Asphalt Pavements Chip Sealing Design and Cost Considerations

Minas Guirguis[1], Ashley Buss[2], Ben Claypool[3]
([1] Civil, Construction and Environmental Engineering Dept. Iowa State University, United States, minas@iastate.edu)
([2] Civil, Construction and Environmental Engineering Dept. Iowa State University, United States), abuss@iastate.edu)
([3] Civil, Construction and Environmental Engineering Dept. Iowa State University, United States
benc@iastate.edu

ABSTRACT

People spend most of their lives on roads. With an abundant presence of challenges, such as poor road design and construction practices, pavement preservation solutions should be used to save time and money. Chip seals have recently been advocated for use as a pavement preservation technique. However, proper design and construction measures are vital for performance success, which has been ignored by many contractors and local road agencies. This paper introduces a framework for chip seal design based upon performance measures. This framework would allow agencies to calculate/check the application rates of their chip seal designs. The proposed framework also includes a cost analysis engine that could be utilized to suggest an optimum chip seal design based upon the least life-cycle costs. The approach introduces three modules to determine a chip seal design: the first module is the "Interactive Database," which includes system setup information, owner's preferences, materials alternatives, cost data, traffic considerations and road factors; the second module is the "Building and Assessment Module," which calculates binders and aggregates application rates according to their associated costs; and the third module is the "Optimization Engine," which is used to suggest optimum chip seal design based upon the least life cycle costs, ensuring not only an economic value but the performance of the design quality as well. A friendly prototype is introduced based on the proposed framework. It represents a comprehensive and easy application tool of chip seal designing and cost estimating for local road agencies and owners. A case study of chip seal projects in Oregon has been used to verify and validate the use of the proposed prototype. Results show possible savings that can reach up to 30%, if using the aforementioned framework that ensures the performance integrity of chip sealed pavements.

Keywords— Chip Seals, Asphalt Preservation Techniques, Life Cycle Costs, Pavement Design, Pavement Performance

1. INTRODUCTION

The responsibility of protecting the performance of America's transportation system has always been in the hands of the government, highway agencies, and DOT's. Developments in research and technology have been made to improve the performance of roadways, a vital resource [1]. Developments incudes the improvement of used materials, the implemented technology, data collection, analysis techniques, and human factors [1]. Since the mid-nineties, the utilization of pavement preservation techniques became the norm in most highway agencies [1].

Many agencies associate chip seal treatments as a demonstration of preservation techniques [2–4]. Chip sealing is the application of either emulsified or hot applied asphalt binder followed with the spreading of a one stone thick layer of aggregate placed side by side [5]. Based upon literature and practice, chip seals have proven to be effective in forming a new waterproof surface layer that protects pavement base materials from damage caused by exposure to water and/or freezing and thawing action [4-5]. Chip seals have further proved effective in providing a cost effective method for enhancing the surface texture and skid resistance properties, providing surface sealing, reducing raveling, and addressing bleeding problems of the pavement surface [6-7].

Chip seal construction might seem simple, however the success of the design is very sensitive to a number of impacting factors [8-10]. Many agencies have decided against following the correct design procedures in estimating the appropriate application rates. This leads to poor pavement performance and pre-mature appearance of distress [11]. In the past, most agencies tend to skip the use of rational design procedures by opting to rely on their past experience and engineering judgement, which can fail them in many cases [2-4-9].

Cost estimation and analysis are indispensable tools in any field. Analysis based upon acquisition/initial costs can be deceiving, especially in pavement design analysis. Life-cycle cost analysis is used in this research to estimate expected expenses related to pavement life span. The life-cycle cost approach is not commonly used by local agencies due to its absence in the incorporation of pavement preservation as well as a belief that it is a complex and time consuming procedure [12].

The purpose of this research was to develop an easy to use chip seal design tool that can be used to preserve the serviceable life of roadways based upon rational design methods. Chip seal design includes the materials being used and their application rates in accordance with cost data and economic value. The effectiveness of this tool would be met if it is (1) easy to use, (2) provides a rational design, and (3) provides cost effective options. This tool should assist local agencies on the selection of materials and their associated chip seal properties. The tool also provides room to owner/engineer preferences and experiences. Users of this tool should be aware that the success of the proposed design would be based upon a multitude of interacting factors, including material quality and availability, contractor capabilities, construction practices, and ambient conditions at the time of construction.

2. CHIP SEAL DESIGN

2.1 Evolvement of Chip Seal Design

The first recorded effort at developing a rational design procedure for chip seals was made by Hanson in 1934 [11-13]. Hanson introduced the concept of aggregate’s embedment and average least dimension (ALD). The second developed method was the Kearby method. This method could determine the application rates and types of asphalt and aggregate using a monograph, but it was only meant for one-course surface treatments [5-12]. Nowadays, most DOTs in the United States follow the third method, which is adopted by Asphalt Institute and named after Norman McLeod. The McLeod design method has a failure criteria for chip seals based upon performance properties such as: bleeding, flushing, and aggregate loss distresses [2].

2.2 Asphalt Institute- (McLeod) Design

McLeod has provided the first exact guidelines for chip seal design in his design method, named *“A General Method of Design for Seal Coats and Surface Treatments*,” which is followed in this study. The design has three main components: (1) binder application rate, (2) aggregate application rate and (3) correction factors related to the aggregate properties, road conditions, and traffic volumes [2-13-14].

McLeod binder application rate ensures that there is enough binder to hold the aggregate in place, but not too much binder to fill the voids or cover the aggregate after traffic forces are present[17]. The aggregate application rate is based on the amount of aggregates needed to create an even, single layer on the pavement surface. Eqs (1,2) are used to calculate the binder and aggregates application rates.

$$\text{Binder Application Rate } (\text{l/m}^2) = [\{(0.40 * ALD) \times T \times V\} + S + A + P]/R \quad (1)$$

$$\text{Aggregate Application Rate } (\text{kg/m}^2) = (1 - 0.4V) * ALD * G * E \quad (2)$$

Where ALD is the aggregate's average least dimension, represented in meters; T is the traffic correction factor; V is the percent of voids in the loose aggregate; and S is the surface condition correction factor, represented in l/m^2. A is the percent of aggregate absorption; P is the surface hardness correction factor; R is the percent of binder in the emulsion; G is the specific gravity of the aggregate; and E is the whip off correction factor.

Corrections to the basic application rates address variables such as aggregate properties, traffic volume and road conditions. These values are retrieved from the McLeod design guidelines [2]. Corrections for absorption are based on shape and texture properties of the chip seal aggregates. According to the McLeod design, both rounded and non-uniform aggregates are not preferred for chip seal construction. Rounded chips create larger voids and do not interlock well, which requires additional binder. In addition, a non-uniformly sized aggregate will produce uneven surfaces. Traffic factors are considered by including their embedment effect, which usually reaches 80 percent. Existing pavement conditions also play a role in determining the optimum binder content. Surface hardness corrections are based on traffic volumes and the existing surface hardness of the pavement determined by the ball penetrometer test.

This section has summarized the approach used to develop the proposed tool. Equations and correction factors have been utilized in the prototype to calculate the required application rates for various aggregates and binders.

3. PROPOSED APPROACH

The proposed framework intends on reaching an optimum chip seal design with the least life-cycle cost. This framework consists of three main modules, which represent the body of the process. These modules are as follows: an interactive database, building and assessments, and an optimization engine.

The first module is the interactive database, and it consists of five main components: (1) construction elements, (2) costs, (3) traffic and road conditions, (4) location, and (5) project information. The construction elements database has a list of different binder and aggregate types, as well as their related properties. Examples of such properties are aggregate median size, flakiness, absorption, bulk specific gravity, loose unit weight, voids in loose aggregate, ALD, and percent binder in emulsion. These properties are either retrieved from the suppliers or measured using laboratory testing. The cost database includes cost related data such as initial costs, maintenance costs, and replacement costs. Such costs can be retrieved from the market or stochastically determined using previous project data [12]. Traffic and road condition data consists of information related to traffic factors, existing road conditions, whip off factors, and surface hardness. The location component mainly includes discount rates and weather limitations. Lastly, project information includes information related to the pavement under study, such as project location, available aggregate and binder types at hand, road type, pavement condition, expected traffic volume, lifetime analysis period, and pavement area. Such information is specific to each project under study and is entered by the user/agency.

The second module is the system's building and assessment. This module first builds different design systems from the available construction elements in the database, then assesses the various systems in terms of design and costs. The systems building is fed from the interactive database to produce different combinations of possible design elements. The systems assessment then conducts all design calculations for each design alternative. By retrieving information from the construction database, along with properties and project information, the life-cycle costs are calculated based upon the initial, maintenance, and replacement costs of each system.

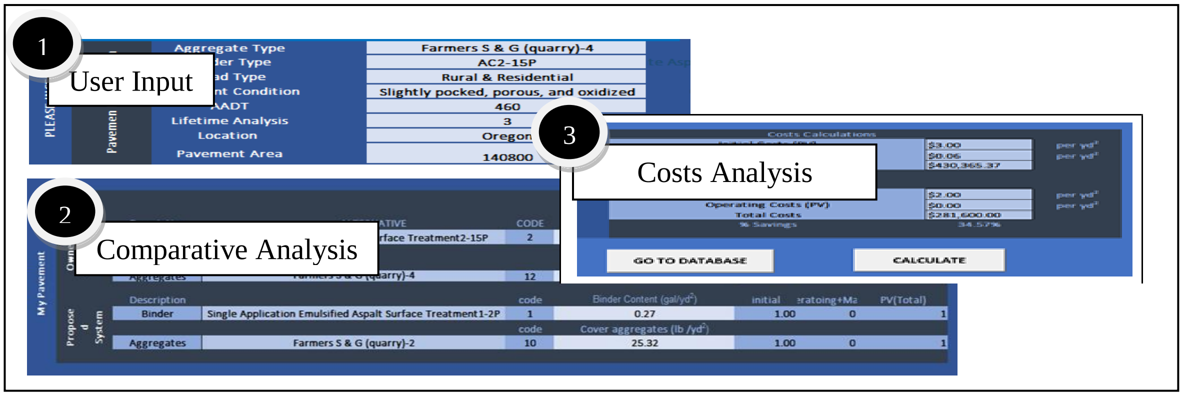
The third and last module is the optimization engine. This engine links the previous modules together in a loop, and it stops when an optimum design of materials and least life-cycle cost is achieved.

4. IMPLEMENTATION OF TOOL/MODEL

A prototype model following the proposed framework was developed. The model was created using MS Excel. The model provides the flexibility to add more construction materials, locations, etc. The prototype includes two interfaces, a user interface and a navigation interface. The user interface has to do with input and output data, and the navigation interface has to do with internal data storage and processing. Throughout the model, there are tabs that move the user through these interfaces, allowing for possible addition or modification of data. For precise analysis results, frequent updating of available materials, costs, and discount rates is necessary.

4.1 User Interface

The user interface is the first window that appears to the user. A table appears with eight sub-divisions requiring entries by the user or local agency. These entries are as follows: preferred aggregate type, preferred binder type, road type, pavement condition, average expected traffic volume, lifetime analysis period, location of project, and pavement area. The user input and output windows are shown in Figure 1. All entries, except for pavement area, are inserted in the form of a drop down list, which allows the user's choices to be linked to the available database. The life time analysis is limited to a twelve year period, as recommended by the literature [12]. The second window that appears to the user presents a comparative analysis between two designs. The first design offers the application rates based upon the user's chosen materials. The second design presents an alternative design that would provide cost savings while maintaining the performance quality of the design. The aggregate application rates are calculated in lb/yd^2, while the binder application rates are calculated in gal/yd^2. The third window that appears to the user is related to the project costs. Life cycle costs are calculated for both designs (the agency selected design and the model suggested design) and actively show the possible savings. It should be known that other windows store and process the user-defined data behind the scenes.



Aggregate Type: Farmers S & G (quarry)-4
AC2-15P
Rural & Residential
Slightly pocked, porous, and oxidized
AADT: 460
Lifetime Analysis: 3
Location: Oregon
Pavement Area: 140800

$3.00 per yd²
$0.06 per yd²
$430,365.37
Operating Costs (PV): $2.00 per yd²
Total Costs: $0.00 per yd²
$281,600.00
% Savings: 34.57%

Description		code	Binder Content (gal/yd²)	initial		PV(Total)
Binder	Single Application Emulsified Aspalt Surface Treatment1-2P	1	0.27	1.00	0	1
		code	Cover aggregates (lb /yd²)			
Aggregates	Farmers S & G (quarry)-2	10	25.32	1.00	0	1

FIGURE 1 User Interface Windows

4.2 Navigation Interface

The interactive database, one of the navigation interfaces, is fed on two levels. The first level is to set up the program, and the second level is to specify the analysis to a single project under investigation. This project is based off the user-defined entries. The interactive database has three main groups feeding its information, as shown in Figure 2. The first group is the list of available materials, including binders and aggregates. The second group is the technical data associated to group 1. The third group is the cost data, including initial, maintenance, and replacement costs.

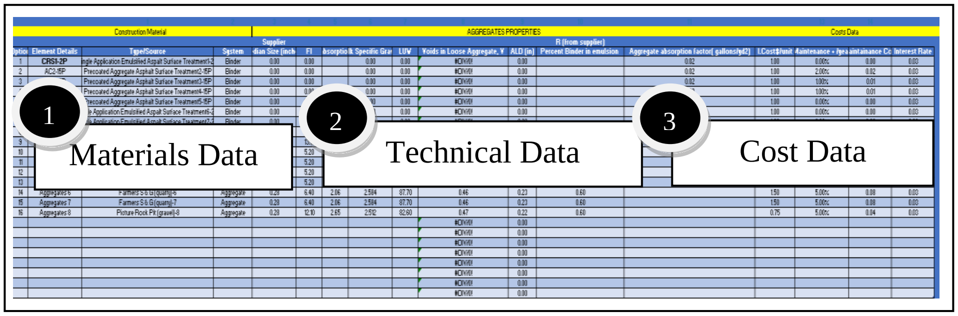


FIGURE 2 Interactive Database

The second navigation interface is the system building, which creates different alternatives for each pavement design. Initial costs, in $/yd^2, includes the material cost, labour cost, and equipment cost. Maintenance and replacement costs are projected as a present value using the location discount rates. These values are added to the initial costs of the pavement system to represent the total life-cycle costs. The costs used in this model are based on Oregon DOT bidding prices prior to the 2017 fiscal year.

The optimum design is formulated as an optimization problem. The analysed variables represent the different materials used in the chip seal design. The model uses genetic algorithms (GAs) through the Evolver package Add-In. The chromosome in this Add-In consists of two genes set as the aggregate and binder type used, and varies from one to up to the number of available alternatives. The objective function is to have the Add-In calculate the optimum system of binder and aggregate that provides a rational design with the lowest LCC.

5. CASE STUDY

A case study of eight chip seal highway projects located in Oregon were used to validate the prototype. Each project had different aggregates, binder types, existing pavement conditions, and traffic volumes. Consequently, they also had different design application rates. The suggested prototype was used after feeding the interactive database with the projects information, available materials at the time of construction, materials properties, costs, discount rates, etc. The actual application rates of the aggregate and binder was based upon the in-house, agency experience and previous practices. Figure 3 shows the difference between the actual application rates and the model-suggested rates for the eight selected projects. From a design perspective, using more/less aggregates causes the pre-mature appearance of distresses. On the other hand, using more/less binder leads to either excess bleeding or bonding problems[5]. This study showed that the average variation of binder and aggregate rates was 20 percent and 30 percent, respectively. After running the model, it was found that the agency could have achieved 15 percent savings if application rates of used materials were adjusted. Savings could easily reach 30 percent if the agency had adopted the suggested model design utilizing the lowest life-cycle costs.

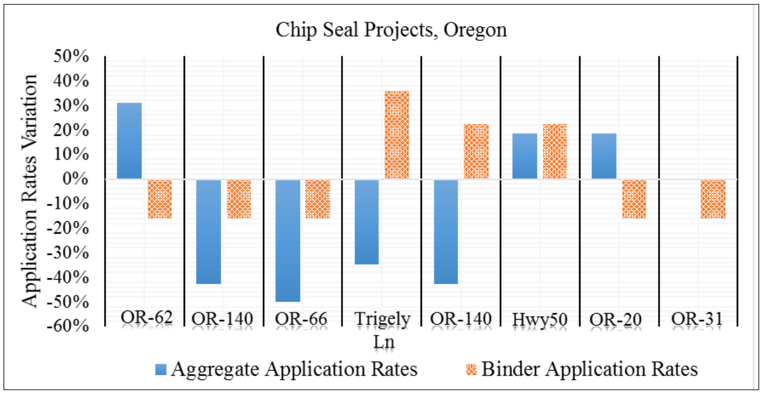


FIGURE 3 Chip Seal Projects: Application Rates Variation (Actual Vs Model)

6. CONCLUSIONS

Local agencies and contractors should reconsider the use of rational chip seal design methodologies rather than relying on trial and error or in-house experiences. This consistent and uniform method can ensure a successful pavement performance. Rational methodologies offer custom designs that can address a multitude of different projects, field conditions, and material properties. A prototype/model was developed according to the McLeod approach and was designed to be generic, flexible, and easy to adopt. This potential support tool for local agencies would allow them to either check or adjust their application rates in a simple time saving manner. Since the model also includes a cost analysis engine, which can be used to suggest optimum application rates and economic value, there is a further benefit of use by the end-user.

A case study of eight chip seal projects in Oregon has been used to verify and validate the use of the proposed prototype. Results show that possible savings reaching 15 percent could be achieved if adjusting the material application rates, and a possible 30 percent savings by the adoption of an alternative design that still ensures quality performance. This prototype could be further adapted to include other pavement preservation methods and assist the decision-making process to be more effective and rational on a project to project basis.

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