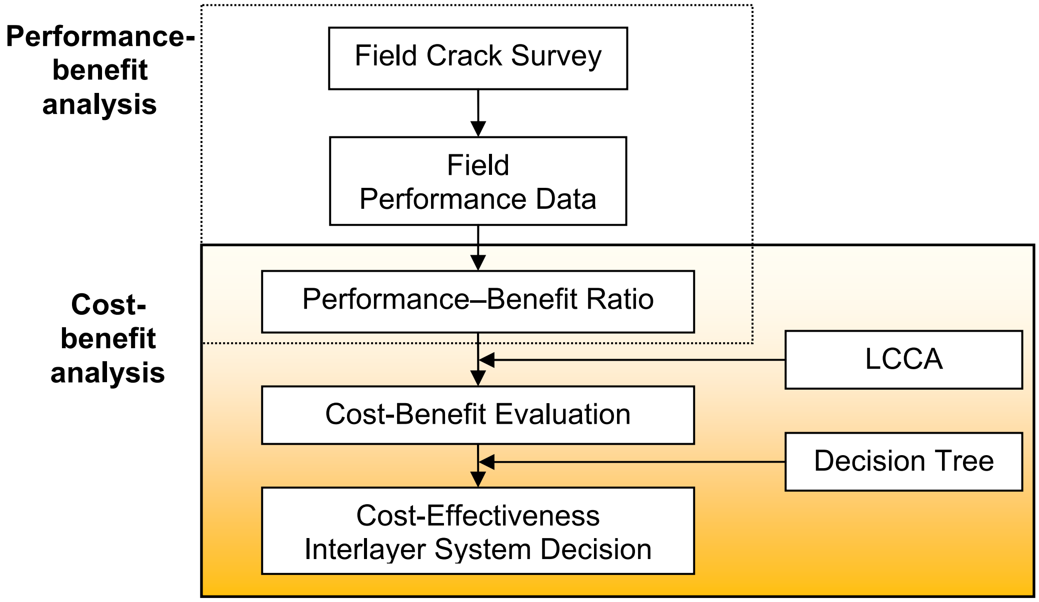


Figure 3. Framework for decision making for interlayer system evaluation to control reflective cracking.

2.2 INTERLAYER SYSTEM PERFORMANCE EVALUATION

In-situ effectiveness assessment of interlayer systems to control reflective cracking was conducted as a basis of cost effectiveness evaluation (Al-Qadi et al., 2008). For the five types of interlayer systems used in Illinois, the extent and severity of reflective cracking was obtained from field data collected from a survey of 24 locations. Based on these data, the performance-benefit ratios (PBRs) were determined to quantify the relative benefit of these interlayer systems to an untreated HMA overlay. For System D, it was reported that the PBR decreases with the increase of annual equivalent single-axle loads (ESALs); statistically, the effect of ESALs on PBR was significant. In addition, lowest monthly average temperature, T_L and joint spacing (JS) were important factors to the performance of System D. A regression model to predict the PBR of System D was developed (Table 1). However, for two area-type interlayer systems, System A and System E, in general, the PBR decreased insignificantly with the increase of ESALs. No obvious variables were found to affect the PBRs of area-type System A and System E. Thus, the average PBR can be used to represent the performance of these two interlayer systems despite having some variations: average PBR is 1.22 for area-type System A and 1.49 for System E.

Table 1. Performance-Benefit Ratio Prediction Model for Interlayer System D (Al-Qadi et al., 2008)

Interlayer system	Performance-benefit ratio prediction model	Eq.
System D (strip)	$PBR = 5.29 – 3.49 \times 10^{-6} (ESALs) – 0.0854 (T_L) – 0.0279 (JS)$	1

2.3 LIFE-CYCLE COST ANALYSIS FOR HMA OVERLAYS

In general, a standard LCCA procedure suggested by FHWA was used for this project (FHWA, 1998). Two modules were added, specifically to consider interlayer systems used in HMA overlays. First, the service life of the HMA overlay with an interlayer system was estimated using the PBR of the interlayer system. Second, additional costs for installing the interlayer system were calculated based on unit price and quantity of the interlayer system. To compute life-cycle cost (LCC) of the HMA overlays with interlayer systems, monetary items such as agency cost, user cost, expenditure diagram, and net present value need to be clarified. Note in the description below that maintenance costs were not considered in this LCCA because they are not a large portion of the total cost, and it was assumed that the same types of routine maintenance, such as crack sealing, are usually scheduled for both control and treated sections. This assumption may decrease the cost effectiveness of interlayer systems when they demonstrate a positive performance benefit. Consequently, it may underestimate the cost effectiveness of the interlayer systems. This conservative approach, however, compensates for the uncertainty of the interlayer system performance based on field survey data from a small number of locations.

2.3.1 Agency Cost

Agency cost comprises all costs of HMA overlay and interlayer systems, including materials and construction. For the HMA, it covers initial and successive HMA overlays needed for the pavement analysis period. Corresponding to HMA overlay design, a quantity of the HMA overlay per lane-mile is computed for the thickness of wearing surface and leveling binder. The unit price of the HMA overlay is expressed as \$/ton, and it is converted into \$/ft^2/in using a constant density of 150 lb/ft^3. This analysis does not take into account any milling, patching, crack sealing, and other rehabilitation activities prior to the overlay. Nonetheless, existing pavements should be carefully treated to ensure the performance of the overlay and interlayer systems.

When an interlayer system is used in the HMA overlay, a supplemental cost for the interlayer system is calculated per lane-mile based on the number of strips for strip-type interlayer systems or applied area for area-wide interlayer systems. For strip-type interlayer systems, when the number of strips is the same as the number of joints—that is, the strips are installed only on joints— the number of strips is indirectly determined from joint spacing of an existing jointed concrete pavement (JCP). Otherwise, the number of strips can be directly determined. Thus, unit price is \$/strip. For area-wide interlayer systems, two approaches are used. Unit price and installation cost of System A are \$/ln.ft and \$/100 ft, respectively; while System E has the same units as HMA overlay, since it is a mixture-type interlayer system.

2.3.2 User Cost

In general, the components of user cost are user delay cost, vehicle operating cost (VOC), and crash cost (FHWA, 1998). The analysis of this research basically followed the one used in RealCost 2.2 to compute user cost. Input items to compute user cost are traffic characteristics, work zone characteristics, and value of travel time. The traffic characteristics are specified by annual average daily traffic (AADT); percentage of passenger cars, single-unit, and combination trucks; and hourly distributions in urban or rural areas, or both. In these calculations, AADT distribution is determined only for principal arterial roads; neither interstates nor minor arterials are considered. The work zone is characterized using work zone length and time, speed change, stopping, and queue idling delay, and VOC. Truck equivalent factors are determined to calculate road capacity assuming that the grade of the road is less than 2%. Regarding the value of travel time, base case values provided in 1996 dollars in the FHWA bulletin (FHWA 1998) are converted into values corresponding to a specific year using an escalation factor. Using a consumer price index (CPI) (U.S. Department of Labor 2008), the escalation factor is computed as a CPI ratio of 1996 to a certain year, as shown in Figure 4.

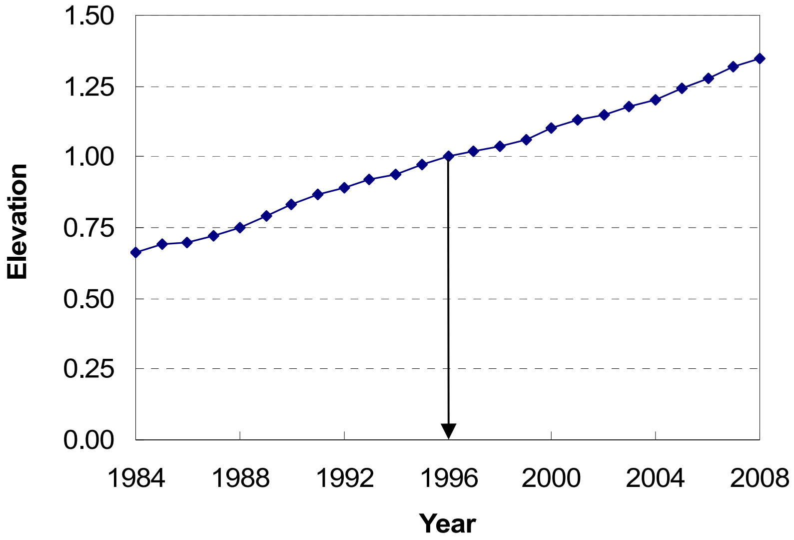
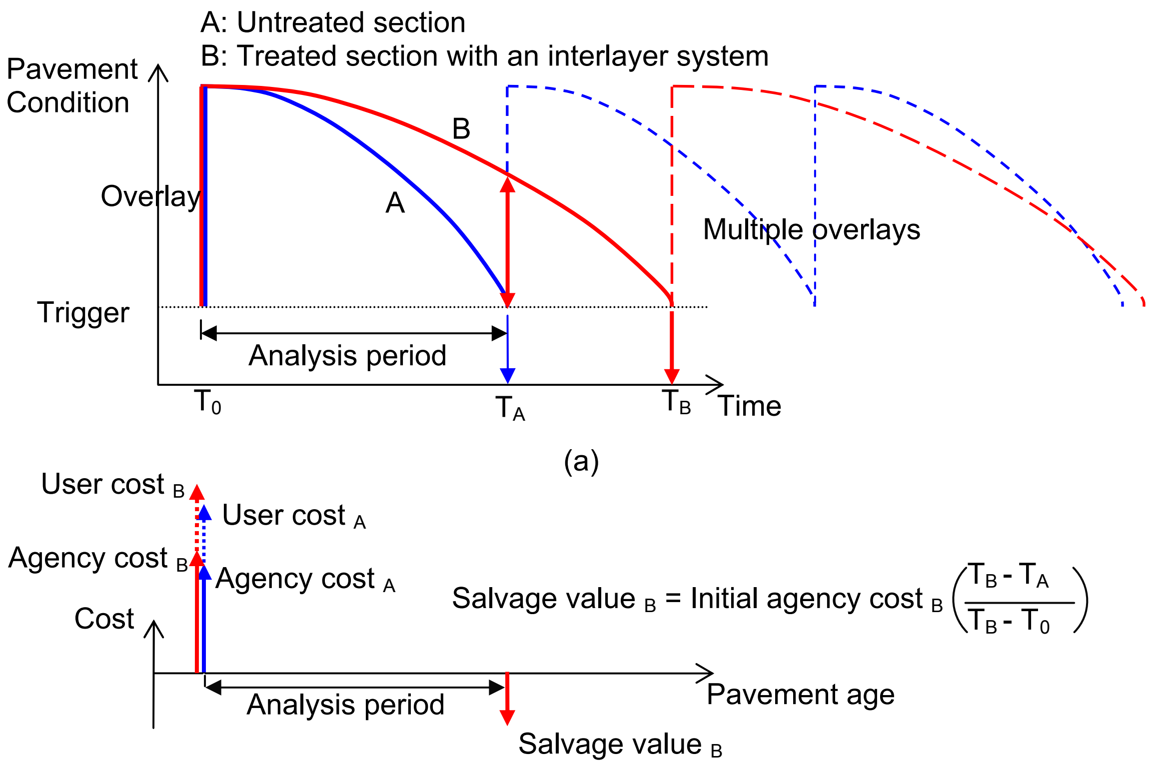


Figure 4. Escalation value variation with base year 1996.

2.3.3 Expenditure Diagram

For two overlay strategies of control and treated sections, pavement condition variations and expenditure diagrams are depicted in Figure 5. For the untreated overlay, the pavement condition drops relatively faster than for a treated section and reaches a trigger value at T_A. On the other hand, the treated section has a longer service life (T_B – T_0) than that of the untreated section (T_A – T_0). When the shorter service life of T_A – T_0 is used as an analysis period in LCCA, the treated overlay is still in a good condition at the end of the analysis period and has a remaining service life of (T_B – T_A). The expenditure diagrams of the overlays are constructed for the one cycle of untreated overlay service life. Since no maintenance is considered, only initial overlay construction and user cost are included in the expenditure diagram. However, to compensate for the remaining service life of the treated overlay, a salvage value is considered as a negative cost. The salvage value is a portion of the initial cost of the treated overlay; and is proportional to the ratio of the remaining service life (T_B – T_A) to the original service life span (T_B – T_0), as shown in Figure 5(b). The longer the service life of the treated section is, the larger the salvage value becomes. When multiple overlays are constructed, a salvage value is computed based on the last overlay span.



(a)

(b)

Figure 5. (a) Pavement condition variation over pavement age and (b) expenditure diagram corresponding to one cycle.

2.3.4 Net Present Value and Equivalent Uniform Annual Cost

When initial and future costs are summed in LCCA, the future cost should be discounted to the base year by means of a discount rate. The discount rate incorporates interest rate and inflation rate. Generally, the discount rate used in pavement analysis ranges from 3.0% to 5.0%. IDOT adopted the discount rate of 3.0% as a default value in LCCA. A net present value (NPV) is the sum of the initial value and the discounted values as follows:

$$\mathrm{NPV} = \text{Initial cost} + \sum \text{Future cost}\left(\frac{1}{1+i}\right)^{n} \tag{2}$$

where,

NPV is net present value; and
n is an expenditure year.

In this equation, no discount rate is applied to the initial cost, and a constant discount rate is applied to additional multiple overlays, as well as the salvage value. For each overlay, NPV can be broken down into agency and user costs, as well as salvage value, as follows:

$$\text{NPV}_A = \text{Initial cost}_A = \text{Agency cost}_A + \text{User cost}_A \qquad (3)$$

$$\text{NPV}_B = \text{Initial cost}_B + \text{Salvage value}_B \left(\frac{1}{1+0.03} \right)^{(T_A - T_0)} \qquad (4)$$

Finally, equivalent uniform annual cost (EUAC) is determined based on NPV, the discount rate, and the number of years into future (n) as follows:

$$\text{EUAC} = \text{NPV}\left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \qquad (5)$$

2.4 COST-EFFECTIVE INTERLAYER SYSTEM DECISION PROGRAM (CIND)

A special-purpose LCCA was developed to determine the cost effectiveness of interlayer systems in HMA overlays: the cost-effective interlayer system decision program (CIND). The LCCA procedure employed in CIND to compute LCC is similar to the approach in RealCost Version 2.2 developed by FHWA (FHWA, 1998). CIND is composed of three modules, shown in Figure 6: input, analysis, and output. In addition, a file input/out (I/O) menu is also provided to import an existing data file or to save current data. Figure 7 shows a main menu of CIND and an I/O option in the design input module. Details of the CIND operation are described in Appendix A (User Manual for CIND Version 1.0).

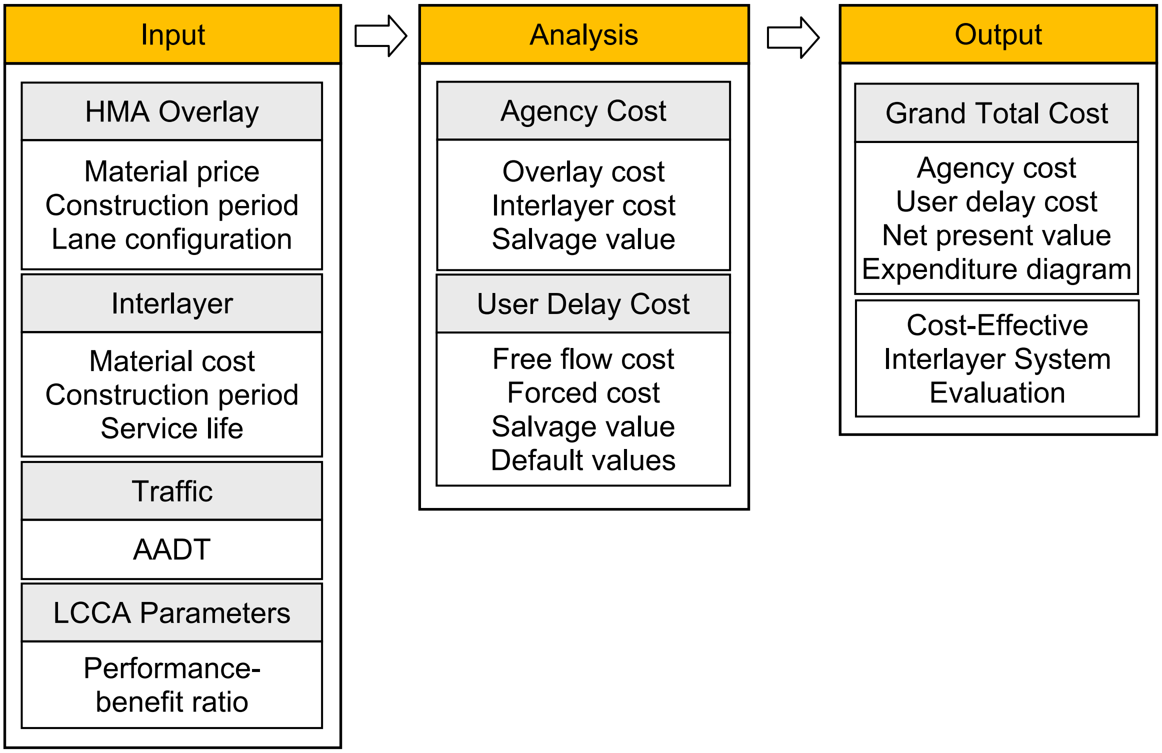


Figure 6. Framework for the **C**ost-effective **IN**terlayer selection **D**ecision program (CIND).

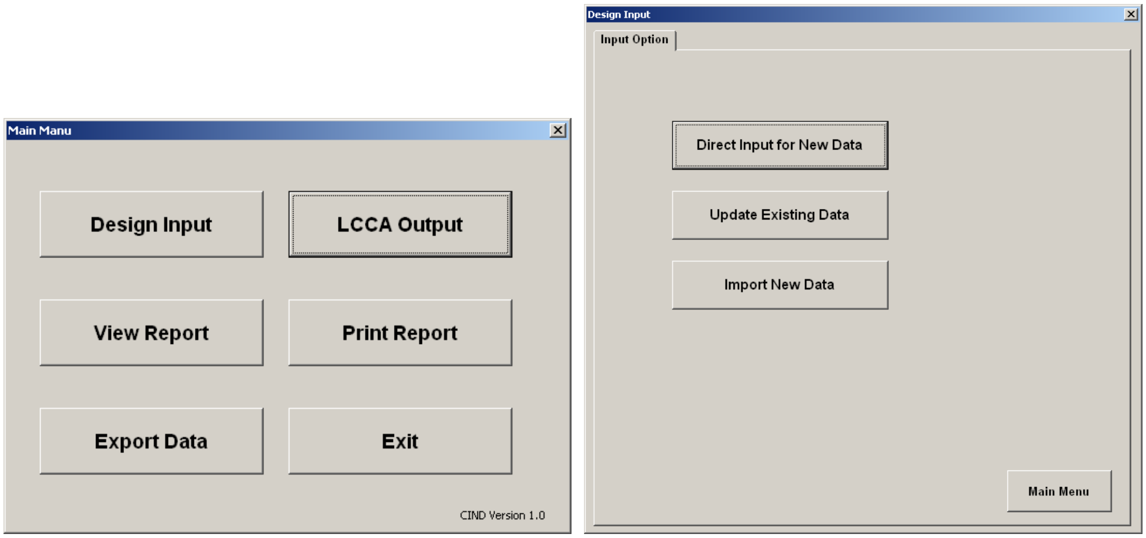
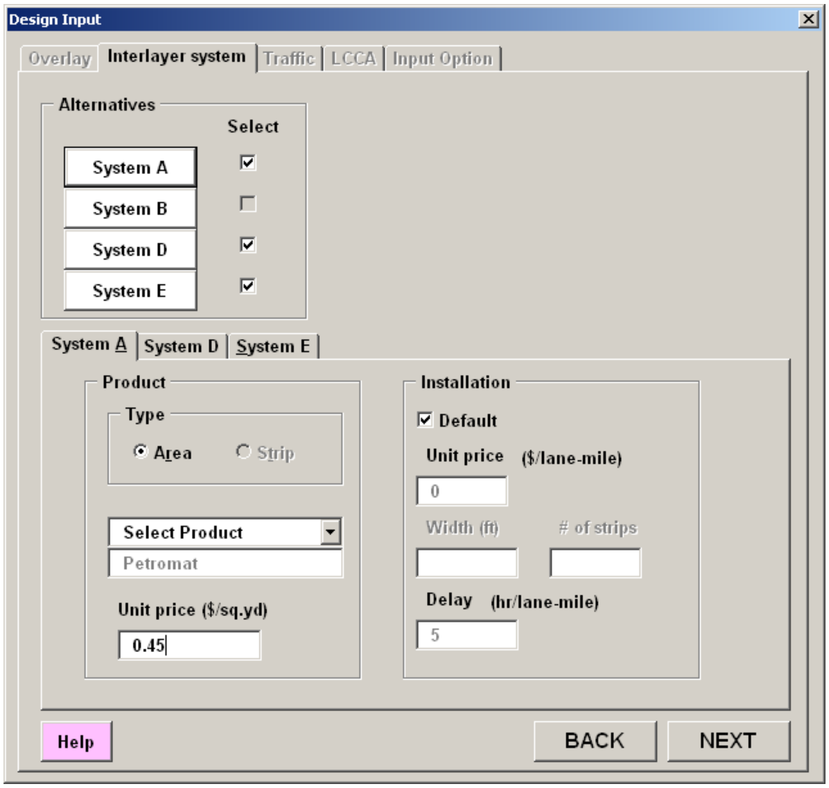


Figure 7. CIND main menu and I/O option.

2.4.1 Input Module

In the CIND input module, input variables are required for geometry, HMA overlay, interlayer system, traffic, work zone, and LCCA parameters. Input variables and their descriptions are presented in Table 2. (More details about these variables are in the CIND user manual in Appendix A.) Default values for some parameters are suggested. The performance-benefit ratio is automatically computed based on the interlayer system and overlay design; however, it can be an input value too. To obtain proper input values, four user-friendly input forms are provided: overlay, interlayer system, traffic, and LCCA. In these input forms, a sample product list and/or typical values for each input variable are given. Figure 8 demonstrates two input forms for interlayer system and LCCA. When incorrect values are entered in a step in CIND, a warning message appears prior to the next step.



Alternatives

	Select
System A	☑
System B	☐
System D	☑
System E	☑

System A | System D | System E

Product

Type: ● Area ○ Strip

Select Product: Petromat

Unit price ($/sq.yd): 0.45

Installation

☑ Default

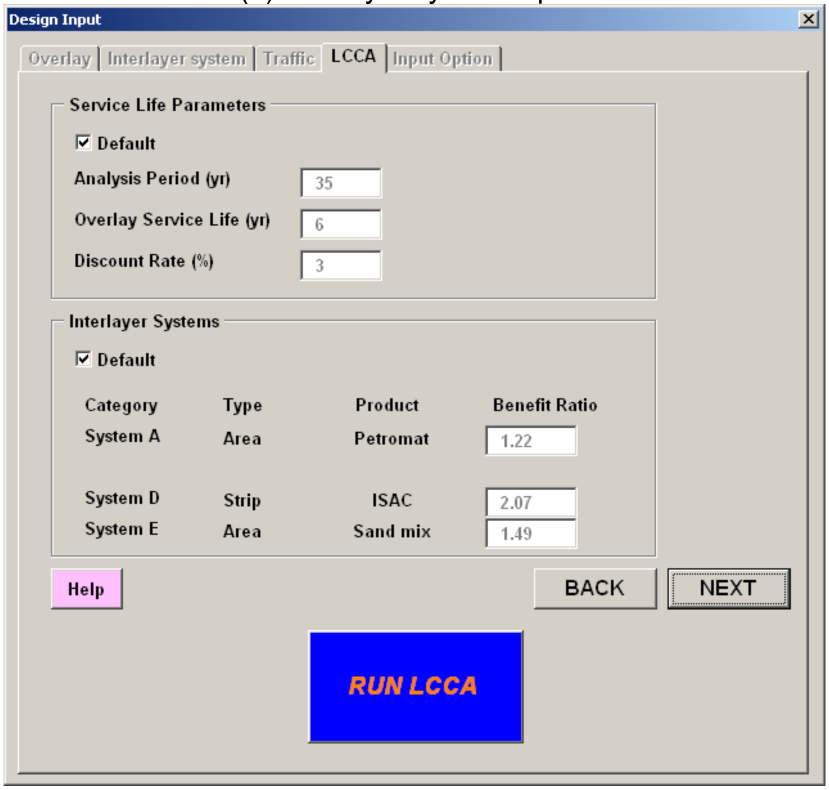
Unit price ($/lane-mile): 0

Width (ft):

\# of strips:

Delay (hr/lane-mile): 5

(a) Interlayer system input.



Service Life Parameters

☑ Default

Analysis Period (yr): 35

Overlay Service Life (yr): 6

Discount Rate (%): 3

Interlayer Systems

☑ Default

Category	Type	Product	Benefit Ratio
System A	Area	Petromat	1.22
System D	Strip	ISAC	2.07
System E	Area	Sand mix	1.49

(b) LCCA input

Figure 8. CIND input forms for (a) interlayer system and (b) LCCA.

Table 2. Overlay Input Variables for CIND

Classification	Option/Input	Description
Geometry	Lane length	Total project lane length or evaluation length (miles)
	Lane width	Default value of 12 ft for inner and outer lane
	Number of lanes	Number of lanes in each direction, up to 3
	Joint spacing	Longitudinal slab span length of pre-existing concrete pavements; range: 10 to 100 ft
New HMA overlay	Thickness	Thickness of wearing surface and leveling binder (in.)
	Material	Material cost ($/ton)
	Construction	Additional construction cost if needed ($/in.-lane-mile)
	Period	Construction period (hr/in.-lane-mile)
Interlayer system	Type	System A (area and strip), System B (strip), System D (strip), and System E (area)
	Product name	Currently used product
	Product unit price	Systems A, B, and D: $\$/yd^2$; System E: $/ton
	Installation unit price	Additional price to install interlayer systems
	Width	Width of a strip for a strip-type interlayer system (ft)
	Number of strips	Same as number of joints or actual number of strips used
	Installation day	Additional period to install interlayer system
	Performance-benefit ratio	Service life extension ratio of an overlay with interlayer systems to an untreated overlay

Table 2 (continued). Overlay Input Variables for CIND

Category	Option/Input	Description
Traffic	Category	Urban or rural
	Priority	Principal arterial or minor arterial (no interstate)
	Current year	First year of the analysis period
	AADT	Annual average daily traffic (AADT) in both directions in current year
	Road class	Illinois road classifications regarding traffic volume and number of lanes
	Growth rate	Annual traffic growth rate of AADT (same rate for all vehicles)
	Passenger cars	% of passenger cars in the AADT
	Single-unit trucks	% of single-unit trucks in the AADT
	All other trucks	% of combination trucks in the AADT
Work zone	Lane opening in work zone	Number of lanes open in work zone area in each direction, up to two lanes
	Upstream speed	Speed limit in normal operation (mph)
	Work zone speed	Speed limit in work zone area (mph)
	Work zone Length	Maximum length of work zone area when vehicle speed is reduced (miles)
	Work zone duration	Duration for work zone (”all day” option is used as default).
Life-cycle cost analysis parameters	Analysis period	Total design year to be analyzed (year), up to 50 years
	Overlay service life	Overlay service life span with no interlayer system (year)
	Discount rate	Rate for discounting future costs to present value (3% to 5%)

2.4.2 Output Module

Using the input variables in the previous section, LCCA is performed to compute agency and user costs for one cycle of the untreated HMA overlay service life, as well as for a total design analysis period. For the one-cycle period, agency cost, user cost, and salvage value are compared for each HMA overlay design to easily obtain the cost reduction when interlayer systems are used. The relative cost benefit of interlayer systems is computed for the total design analysis period based on a ratio of total cost of the treated overlay to that of the untreated HMA overlay. The LCCA results are presented in the output module as a summary report and five charts for the LCC components.

The cost benefit of an interlayer system is defined as a ratio of EUAC saved through the use of the interlayer system to EUAC of an HMA overlay without interlayer systems (see Equation 10); so-called a benefit-cost ratio (B/C). From LCCA, the EUAC of each HMA overlay is obtained based on the PBR of interlayer systems used in the HMA overlays and the material costs of the HMA overlays and the interlayer systems. Figure 9 presents a typical B/C output for four interlayer systems.

$$B / C\ (\%) = \frac{C_U - C_T}{C_U} \times 100 \qquad (6)$$

where,

B/C is a benefit-cost ratio as a percentage; and

C_U and C_T are EUAC of an untreated and treated overlay for a design life span.

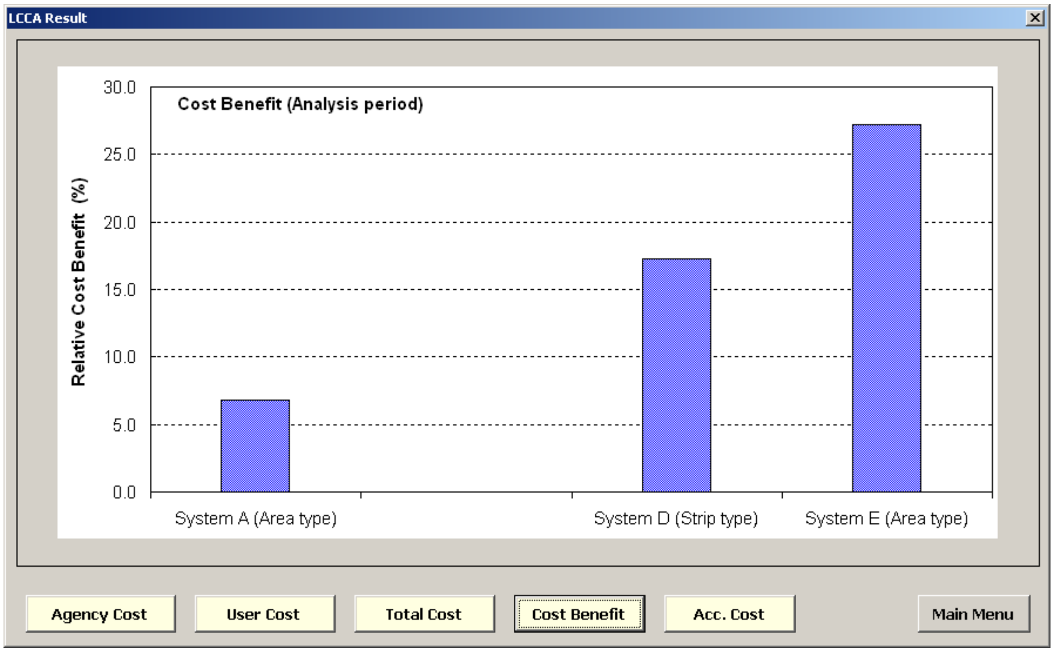


Figure 9. CIND output form demonstrating a benefit-cost ratio.

3. EVALUATION OF COST EFFECTIVENESS OF INTERLAYER SYSTEMS

3.1 COST BENEFIT

For 25 interlayer systems, cost effectiveness was evaluated using a benefit-cost ratio (B/C). The material costs of the interlayer systems and HMA overlays are listed in Table 3. Since material prices vary locally depending on the quantity of materials, manufacturers, and other factors, the average values obtained from available sources were used for this evaluation. According to Buttlar et al. (2000), fabric cost was categorized in terms of quantity. For low, medium, and high quantity, the fabric cost was \$1.23, \$0.84, and \$0.65/yd^2 for area-type System A and \$0.51, \$0.30, and \$0.23/ln.ft for strip-type System A. According to one manufacturer, System B was \$0.89/ft^2 and System D (ISAC) was \$2.39/ft^2. For mixture costs, IDOT provided numbers for four projects constructed in 2003: IL 130 Philo, IL 17 Aledo, IL 117 Benson, and IL 76 Belvidere. For the four projects, the average cost was \$49.30/ton for IL 4.75-mm mix, \$38.60/ton for IL 9.5-mm mix, and \$38.20/ton for surface mix. The reference year, in terms of when those interlayer systems' costs were surveyed, does not coincide with the evaluation year for each project. Therefore, these reference year costs were converted to correspond with each evaluation year using the escalation factors shown in Appendix B. There are some limitations, however, in using these sources to represent real and current market prices of materials. For this reason, the effect of material prices on benefit -cost are analyzed later to validate the benefit-cost analysis and to reflect the variability of the material prices.

Table 3. Material Prices for Evaluated Interlayer Systems

Material				Unit price	Unit	Reference year
HMA Overlay	Wearing surface		Mix "D"	38.2	\$/ton	2003
	Leveling binder		IL9.5	38.6	\$/ton	
Interlayer System	System A	Area	<20,000	1.23	$\$/\text{yd}^2$	2000
			20,000-70,000	**0.84**	**$\$/\text{yd}^2$**	
			>70,000	0.65	$\$/\text{yd}^2$	
	System A	Strip	<18,000	0.51	\$/ln.ft	2000
			18,000-100,000	**0.30**	**\$/ln.ft**	
			>100,000	0.23	\$/ln.ft	
	System B	Strip	PavePrepSA Roadtac	**8.01**	**$\$/\text{yd}^2$**	2008
	System D	Strip	ISAC	**21.5**	**$\$/\text{yd}^2$**	2008
	System E	Area	IL130	61.0	\$/ton	2003
			IL17	51.8	\$/ton	
			IL117	44.1	\$/ton	
			IL76	40.3	\$/ton	
			Average	**49.3**	**\$/ton**	

3.1.1 System A (Area)

Figure 10 shows B/C at various PBR values and three cost levels for the area-type System A. B/C variation is in the range of ±20% at each cost level due to various PBR values of the interlayer systems. In addition, the B/C decreases with the increase of the cost level. To achieve positive cost effectiveness, then, an area-type System A should have a marginal level of performance, as well as lower cost. When the System A has a medium level cost of $\$0.84/\text{yd}^2$, for example, a minimum PBR of 1.3 is required for the system to be cost effective (Figure 11). Thus, despite a positive PBR value, cost effectiveness of the system cannot be achieved unless material cost becomes cheaper than a truncate value. For a given set of traffic and environmental conditions at a location, the performance of the interlayer system can be estimated and consequently, the truncate material cost can be determined. If an area-type System A interlayer that is cheaper than truncate cost is available locally, the System A can be cost effective. (Detailed LCCA results are shown in Appendix B.)

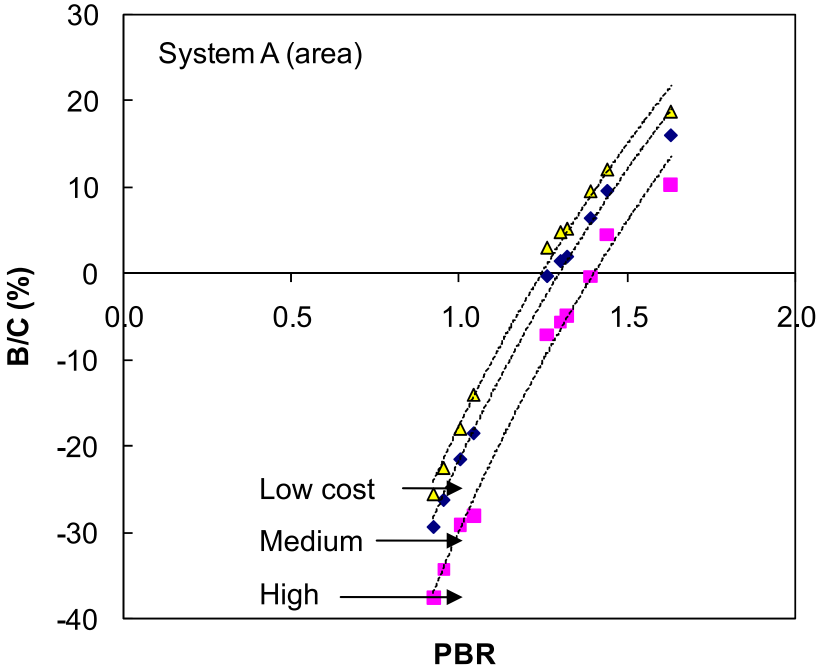


Figure 10. B/C of area-type System A with respect to PBR and cost level.

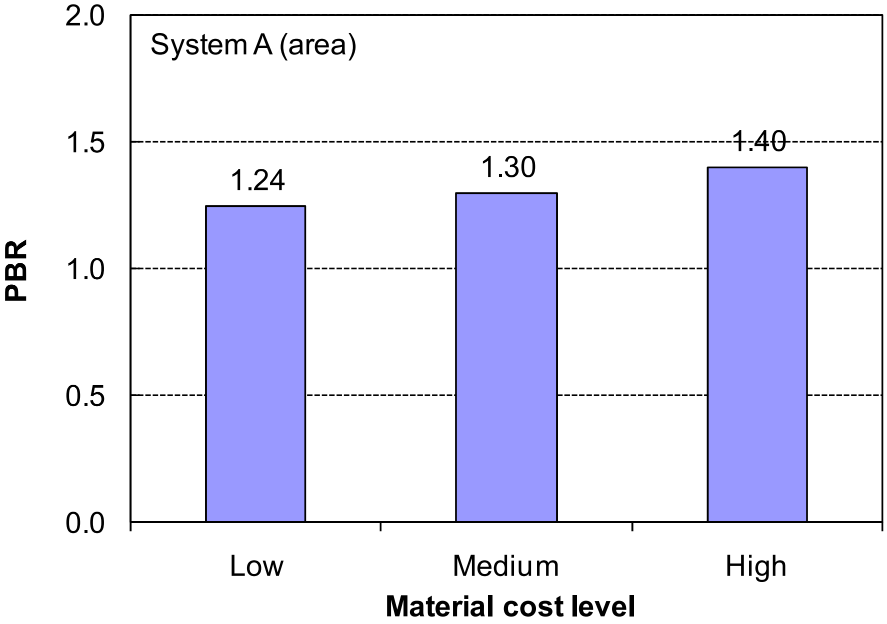


Figure 11. Minimum PBR at three material cost levels for area-type System A.

3.1.2 System A (Strip) and System B

According to field evaluations, the PBRs of strip-type System A and System B (Al-Qadi et al., 2008) are always equal to or less than 1.0 at five surveyed locations: 0.65, 0.35, and 0.80 for the System A; and 1.0 and 0.93 for the System B. Regardless of the systems' material costs, they cannot be considered cost effective because the PBR values are negative or, at most, equal to one.

3.1.3 System D

Figure 12 shows B/Cs at various PBR values and three cost levels for System D. B/Cs vary in a wide range around ±5% or less at each cost level due to various PBR values of the interlayer system and the reduction in B/C as the cost level increases from low (-20%) to high (+20%). (Detailed LCCA results are presented in Appendix B.) Of the four sections with positive PBR, three have positive B/C regardless of material cost, and one section (IL 29 Creve Coeur) has negative B/C in spite of a relatively high PBR value of 1.44. To account for interlayer system installation, extra construction time was added in the calculation of user delay cost and additional construction cost was included in agency cost. According to previous research by IDOT (Vespa, 2005), it took 1.5 hrs for 47 ISAC strips (0.032 hr/ea) at the US 136 section and 7.0 hrs for 103 ISAC strips (0.068 hr/ea) at the IL 267 section to be installed. Since the other reported sections did not have any information on installation time, a slow installation rate (0.08 hr/ea) was used [as a default. Figure 13 shows the minimum PBR at the material cost levels for System D to achieve zero cost effectiveness. Due to the relatively high material cost of the system, the minimum PBR is greater than 1.60. This suggests that System D should demonstrate at least 60% or better performance to be a cost-effective technique under the conditions used in this analysis. (Detailed LCCA results are shown in Appendix B.)

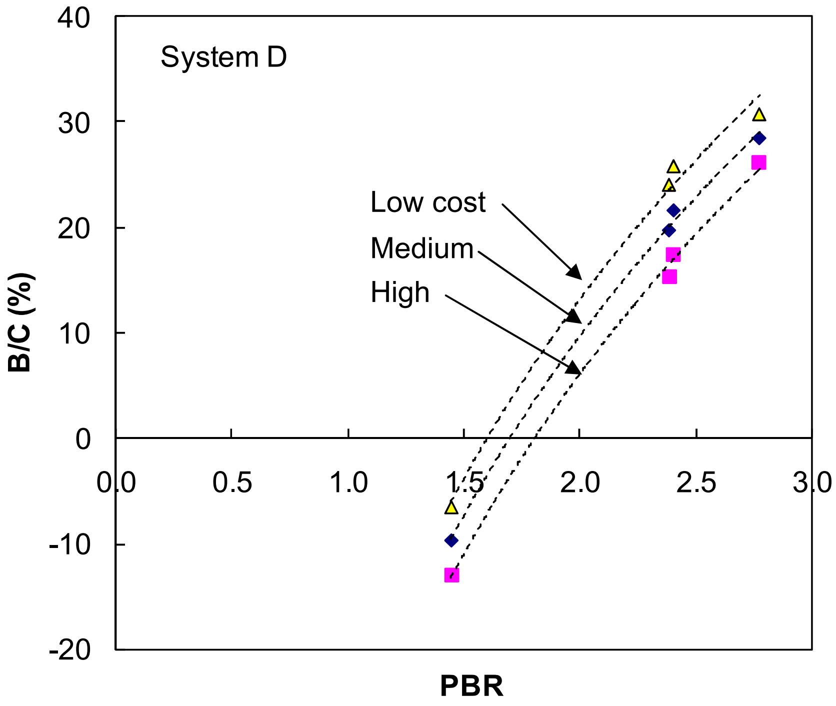


Figure 12. B/C of System D with respect to PBR and cost level.

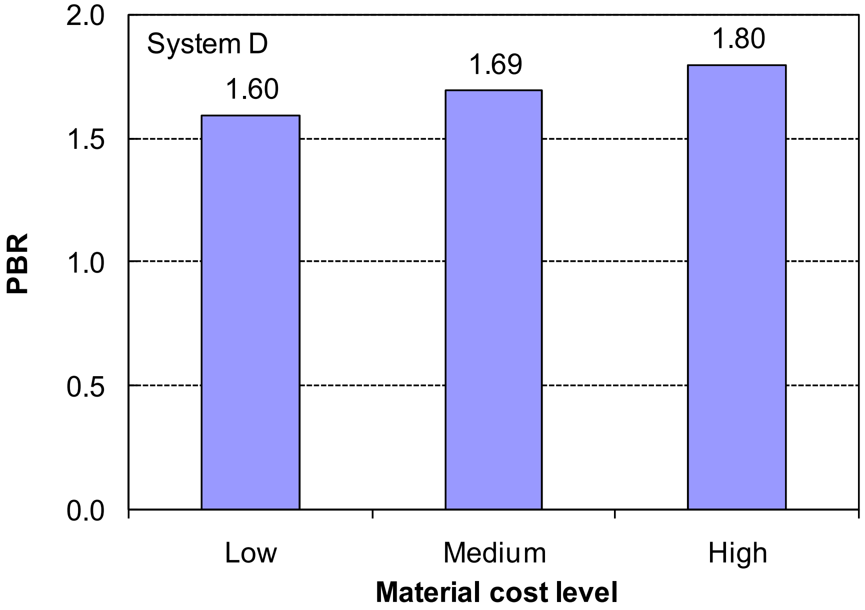


Figure 13. Minimum PBR at three material cost levels for System D.

3.1.4 System E

Based on material cost in four projects from 2003, the average unit price of IL 4.75-mm mixtures used as System E is $49.3/ton, ranging from $40.3 to $61.0/ton; that of IL 9.5-mm mixtures as a conventional leveling binder mixture is $38.6/ton, and that of wearing surface mixtures is $38.2/ton. In each project, the total cost ratio of the treated to untreated overlay is constant (around 1.09), though each material cost is different. In addition, no material cost information was available for two other sections for which different types of materials (sand anti-fracture, SAF) were used. The same average material cost for IL 4.75-mm mixtures was used for these two sections. Thus, B/C was investigated with respect to PBR at the three material cost levels: high (20% above the medium), medium, and low (20% below medium). Detailed LCCA results are presented in Appendix B.

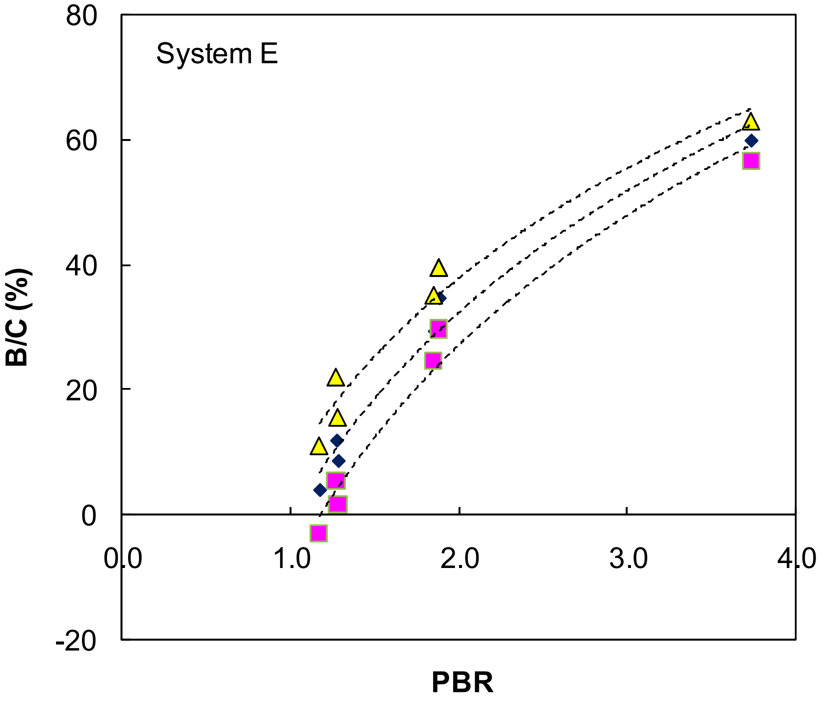


Figure 14Figure 14 shows the B/C variation for the three material cost levels with respect to PBR of the six projects. The B/C decreases with the decrease of PBR, but it is greater than zero for all cases except one whose material cost is high and PBR is relatively low. The minimum PBR corresponding to zero B/C is presented for each material cost level in Figure 15. At the medium and high material cost levels, System E can be cost effective when it has a minimum performance benefit ratio of 1.08 and 1.21, respectively. The minimum PBR is less than 1.0 for the low material cost level in which System E is cheaper than the leveling binder, but it is not possible. The main reasons why System E is cost effective are that System E has higher PBR, lower material cost, and no installation cost.

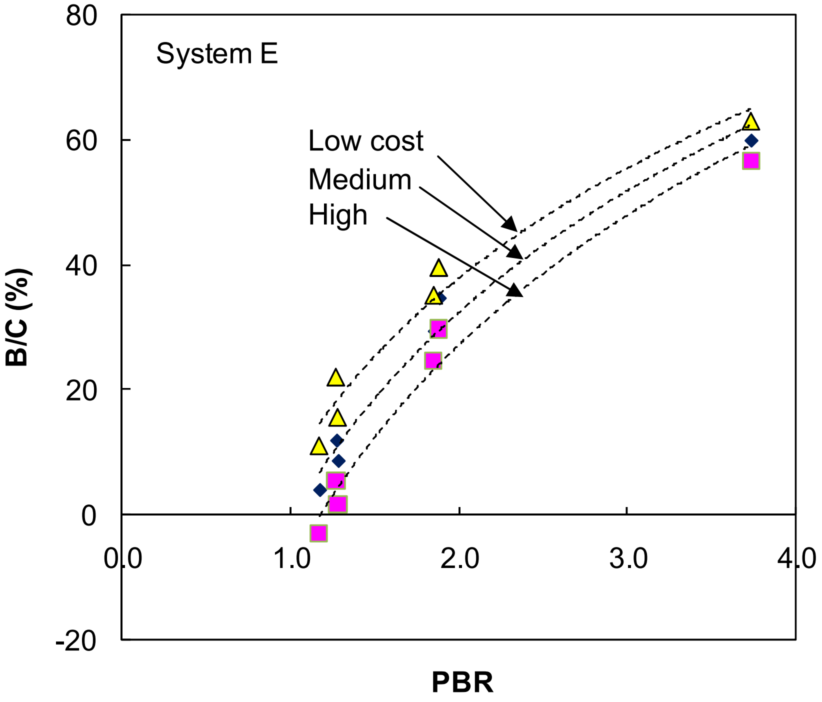


Figure 14. B/C of System E with respect to PBR.

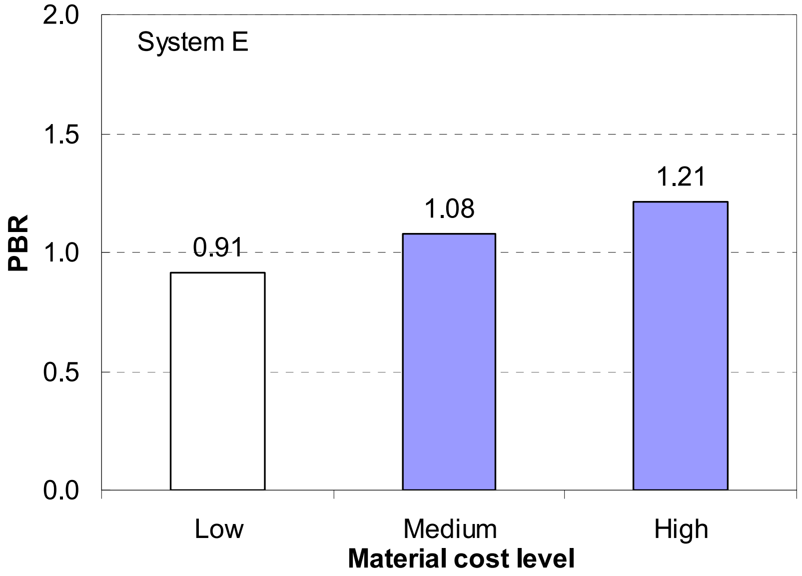


Figure 15. Minimum PBR at three material cost levels for System E.

3.2 COST-EFFECTIVENESS EVALUATION OF THE INTERLAYER SYSTEMS

The cost effectiveness of interlayer systems was evaluated for the short- and long-term periods. Crack survey and performance benefit analysis of the interlayer systems were conducted for their in-service life, mostly less than ten years. Since no multiple overlays were considered in developing the PBR, overlays added in the future were not included in this LCCA. Hence, LCC of the overlay was determined for a relatively short-term period. In addition, under the assumption that subsequent overlays can perform as well as previous ones, LCCA was conducted to evaluate the cost effectiveness for a period of 30 years. Such a long-term evaluation can be of use to standardize cost effectiveness with respect to overlay service life and analysis period, which is different for each project.

3.2.1 Short-Term Evaluation

Cost effectiveness of the interlayer systems was evaluated based on performance and cost benefit. As mentioned, no interlayer system could be systematically cost effective unless the PBR of the interlayer system is greater than 1.0. Cost effectiveness only for interlayer systems with positive PBR was examined by means of B/C obtained at the medium material cost level. The evaluation results are summarized in Table 4. Using B/C as well as PBR, cost effectiveness was grouped into three categories: “inefficient,” “insignificant,” and “efficient”. Within the inefficient group with negative B/C (designated “X” in Table 4), an interlayer system whose PBR is even less than1.0 is downgraded into a “too inefficient” level (designated “XX” in Table 4). The insignificant group (designated “Δ” in Table 4) has positive B/C, but the B/C is less than 10%, which cannot unconditionally guarantee the cost effectiveness of an interlayer system. When local material costs increase during a bidding process, the marginal cost benefit could be negative. In the IL148 Christopher section, for instance, B/C at the medium material cost level is positive (1.9%), but it becomes negative (-4.8%) at the high material cost level. Thus, interlayer systems in the insignificant group are only conditionally cost effective. The efficient group (designated “O” in Table 4) has 10% B/C or greater at the medium material cost level and B/C is unconditionally positive regardless of material cost variation. For example, the IL40 Deer Grove section demonstrates B/C of 10.4%, 16.0%, and 18.7% at high, medium, and low material cost levels, respectively. In cases in which B/C is over 20%, an interlayer system is absolutely regarded as a very cost-effective alternative system (designated “OO” in Table 4).

B/C–PBR curves for System A (area-type), System D, and System E at the medium material cost level are compared in Figure 16. The B/C ranges from -29.4% to 16.0% for System A; 3.4% to 28.5% for System D; and 4.0% to 59.8% for System E. Based on the B/C levels and PBR values, each project is grouped into five levels. In the same group, the PBR of each interlayer system is presented at different ranges. Since the material cost varies, a different PBR is required to achieve the same level of B/C. System D requires the highest PBR; System A (area-type), an intermediate one; and System E, the lowest PBR to obtain the same B/C. Figure 17 shows the minimum PBR for the three systems at the medium material cost level to reach a B/C of 0%, 10%, and 20%. The minimum PBR increases as the target B/C increases from 1.00 to 2.38, corresponding to a PBR of 0% to 20%. To have “very efficient” cost effectiveness (B/C > 20%), the minimum PBR of the area-type System A, System D, and System E is, respectively, 1.65, 2.38, and 1.52. The minimum PBR can be useful in deciding the cost effectiveness of an interlayer system instead of estimating B/C at a given material cost level.

Table 4. Summary of Cost-Effectiveness Evaluation of the Interlayer Systems

Interlayer system	Location	PBR	B/C (%)			Cost Effectiveness*
			High	Medium	Low	
System A (area)	IL 148 Christopher	1.32	-4.8	1.9	5.2	Δ
	IL 251 N. of US30	1.44	4.5	9.6	12.1	Δ
	IL 29 Chillicothe	0.95	-34.2	-26.3	-22.4	XX
	IL 9 E. of IL41	1.04	-28.1	-18.5	-14.0	X
	IL 29 Mossville	0.92	-37.5	-29.4	-25.4	XX
	IL 40 Deer Grove	1.63	10.4	16.0	18.7	O
	US 34 Mendota	1.26	-7.0	-0.3	3.0	X
	US 136 E. San Jose	1.39	-0.3	6.4	9.6	Δ
	IL 111 Pontoon Beach	1.00	-29.1	-21.6	-17.9	X
System A (strip)	IL 130 Villa Grove	0.80	-	-	-	XX
	IL 178 Oglesby	0.65	-	-	-	XX
	US 34 Kirkwood	0.35	-	-	-	XX
	Mattis Ave.	0.98	-	-	-	XX
System B	IL 29 Creve Coeur	1.02	-	-	-	X
	Mattis Ave.	0.93	-	-	-	XX
System D	IL 29 Creve Coeur	1.44	-13.3	-9.77	-6.52	X
	Mattis Ave.	2.77	26.3	28.5	30.7	OO
	US136 E. San Jose	2.40	17.5	21.6	25.8	OO
	IL 267 Greenfield	2.38	15.4	19.7	24.0	O
System E	IL 76 Belvidere	1.17	-3.0	4.0	11.1	Δ
	IL 17 Aledo	3.73	6.1	59.8	63.0	OO
	IL 117 Benson	1.88	29.6	34.6	39.6	OO
	IL 130 Philo	1.27	5.4	11.9	22.1	O
	US 136 E. San Jose	1.85	24.6	29.4	35.2	OO
	US 136 W. San Jose	1.28	1.7	8.7	15.7	Δ

* XX: too inefficient (PBR < 1.0), X: inefficient (B/C ≤ 0%), Δ: insignificant (0% < B/C ≤ 10%), O: efficient (10% < B/C ≤ 20%), and OO: very efficient (B/C > 20%)

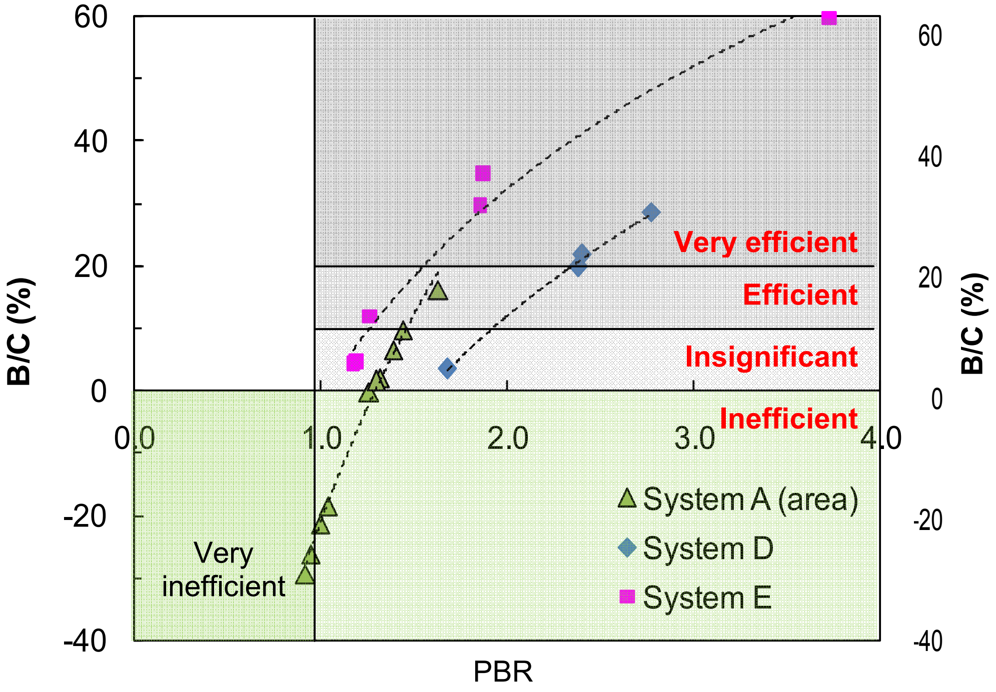


Figure 16. Correlation between performance–benefit ratio (PBR) and benefit-cost ratio (B/C) for all interlayer systems.

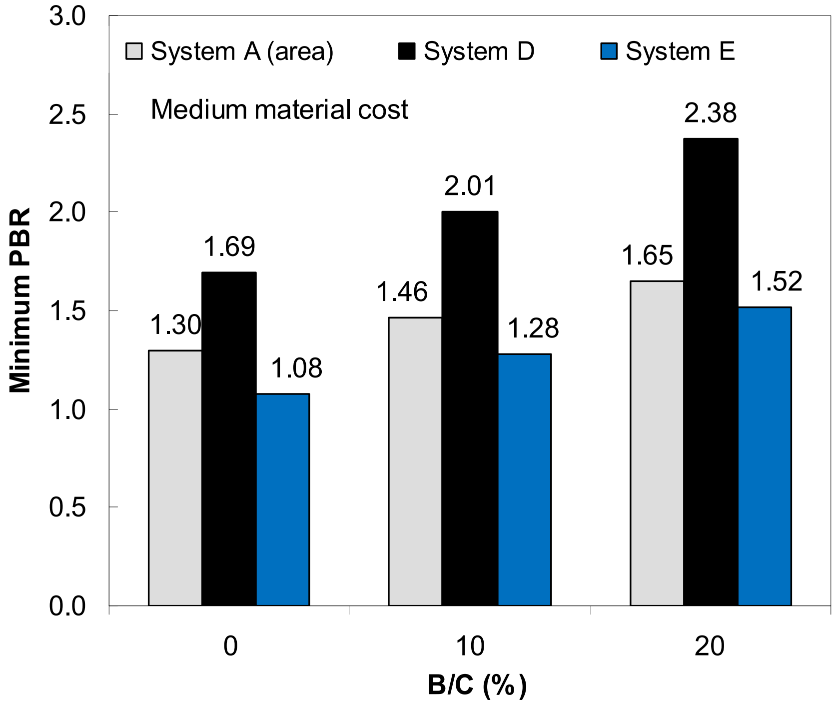


Figure 17. Minimum PBR to achieve various B/Cs for Systems A (area-type), D, and E.

3.2.2 Long-Term Evaluation

The cost effectiveness of interlayer systems was investigated for a long-term period of 30 years. A control HMA overlay is assumed to have a service life of 10 years, so a total of three untreated consecutive overlays was considered for this purpose. A treated HMA overlay with an interlayer system has a longer service life proportional to its performance-benefit ratio. If the PBR is high enough, the treated overlay can be cost effective due to a smaller number of overlay constructions, as well its salvage value at the end of the analysis period. On the other hand, in the short-term cost-effectiveness evaluation, all cost benefit results from the salvage value, which could account for the relative extension of the overlay service life. Thus, in the long-term evaluation, except for the overlay service life and analysis period, the other variables were the same as for the short-term cost-effectiveness evaluation at the medium material cost level.

Table 5 lists the results of the short-term and long-term cost-effectiveness evaluation for 19 projects. Long-term B/Cs are greater than short-term B/Cs in 11 projects and are smaller than the short-term B/Cs in the other eight projects. Nonetheless, the same cost-effectiveness evaluation level could be achieved in 16 out of 19 projects: Only three projects, highlighted in boldface in the table, have different CE evaluation. System A at IL 251 section is at the “insignificant” level (9.6% of B/C) in the short-term cost effectiveness evaluation; while it is classified at the “effective” level (15.4% of B/C) in the long-term cost-effectiveness evaluation. Similarly, System D at IL 267 section is at the “effective” level in the short-term cost-effectiveness evaluation; but it is upgraded to the “very effective” level in the long-term cost-effectiveness evaluation. However, these level upgrades are not critical, as their B/Cs of 9.6% and 19.7% in the short-term evaluation are very close to the trigger values of 10% and 20%, respectively. Thus, the salvage value used in the short-term evaluation can be considered to accurately reflect the cost benefit of interlayer systems in the long-term evaluation. In spite of there being a few differences, the outcomes of the short-term and long-term evaluations both are acceptable enough to use for the cost-effectiveness evaluation of interlayer systems.

Table 5. Summary of Cost-Effectiveness Evaluation of the Interlayer Systems

Interlayer system	Location	PBR	Short-term (in-service)		Long-term (30yr)	
			B/C (%)	CE	B/C (%)	CE
System A (area)	IL 148 Christopher	1.32	1.9	Δ	3.1	Δ
	IL 251 N. of US30	1.44	**9.6***	**Δ**	**15.4**	**O**
	IL 29 Chillicothe	0.95	-26.3	XX	-33.8	XX
	IL 9 E. of IL41	1.04	-18.5	X	-17.4	X
	IL 29 Mossville	0.92	-29.4	XX	-35.2	XX
	IL 40 Deer Grove	1.63	16.0	O	19.8	O
	US 34 Mendota	1.26	-0.3	X	-0.3	X
	US 136 E. San Jose	1.39	6.4	Δ	9.4	Δ
	IL 111 Pontoon Beach	1.00	-21.6	X	-22.4	X
System D	IL 29 Creve Coeur	1.44	-9.77	X	-4.7	X
	Mattis Ave.	2.77	28.5	OO	35.3	OO
	US 136 E. San Jose	2.40	21.6	OO	27.1	OO
	IL 267 Greenfield	2.38	**19.7**	**O**	**27.3**	**OO**
System E	IL 76 Belvidere	1.17	4.0	Δ	2.6	Δ
	IL 17 Aledo	3.73	59.8	OO	56.7	OO
	IL 117 Benson	1.88	34.6	OO	33.3	OO
	IL 130 Philo	1.27	11.9	O	10.5	O
	US 136 E. San Jose	1.85	29.4	OO	31.7	OO
	US 136 W. San Jose	1.28	**8.7**	**Δ**	**11.7**	**O**

* Note that the long- and short-term evaluations yield different cost effectiveness.

4. DEVELOPMENT OF A B/C PREDICTION MODEL

4.1 B/C VARIABLES

Numerous variables influence the B/C of interlayer systems. These variables can be categorized into two groups, interlayer system variables and LCCA variables. Figure 18 illustrates the two groups of variables considered in the B/C prediction model. The interlayer system variables describe the features of each interlayer system and overlay in terms of performance-benefit ratio (PBR), material cost ratio (MCR), and construction time ratio (CTR). As mentioned, PBR represents the performance of interlayer systems in extending the service life of the treated overlay. PBR is determined using ESALs, T_L, and JS. MCR and CTR are used to specify the relative material cost and construction time of the treated overlay. MCR is calculated using interlayer system and overlay unit price (C), overlay thickness (H), and joint spacing (JS) for System D only. CTR is a function of construction time (T) and two geometric variables, H and JS. A discount rate is used to calculate future agency and user costs. In addition, work zone characteristics and other cost- and traffic-related parameters can be classified into the LCCA variables.

A representative HMA overlay pavement commonly used in Illinois was used to develop a B/C prediction model. Among various overlay designs surveyed in this project, the majority of overlays consisted of a 1.5-in.-thick wearing surface and a 0.75-in.-thick leveling binder, which was placed over a composite pavement with 30-ft joint spacing (Figure 19). System A (area-type) and System E were placed under the leveling binder and System E was substituted for the leveling binder. The PBR of the interlayer system was calculated using the PBR prediction models for System A (area-type), System D, and System E, respectively. To cover the field performance evaluation of each interlayer system, the B/C prediction model was developed for a wide range of PBRs, from 0.9 to 3.0.

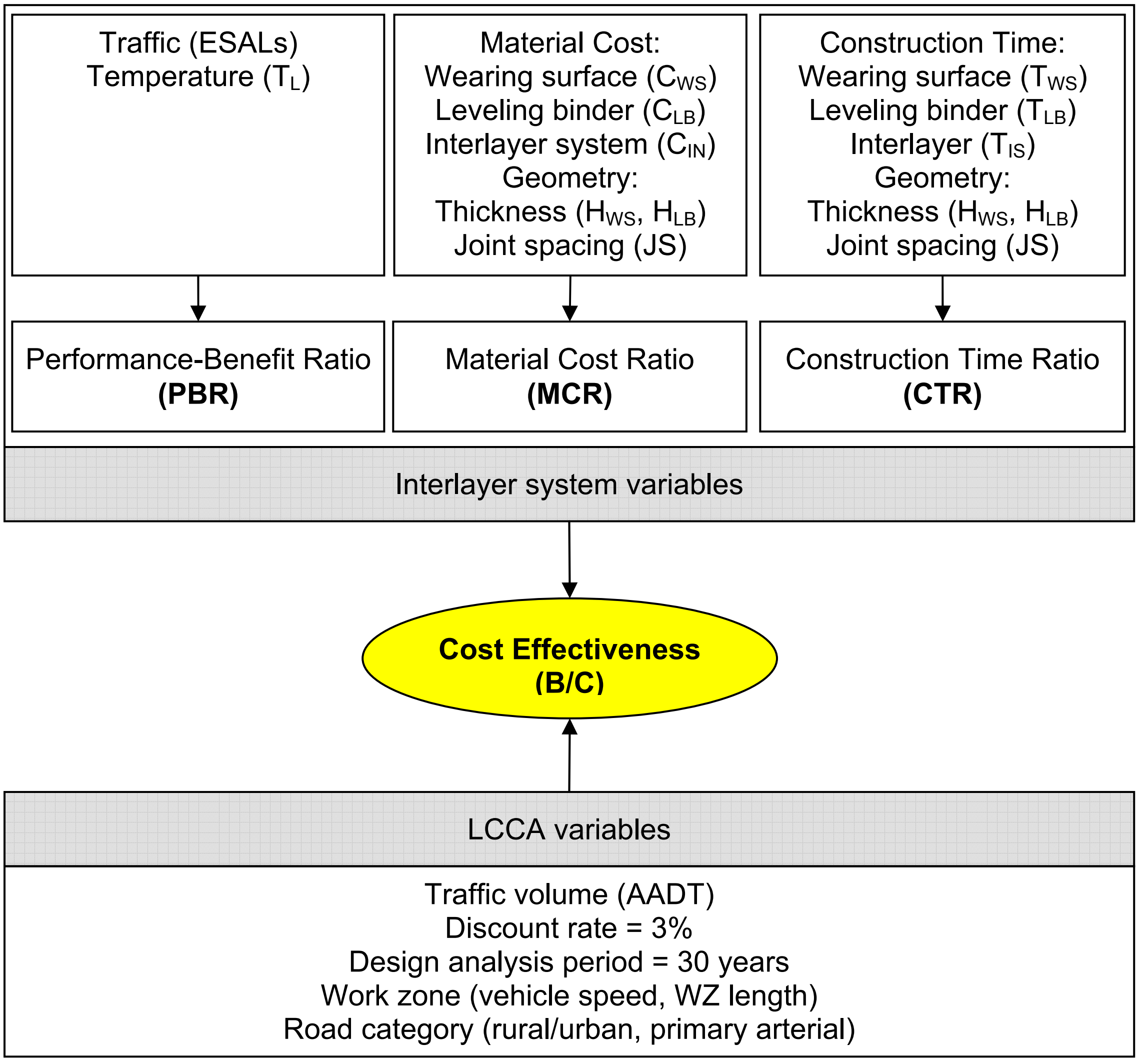


Figure 18. Main variables of a B/C prediction model.

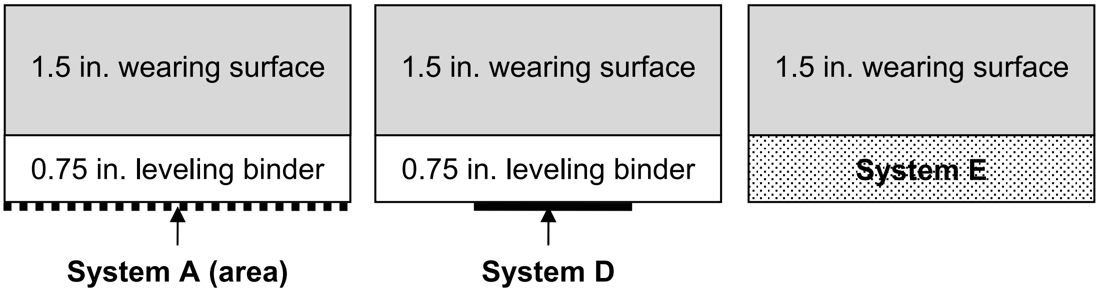


Figure 19. Representative HMA overlay and interlayer systems.

4.1.1 Material Cost Ratio

In LCCA, the major agency cost is the material cost needed over the analysis period. The total cost of a new HMA overlay per mile-lane is simply computed by multiplying layer thickness and the unit price of the overlay for a mile-lane. When an interlayer system is incorporated, the interlayer systems' cost is added accordingly. While area-type System A is placed over the whole area under HMA overlay, System D strips are applied only over discontinuities of existing pavements, as shown in Figure 19. Hence, the quantity of strip-type interlayer systems depends on the number of discontinuities and strip width. Since the width of System D is generally 3 ft and the strips are usually installed on joints, the quantity of the strips can be determined by means of joint spacing (JS). For System E, the system replaces the leveling binder.

Material cost ratio (MCR) is defined as a ratio of unit material cost for a one-lane, 1.0-mile-long (5280 ft), (12 ft-wide-) HMA overlay, which includes an interlayer system, to that for an overlay without an interlayer system. For each interlayer system, MCR is calculated as follows:

For the area-type System A,

$$\begin{aligned} MCR_{AA} &= \frac{\left(C_{WS} \times H_{WS} + C_{LB} \times H_{LB}\right) \times (4 \times 5280/3) + C_{INAA} \times (4 \times 5280/9)}{\left(C_{WS} \times H_{WS} + C_{LB} \times H_{LB}\right) \times (4 \times 5280/3)} \\ &= \frac{C_{WS} \times H_{WS} + C_{LB} \times H_{LB} + C_{INAA}}{C_{WS} \times H_{WS} + C_{LB} \times H_{LB}} \end{aligned} \tag{7}$$

For the System D,

$$\begin{aligned} MCR_{D} &= \frac{\left(C_{WS} \times H_{WS} + C_{LB} \times H_{LB}\right) \times (4x5280/3) + C_{IND} \times (4) \times (5280/JS)}{\left(C_{WS} \times H_{WS} + C_{LB} \times H_{LB}\right) \times (4x5280/3)} \\ &= \frac{C_{WS} \times H_{WS} + C_{LB} \times H_{LB} + C_{INAA} \times (3/JS)}{C_{WS} \times H_{WS} + C_{LB} \times H_{LB}} \end{aligned} \tag{8}$$

For the System E,

$$MCR_{E} = \frac{C_{WS} \times H_{WS} + C_{INE} \times H_{LB}}{C_{WS} \times H_{WS} + C_{LB} \times H_{LB}} \tag{9}$$

where,

MCR_{AA}, MCR_{D}, and MCR_{E} are material cost ratio for System A (area), System D, and System E, respectively;
C_{WS} and C_{LB} are unit price of wearing surface and leveling binder whose unit price is converted from \$/ton into \$/yd^2-in by multiplying 0.05625 (= ton/yd^2-in. = [1ton/2000lbs] x [150lbs/ft^3] x [9ft^2/yd^2] x [1ft/12in.]);
C_{INAA}, C_{IND}, and C_{INE} are unit price of interlayer systems in \$/yd^2, \$/yd^2, and \$/yd^2-in. for the Systems A, D, and E, respectively;
H_{WS} and H_{LB} are thickness of wearing surface and leveling binder in inch; and
JS is joint spacing in ft.

According to the material costs used in the field evaluation, MCR_{AA} is 1.27, 1.18, and 1.14 for high, medium, and low material cost levels, respectively, of area-type System A. This suggests, for example, that when medium material cost-level System A (area) is used, the material cost increases 18% compared to untreated overlay. For System D, MCR_{D} is 1.39, 1.32, and 1.26 for the three cost levels, respectively. It should be noted that MCR_D is affected by the number of joints. Under the same conditions, the larger the number of joints the pavement has, the higher the MCR_D becomes. For System E, MCR_E is 1.18, 1.09, and 1.01 for the three field material cost levels. Table 6 summarizes the range of MCR of these interlayer systems.

4.1.2 Construction Time Ratio

The computed user cost in LCCA for HMA overlay is highly affected by two parameters: traffic volume and overlay construction time. Traffic volume is a given value for a specific location, but construction time is a variable; it depends on overlay thickness and the applied interlayer system. Total construction time of the overlay per mile-lane is simply computed by multiplying layer thickness and unit construction time of the overlay for a mile-lane. Additional time needs to be considered when an interlayer system is installed. Unit construction time is hr/mile-lane for area-type System A and hr/strip-lane for System D. System E has the same construction time of overlay, hr/mile-lane-in.

Construction time ratio (CTR) is defined as a ratio of unit construction time for a 1.0-mile-long one-lane HMA overlay with an interlayer system to that for an overlay alone. For each interlayer system, CTR is calculated as follows:

For System A (area-type):

$$CTR_{AA} = \frac{T_{WS} \times H_{WS} + T_{LB} \times H_{LB} + T_{IAA}}{T_{WS} \times H_{WS} + T_{LB} \times H_{LB}} \tag{10}$$

For System D:

$$CTR_D = \frac{T_{WS} \times H_{WS} + T_{LB} \times H_{LB} + \left(T_{ID} \times 5280 / JS\right)}{T_{WS} \times H_{WS} + T_{LB} \times H_{LB}} \tag{11}$$

For System E:

$$CTR_E = \frac{T_{WS} \times H_{WS} + T_{IE} \times H_{LB}}{T_{WS} \times H_{WS} + T_{LB} \times H_{LB}} \tag{12}$$

where,

CTR_{AA}, CTR_D, and CTR_E are construction time ratios for System A (area-type), System D, and System E;

H_{WS} and H_{LB} are thicknesses of wearing surface and leveling binder (in);

T_{WS}, T_{LB}, and T_{IE} are construction times of wearing surface, leveling binder, and System E (hr/mile-lane-in); and

T_{IAA} and T_{ID} are installation time for area-type System A (hr/mile-lane) and of System D (hr/strip-lane).

Due to insufficient information about the construction procedure of interlayer systems, a wide range of CTRs was assumed for each system. As default values, overlay construction time was assumed as 4.0 hr/mile-lane-in; additional construction time was assumed as 4.0 hr/mile-lane for area-type System A and 0.08 hr/strip-lane for System D. No additional construction time is required for System E. For the B/C prediction model, a wider range of CTRs was used, as shown in Table 6.

4.1.3 Typical Values of B/C Variables

For the main variables of PBR, MCR, CTR and AADT, a certain range of values was suggested. An interlayer system can be characterized by a combination of PBR, MCR, and CTR. For example, a medium-level area-type System A can have a PBR of 1.2, an MCR of 1.25, and a CTR of 1.4. In addition, typical values may be assumed for other parameters in LCCA that are not considered variables in a B/C prediction model. Table 6 presents typical values of these parameters, as well as typical corresponding ranges. While overlay service life varies, it was assumed to be 10 years in this model. For evaluating long-term cost effectiveness, the design analysis period was assumed to be 30 years using a 3.0% discount rate.

Table 6. Default Values and Ranges for B/C Variables.

Variable		Typical value	Range
System A (area)	PBR	-	1.0 – 1.5
	MCR*	-	1.10 – 1.40
	CTR**	-	1.0 – 1.8
System D	PBR	-	1.5 – 3.0
	MCR*	-	1.10 – 1.60
	CTR**	-	1.8 – 2.6
System E	PBR	-	1.0 – 4.0
	MCR*	-	1.00 – 1.40
	CTR**	-	1.0
Traffic volume	AADT	-	500 – 30,000
	ADTT	-	10% of AADT
Wearing surface	T_{WS}	1.5 in.	-
	C_{WS}	$43.70/ton	-
Leveling binder	T_{LB}	0.75 in.	-
	C_{LB}	$44.16/ton	-
Discount rate		3.0%	-
Design analysis period		30 years	-
Basic overlay service life		10 years	-

* In 2008, System A (area): $1.11/yd^2 for MCR of 1.20; System D: $22.20/yd^2 for MCR of 1.40; System E: $70.47/ton for MCR of 1.20; Total material costs corresponding to MCR is presented in Appendix B.5.

** System A (area): 4.0 hr/mile-lane for CTR of 1.4; System D: 0.08 hr/strip-lane for CTR of 1.8. No additional installation time for System E, i.e., CTR = 1.0.

4.2 B/C PREDICTION MODEL AND EFFECT OF THE MAIN VARIABLES

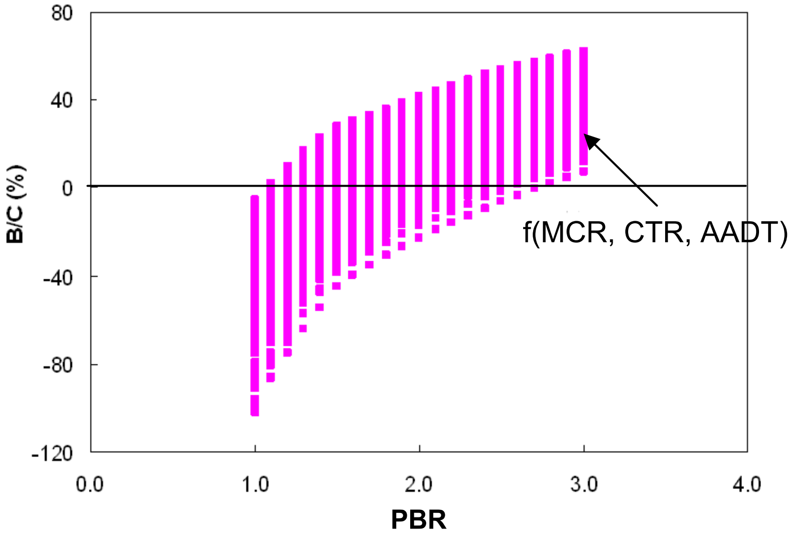
A long-term B/C prediction model was developed using a linear function of four variables: PBR, MCR, CTR, and AADT (see Equation 13). The effect of each variable on the B/C model was evaluated as presented below.

$$B/C = f\,(PBR, MCR, CTR, AADT) \qquad (13)$$

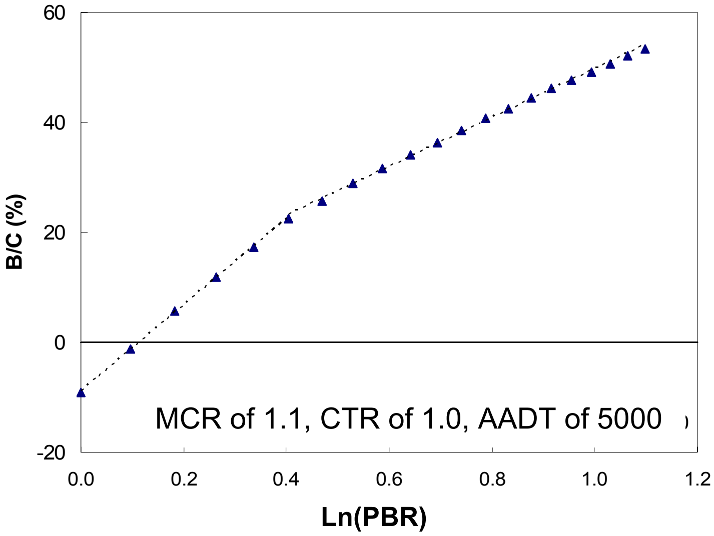
where,

B/C is a benefit-cost ratio as a percentage;
PBR is performance benefit ratio;
MCR is material cost ratio;
CTR is construction time ratio; and
AADT is annual average daily traffic.

The effect of the interlayer system PBR on B/C was investigated. For given ranges of MCR, CTR, and AADT, B/C variations are shown in Figure 20(a). Generally, B/C increases with the increase of PBR. The increasing B/C rate with respect to PBR tends to decline as PBR increases; B/C-log(PBR) is plotted in Figure 20(b). It is clear that the B/C prediction model can use a bi-linear or linear logarithmic function for PBR.



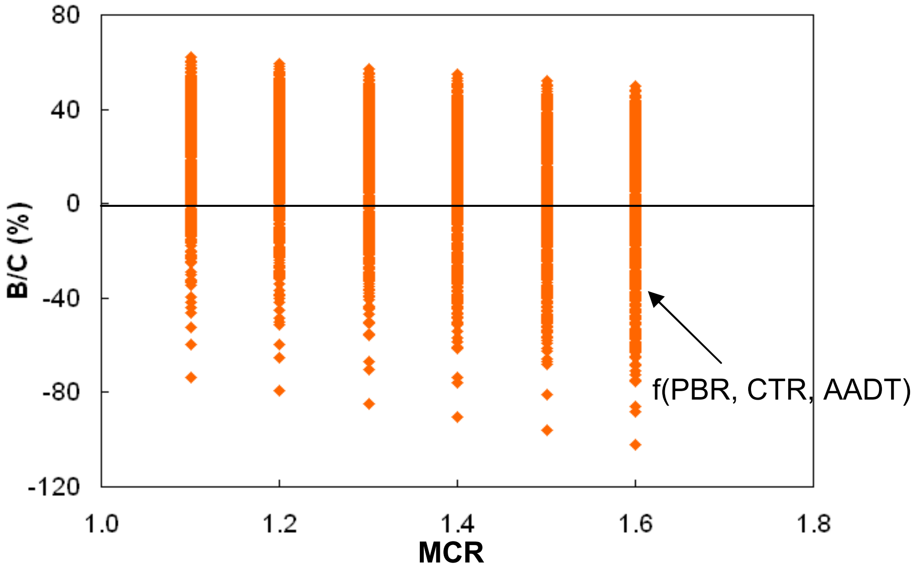
(a)



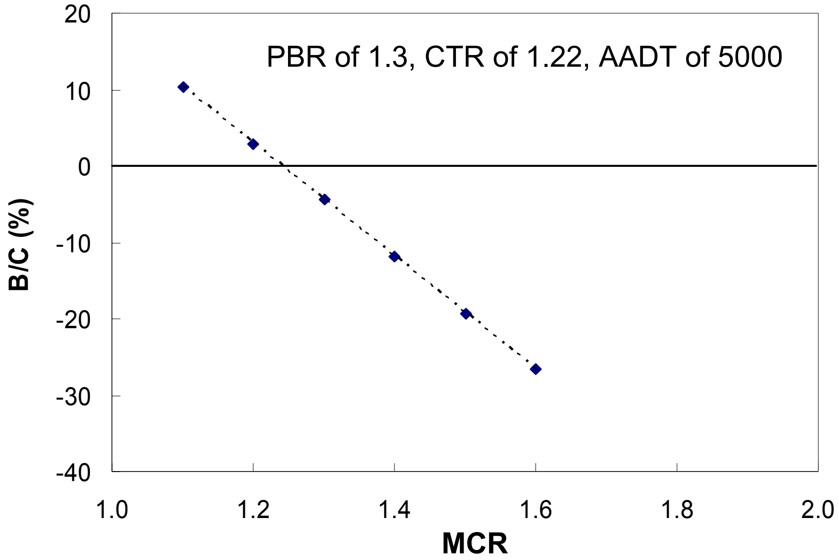
(b)

Figure 20. B/C variations with PBR: (a) at various MCR, CTR, and AADT; and (b) at MCR of 1.1, CTR of 1.0, and AADT of 5000.

B/C variations with respect to MCR are shown in Figure 21(a) for a given range of PBR, CTR, and AADT. Compared to B/C variations with PBR as shown in Figure 20(a), B/C has a greater range of a maximum of 152%, compared to 98% in the case of PBR. This implies that PBR has more influence on B/C than MCR does. For the same PBR, CTR, and AADT, B/C variations are plotted against MCR in Figure 21(b). As the figure shows, B/C has a linear function in relation to MCR.



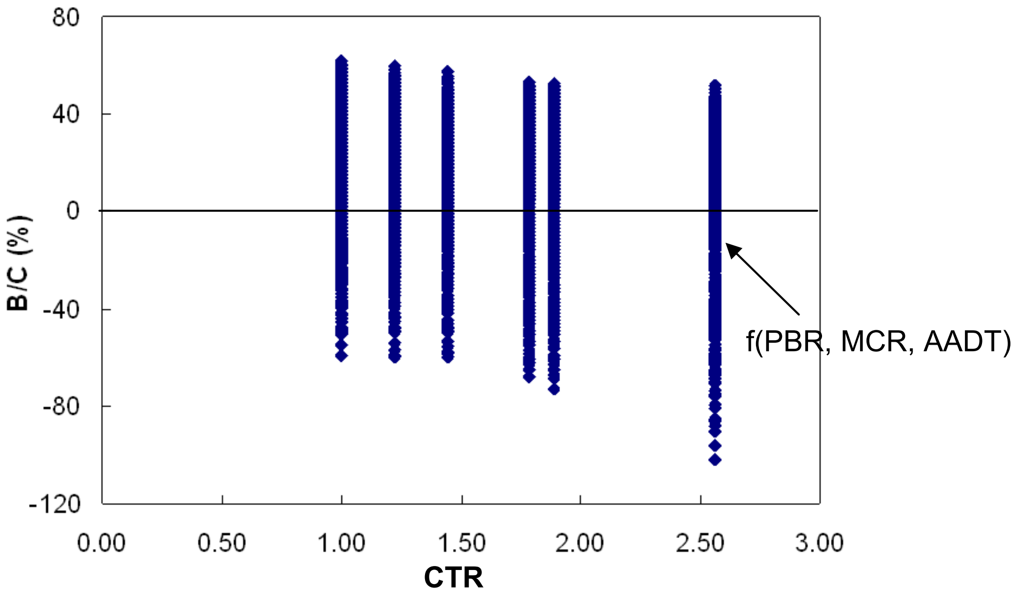
(a)



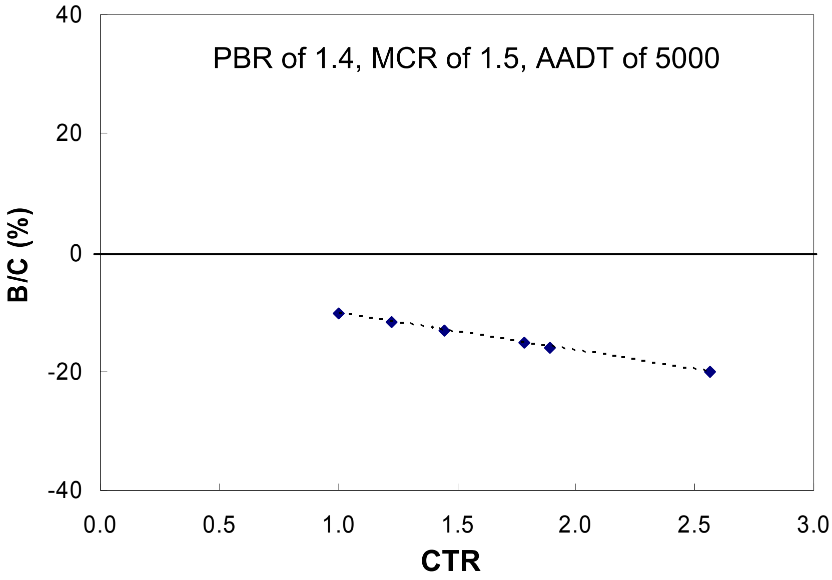
(b)

Figure 21. B/C variations with MCR: (a) at various PBR, CTR, and AADT; and (b) at PBR of 1.3, CTR of 1.22, and AADT of 5000.

B/C variations with CTR are shown in Figure 22(a) for a given range of PBR, MCR, and AADT. Compared to B/C variations for PBR, as shown in Figure 20(a), B/C has a range of 153% maximum. For the same PBR, MCR, and AADT, B/C variations with CTR are plotted in Figure 21(b). As the figure shows, B/C decreases linearly with CTR.



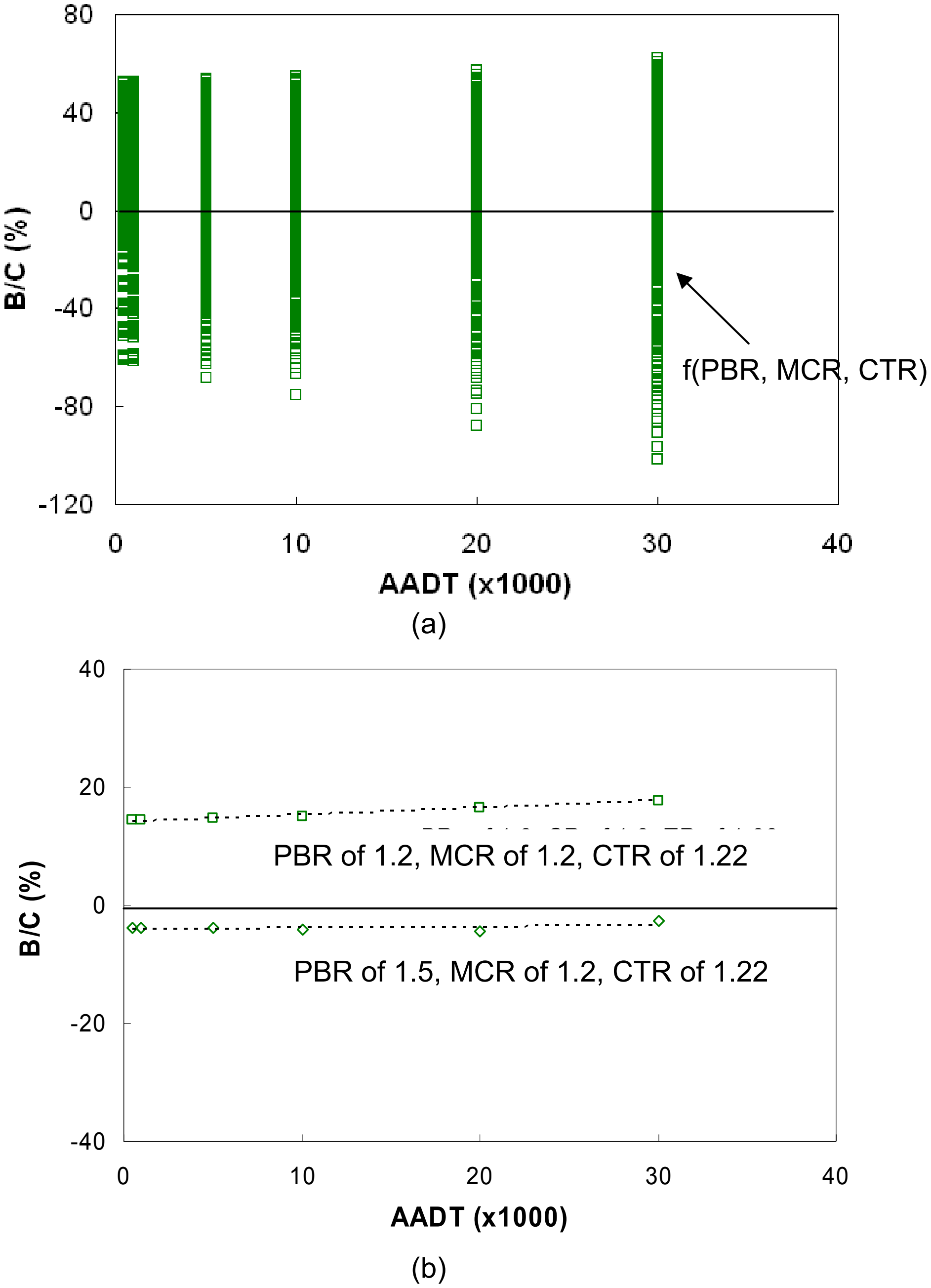
(a)



(b)

Figure 22. B/C variations with CTR: (a) at various PBR, MCR, and AADT; and (b) at PBR of 1.4, MCR of 1.5, and AADT of 5000.

The effect of AADT on B/C was investigated for given ranges of PBR, MCR, and CTR as shown in Figure 24(a). There is no obvious correlation between B/C and AADT; especially for positive B/C. As Figure 24(b) shows, the change in B/C for various AADT levels is insignificant. While the total LCC of both treated and untreated overlays increases as AADT increases, B/C is less dependent on AADT because B/C is a ratio of the LCC of the two overlay alternatives. It can be concluded that AADT is not an influential variable on the B/C model.



(a)

(b)

Figure 23. B/C variations with AADT: (a) at various PBR, MCR, and CTR; and (b) at PBR of 1.2 and 1.5, MCR of 1.2, and CTR of 1.22.

Using sensitivity analysis of potential variables, long-term B/C for 30 years is found to be a function of PBR, MCR, and CTR. The B/C prediction model is developed through a simple linear regression using ln(PBR), MCR, and CTR as independent variables. The B/C prediction model is constructed. The analysis of variation (ANOVA) and regression results are listed in Table 7. For each variable, *P*-values are found to be extremely small; hence the variables are significantly important to B/C.

Table 7. Analysis of Variation and Regression Coefficients for B/C Prediction Model

Regression Statistics	
Multiple R	0.966
R^2	0.932
Adjusted R^2	0.932
Standard error	6.83
Observations	4536

ANOVA

	Df	SS	MS	F	Significance F
Regression	3	2918584	972861	20864	0.0
Residual	4532	211320	46.6		
Total	4535	3129904			

Variables	Coefficients	Standard Error	*t*-Stat	*P*-value
Intercept	54.0	0.98	60.3	0.0
LN(PBR)	71.5	0.31	229.4	0.0
MCR	-52.3	0.59	-88.0	0.0
CTR	-9.3	0.20	-46.9	0.0

Thus, the B/C prediction model can be established as follows:

$$B/C = 54.0 + 71.5\ \ln(PBR) - 52.3\ (MCR) - 9.3\ (CTR) \qquad (14)$$

where,

B/C is a benefit-cost ratio in a percentage;
PBR is a performance-benefit ratio;
MCR is a material cost ratio; and
CTR is a construction time ratio.

For a given range of PBR, MCR, and CTR, the B/C results obtained from CIND and predicted from Equation 14 are compared in Figure 24. The R^2 is 0.932 and the standard error is 6.83. Thus, from a statistical point of view, the regression model for B/C prediction provides a good explanation of the data. In particular, the prediction model is matched better for positive B/Cs so that the model is more accurate for estimating positive B/C, which is more important for evaluating cost effectiveness.

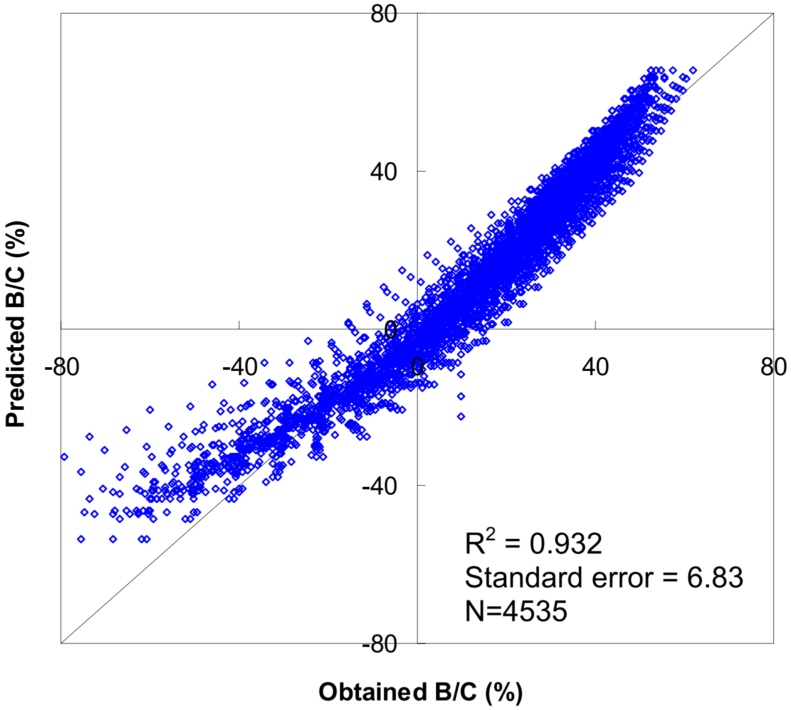


Figure 24. Comparison of obtained and predicted B/C.

4.3 MODEL VALIDATION

For the medium level of material cost and construction time, two levels of model validation were conducted to examine the proposed B/C prediction model. In the first-level validation, the B/C prediction model was validated using the PBR of interlayer systems obtained from the field. Figure 25 shows the comparison of B/C obtained from field evaluation and B/C predicted from the proposed model. Based on 19 data points, a very good correlation (R^2 of 0.906 and a standard error of 7.69) is achieved in a B/C range of -33.8% to 56.7% for the three interlayer systems. Figure 26 shows the B/C difference distributions. The absolute error of the B/C is less than 10% in most cases (95%). There is only one out of the 19 locations in which the B/C difference is greater than 20%. The greatest difference in B/C—24.9%— came from the IL17 section where B/C (56.7%) and PBR (3.73) of the System E are extraordinarily high compared to the other sections.

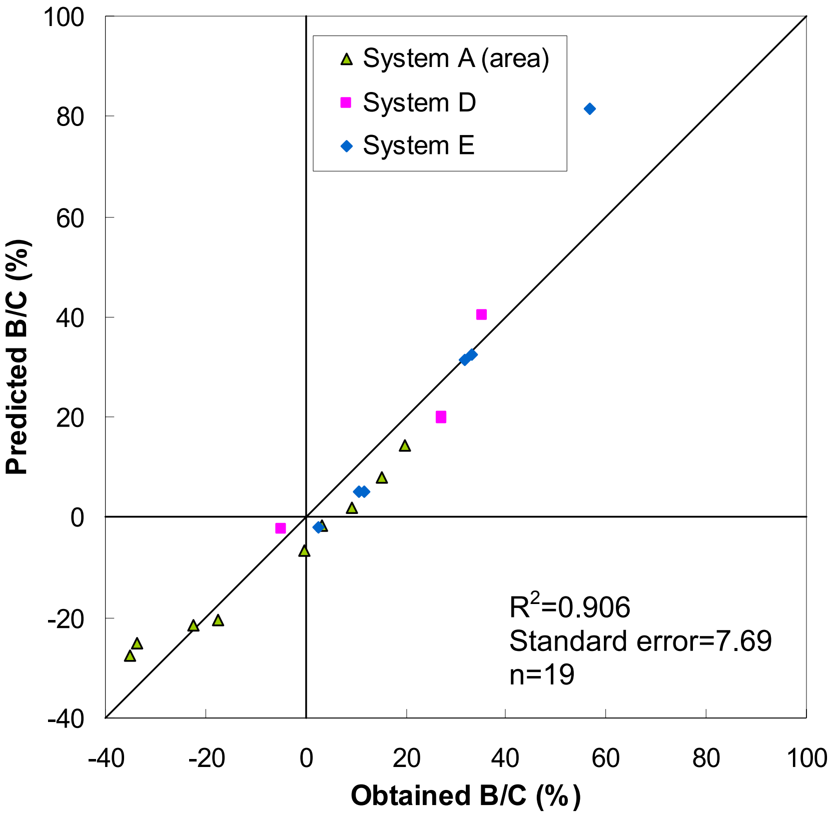


Figure 25. Comparison of B/C obtained from field evaluation and from the B/C prediction model using PBR obtained from field data.

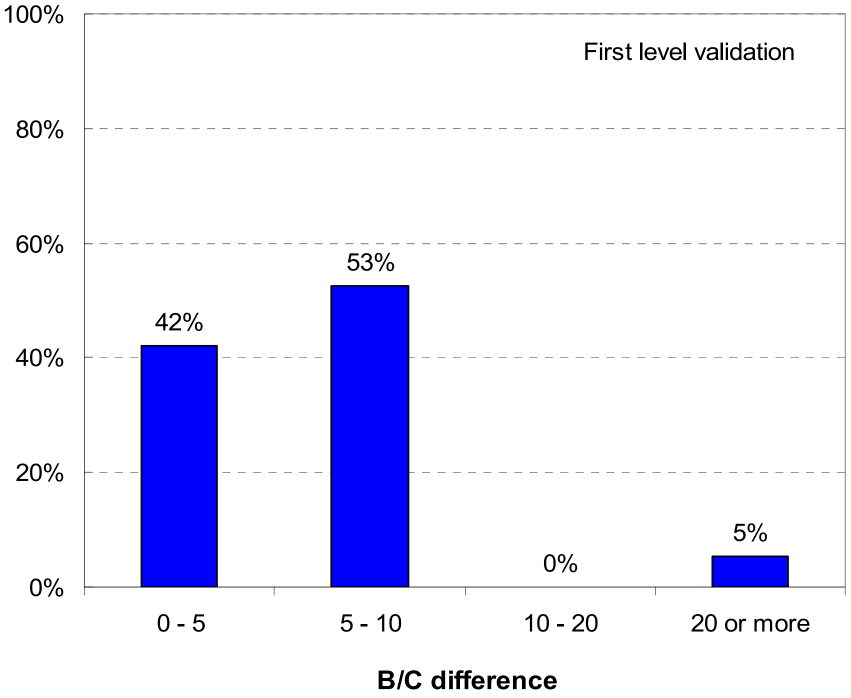
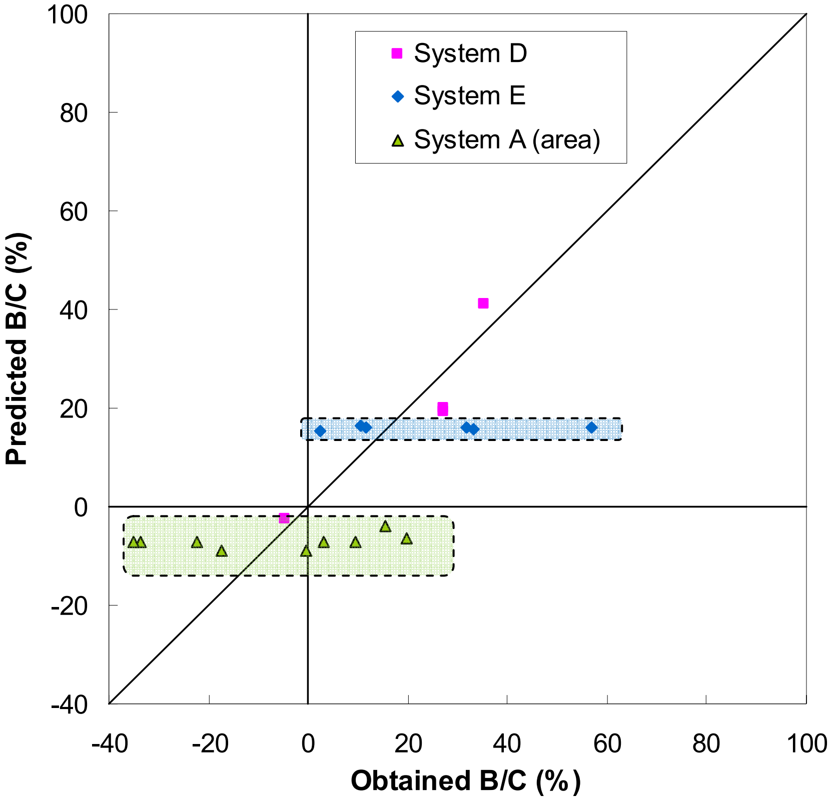


Figure 26. B/C difference distribution in the first-level validation.

In the second level, predicted PBR was used for the B/C prediction model validation. Figure 27 shows a comparison of the B/C obtained from field evaluation and the B/C predicted from the proposed model. For area-type System A and for System E, very poor correlations were obtained (R^2 of 0.495 and a standard error of 17.84), while for System D, the B/C prediction model was acceptable (R^2 of 0.868 and a stand error of 7.89). Since a constant PBR was incorporated into the B/C prediction model, the predicted B/Cs are distributed in a narrow range: -7.2% (± 1.5%) for area-type System and 16.0% (± 0.4%) for System E. Thus, the B/C prediction model is valid as long as an accurate PBR is used in the model. One of the features of the B/C prediction model is its simplicity, as it accounts for only four variables instead of the higher number of variables needed in LCCA.



	All	System A (area)	System D	System E
R^2	0.479	0.176	0.860	0.005
Standard error	18.13	20.28	8.12	22.34
N	19	9	4	6

Figure 27. Comparison of B/C obtained from field evaluation and predicted from the B/C prediction model using predicted PBR.

4.4 APPLICATION RANGE OF INTERLAYER SYSTEMS

Using the B/C prediction model, upper and lower B/C limits for the three interlayer systems regarding PBR are determined using the maximum and minimum

MCR and CTR. Figure 28 illustrates the B/C limits of the interlayer systems at AADT of 5000. Maximum B/C limits can be attained when no additional material cost and construction time are needed (MCR of 1.0 and CTR of 1.0). Since each interlayer system has its own MCR and CTR for various ranges, the B/C of an interlayer system is reduced in terms of the MCR and CTR from the maximum B/C corresponding to PBR. Thus, each interlayer system has its application area bounded by the upper and lower B/C limits. Comparing those application areas, the B/C of System E is close to the maximum limit, while the B/C of System D is the farthest from the maximum limit. This indicates that for the same PBR, the B/C for System E is higher than that for System D due to the lower MCR and CTR for System E. However, since the PBR for System E is lower than that for System D in the field, it is not easy to compare B/C only with PBR for these interlayer systems.

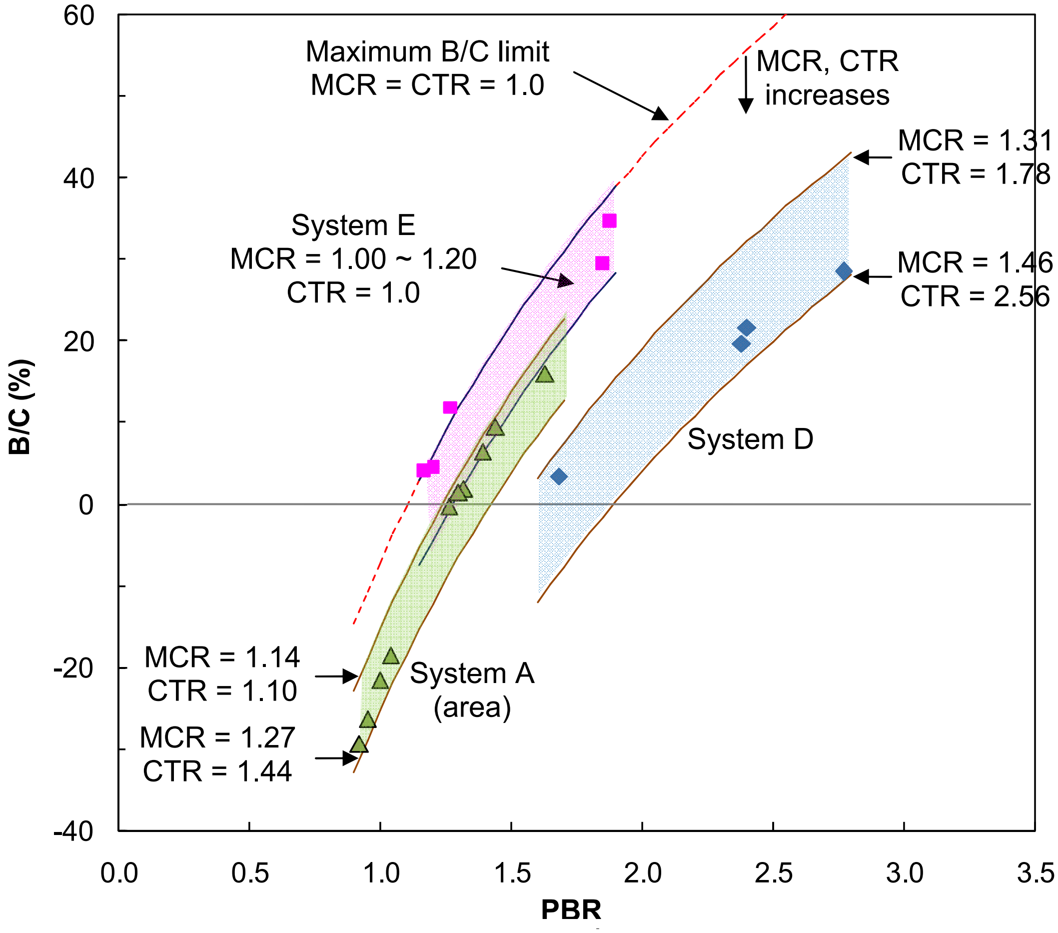
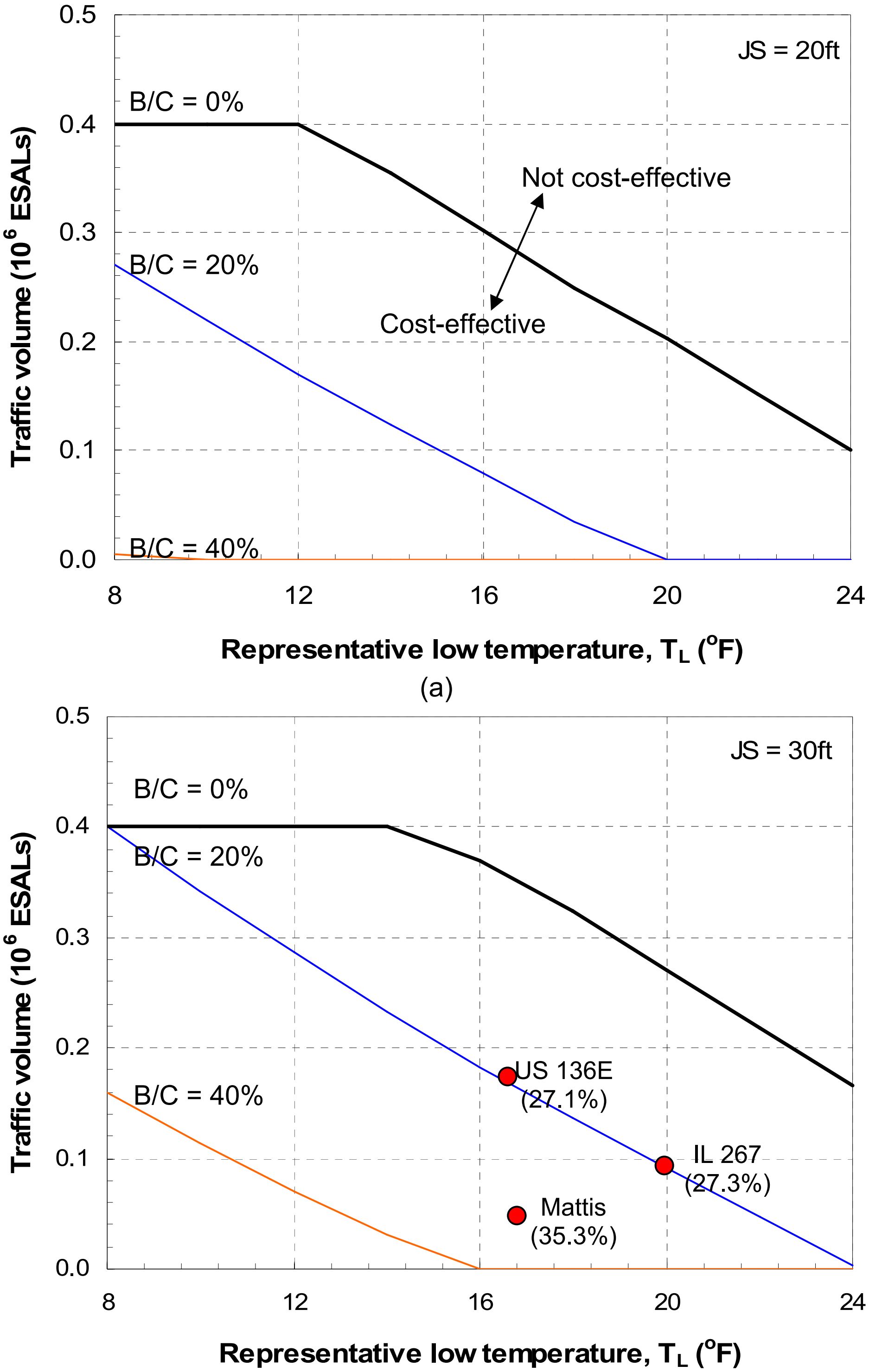


Figure 28. Upper and lower B/C limits for area-type System A, System D, and System E at AADT of 5000.

For System D, the effect of ESALs, T_L, and JS on B/C can be directly investigated through predicted PBR; PBR is correlated with these variables. Figure 29 shows maximum ESALs variations with respect to T_L for three B/C levels at JS of 20 ft, 30 ft, 50 ft, and 100 ft. Overall, maximum ESALs decreases as T_L increases and the target B/C increases. For example, at JS of 20 ft for a B/C of 0.0%, the maximum traffic volume is 0.4 million ESALs at 12°F; and it decreases linearly to reach 0.1 million ESALs at 24 °F. For this case, then, System D can be cost effective when it is used in an HMA overlay for which traffic volume is less than the maximum ESALs-corresponding T_L: For 0.3 million ESALs, System D is cost effective at T_L of 12^{o}F; but not cost effective at T_L of 20^{o}F. At JS of 30 ft, allowable maximum ESALs become greater than that at JS of 20 ft for the considered temperature range. As joint spacing becomes greater, the allowable maximum ESALs diminish because of lower PBR for System D, despite lower MCR and CTR values. Especially, an applicable region is very limited to a low-volume (0.14 million ESALs) road at cold regions (T_L of 14^{o}F). The most cost-effective interlayer system is dependent on ESALs, T_L and JS.

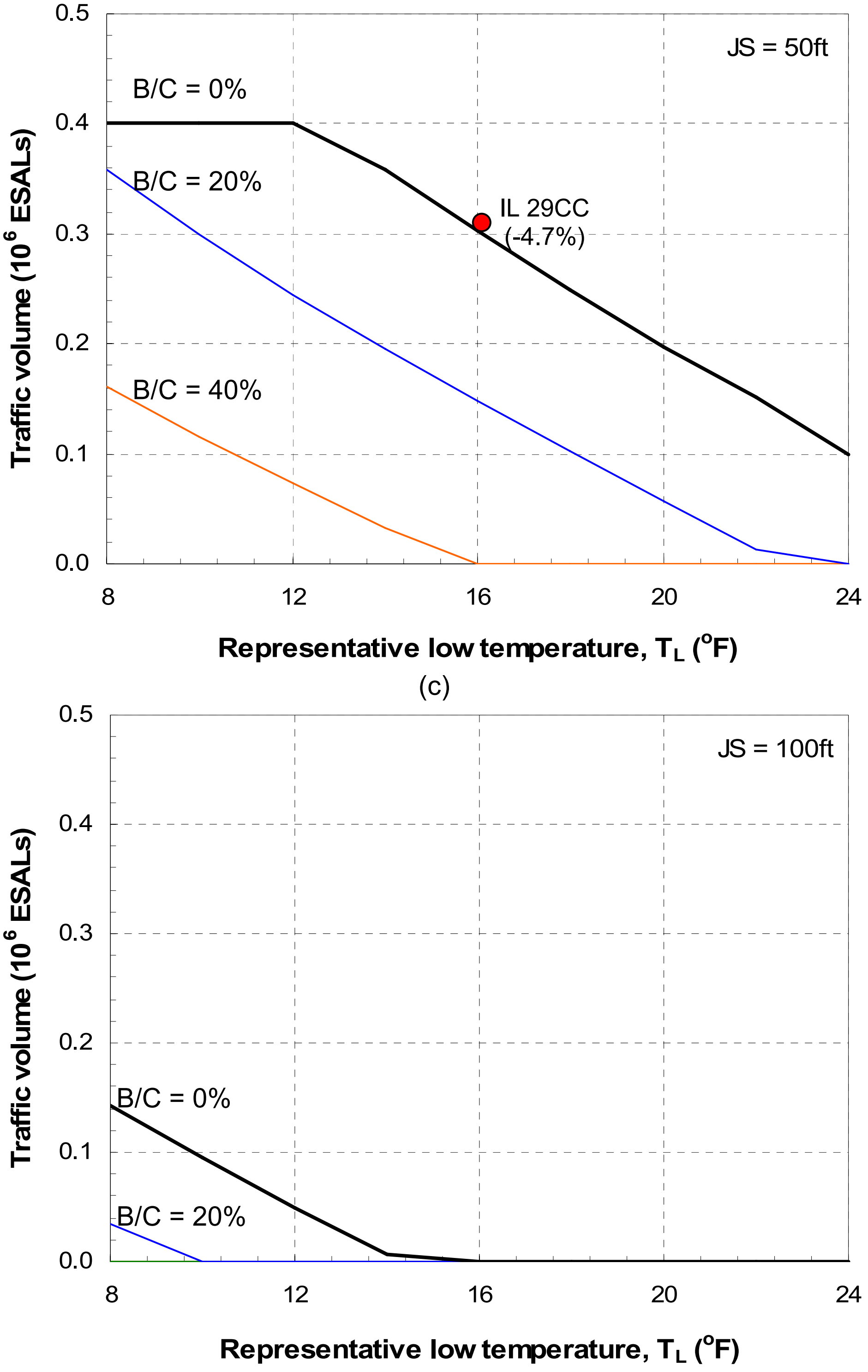
The expected B/C for System D can be validated using the information in Figures 29(b) and (c). Three of the four sections are within the maximum ESALs limit—US 136E (at east of San Jose), IL 267 (at Greenfield), and Mattis (at Champaign)—while the section at IL 29CC (at Creve Coeur) is beyond the maximum ESALs limit. As a result, System D proved to be a cost-effective method at the first three locations; but was found to be inefficient at IL 29CC despite the positive PBR value of 1.44.



(a)

(b)

Figure 29. Upper limit of traffic volume (ESALs) and climate (T_L) for System D: (a) JS = 20 ft, (b) JS = 30 ft, (c) JS =50 ft, and (d) JS = 100 ft. (Percentages in parentheses are B/Cs obtained from field data.)



(c)

(d)

Figure 29 (continued). Upper limit of traffic volume (ESALs) and climate (T_L) for System D: (a) JS = 20 ft, (b) JS = 30 ft, (c) JS = 50 ft, and (d) JS = 100 ft. (Percentages in parentheses are B/Cs obtained from field data.)

On the other hand, B/C for area-type System A and for System E was found to be insensitive to ESALs and T_L. Based on Equation 14 with medium-level MCR and CTR values, the average B/C of area-type System A and System E becomes -7.3% and 17.6%, respectively. Using the B/C of System E as a trigger value, the most cost-effective interlayer system can be determined with respect to ESALs and T_L at various joint spacing. Figure 30 illustrates the most cost-effective interlayer system application ranges at joint spacing of 30 ft. Under the maximum ESALs limit for the B/C of 17.6%, System D is more cost effective, and System E can show better efficiency above the limit. In addition, a transition zone is established to take the uncertainty of the B/C of System E into consideration. The transition zone is bounded by upper and lower ESALs limits corresponding to B/C of 7.6% and 27.6%, respectively. Thus, the cost effectiveness of System D and System E are regarded as being comparable in the transition zone. For the application area systems, System D is relatively cost effective at low temperature with low traffic volume; System E works better at high temperature and high traffic volume. Since each district in Illinois can be represented in terms of T_L, System D is generally cost effective in most northern districts and System E is ideal for southern districts.

A section at US 136 east of San Jose is the only location to use System D and System E both. Based on its ESALs (0.18 million) and T_L (16.9 °F), the section lies in the transition zone. Hence, it is expected that comparable B/Cs are achieved for the two interlayer systems. As listed in Table 5, the B/C obtained is 27.1% and 31.7%, respectively, for System D and System E. This suggests that both these interlayer systems are cost effective and that their difference is marginal. This may validate the expectations obtained from the application map, but further validation is required in future studies that include ESALs and T_L in B/C prediction for System E; to reduce the transition zone and to expand ESALs and T_L ranges.

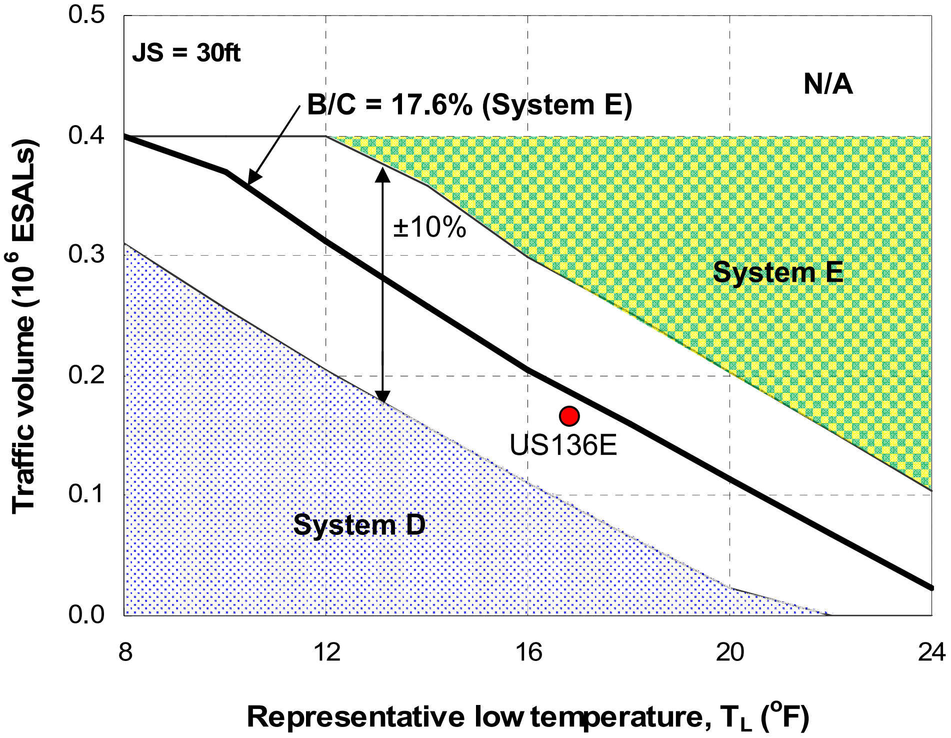


Figure 30. Application area for System D and System E with respect to ESALs and T_L at JS of 30 ft.

5. INTERLAYER SYSTEM SELECTION DECISION-MAKING

5.1 DECISION TREE FOR INTERLAYER SYSTEM SELECTION

A comprehensive decision-making procedure is needed to select the most appropriate interlayer system for an HMA overlay design. The decision tree developed considers not only cost effectiveness, but also design compatibility and the availability of interlayer systems (Figure 31). For a given HMA overlay design, three interlayer systems which have demonstrated performance benefit are provided as default alternatives. The following steps are suggested:

1. Check design compatibility with the interlayer systems. Each interlayer system has several basic constraints. Table 8 lists the constraints associated with the three interlayer systems under investigation. Area-type System A is applicable only on a flexible base such as full-depth HMA pavement and HMA-overlaid PCC pavement (IDOT, 2002). If transverse cracks or joint spacing of PCC pavement is less than 10 ft, it is regarded as a flexible base (IDOT, 2002). Also, as a general restriction for the use of fabric interlayer systems, area-type System A is not suitable when vertical joint deflection is greater than 0.008 in and/or horizontal joint movement is greater than 2.0 in. (Button and Lytton, 2007). For System D, a 2.0-in.-thick HMA overlay is recommended as a minimum application thickness. For System E, there are no particular constraints. Consideration must also be given to which interlayer systems are currently available in a particular market.

Table 8. Interlayer System Constraints for HMA Overlays

Interlayer System	Application Constraint
System A (area)	• Do not apply right over bare PCC pavements. • Do not apply if transverse cracks or joint spacing ≥ 10 ft. • Do not apply if vertical joint deflections > 0.008 in. and/or horizontal joint movement > 0.05 in.
System D	• Do not place when HMA overlay must be less than 2.0 in.
System E	• N/A

2. Calculate PBR for interlayer systems to satisfy the constraints using the PBR prediction model for System D with ESALs, T_L, and JS; or by using the average PBR of 1.22 and 1.49 for area-type System A and for System E. Interlayer systems whose PBR is less than 1.0 are discarded because there is no possibility of them being cost-effective.
3. Evaluate the cost effectiveness of the interlayer systems to select the most cost-effective based on the level of project importance and data availability. Unless information on specific interlayer systems and HMA overlay is available, the most cost-effective interlayer system can be simply determined based on the information in Figures 29 and 30 (Level I), assuming that a medium cost level interlayer system and an HMA overlay system is used.
4. The optimal interlayer system is determined using ESALs, T_L, and JS. If ESALs, T_L, and JS are out of the ranges provided in the Figure 29 and Figure 30 and/or a

specific material cost and construction time can be known, the B/C prediction model (see Equation. 14) can be used to achieve the B/C for each interlayer system (Level II). However, since the B/C prediction model was developed using a discount rate of 3.0%, the model may not be valid for other discount rates. If the calculated B/C of an interlayer system is between -10% and 10%, a more accurate B/C calculation is suggested because the B/C prediction model standard error is 6.8%.

5. CIND may be used to obtain the most accurate B/C for interlayer systems (Level III), which requires detailed characteristics of the interlayer systems, overlays, and other variables related to LCCA.
6. By comparing the B/C values of alternative interlayer systems, the most cost-effective interlayer system can be determined.

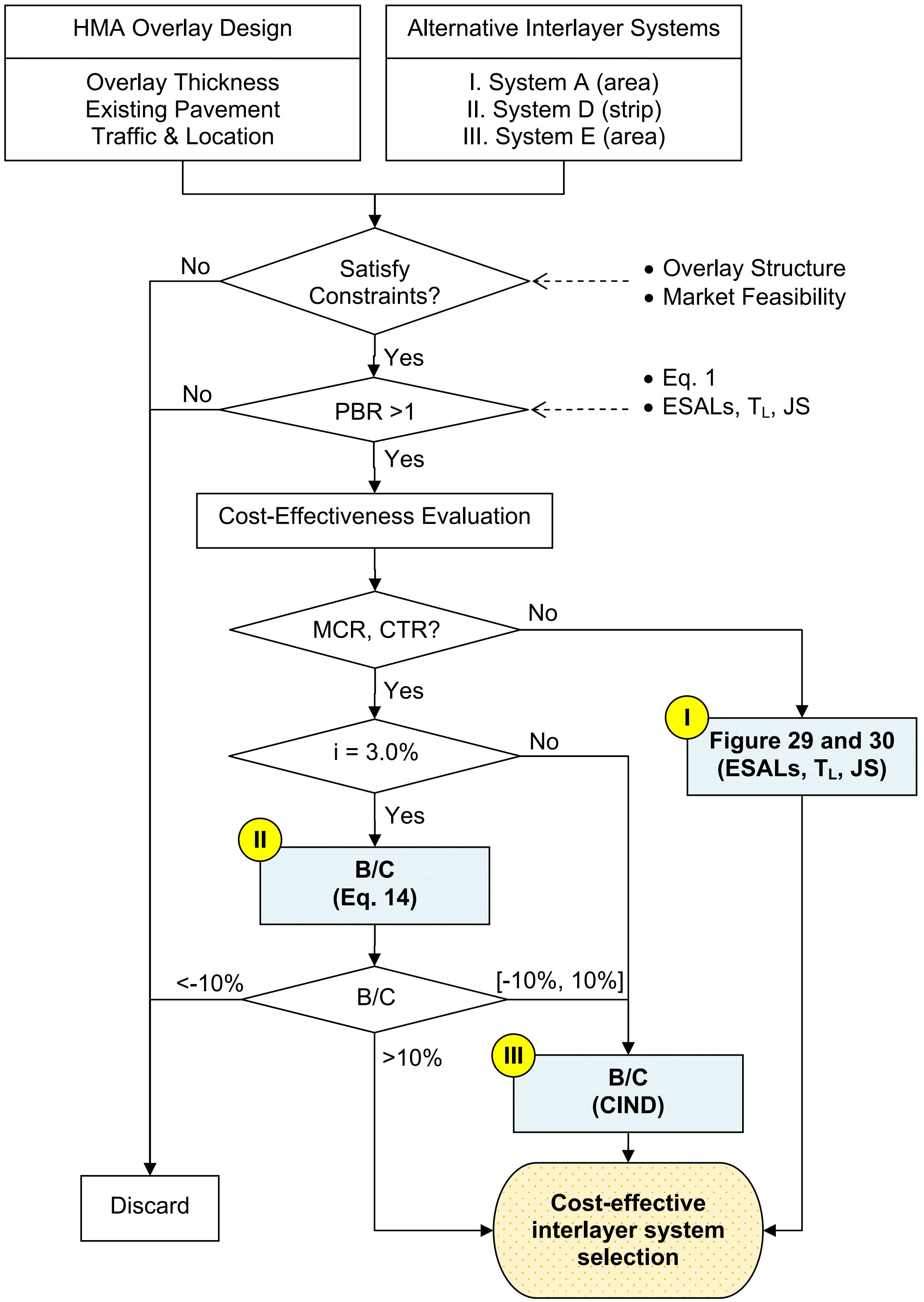


Figure 31. Decision tree for selecting a cost-effective interlayer system for HMA overlay.

5.2 DECISION TREE VALIDATION

For the decision tree validation, the most cost-effective interlayer system is selected using the values shown in Table 9. Three interlayer systems were chosen as alternatives, while one or two interlayer systems were actually applied in most of the locations. First, the three constraints listed in Table 8 for area-type System A were validated. HMA overlays were placed right over PCC pavements in five locations: IL 29 Mossville-Chillicothe, IL 29 Creve Coeur, Mattis Ave., IL 111 Pontoon Beach, and IL 148 Christopher. Area-type System A had no utility in the five locations (noted as “N/A” in the Field PBR column of Table 9). The HMA overlay was thicker than 2.0 in. for all locations, so that no limit was applied for System D. Next, interlayer systems with a PBR of less than 1.0 were excluded in the cost-benefit analysis (noted as “N/A” in the field PBR column of Table 9).

The most cost-effective interlayer systems are determined by means of the following three procedures:

1. The optimal systems are selected using the information in Figures 29 and 30 for ESALs, T_L and JS. In this evaluation, the discount rate is fixed at 3.0% so the B/C prediction model can be applicable in the evaluation level II and CIND can also be used in the evaluation level III using field inputs.
2. B/C values were compared for the three systems for the US 136 section. The most cost-effective interlayer systems were determined and are highlighted in the columns in Table 9.
3. The cost-effectiveness of the interlayer systems was found to match well. Figure 32 summarizes the percentage of successful identifications. When calculated PBR is used in B/C prediction, 83.3%, 83.3%, and 88.9% of the evaluations in the Levels I, II, and III, respectively, are the same as that in the Evaluation level III by CIND with field-based PBR in Table 9. The mismatches occurred in area-type System A whose PBR was assumed as 1.22. The validation suggested that despite the small differences, the three selection procedures are valid for selecting the most cost-effective interlayer system.

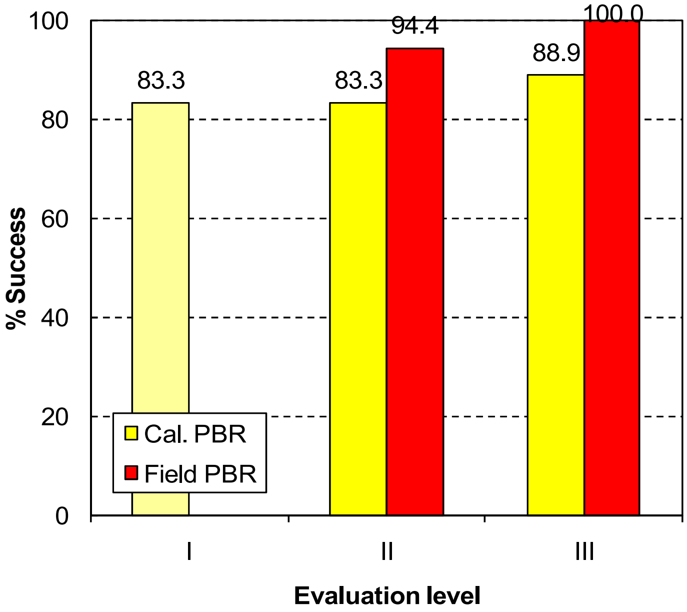


Figure 32. Cost-effectiveness evaluation success at the three evaluation levels using field-based PBR and calculated PBR.

Table 9. Comparison of Cost-Effective Interlayer System Selection

Location	Int. sys.*	ESALs (10^6)	T_L (°F)	Field PBR	Cal. PBR#	MCR	CTR	Evaluation level				
								I	II	III	II	III
								Fig. 29 30	Eq. 14 w/ cal. PBR#	CIND w/ cal. PBR#	Eq. 14 w/ field PBR	CIND w/ field PBR
IL 9 east of IL41	AA	0.021	15.1	1.04	1.22	1.21	1.50	N/A	-9	-4.7	-20.4	-17.4
IL 17 Aledo	E	0.073	13.2	3.73	1.49	1.09	1.00	**OK**	**16.2**	**22.2**	**81.8**	**56.7**
IL 29 Mossville-Chillicothe	AA+	0.193	16.2	N/A	1.22	1.19	1.44	N/A	N/A	N/A	N/A	N/A
IL 29 Creve Coeur	D	0.308	16.2	1.44	1.44	1.23	1.94	N/A	-2.3	-4.7	-2.3	-4.7
IL 40 Deer Grove	AA	0.124	12.1	1.63	1.22	1.17	1.42	N/A	-6.2	-1.9	**14.5**	**19.8**
IL 76 Belvidere	E	0.194	12.4	1.17	1.49	1.10	1.00	**OK**	**15.7**	**22.2**	-1.6	2.6
IL 111 Pontoon Beach	AA+	0.232	23.7	N/A	1.22	1.19	1.44	N/A	N/A	N/A	N/A	N/A
IL 117 Benson	E	0.026	14.0	1.88	1.49	1.10	1.00	**OK**	**15.7**	**21.7**	**32.3**	**33.3**
IL 130 Philo	E	0.066	17.2	1.27	1.49	1.08	1.00	**OK**	**16.7**	**23.1**	5.3	**10.5**
IL 148 Christopher	AA+	0.090	23.4	N/A	1.22	1.19	1.44	N/A	N/A	N/A	N/A	N/A
IL 251 north of US 30	AA	0.046	10.9	1.44	1.22	1.14	1.33	N/A	-3.8	1.8	8.1	**15.4**
IL 267 Greenfield	D	0.099	20.3	2.38	2.37	1.39	2.56	**OK**	**19.2**	**27.3**	**19.5**	**27.3**
US 34 Mendota	AA	0.033	15.0	1.26	1.22	1.21	1.50	N/A	-9	-1.9	-6.7	-0.3
US 136 east of San Jose	AA	0.177	16.9	1.39	1.22	1.19	1.44	N/A	-7.4	-3.4	1.9	9.4
	D			2.40	2.39	1.39	2.56	**OK**	**19.8**	**28.5**	**20.1**	**27.1**
	E			1.85	1.49	1.09	1.00	**OK**	**16.2**	**22.3**	**31.7**	**31.7**
US 136 west of San Jose	E	0.165	16.9	1.28	1.49	1.09	1.00	**OK**	**16.2**	**22.2**	5.3	**11.7**
Mattis Ave.	D	0.053	17.2	2.77	2.80	1.28	2.13	**OK**	**40.9**	**35.3**	**40.1**	**35.3**

*: Area-type System A; D: System D; and E: System E.
+: not applicable because HMA overlay is placed over PCC pavement directly.
#: PBR for System D is from Equation 1; for area-type System A and System E, 1.22 and 1.49 on average.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

Life-cycle cost analysis (LCCA) was conducted to assess the engineering value of interlayer systems used in Illinois to control reflective cracking. Cost effectiveness was evaluated by means of a benefit-cost ratio (B/C) obtained through LCCA. A user-friendly LCCA spreadsheet-based program was developed called **C**ost-effective **IN**terlayer system **D**ecision (CIND). Field performance data, material costs, and construction procedures were used to develop a regression model to predict the B/C of the interlayer systems. Using this model, a schematic illustrating cost-effective regimes for the employment of interlayer systems was developed as a function of traffic volume and climatic region within Illinois. From this, a decision tree was constructed to aid the designer in the selection of a cost-effective and compatible interlayer system for a given pre-existing pavement system.

Of the five interlayer systems evaluated in the companion report, Volume I (Al-Qadi et al. 2008) conducted in Illinois, three interlayer systems with positive performance-benefit ratio were investigated: area-wide System A (a nonwoven polypropylene geotextile fabric); System D (an interlayer stress-absorbing composite [ISAC] strip treatment); and System E (a sand-sized aggregate gradation with high binder content and a highly modified binder).

Based on the research, the following conclusions have been made:

- Based on a statistical analysis of the B/C prediction model's ability to predict field performance data, the model was found to be effective for estimating the B/C of interlayer systems over a 30-year analysis period using just three variables: performance-benefit ratio (PBR), material cost ratio (MCR), and construction time ratio (CTR).
- Based on 19 interlayer systems evaluated in the field, the B/C of area-type System A ranged from -29.4% to 16.0%; while Systems D and E carried B/C ratios of -9.7% to 28.5% and 4.0% to 59.8%, respectively. Strip applications involving Systems A and B were found to have negative B/C, due to their poor performance in terms of abating reflective cracking as measured in field surveys.
- The effects of PBR, MCR, and CTR on the benefit versus cost of interlayer systems were clearly demonstrated. B/C increases linearly as ln(PBR) increases; but decreases linearly as MCR and CTR increase.
- Among the three interlayer systems, System D has the widest application range in terms of ESALs, T_L, and JS, especially in colder regions in Illinois with lower traffic volume. On the other hand, System E is cost effective in warmer regions with higher traffic volume. As joint spacing increases, the application range of System D is diminished. Area-type System A exhibited a marginal cost effectiveness only in limited survey locations.

6.2 EXPECTED BENEFITS

This study developed a decision-making procedure for selecting a cost-effective interlayer system in the State of Illinois when HMA overlay is used for pavement rehabilitation. A simple decision tree was developed, based on comprehensive analyses conducted using an LCCA program, a B/C prediction model, and application range tables developed in this study. For convenience, a chart method was developed to guide the designer in interlayer system selection with respect to equivalent single-axle loads (ESALs), representative low temperature (T_L) in the design location in Illinois, and PCC pavement joint spacing (JS). Local agencies and/or pavement engineers can use one or more of these decision-making tools, which range in complexity based on project size and/or importance. Using this adaptive approach is expected to save significant cost and time and to produce more predictable performance outcomes when using reflective crack control treatments in conjunction with HMA overlays in Illinois.

6.3 RECOMMENDATIONS

- The accuracy of the LCCA program and CIND mainly depends on the performance-benefit ratio of interlayer systems. Using reliable input variables into the LCCA program and CIND are recommended for selecting cost-effective interlayer systems for larger, high-profile rehabilitation projects. For the purpose of preselection or lower-profile projects, the B/C prediction model and/or application tables are recommended for use.
- More data and efforts are needed to fine-tune the B/C prediction model which is only valid for low traffic volume roads, not for interstate. This can be accomplished by surveying additional sections and/or by obtaining more data from previously surveyed sections.

7. REFERENCES

Al-Qadi, I. L., W. G. Buttlar, J. Baek, and M. Kim (2008). *Cost Effectiveness and Performance of Overlay Systems in Illinois-Volume I: In-Situ Assessment of Interlayer Systems Used in Illinois*. Final Report, Illinois Center for Transportation, Illinois Department of Transportation, Springfield.

Beg, M. A., Z. Zhang, and W. R. Hudson (2000). Development of Pavement Type Evaluation Procedure for Texas Department of Transportation, *Transportation Research Record: Journal of the Transportation Research Board*, No. 1699, Transportation Research Board of the National Academies, Washington, D.C., pp. 23–32.

Buttlar, W. G., B. Diyar, and B. Dempsey (1999). *Evaluation of Reflective Crack Control Policy*, Report No. ITRC FR 95/96-4, Illinois Transportation Research Center, University of Illinois at Urbana-Champaign, Urbana.

Buttlar, W. G., B. Diyar, and B. Dempsey (2000). Cost-Effectiveness of Paving Fabric Used to Control Reflective Cracking, *Transportation Research Record: Journal of the Transportation Research Board,* No. 1730, Transportation Research Board of the National Academies, Washington, D.C., pp. 139–149.

Button, J. W. and R. L. Lytton (2007). *Guidelines for Using Geosynthetics with Hot Mix Asphalt Overlays to Reduce Reflective Cracking*. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Federal Highway Administration, (1998). *Life Cycle Cost Analysis in Pavement Design*. Publication FHWA-SA-98-400, U.S. Department of Transportation.

Geoffrey, D. N. (1996). Cost-Effective Preventive Pavement Maintenance.. *NCHRP Synthesis 223*, Transportation Research Board, Washington, D.C.

IDOT, (2002). *Bureau of Design and Environment Manual*, Illinois Department of Transportation, Springfield.

Lamptey, G., M. Ahmad, S. Labi, and K. Sinha (2005). *Life Cycle Cost Analysis for INDOT Pavement Design Procedures*. Publication FHWA-IN-JTRP-2004-28, Purdue University, West Lafayette, Ind.

NCHRP (2003). *NCHRP 2002 Design Guide – Pavement Analysis and Design System*, NCHRP 1-37a. ERES Division of Applied Research Associates and Arizona State University, Tempe.

U.S. Department of Labor. Consumer Price Index. http://www.bls.gov/CPI/. Accessed May 1st, 2008.

Vespa, J. W. (2005). *An Evaluation of Interlayer Stress Absorbing Composite Reflective Crack Relief System*. Publication FHWA-IL-PRR-150, Illinois Department of Transportation, Springfield.

Wei, C. and S. Tighe (2004). Development of Preventive Maintenance Decision Trees Based on Cost-Effectiveness Analysis, *Transportation Research Record: Journal of the Transportation Research Board*, No. 1866, Transportation Research Board of the National Academies, Washington, D.C., pp. 9–19.

APPENDIX A

User Manual for CIND Version 1.0

Life-Cycle Cost Analysis Program:
Cost-Effective Interlayer System Decision for Hot-Mix Asphalt Overlay

CIND

Version 1.0

User Manual

December 2008

Illinois Department of Transportation

Illinois Center for Transportation

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A.1 INTRODUCTION

Interlayer systems are used in hot-mix asphalt (HMA) overlays to retard reflective cracking. Among various alternatives, a cost-effective interlayer system is determined through a life-cycle cost analysis (LCCA). Based on the performance benefit of interlayer systems to control reflective cracking, the relative cost benefit of interlayer systems is computed as a benefit-cost ratio (B/C) using a cost-effective interlayer system decision program (CIND). The program is coded with Microsoft Excel Visual Basic for Application (VBA). In CIND, the LCCA procedure suggested by the Federal Highway Administration (FHWA, 1998) is adapted and the same approach of RealCost Version 2.2 (FHWA, 2004) is used to compute user costs. Furthermore, the LCCA procedure is modified appropriately for HMA overlays.

A.2 CIND DESCRIPTION

A.2.1 CIND Framework

CIND consists of three main modules shown in Figure A.1: Input, Analysis, and Output. In the input module, all input variables are given for HMA overlay, interlayer systems, traffic, and LCCA parameters. Users enter information for major parameters for overlay geometry, interlayer type, and traffic; minor or unfamiliar parameters are provided as default values by the program. In particular, performance-benefit ratio is also provided as a default value. During LCCA analysis, agency and user costs are computed based on user's input variables and default values. Finally, the LCCA results are presented in the output modules as a summary report, as well as graphs for each cost component. The most cost-efficient interlayer system is computed based on the relative B/C.

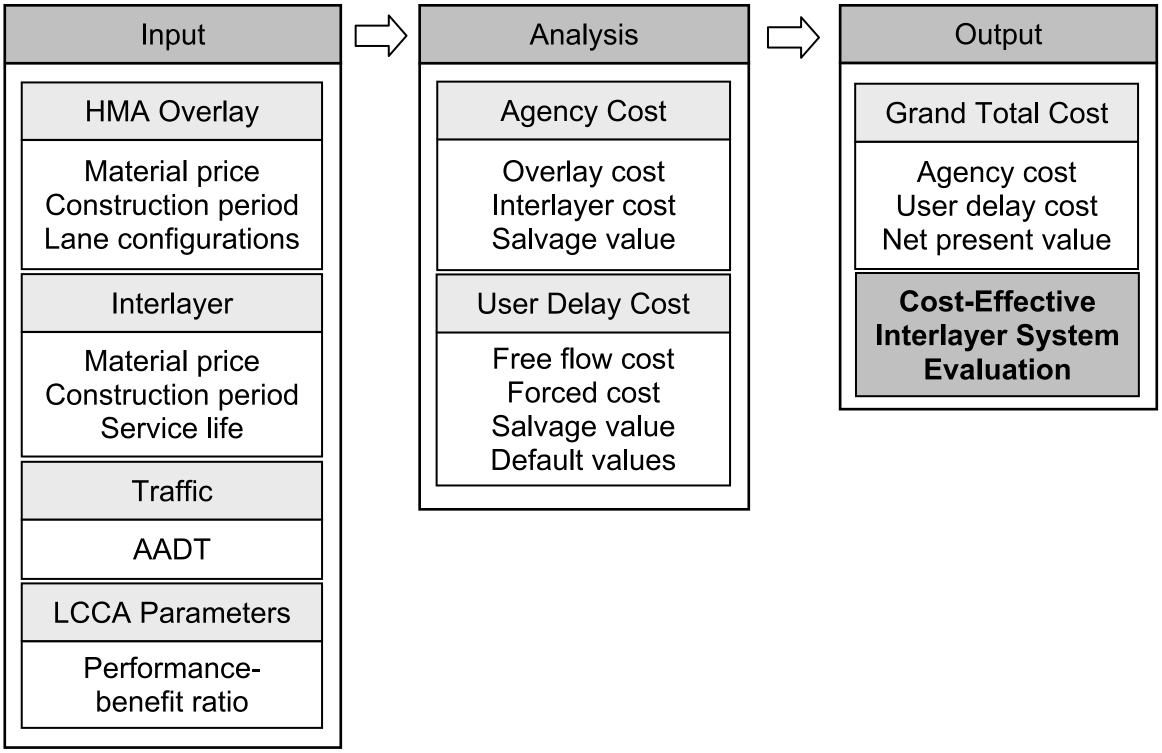
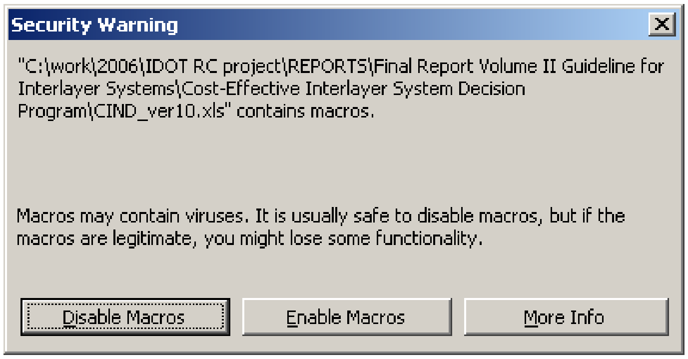


Figure A.1. Framework for the cost-effective interlayer selection decision program (CIND).

A.2.2 Starting CIND

Under a medium security level in Excel 2003 or other versions, security warning options are shown (Figure A.2) whenever CIND starts. To run CIND, the “Enable Macros” option should be chosen.



"C:\work\2006\IDOT RC project\REPORTS\Final Report Volume II Guideline for Interlayer Systems\Cost-Effective Interlayer System Decision Program\CIND_ver10.xls" contains macros.

Macros may contain viruses. It is usually safe to disable macros, but if the macros are legitimate, you might lose some functionality.

Figure A.2. Microsoft Excel 2003 macro options form

When CIND opens correctly, a CIND startup form appears as the “main” worksheet as shown in Figure A.3.

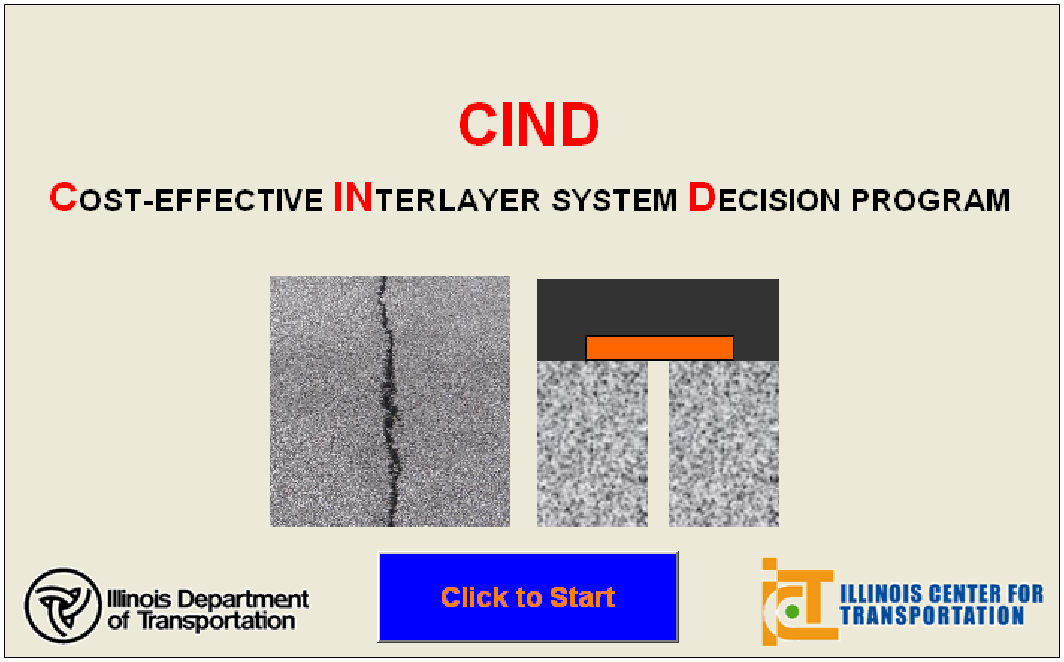


Figure A.3. CIND startup form

After clicking the startup form or the “Click to Start” button, the main menu appears (Figure A.4). The main menu contains six items as follows:

- Design Input:	All data for pavement structure, costs, traffic, and performance are entered via an input form.
- LCCA Output:	LCCA analysis outputs are shown with five charts for agency, user, total, and accumulated costs, and B/C.

- View Report: Users can modify design input directly in a “Report” worksheet; moreover, a new LCCA can be run.
- Print Report: The summary report can be printed out.
- Export Data: Data can be stored in a separate file which can be imported later. The export data is saved in the same directory where CIND is working.
- Exit: Terminate the CIND and return to a “Main” worksheet.

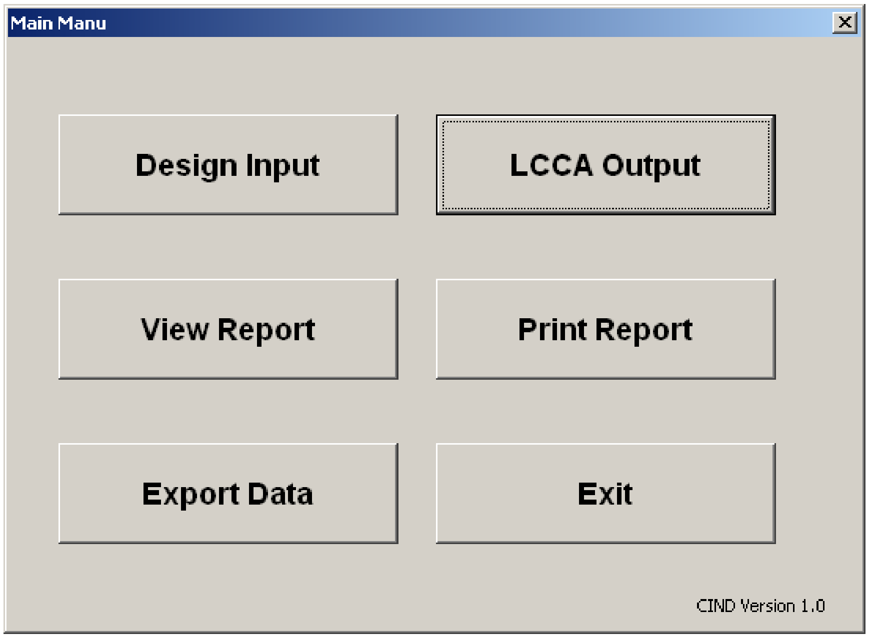


Figure A.4. Main menu in CIND

A.2.3 Design Input Variables

A.2.3.1 Input option

There are three input method options: Direct Input for New Data; Update Existing Data; and Import New Data (see Figure A.5). When users create new design input data, previous data is deleted and all design variables are initialized accordingly. Once input data are imported or modified by users in a “Report” worksheet, the data can be updated by selecting “Update Existing Data.” The last input option can be chosen when input data files have already been generated.

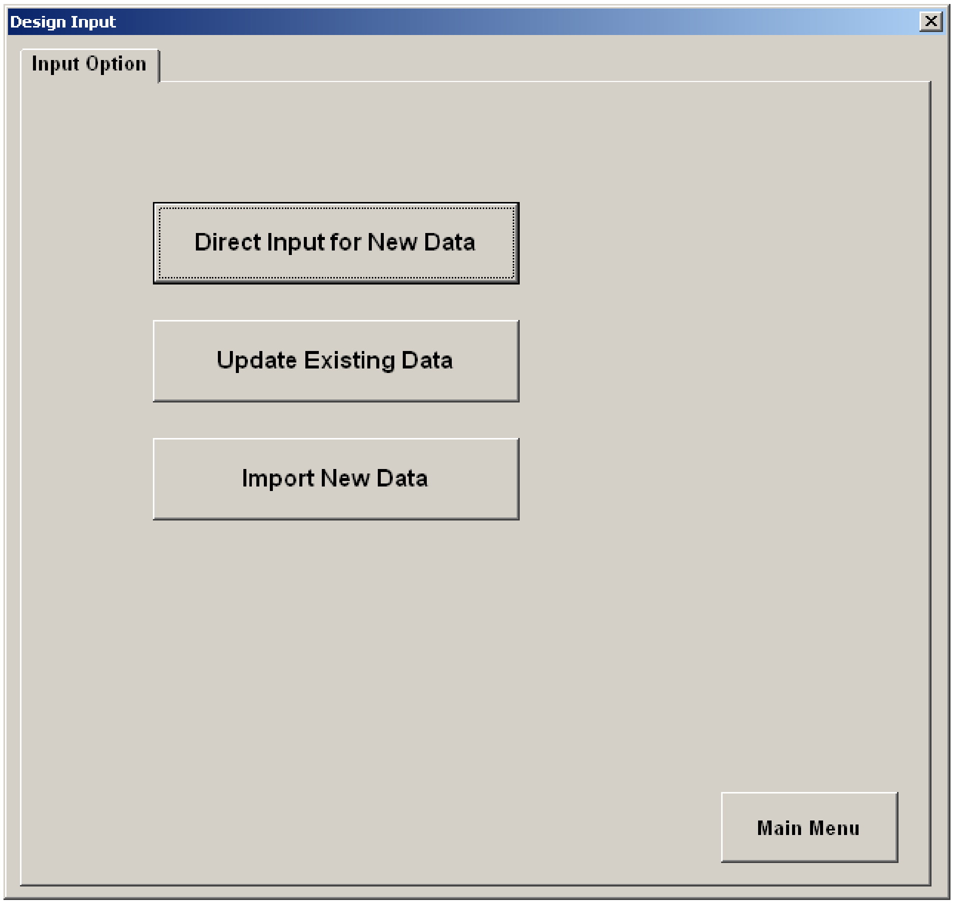


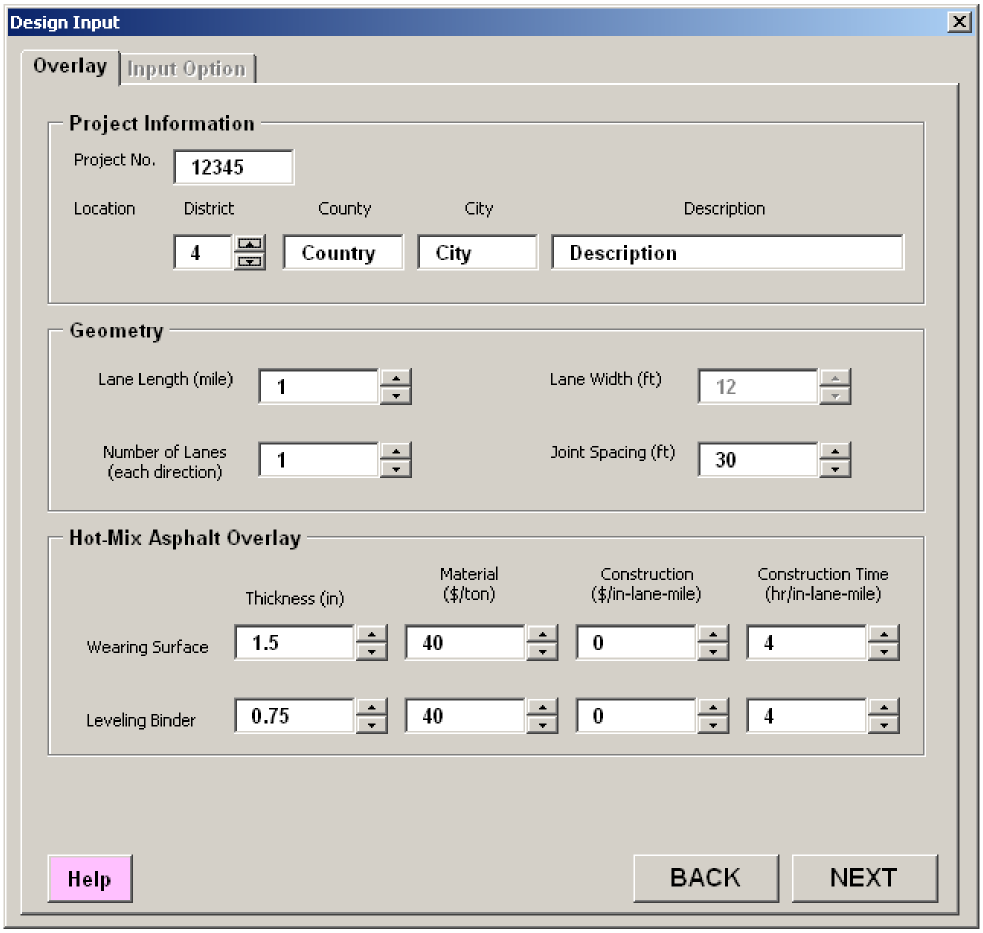
Figure A.5. Data input option form

The design input has four categories for overlay, interlayer system, traffic, and LCCA parameters as follows:

- Overlay	Project identification, geometry, and HMA overlay information are given.
- Interlayer system:	Alternative interlayer systems and details for material price and installation period are given.
- Traffic:	Road category, work zone, and annual average daily traffic (AADT) are given when user costs are included.
- LCCA:	Design year and performance-benefit ratio are given.

A.2.3.2 Overlay

Figure A.6 shows the input form to be filled in to identify project, specify overlay geometry, and identify costs for materials and construction . Overlay input variables and their descriptions are listed in Table A.1. In each design input form, users can bring up a table for design variables through the “Help” button. The next step is activated by pressing the “Next” button. If necessary data are missing, an error message is shown and the user is returned to the overlay design input form. Users can click the “Back” button to return to the input option.



Project Information

Project No. 12345

Location	District	County	City	Description
	4	Country	City	Description

Geometry

Lane Length (mile) 1

Lane Width (ft) 12

Number of Lanes (each direction) 1

Joint Spacing (ft) 30

Hot-Mix Asphalt Overlay

	Thickness (in)	Material ($/ton)	Construction ($/in-lane-mile)	Construction Time (hr/in-lane-mile)
Wearing Surface	1.5	40	0	4
Leveling Binder	0.75	40	0	4

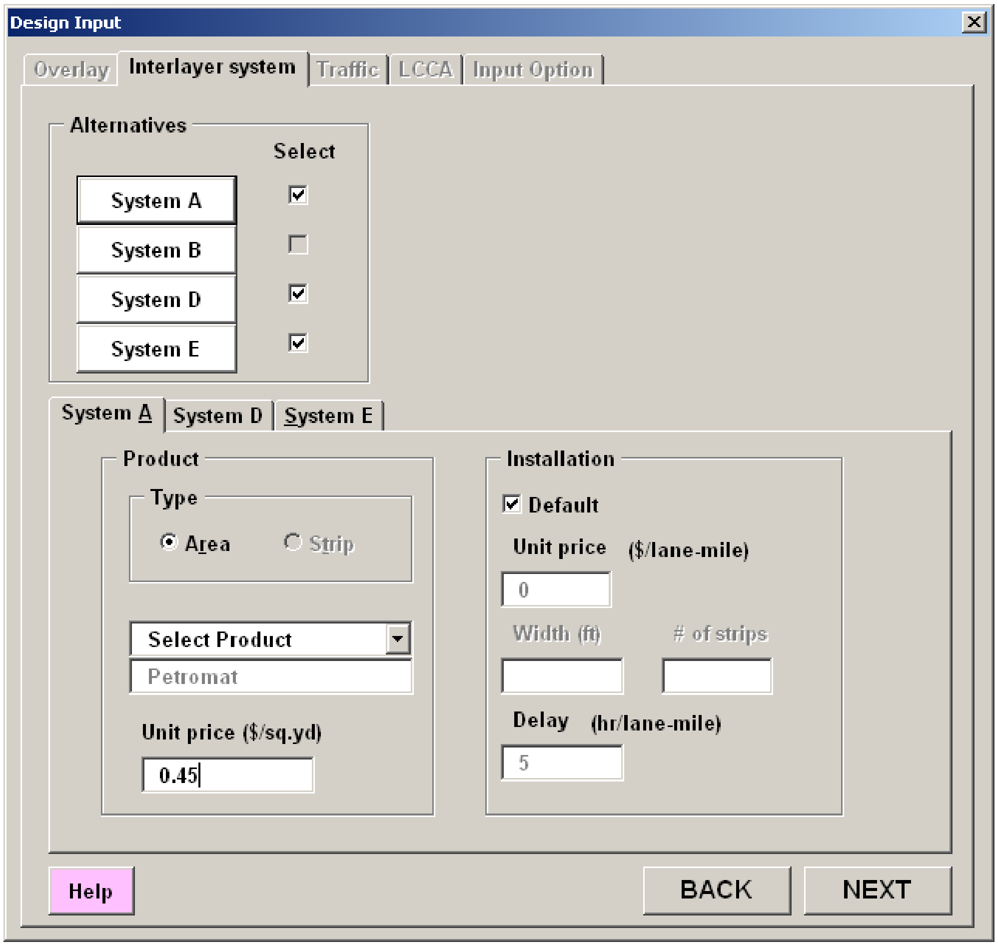
Figure A.6. Project identification and overlay information input form

Table A.1. Overlay Input form Variables

Category	Option/Input	Description
Geometry	Lane length	Total project lane length or evaluation length (miles)
	Lane width	Default value of 12 ft regardless of inner or outer lane
	Number of lanes	Number of lanes in each direction, up to 3
	Joint spacing	Longitudinal slab span length of pre-existing concrete pavements, ranging from10 to 100ft
HMA overlay	Thickness	Thickness of wearing surface and leveling binder (in.)
	Material	Material price ($/ton)
	Construction	Additional construction cost if needed ($/in-lane-mile)
	Period	Construction period (hr/in-lane-mile)

A.2.3.3 Interlayer system

Figure A.7 shows the CIND interlayer system variable input form. In this form, four types of interlayer system alternatives are provided; only three interlayer systems having positive performance-benefit ratio can be available to choose: System A (area-type), System D, and System E. General information appears when an interlayer system name is clicked (see Figure A.8). When a box next to the name is checked, the interlayer system is selected and then the second input tab is activated. Type, product, and unit price of the interlayer system material and installation are entered accordingly. Unless the desired product is found in the product list, “User-defined” is selected and a specific product name and unit price are entered in a pop-up input box. According to the selected product, unit price is provided as a default, but also can be entered manually. When installation information is not available, users can use default values as given; specific unit price, width and number of strips, as well as installation period. This can be repeated until all information is correctly entered. Detailed input variables are listed in Table A.2. The next step is activated by pressing the “OK” button. If necessary data are missing, an error message will appear as shown in Figure A.9 and the user is guided to the input form.



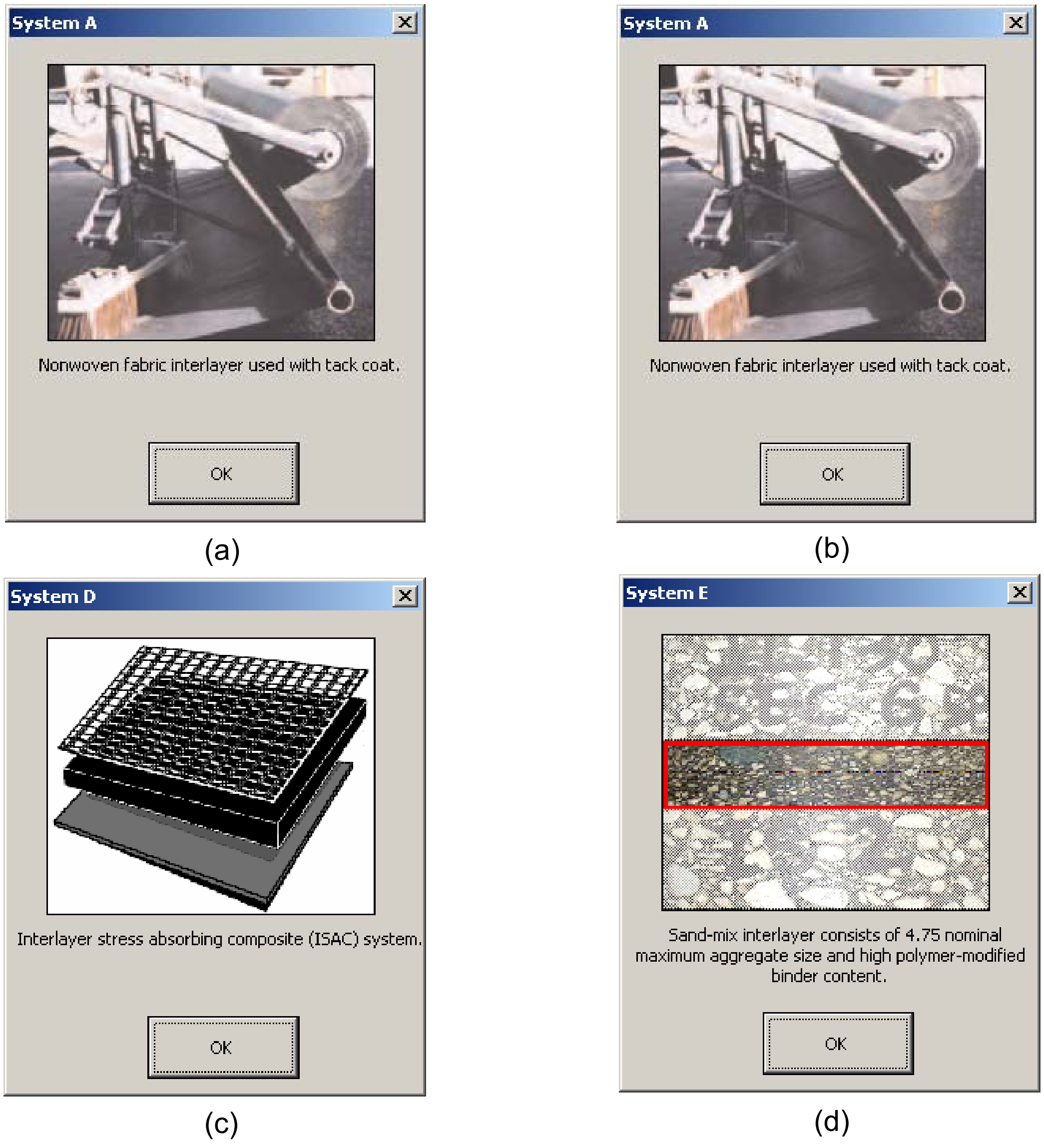
System A ☑
System B ☐
System D ☑
System E ☑

System A | System D | System E

Type: ● Area ○ Strip
Select Product: Petromat
Unit price ($/sq.yd): 0.45

☑ Default
Unit price ($/lane-mile): 0
Width (ft):
# of strips:
Delay (hr/lane-mile): 5

Figure A.7. Interlayer system variables input form



Nonwoven fabric interlayer used with tack coat.

Nonwoven fabric interlayer used with tack coat.

(a)

(b)

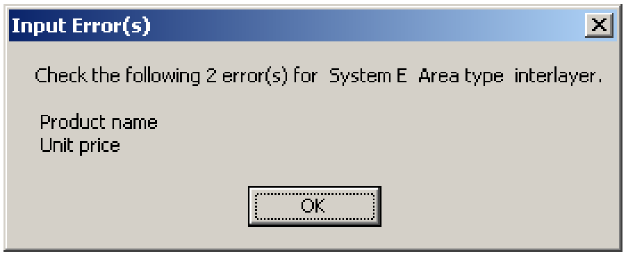
Interlayer stress absorbing composite (ISAC) system.

Sand-mix interlayer consists of 4.75 nominal maximum aggregate size and high polymer-modified binder content.

(c)

(d)

Figure A.8. General information for four interlayer systems



Check the following 2 error(s) for System E Area type interlayer.

Product name
Unit price

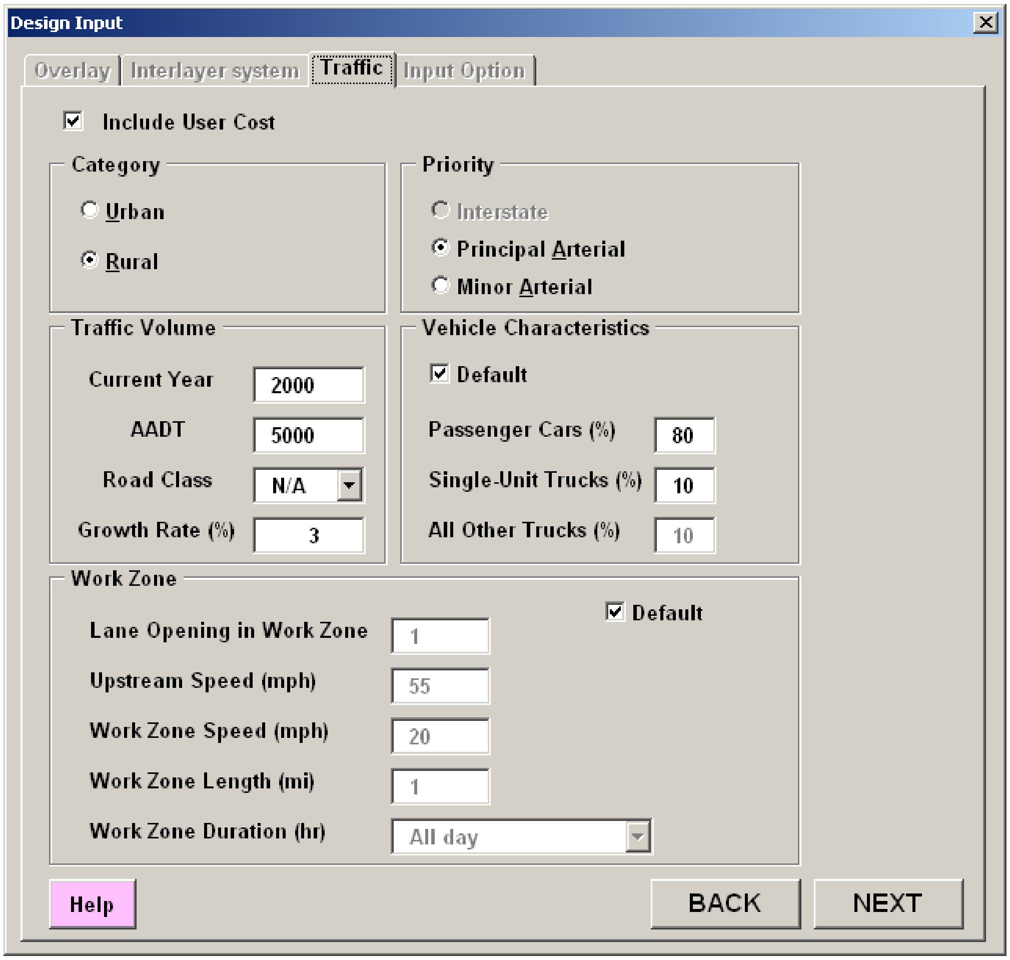
Figure A.9. Warning message for input error

Table A.2. Interlayer System Input Variables

Category	Option/Input	Description
Interlayer system	Type	System A: area System D: strip System E: area
	Product name	Currently used product
	Product unit price	Systems A and D: \$/yd^2 System E: \$/ton
	Installation unit price	Additional price to install interlayer systems Strip type: \$/strip (System D) Area type: \$/lane-mile (System A) \$/in-lane-mile (System E)
	Width	Width of strip type interlayers (ft)
	Number of strips	Same as the number of joints or actual number of strips used
	Installation day	Additional time to install interlayer system Strip type: hr/strip (System D) Area type: hr/lane-mile (System A) hr/in-lane-mile (System E)

A.2.3.4 Traffic

User cost is calculated based mainly on traffic volume of a road as well as geometry. A box is checked to include the user cost. Otherwise, only agency cost is considered to evaluate the cost benefit of interlayer systems. Figure A.10 shows a traffic input form. Detail input variables are listed in Table A.3. In order to determine hourly traffic distribution, it needs to determine the category and priority of a road: Urban or Rural; and interstate, principal arterial, and minor arterial. Interstate highways are not incorporated in this program since the performance-benefit ratio of the interstate highways is not included. Traffic volume is given based on a current (construction) year by means of annual average daily traffic (AADT), which is divided into three classes: passenger cars, single-unit trucks, and multiple-unit trucks to include all other trucks. Annual ESALs in a design lane is calculated base on the traffic volume and road class. If the class of a design road is known, this should be selected. Otherwise, "N/A" can be chosen; it will then be determined from number of lanes and AADT. The growth rate of the traffic volume is given; it is uniform to the three classes of vehicles. Work zone capacity is computed based on lane opening, speed change, and length of the work zone area, as well as period of work zone in effect.



☑ Include User Cost

Category
○ Urban
● Rural

Priority
○ Interstate
● Principal Arterial
○ Minor Arterial

Traffic Volume

Current Year	2000
AADT	5000
Road Class	N/A
Growth Rate (%)	3

Vehicle Characteristics

☑ Default

Passenger Cars (%)	80
Single-Unit Trucks (%)	10
All Other Trucks (%)	10

Work Zone

☑ Default

Lane Opening in Work Zone	1
Upstream Speed (mph)	55
Work Zone Speed (mph)	20
Work Zone Length (mi)	1
Work Zone Duration (hr)	All day

Figure A.10. Traffic parameters input form

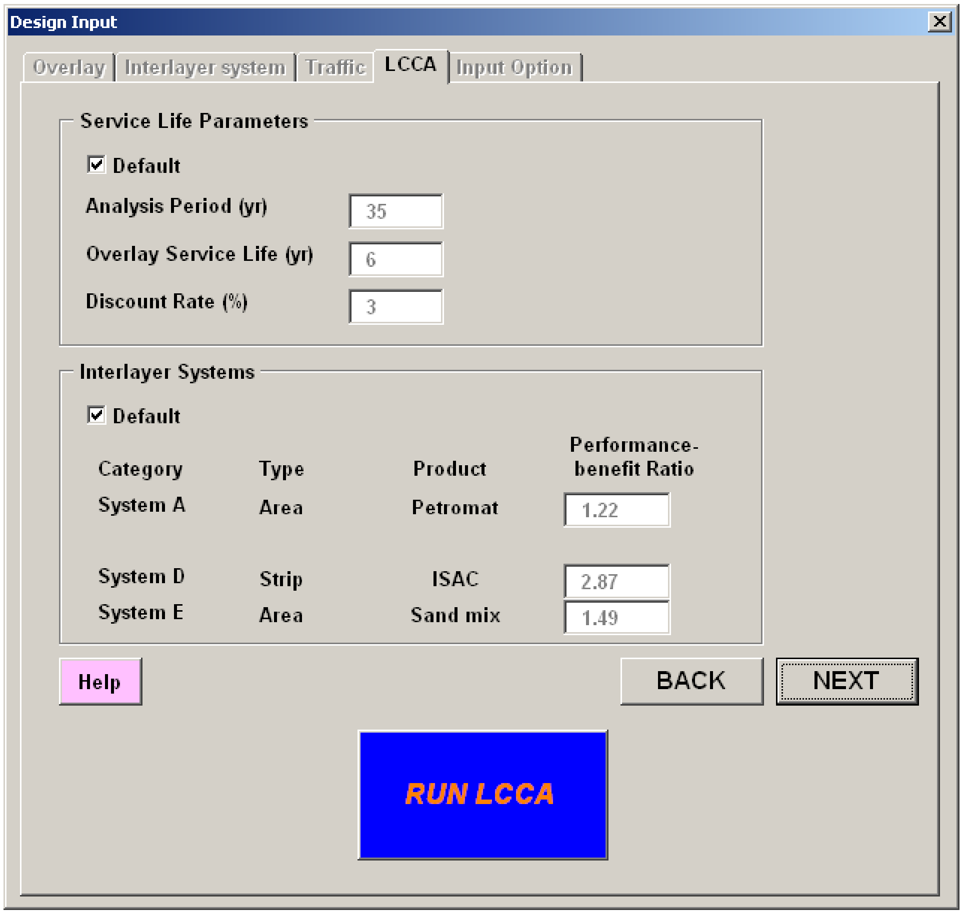
Table A.3. Traffic Input Variables

Category	Option/Input	Description
Traffic	Category	Urban or rural
	Priority	Principal arterial and minor arterial
	Current Year	First year of the analysis period used as base year of an expenditure diagram
	AADT	Annual average daily traffic in both directions in current year
	Road Class	Illinois road classifications regarding traffic volume and number of lanes (1: more than 4 lanes, 2: AADT >= 1000, 3: AADT >= 400, 4 AADT < 400
	Growth Rate	Annual traffic growth rate of AADT (same rate for all vehicles)
	Passenger Cars	% of passenger car in AADT
	Single-Unit Trucks	% of single-unit trucks in AADT
	All Other Trucks	% of combination trucks in AADT
Work zone	Lane Opening in Work Zone	Number of lanes open in work zone area in each direction, up to two lanes
	Upstream Speed	Speed limit in normal operation (mph)
	Work Zone Speed	Speed limit in work zone area (mph)
	Work Zone Length	Maximum length of work zone area when vehicle speed is reduced (miles)
	Work Zone Duration	Duration for work zone in effect; (“all day” option used as default)

A.2.3.5 LCCA

A life-cycle cost analysis is executed with the parameters shown in Table A.4 to define a service life span for each overlay design. Figure A.11 shows an LCCA input form. For an analysis period, multiple overlays are considered corresponding to the service life of overlays. Future cost is converted to a current value via a discount rate, and a net present value (NPV) is computed to sum all agency and user costs in initial and consecutive sequences during the analysis period. To compensate for a remaining life of the last overlay, a salvage value is determined at the end of the analysis period. The most important parameter of the LCCA is a performance-benefit ratio of interlayer systems. The benefit ratio, PBR, is a ratio of deteriorated rate of an overlay to an overlay with an interlayer system as follows:

$$BR_P = \frac{Service\,life\,span\,of\;\;an\;HMA\,overlay\,with\,an\,interlayer\,system}{Service\,life\,span\,of\;\;an\;HMA\,overlay\,without\,an\,interlayer\,system} \tag{A.1}$$



Service Life Parameters

☑ Default

Analysis Period (yr)	35
Overlay Service Life (yr)	6
Discount Rate (%)	3

Interlayer Systems

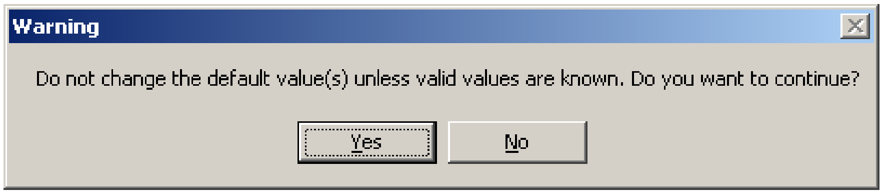
☑ Default

Category	Type	Product	Performance-benefit Ratio
System A	Area	Petromat	1.22
System D	Strip	ISAC	2.87
System E	Area	Sand mix	1.49

Figure A.11. LCCA parameters input form

A higher benefit ratio indicates a longer service life for the overlay section with an interlayer system compared to the control. The benefit ratio of a specific interlayer system is a default value in the program, based on a companion research report (Al-Qadi et al., 2008). If users have their own source for the benefit ratio, it can be substituted. Care must be exercised as this value has a significant effect on the LCCA, so a warning message pops up when the default benefit ratios are to be changed (see

Figure A.12). With the exception of the parameters given in Table A.4, all other parameters required for the LCCA are default values in the program; such as value of travel time (11.58$/veh-hr for passenger cars, 18.54$/veh-hr for single-unit trucks, and 22.31$/veh-hr for other trucks). These values reflect adjusted dollar values in terms of the 1996 base year, using an inflation rate calculated based on the U.S. consumer price index (U.S. Department of Labor, 2008). Detailed values for the LCCA are shown in an “intermediate results” worksheet. Finally, a “Run LCCA” button at the end of the LCCA part of the program executes the LCCA ; the results are shown in a form.



Do not change the default value(s) unless valid values are known. Do you want to continue?

Figure A.12 Warning message to alert to change in default values

Table A.4. LCCA Input Variables

Category	Option/Input	Description
Service life parameters	Analysis period	Total number of years to be analyzed, up to 50 years
	Overlay service life	Overlay service life span with no interlayer system (years)
	Discount rate	Rate to convert future cost to present value (3% to 5%)
Interlayer systems	Benefit ratio	Ratio to extend service life of overlay with interlayer systems compared to untreated overlay

A.2.4 LCCA Results

In the LCCA output module, LCCA results are shown in a chart form: for the first overlay service life span, agency and user costs; and for the entire analysis period, total cost as equivalent uniform annual cost (EUAC), B/C, and accumulated cost.

A.2.4.1 Agency cost

Agency cost is comprised of basic construction cost for the HMA overlay, additional cost for interlayer systems, and a salvage value. For the first overlay service life span corresponding to the control section, the salvage value is negative if the performance-benefit ratio of an interlayer system is greater than 1.0, which reduces the total agency cost of the interlayer system. In the example shown in Figure A.13, all interlayer systems have positive salvage values because their PBRs are greater than 1.0. Total agency cost of an alternative design becomes higher than that of the control section when an additional cost is higher than the salvage value.

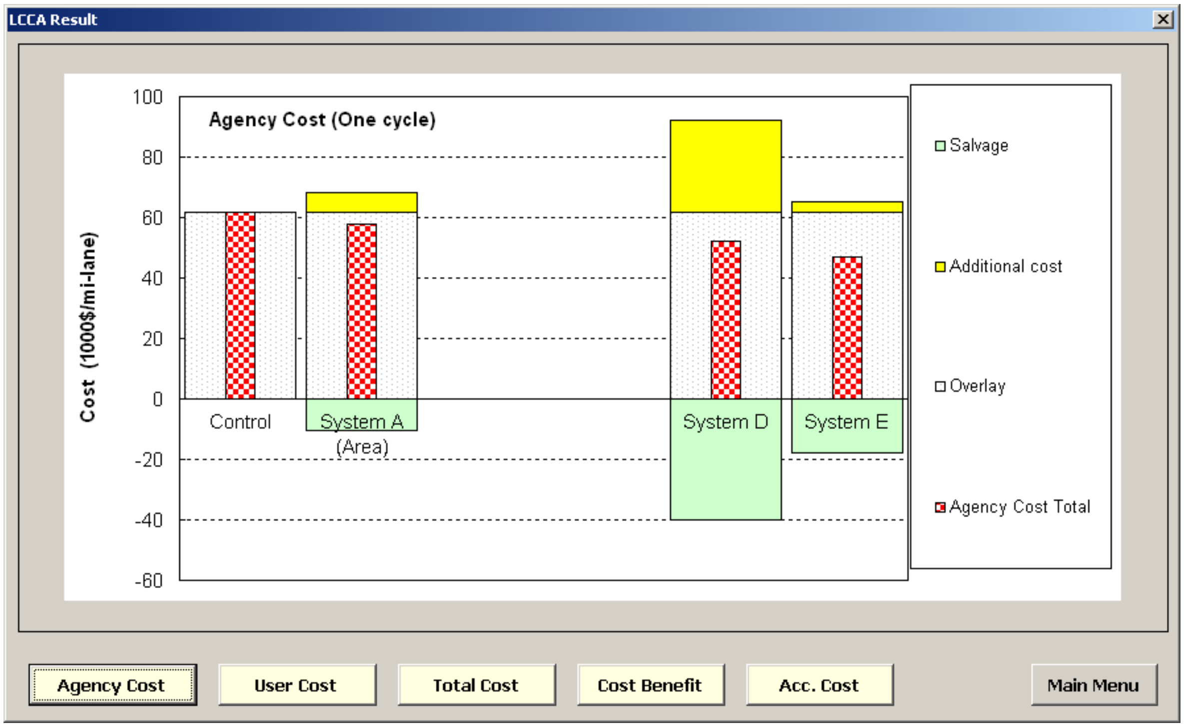


Figure A.13. Agency cost result form

A.2.4.2 User cost

In Figure A.14, user costs of alternatives are compared. The user cost is comprised of the same components of the agency cost: basic user cost to build an HMA overlay, additional cost to install interlayer systems, and a salvage value. The additional cost is required to install an interlayer system before the HMA overlay construction. During the extra time for the installation, additional traffic control in the work zone results in higher user cost. (System E—a mixture-type interlayer system—does not require any additional time to install the interlayer system.)

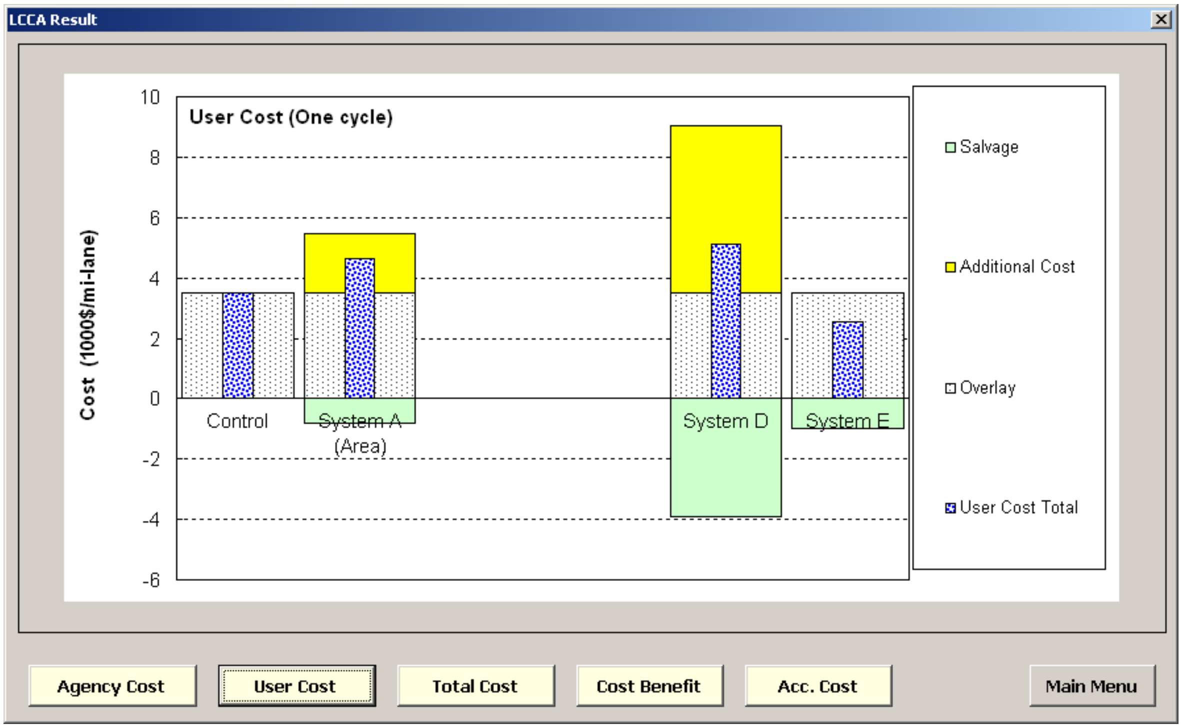


Figure A.14. User cost results form

A.2.4.3 Total cost

Instead of net present value, an equivalent uniform annual cost (EUAC) is computed to compare total cost for the HMA overlay life cycle. The EUACs for the various alternative designs are shown in Figure A.15. The alternative design, whose EUAC is lower than that of the control section, has a positive B/C. In addition, the ratio of the agency cost to user cost implies which of these is more important for the selection of an interlayer system for a given project. Figure A.15 is a good example demonstrating that user cost does not have a major impact on LCCA because of its relatively low contribution compared to the agency cost, regardless of the interlayer systems.

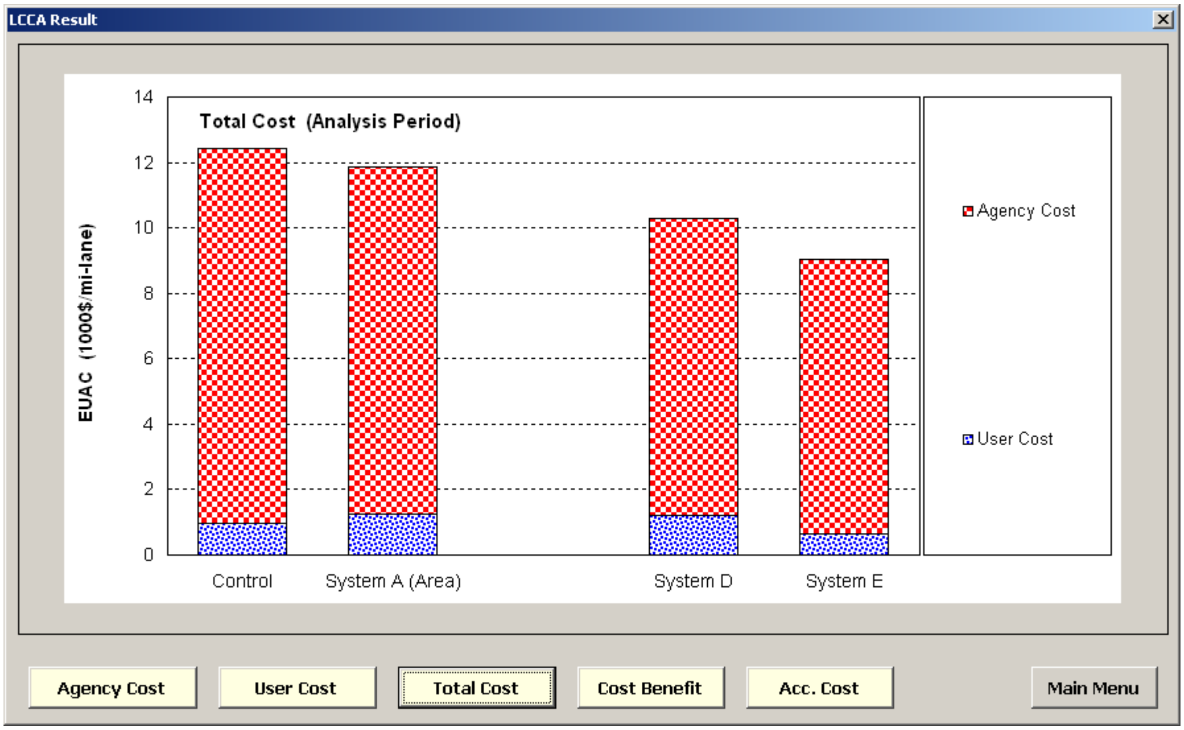


Figure A.15. Total cost results form

A.2.4.4 Cost benefit

Using the EUAC for alternative HMA overlay sections, B/C of the alternatives is calculated and compared to that of the control section. Figure A.16 shows the B/C of the alternatives. System E has the highest B/C among the interlayer systems. The cost benefit result is shown in a pop-up window (see Figure A.17(a) or A.17(b)). Also, the LCCA input and output can be verified in a “Report” worksheet.

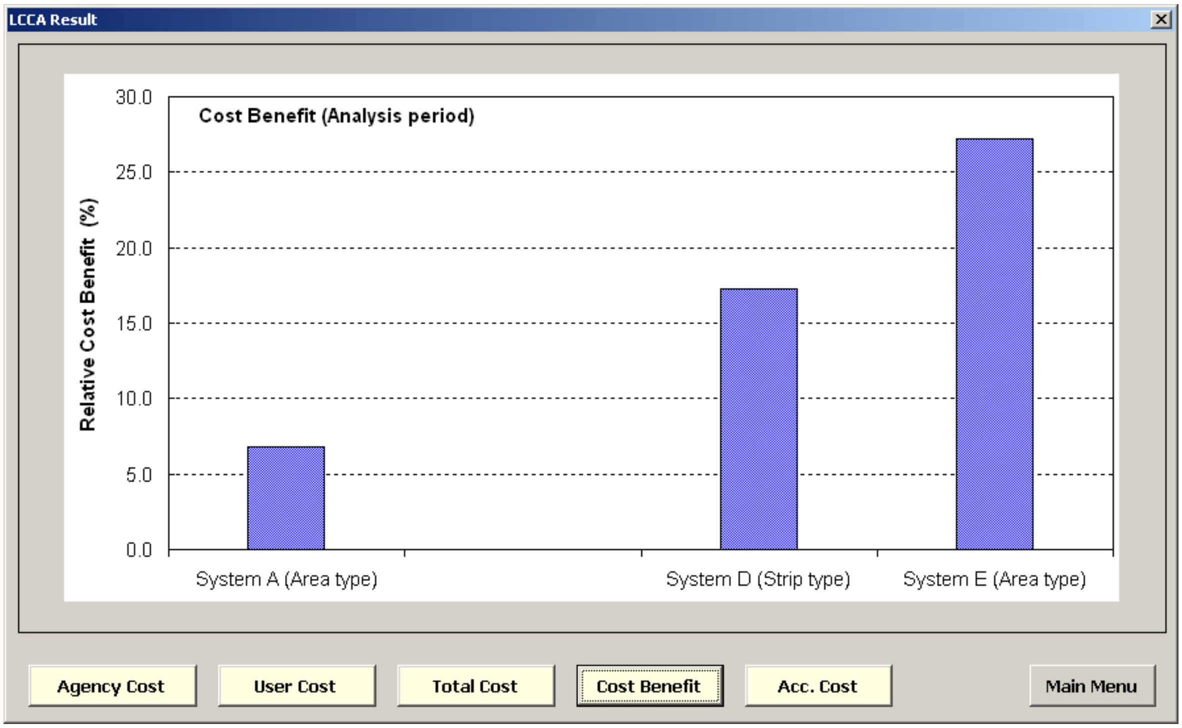
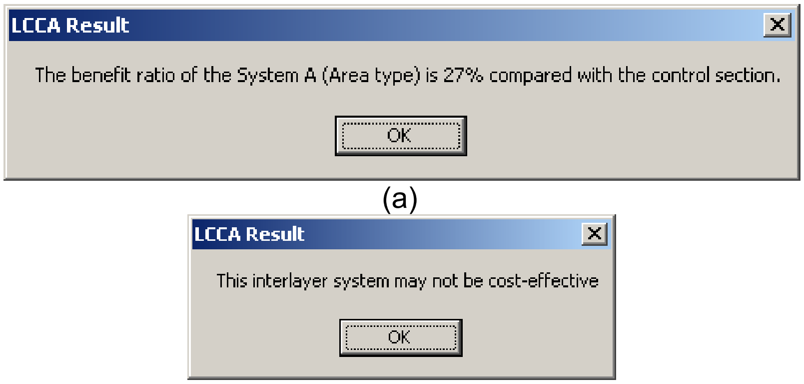


Figure A.16. Cost benefit results form



The benefit ratio of the System A (Area type) is 27% compared with the control section.

(a)

This interlayer system may not be cost-effective

(b)

Figure A.17. Cost benefit result of the alternatives when (a) there is a cost-effective interlayer system and (b) there is no cost-effective system.

A.2.4.5 Accumulated cost

Figure A.18 shows that the total costs for the HMA overlay construction and user delay are accumulated. In this figure, the control section requires six overlays over the analysis period while overlay design with System D requires only three overlays. However, the cost of System D for one-time overlay construction is higher than that of the control section. System E requires a comparable cost each time; but less frequent constructions. Hence, it shows the best cost benefit.

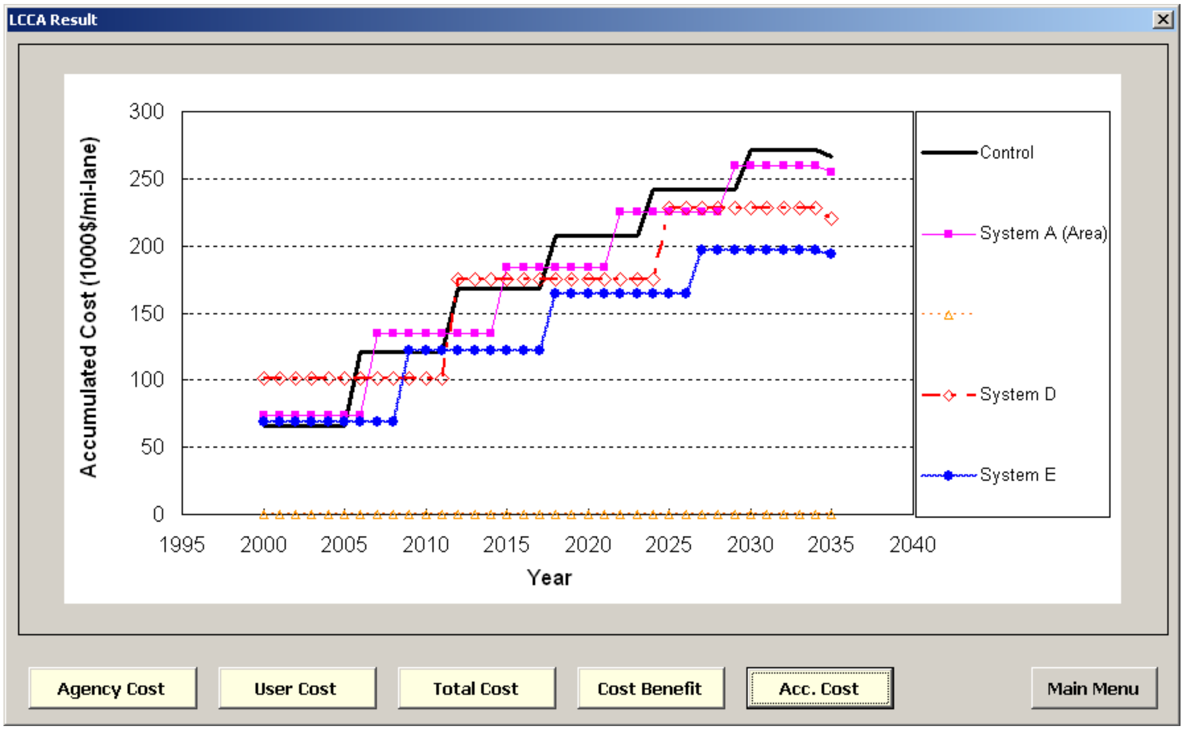


Figure A.18. Accumulated costs form for the analysis period

A.2.5 Report

The last command in the main menu is “Print Report” to print a brief report on the LCCA input and output. As shown in Figure A.19, the report contains all entered data in the design module, charts shown in the LCCA output, NPVs, EUACs, and B/C for the alternative designs.

Life-Cycle Cost Analysis Report on Project #12345

1. Project Information

Project	No.	12345	
Location	District	4	
	County	Country	
	City	City	
	Description	Description	
Geometry	Lane Length	1	mi
	Lane Width	12	ft
	Number of Lanes	1	in each direction
	Joint Spacing	30	ft
Overlay	*Wearing surface*		
	Thickness	1.50	in
	Material Unit Price	40.0	$/ton
	Construction cost	0.0	$/in-lane-mile
	Construction Time	4	hr/in-lane-mile
	Leveling binder		
	Thickness	0.75	in
	Material Unit Price	40.0	$/ton
	Construction cost	0.0	$/in-lane-mile
	Construction Time	4	hr/in-lane-mile

2. Interlayer System Alternatives

Alternative 1	***System A***			Alternative 3	***System D***		
	Type	Area			Type	Strip	
	Manufacturer	Petromat			Manufacturer	ISAC	
	Unit Price	0.45	$/sq.yd		Unit Price	21.51	$/sq.yd
	Width		N/A		Width	3	ft
	Number of Strips		N/A		Number of Strips	352	
	Intallation Price	0	$/lane-mile		Intallation Price	0	$/strip
	Delay Time	5	hr/lane-mile		Delay Time	0.08	hr/strip
Alternative 2	System B			Alternative 4	***System E***		
					Type	Area	
					Manufacturer	IL4.95mm	
					Unit Price	46.2	$/ ton
					Width		N/A
					Number of Strips		N/A
					Intallation Price	0	$/lane-mile
					Delay Time	0	hr/lane-mile

3. Traffic Information

Category	Rural					
	Principal Arterial			Class	2	
Traffic volum	Current Year	2000				
	AADT	5000		ESAL	623	
Vehicle	Passinger Cars	80	%	Growth rate	3	%
	Single-Unit Trucks	10	%			
	Combination Trucks	10	%			
Work zone	Lane Opening	1				
	Upstream Speed	55	mph			
	Work Zone Speed	20	mph			
	Work Zone Length	1	mile			
	Work Zone Duration	All day				

4. Life-Cycle Cost Analysis Input

Parameter	Overlay service life	6	years	Design year	35	years
	Discount rate	3	%			
Benefit ratio	System A	Area	Petromat	1.22		

Figure A.19. Sample brief report

A.3 REFERENCES

1. Federal Highway Administration (1998), Life-Cycle Cost Analysis in Pavement Design, *Report FHWA-SA-98-079*, U.S. Department of Transportation.
2. Federal Highway Administration (2004), Life-Cycle Cost Analysis: RealCost, *User Manual*, Office of Asset Management, FHWA, U.S. Department of Transportation.
3. U.S. Department of Labor (2008), Consumer Price Index. http://www.bls.gov/CPI/ Accessed on May 1, 2008.
4. Al-Qadi, I. L., W. G. Buttlar, J. Baek, and M. Kim (2008), Cost Effectiveness and Performance of Overlay Systems in Illinois – Volume 1: Effectiveness Assessment of HMA Overlay Interlayer System Used to Retard Reflective Cracking, *Report FHWA-ICT-00-000*, Illinois Center for Transportation, Illinois Department of Transportation, Springfield, IL.

APPENDIX B

B.1 Elevation Factors for Each Category

Year	Elevation Factor				
	Traffic	System A	System B	System D	System E
1984	0.660	0.600	0.489	0.489	0.559
1985	0.690	0.627	0.511	0.511	0.585
1986	0.700	0.636	0.519	0.519	0.593
1987	0.720	0.655	0.533	0.533	0.610
1988	0.750	0.682	0.556	0.556	0.636
1989	0.790	0.718	0.585	0.585	0.669
1990	0.830	0.755	0.615	0.615	0.703
1991	0.870	0.791	0.644	0.644	0.737
1992	0.890	0.809	0.659	0.659	0.754
1993	0.920	0.836	0.681	0.681	0.780
1994	0.940	0.855	0.696	0.696	0.797
1995	0.970	0.882	0.719	0.719	0.822
1996	1.000	0.909	0.741	0.741	0.847
1997	1.020	0.927	0.756	0.756	0.864
1998	1.040	0.945	0.770	0.770	0.881
1999	1.060	0.964	0.785	0.785	0.898
2000	**1.100**	**1.000**	0.815	0.815	0.932
2001	1.130	1.027	0.837	0.837	0.958
2002	1.150	1.045	0.852	0.852	0.975
2003	1.180	1.073	0.874	0.874	**1.000**
2004	1.200	1.091	0.889	0.889	1.017
2005	1.240	1.127	0.919	0.919	1.051
2006	1.280	1.164	0.948	0.948	1.085
2007	1.320	1.200	0.978	0.978	1.119
2008	1.350	1.227	**1.000**	**1.000**	1.144

Table B.2 LCCA Result for Area-Type System A

US34		PBR	Construction	Service life (year)		Analysis period (year)		
Mendota		1.26	1997	11		11		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. A (area)	H	33.02	33.37	1.31	7.27	0.16	7.43	-7.04
	M			1.21	6.80	0.16	6.96	-0.32
	L			1.16	6.57	0.16	6.73	3.04
Control				-	6.81	0.13	6.94	0.00
IL40		PBR	Construction	Service life (year)		Analysis period (year)		
Deer Grove		1.63	1998	10		10		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. A (area)	H	33.67	34.02	1.25	6.73	0.19	6.92	10.37
	M			1.17	6.29	0.19	6.48	16.01
	L			1.13	6.08	0.19	6.27	18.75
Control				-	7.53	0.19	7.72	0.00
IL251		PBR	Construction	Service life (year)		Analysis period (year)		
North of US30		1.44	1995	13		13		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. A (area)	H	31.40	31.73	1.20	6.69	0.09	6.78	4.54
	M			1.14	6.33	0.09	6.42	9.56
	L			1.11	6.15	0.09	6.24	12.07
Control				-	7.02	0.09	7.10	0.00

Table B.2 (Continued). LCCA Result for Area-Type System A

IL9		PBR	Construction	Service life (year)		Analysis period (year)		
East of IL41		1.04	1988	20		20		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. A (area)	H	24.28	24.53	1.31	3.32	0.04	3.36	-28.07
	M			1.21	3.07	0.04	3.11	-18.54
	L			1.16	2.95	0.04	2.99	-13.95
Control				-	2.60	0.03	2.63	0.00
IL29		PBR	Construction	Service life (year)		Analysis period (year)		
Chillicothe		0.95	1998	10		8		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. A (area)	H	33.67	34.02	1.27	9.55	1.42	10.97	-34.22
	M			1.19	8.90	1.42	10.32	-26.27
	L			1.14	8.58	1.42	10.00	-22.40
Control				-	7.23	0.95	8.17	0.00
IL29		PBR	Construction	Service life (year)		Analysis period (year)		
Mossville		0.92	1998	10		8		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. A (area)	H	33.67	34.02	1.27	9.78	1.46	11.24	-37.54
	M			1.19	9.12	1.46	10.57	-29.40
	L			1.14	8.79	1.46	10.25	-25.43
Control				-	7.23	0.95	8.17	0.00

Table B.2 (Continued). LCCA Result for Area-Type System A

US136		PBR	Construction	Service life (year)		Analysis period (year)		
East of San Jose		1.39	1999	9		9		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
Sys. A (area)	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
	H	34.32	34.67	1.27	7.88	0.23	8.11	-0.27
	M			1.19	7.34	0.23	7.57	6.40
	L			1.14	7.08	0.23	7.31	9.56
Control				-	7.88	0.21	8.09	0.00
IL148		PBR	Construction	Service life (year)		Analysis period (year)		
Christopher		1.32	1998	10		10		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
Sys. A (area)	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	Sys. A (area)	Cost level	Wearing surface ($/ton)
	H	33.67	34.02	1.27	7.36	0.18	H	33.67
	M			1.19	6.86	0.18	M	1.42
	L			1.14	6.61	0.18	L	4.84
Control				-	7.06	0.34	Control	0.00
IL111		PBR	Construction	Service life (year)		Analysis period (year)		
Pontoon Beach		1	1994	14		14		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
Sys. A (area)	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
	H	30.43	30.75	1.27	6.12	0.88	7.00	-29.14
	M			1.19	5.71	0.88	6.59	-21.55
	L			1.14	5.51	0.88	6.39	-17.87
Control				-	4.81	0.61	5.42	0.00

Table B.3 LCCA Result for System D

IL29		PBR	Construction	Service life (year)		Analysis period (year)		
Creve Coeur		1.68	1997	11		11		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. D (strip)	H	33.02	33.37	1.28	5.71	2.27	7.98	-13.03
	M			1.23	5.48	2.27	7.75	-9.77
	L			1.19	5.25	2.27	7.52	-6.52
Control				-	5.55	1.50	7.05	0.00
Mattis Ave.		PBR	Construction	Service life (year)		Analysis period (year)		
Champaign		2.77	2000	8		8		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. D (strip)	H	35.61	35.98	1.33	8.34	3.20	11.54	26.28
	M			1.28	8.00	3.20	11.19	28.50
	L			1.22	7.65	3.20	10.84	30.73
Control				-	12.62	3.03	15.65	0.00
US136		PBR	Construction	Service life (year)		Analysis period (year)		
East of San Jose		2.40	1999	9		9		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. D (strip)	H	34.32	34.67	1.46	6.38	0.29	6.68	17.45
	M			1.39	6.05	0.29	6.34	21.63
	L			1.31	5.71	0.29	6.00	25.80
Control				-	7.88	0.21	8.09	0.00

* is cost ratio of interlayer system—unit price of HMA overlay with the interlayer system to that without the interlayer system per 100 ft-lane.

Table B.3 (Continued). LCCA Result for System D

IL267		PBR	Construction	Service life (year)	Analysis period (year)			
Greenfield		2.38	1998	10		10		
		Material cost (unit price)		EUAC (1000$/mi-lane)				
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. D (strip)	H	33.67	34.02	1.46	5.88	0.22	6.10	15.42
	M			1.39	5.57	0.22	5.79	19.74
	L			1.31	5.26	0.22	5.48	24.04
Control				-	7.06	0.15	7.21	0.00

Table B.4 LCCA Result for System E

IL76	PBR	Construction	Service life (year)	Analysis period (year)
Belvidere	1.17	2003	5	5

		Material cost (unit price)				EUAC (1000$/mi-lane)		
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. E (area)	H	31.30	30.60	1.19	12.58	0.74	13.32	-3.04
	M			1.10	11.66	0.74	12.40	4.04
	L			1.02	10.75	0.74	11.49	11.11
Control				-	12.08	0.84	12.92	0.00

IL17	PBR	Construction	Service life (year)	Analysis period (year)
Aledo	3.73	2003	5	5

		Material cost (unit price)				EUAC (1000$/mi-lane)		
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. E (area)	H	37.50	41.00	1.18	6.56	0.13	6.69	56.56
	M			1.09	6.06	0.13	6.19	59.78
	L			1.00	5.57	0.13	5.70	63.00
Control				-	15.05	0.35	15.40	0.00

IL117	PBR	Construction	Service life (year)	Analysis period (year)
Benson	1.88	2003	5	5

		Material cost (unit price)				EUAC (1000$/mi-lane)		
	Cost level	Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
Sys. E (area)	H	35.40	33.90	1.18	9.56	0.06	9.62	29.63
	M			1.10	7.71	0.06	7.77	34.62
	L			1.01	7.12	0.06	7.18	39.61
Control				-	13.57	0.10	13.67	0.00

Table B.4 (Continued). LCCA Result for System E

IL130	PBR	Construction	Service life (year)	Analysis period (year)
Philo	1.27	2003	5	5

Sys. E (area)	Cost level	Material cost (unit price)		EUAC (1000$/mi-lane)				
		Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
	H	48.50	49.00	1.17	15.65	0.63	16.28	5.41
	M			1.08	14.53	0.63	15.16	11.93
	L			1.00	13.41	0.00	13.41	22.09
Control				-	16.44	0.77	17.21	0.00

US136	PBR	Construction	Service life (year)	Analysis period (year)
East of San Jose	1.85	1999	9	9

Sys. E (area)	Cost level	Material cost (unit price)		EUAC (1000$/mi-lane)				
		Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
	H	34.32	34.67	1.18	5.97	0.13	6.10	24.56
	M			1.09	5.58	0.13	5.71	29.35
	L			1.01	5.11	0.13	5.24	35.18
Control				-	7.88	0.21	8.09	0.00

US136	PBR	Construction	Service life (year)	Analysis period (year)
West of San Jose	1.28	1998	10	10

Sys. E (area)	Cost level	Material cost (unit price)		EUAC (1000$/mi-lane)				
		Wearing surface ($/ton)	Leveling binder ($/ton)	MCR	Agency	User	Total	B/C (%)
	H	33.67	34.02	1.18	6.1	0.1	6.2	1.7
	M			1.09	5.6	0.1	5.7	8.7
	L			1.01	5.2	0.1	5.3	15.7
Control				-	6.1	0.2	6.3	0.00

Table B.5. Interlayer System Material Cost Corresponding to MCR

Interlayer system	MCR										
	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
System A (area)*	0.00	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.44	5.00	5.55
System D*	0.00	5.55	11.10	16.65	22.20	27.75	33.30	38.85	44.40	49.95	55.51
System E**	44.16	57.32	70.47	83.63	96.79	109.94	123.10	136.26	149.42	162.57	175.73

* Unit: $/yd^2

** Unit: $/ton

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