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Utilizing Reclaimed Asphalt Pavement in Preservation Treatments

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16. Abstract

The use of reclaimed asphalt pavement (RAP) has economic and environmental impacts. This report investigates the prospective use of RAP in preservation treatments (mainly chip sealing and microsurfacing) in Illinois. A review of the current state of knowledge and practice was conducted. The economic and logistic feasibility of using RAP in preservation treatments in Illinois were investigated. Data were collected on RAP availability in the state followed by a survey distributed to district engineers and highway construction contractors. The survey asked about the availability of RAP, its viability in preservation treatments, and the readiness for its application. A unit price analysis was conducted to assess the financial viability of using RAP compared to virgin aggregate. The results suggested there was an excess of good quality and fractionated RAP, and contractors are open to using RAP in various applications. Considering contract unit prices in Illinois, no significant difference would be expected when RAP is used in place of virgin aggregate. Hence, using RAP in preservation treatments would probably make preservation treatments more viable. Economic and environmental analyses demonstrated that using RAP in preservation treatments would reduce the impact on the environment by reducing energy, global warming potential, and greenhouse gases while providing cost savings. A simple decision tool was developed to provide guidance on using RAP in preservation treatments.

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EXECUTIVE SUMMARY

The use of recycled materials in the highway industry has been on the rise due to a lack of resources and concerns about climate change. In addition, recycled materials could provide economic savings. Because of the abundance of reclaimed asphalt pavement (RAP), there has been a trend to include RAP more often in asphalt construction, including pavement preservation.

This study investigated the use of RAP in preservation treatments (e.g., microsurfacing and chip sealing). The objectives of the study were to assess the feasibility of using RAP in preservation treatments and its prospective impact. The methodology included examining the current state of knowledge and practice as well as the inventory of RAP availability in Illinois. RAP availability by district was collected through contractor and agency engineers. Economic and environmental analyses were conducted to study the feasibility of using RAP in Illinois. A decision tool (i.e., a flowchart) was developed to direct different districts on whether to use RAP or virgin aggregates.

The study showed that there was an abundance of RAP in Illinois, as the stockpiled RAP is four times the annual use. However, good quality RAP does not exist in all districts. Economic and environmental analyses showed that using RAP in preservation treatments would reduce the impact on the environment by reducing energy, global warming potential, and greenhouse gases while potentially providing cost savings.

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CHAPTER 1: INTRODUCTION

BACKGROUND

To improve the sustainability and cost-effectiveness of pavement construction, the asphalt industry has increasingly used reclaimed asphalt pavement (RAP) in flexible pavements. The average RAP content in hot-mix asphalt (HMA) in Illinois was around 23% in 2019 (Williams et al., 2020), and this percentage has been increasing ever since. More than 1 million tons of RAP were used in HMA production in Illinois in 2019 (Morse, 2021). In some regions, the amount of RAP produced is greater than what can be used in HMA. For example, in southern California urban areas, despite the increasing use of RAP in HMA, there is still excess RAP stockpiled (Updyke & Ruh, 2016). Ohio stockpiled the highest amount of RAP in 2018 with 11.2 million tons (Williams et al., 2020).

Hence, RAP has been used in other applications such as aggregate in concrete and pavement preservation treatments (e.g., chip seal, slurry seals, and microsurfacing) (Linek et al., 2023; Duncan et al., 2020; Updyke & Ruh, 2016). In addition, there is a trend of moving toward repeated recycling of asphalt pavement (referred to as R^nAP), which will include new uses of RAP such as preventive maintenance (Zhang et al., 2022; Di Mino et al., 2023). Another reason to increase the use of RAP in preservation treatments is the possible scarcity of virgin aggregates (Updyke & Ruh, 2016).

Preservation treatments are intended to maintain and improve pavement functional condition, driving safety, and extend pavement service life in a cost-effective way (Mamlouk & Zaniewski, 2001). Currently, preservation treatments receive increased attention compared to reconstruction and rehabilitation because of new asset management strategies (Ma et al., 2021; IDOT, 2019b). These treatments may also help preserve the structural capacity of asphalt pavements by sealing cracks and improving the surface condition. However, they are not expected to add structural capacity (FHWA, 1999).

There are many types of preservation treatments. Two of the most common are chip sealing and microsurfacing. Chip sealing is the application of a thin layer of emulsified asphalt binder on the pavement surface, followed by a layer of one-size chips (i.e., coarse aggregate). The chips are seated by a roller to achieve adhesion and sufficient embedment in the emulsion. Microsurfacing is a mixture of polymer-modified asphalt emulsion, fine aggregate, miller filler, and water applied to the pavement surface.

RESEARCH OBJECTIVES AND SCOPE

The objectives of this study were as follows:

1. Review existing literature on the use of RAP in preservation treatments both within the US and abroad.

2. Estimate the financial benefits of using RAP in preservation treatments in Illinois. This step included determining the RAP inventory and distribution across the state.

3. Provide an insight into the feasibility of using RAP in preservation treatments in Illinois. This step includes introducing a producer-specific decision process (i.e., a flowchart) for the use of RAP in preservation treatments in Illinois.

To achieve these objectives, data were collected from various sources, including Illinois Department of Transportation (IDOT) districts for RAP availability and productivity in the state of Illinois. Surveys were sent to both IDOT districts and contractors in Illinois. In addition, a cost analysis of the worst-case scenario for using RAP in preservation treatments was performed to determine its economic feasibility. Finally, a decision tool and conclusions were introduced.

MATERIALS USED FOR MICROSURFACING AND CHIP SEALING IN ILLINOIS

The materials used for microsurfacing and chip sealing in Illinois are described in this section.

Aggregate Type

Chips that are used in chip seals include a wide range of coarse aggregates (e.g., gravel, chert gravel, crushed gravel).

Aggregate Gradation

For chip seal treatments in Illinois, the 2020 IDOT special provisions on bituminous surface treatments (i.e., chip seals) states that aggregates used shall be graded CA 14, CA 15, CA 16, CA 20, FA 1 (Special), FA 4 (Special), or FA 22, with C 20 encouraged (IDOT, 2020b). In this context, open-graded aggregates are uniform in size, meaning most of the particles fall under one or two sizes.

IDOT states that the use of well-graded aggregates is not desirable for the following reasons. Because of less uniform height, tires will not have direct contact with all aggregates, which will result in partial loss of friction. In addition, larger aggregates are prone to being removed by vehicles or during snowplowing. In contrast, the use of smaller aggregates may cause them to be surrounded by oil, resulting in bleeding. Open-graded aggregates are desirable for friction, for better embedment of aggregates, and good drainage of water.

Aggregate Quality

Aggregate quality of class B and higher is used for chip seal according to the IDOT special provisions (IDOT 2020b). The aggregate quality requirements are presented in Table 1.

Aggregate Shape

IDOT recommends using cubical aggregates rather than flat and elongated aggregates, as the former provides a uniform height of the coat and, consequently, a flatter surface. According to West (2015), RAP aggregates milled from the same projects usually have uniform characteristics (e.g., gradation and asphalt content). However, different sized aggregates could still be crushed and fractionated and then batched to produce the required gradation.

Table 1. Coarse Aggregate Quality Requirements (IDOT, 2017)

Quality Test	Class			
	A	B	C	D
Na_2SO_4 soundness 5 cycles, ITP 104, % Loss max	15	15	20	25
Los Angeles Abrasion, ITP 96, % Loss max	40	40	40	45
Minus No. 200 sieve material, ITP 11	1.0	–	2.5	–
Deleterious Materials				
Shale, % max	1.0	2.0	4.0	–
Clay lumps, % max	0.25	0.5	0.5	–
Coal & Lignite, % max	0.25	–	–	–
Soft & unsound fragments, % max	4.0	6.0	8.0	–
Other deleterious, % max	4.0	2.0	2.0	–
Total deleterious, % max	5.0	6.0	10.0	–

*ITP: Illinois Test Procedure

Emulsifying Agents

Currently, IDOT’s BDE special provisions specify that CRS-2P or HFRS-2P shall be used in chip seal.

Asphalt Binder

Asphalt binder—or oil, as referred to sometimes in this context—is an important material in chip seals. The characteristics of the bituminous materials used in the seal can improve the performance of the seal. Some important characteristics include the type of bitumen, setting speed, viscosity, and residue penetration. Bitumen types include cutback asphalts, asphalt emulsions, and road oils.

Cutback asphalt is prepared by dissolving asphalt materials in a solvent made from petroleum. Cutback asphalt is less used currently in chip seals because of environmental and health-related concerns, as these materials evaporate into the atmosphere. Emulsions, which consist of asphalt materials, water, and an emulsifying agent (i.e., a chemical solution), are more commonly used in chip seals today. Performance-graded (PG) binders are not common in chip seals.

Microsurfacing specifications may be found in IDOT’s *Standard Specifications for Road and Bridge Construction* (IDOT, 2022). The main materials requirements are summarized below.

Mineral Filler

The mineral filler used is Type I Portland cement.

Aggregate Quality

Class B quality aggregate is used for microsurfacing (Table 1). This would include RAP from HMA surface courses.

Aggregate Gradation

Rut filling mixes are FA 23, while FA 24 is used for surface mixes. The specification states that aggregates shall be stone sand, wet bottom boiler slag, slag sand, granulated slag sand, steel slag sand, or crushed concrete sand.

Mix Proportioning

Microsurfacing mixes usually have the following proportions/mix designs. Mineral aggregates are added with a dry weight of 15–50 lb/yd^2. Latex emulsified asphalt residue is added at a rate of 7.0%–10.5% by weight of aggregate. A latex base modifier is added as required with a minimum of 3% of the weight of the binder. Mix set additive is added as required. Mineral filler is added at a range of 0.25%–3% of the weight of the aggregate depending on weather conditions.

SMART OVERLAYS

Surface maintenance at the right time (SMART) overlay is a thin overlay used in Illinois. This practice was initiated in 1986 to restore functionality to low-volume roads (Wolters et al., 2008). However, it should be noted that this treatment is no longer limited to low-volume roads. This overlay type is most common in District 1. Thickness is either 1.5 in (applied over composite pavements and stone matrix asphalt (SMA) surfaces) and 2 in (applied over full-depth HMA surfaces). Around 250 lane-miles were treated with SMART overlays in 2009 (Wisdom, 2010).

FHWA (2019) published a tech brief about the use of thin asphalt overlays in preservation treatments. In the tech brief, thin overlays were defined as dense-graded mixtures placed at a thickness of 1.5 in or less. This document mentioned that such mixtures usually have a small nominal maximum aggregate size and are produced and placed using conventional asphalt production and replacement methods. It was mentioned in this TechBrief that RAP can successfully be incorporated into thin asphalt overlay design, but details were not provided.

Gong et al. (2018) studied the field performance of asphalt overlays in the Long-Term Pavement Performance program. The study used data from SPS-5 experimental sections. There were both thin (around 2 in) and thick (around 4.5 in) overlays. The study concluded that using RAP in overlays reduced the potential for rutting, but slightly increased the potential of fatigue cracking, with minimal impact on wheel path and non-wheel-path longitudinal cracking.

REPORT ORGANIZATION

The remainder of the report is organized as follows. Chapter 2 introduces the current state of knowledge. In Chapter 3, the cost-effectiveness and environmental impact of the use of RAP in preservation treatments are analyzed. Chapter 4 demonstrates a decision tool of the cases in which RAP could be used in preservation treatments based on evidence from the literature. Chapter 5 provides a summary and findings of this study.

CHAPTER 2: CURRENT STATE OF KNOWLEDGE

This chapter presents a review of the existing literature. The literature on this topic was divided into two types. The first type was literature that concludes the use of RAP in preservation treatments based on lab studies and other highly specific studies of single parameters. The second type is literature that summarizes the experience of different agencies in using RAP in preservation treatments. Most of the existing peer-reviewed literature falls under the first type. The rest of this chapter details studies that fall under the two types.

ENVIRONMENTAL IMPACTS

The environmental impacts of preventive maintenance have been widely studied by many researchers. For example, Ma et al. (2021) investigated the environmental impact of different pavement maintenance alternatives. Based on a case study of a Chinese highway, they found that microsurfacing and fog sealing result in the lowest greenhouse gas emissions. Wang et al. (2020) compared the environmental impact of thin overlays, chip sealing, and crack sealing by conducting a life cycle assessment for the construction and use stages. They found that thin overlays resulted in the highest reduction in CO_2 emissions, while crack sealing resulted in the lowest reduction in CO_2 emissions. However, the change in environmental impact attributable to using RAP in preservation treatments has not been widely investigated. This preservation technique is relatively new and has not been used at scale, so the full impacts are thus far difficult to determine, especially in terms of life cycle assessment for the use stage.

IMPACT ON AGGREGATE RETENTION

Rahman et al. (2012) conducted a laboratory study on chip seals that compared virgin aggregates and RAP as chips. Seven types of aggregates were used. These aggregates included expanded shale and clay from Colorado, a lightweight aggregate sourced from Oklahoma, and expanded shale from Missouri. Two types of standard-weight aggregates were used: limestone from northeastern Kansas and crushed gravel from western Kansas. The RAP used was obtained from the ultrathin bonded bituminous surface milling of I-70 in Kansas. Two emulsifying agents were used: CRS-1HP and CRS-2P. The ASTM-7000 Sweep Test and the Modified Sweep Test were conducted. Three precoating conditions were used: 0%, 1.5%, and 2%. The study found that RAP aggregates had similar aggregate loss (and aggregate retention) compared to virgin aggregates when emulsion CRS-1HP was used. The study reported that RAP might show good retention because of the residual asphalt, which causes better adhesion of the aggregates (AASHTO, 2020).

IMPACT ON ASPHALT BLEEDING

Asphalt bleeding is a pavement distress that takes place when excess asphalt binder finds its way to the surface of the pavement. This process results in the creation of a thin film of asphalt that is shiny and glass-like. Bleeding may cause issues like loss of friction, especially when the surface is wet (Khosravi et al., 2013). This could be attributed to environmental conditions (e.g., high temperature) and excess binder content. It is possible that RAP may release some binder during its lifetime. As such, this could cause bleeding of the preserved surface if not accounted for during mix design. To the best of the authors' knowledge, the impact of using RAP in preservation treatments has been overlooked in the literature. However, the lack of reporting of such an issue from projects conducted in warmer climates (e.g., Los Angeles and New Mexico) could suggest that this is not a major concern.

IMPACT ON FRICTION

Saghafi et al. (2019) investigated the feasibility of using RAP in slurry seal mixtures. Two mixtures were prepared, one that included aggregates from RAP and another that contained virgin aggregates. The wet track abrasion test and the loaded wheel test were used to evaluate slurry seal performance. The best-performing mixtures underwent cohesion and friction tests (namely, the sand patch and British pendulum tests). Although curing time increased by 1 hour when RAP was used in lieu of virgin aggregates, abrasion decreased by half. Friction tests demonstrated that slurry seal produced with RAP should be slightly rolled to increase friction. It should be noted that the researchers did not conduct any performance testing of RAP aggregate but did characterize its lithology via x-ray fluorescence (XRF).

FINANCIAL IMPLICATIONS

In their lab study, Saghafi et al. (2019) reported a 14% reduction in cost owing to the introduction of RAP aggregates in slurry seals compared to virgin aggregates. Tarefder and Ahmad (2017) estimated the savings from using RAP for three different NMDOT districts (1, 4, and 6) based on survey data using life cycle cost analysis (LCCA). The study reported a cost-effectiveness index ranging from 23% to 37%, depending on the district in which RAP was used.

FIELD EXAMPLES

A literature review indicated a few recent studies have been completed on the use of RAP in chip seal applications. A study by the Federal Highway Administration (FHWA) documented case studies, best practices, and other aspects such as costs of using RAP in preservation treatments (Duncan et al., 2020). The study identified six agencies that used RAP in preservation treatments. These agencies included the Los Angeles County Department of Public Works, the San Bernardino County Department of Public Works, and the New Mexico Department of Transportation (NMDOT).

In one example from this study, San Bernardino County, RAP aggregates were used in chip seal projects with San Bernardino County's most commonly used emulsion type is polymer-modified cationic rapid set emulsion. To minimize chip loss and ensure uniform black color of the pavement surface, a cationic quickset emulsion (CQS-1h) fog seal is applied over the chip seal.

RAP has been used in chip seal projects since at least 2008 beginning in California. However, it has been used less often in microsurfacing projects (Duncan et al., 2020). Examples from various states are described as follows:

- California: Examples include Lake Los Angeles area chip seal (2008) and scrub seal (2013) projects. Both projects reported good performance as of 2016 (Updyke & Ruh, 2016). Also, a microsurfacing project was constructed including RAP aggregates on Soledad Canyon Road in 2010.

- New Mexico: Many chip seal projects were reported to use RAP. RAP chip seals performed the same as virgin aggregate chip seals (AASHTO, 2020). Other advantages related to safety were reported. For example, the darker surface of RAP-aggregate-chipped highways resulted in better contrast with road markings, which may lead to improved road safety. In-house crews also found it easier to work with RAP chips compared to chips from virgin aggregates. This could be attributed to the cohesion between the binder in the RAP aggregates and the added oil rather than the adhesion between the added oil and the virgin aggregates. In addition, virgin aggregates could have more dust on their surface, which adversely affects adhesion.
- Pennsylvania: The Pennsylvania Department of Transportation (PennDOT) developed a method to use RAP aggregates as chips in low-volume roads. A study reported that the development of precoated chips from RAP could produce effective coats that could be used on roads with average daily of traffic less than 1,000. However, to the authors' best knowledge, there has not been any field project reported in which PennDOT used aggregates from RAP in chip seals (Jahangirnejad et al., 2019).
- Ohio: The Ohio Department of Transportation recently sponsored a research project in which mix designs were developed for microsurfacing and chip sealing that included aggregates from RAP (Robbins et al., 2021).

Like what has been reported in the lab on slurry seals, a tech brief on preservation in Arizona, Texas, Utah, and New Mexico mentions some of these states use 100% recycled asphalt pavement in their chip seals (Scofield et al., 2020). The tech brief also summarizes the state of practice in chip sealing, microsurfacing, and slurry sealing.

TRAFFIC LEVEL

Traffic levels experienced by the projects in which RAP was used in preservation vary. For example, Durrani (2021) designed chip seals containing RAP aggregates for low-volume roads. The AASHTO Design Guidelines for Pavement Structures was used to define low-volume roads, which have traffic between 30,000 and 50,000 equivalent single axle loads (AASHTO, 1993). Similarly, Pennsylvania suggested the use of RAP in preservation of low-volume roads.

Although insufficient information was found on traffic levels for all field projects, some supporting data were collected. For example, Caltrans traffic data from the year 2010 reported an annual average daily traffic (AADT) of around 96,000 vehicles on Soledad Canyon Road/Sierra Highway (Caltrans, 2010). The road, which was microsurfaced using aggregates from RAP in 2010, experienced traffic values that were relatively high compared to those mentioned by other states. According to FHWA (2014), highways with an AADT of 50,000 vehicles or more are considered high-volume roads.

IDOT BDE Chapter 53 currently recommends the use of chip seal for roads with traffic volumes less than 10,000 average daily traffic (ADT) while microsurfacing is recommended for any traffic level (IDOT, 2020).

CHAPTER 3: COST-EFFECTIVENESS AND ENVIRONMENTAL ANALYSES

Cost analyses are ideally performed from a life cycle cost perspective. However, an important factor in determining the economic feasibility of using RAP is its impact on roughness progression, which is usually measured by IRI (Sayers, 1998). In turn, IRI affects user cost (e.g., fuel cost as well as tire wear and tear costs). As presented in Chapter 2, there is limited evidence that using RAP in preservation treatments would substantially impact performance. Because of the limited quantitative evidence on performance (especially in an environment like Illinois'), a full-scale LCCA would not be beneficial. User costs do not change if IRI progression is the same between two alternatives, as these are reported to be a function of IRI (Ziyadi et al., 2018; Okte et al., 2019). Alternatively, a cost-effectiveness analysis was conducted. The analysis focused on determining the generic economic feasibility of using RAP and whether IDOT should follow this direction. As such, this analysis could be viewed as a simplified version of LCCA.

Many assumptions need to be made to simplify the analysis to the point where a cost-effectiveness analysis could be used instead of LCCA. These assumptions include, but may not be limited to, the similarity in performance, which not only includes aspects like pavement damage, but also safety (e.g., due to possible loss of friction, loss of aggregate retention, or both).

DATA ON THE USE OF RAP IN PRESERVATION TREATMENTS

Some generic data were found online in published reports. However, to get specific data that would help with the analysis, two surveys were distributed among IDOT districts as well as among contractors within Illinois. Table 2 summarizes some of the data found online related to the use and availability of RAP. The data were used to initially check if the problem is worth further investigation (i.e., if there is excess RAP stockpiled in Illinois), and the data indicated there is excess RAP in Illinois.

Table 2. Data Found Online on the Availability and Use of RAP

Data Item	Value
RAP used in HMA production in 2019	821,233 tons (Morse, 2021)
RAP used in HMA production in 2020	1,113,695 tons (Morse, 2021)
RAP used in HMA production in 2021	886,544 tons (Morse, 2021)
RAP stockpiled in 2018 (nationwide)	110 million tons (Williams et al., 2020)
RAP stockpiled in Illinois in 2018	3.9 million tons (NAPA, 2018)

INVENTORY ANALYSIS

Two surveys were conducted across the state of Illinois through IDOT and the Illinois Asphalt Pavement Association membership. One survey was directed toward IDOT districts (i.e., through district engineers), while the other survey was directed toward contractors and asphalt plants in Illinois. The joint objectives of the two surveys were as follows:

- Determine whether there is abundance of quality RAP that could be used in preservation treatments in each district.
- Determine whether contractors are willing to use RAP in preservation treatments. This objective was linked to the contractors' motivation to use RAP. As most contractors might argue that they use RAP to save costs, asphalt binder replacement (ABR) might not be considered when RAP is used in preservation treatments. Consequently, there is a need to evaluate whether contractors would still be interested in using RAP in preservation treatments even when ABR is not accounted for.
- Estimate the extent of using preservation treatments in Illinois. This step would help determine the amount of aggregate used annually in preservation and how much RAP might be used in preservation.
- Determine whether RAP is processed or fractionated, or both, in different districts. This step would help estimate the difference in cost due to using RAP instead of virgin aggregates in preservation treatments.
- Determine the extent of expertise in using RAP by contractors in Illinois.
- Understand any other RAP-related problems in Illinois as observed by district engineers and contractors in Illinois.

When possible, contractor and district surveys were used to check the information extracted from the other survey. This process was achieved by dividing the contractor results by district and comparing the outcomes of the contractor and district surveys. This step was needed because some survey responses were provided as estimates rather than specific known values. The following section highlights the main outcomes of the two surveys.

SURVEY OUTCOMES

Note that the results of the two surveys were anonymized for the sake of confidentiality unless the results needed to be made explicit. Arbitrary codes were used to refer to the districts (in the range of A–I) and contractors (in the range of 1–9). Codes in different figures do not necessarily refer to the same district and are arbitrarily given (i.e., not consistent between different figures).

District Survey

When asked about RAP stockpiled in the district, six districts provided numerical replies. One district stated that the amount of RAP stockpiled varies by producer, and two districts abstained from answering. The answers are presented in Figure 1.

Figure 1. Bar chart. Estimated RAP stockpiled by district.

District engineers were asked about the number of lane-miles preserved using chip seals in their district. Six responses gave numerical responses, as presented in Figure 2. One district answered with “almost none.”

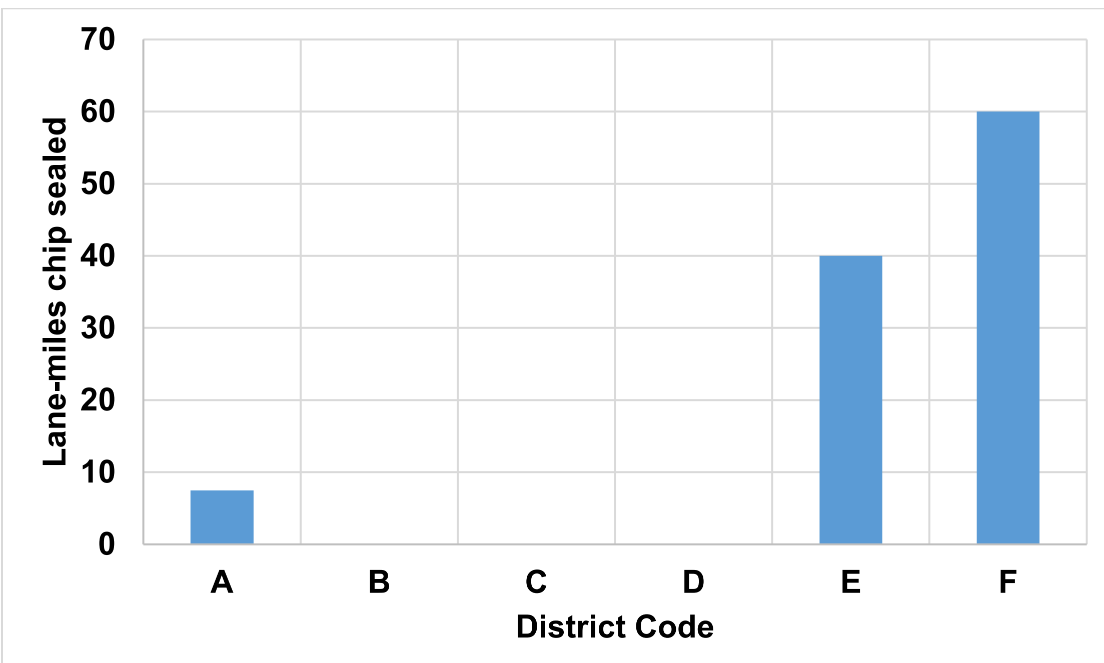

Figure 2. Bar chart. Number of lane-miles chip sealed annually by district.

Seven districts provided numerical answers when asked about the number of lane-miles microsurfaced annually (presented in Figure 3). The responses ranged between 0 and 50 lane-miles. Responses from the three remaining districts were as follows. One district reported that the number of lane-miles microsurfaced annually varies but that the district avoids it reportedly because of a bad experience. Another district responded that “some centerline repair was applied at the state level and higher at the local level,” which leads to an important point: district engineers may have reported different values depending on whether they reported for local roads or for state roads. The last district reported that they were unsure. As it is difficult to tell what their intention was or even whether they would be able to report the exact number if asked, only the order of magnitude is important.

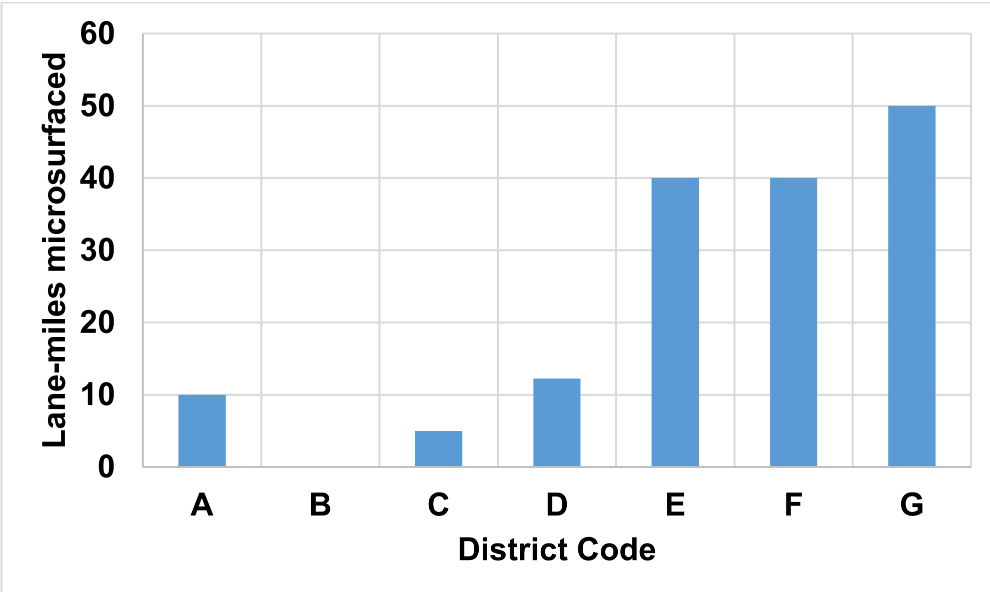

Figure 3. Bar chart. Lane-miles microsurfaced annually by district.

Although this study focused on chip sealing and microsurfacing, the survey included a question about the lane-miles of roads annually slurry sealed in Illinois. Four respondents provided zero as their answer. Only one district reported that around 50 lane-miles were slurry sealed annually. Other answers were not numerical or were not clear.

In some of the districts where preservation is popular, around 100 lane-miles are preserved annually. While these numbers may not be accurate, a quick check of the order of magnitude proved them to be generally appropriate. For example, District 6 in NMDOT reported using chip seal, which is the main preservation technique there, in 200 lane-miles annually out of the 3,100 lane-mile network they manage (AASHTO, n.d.).

When asked about whether RAP was fractionated in the district, none of those districts responded negatively to the question (out of eight responses). When asked whether RAP was processed before reuse, all nine districts answered “yes.”

When asked about the availability of excess good quality RAP, five of the seven districts that responded answered with “yes,” while the remaining two districts answered “no.” Extra comments included how long some RAP was stockpiled, with districts reporting some RAP was stockpiled for 10 or even 20 years.

Contractor Survey

Nine contractors responded to the contractor survey. An important question was about whether RAP was accepted and recycled in different forms (i.e., as HMA/warm-mix asphalt [WMA], as a base, or as a warm mix, or for any other use). Contractor coded 1 did not report an amount when asked about recycled HMA/WMA. The average recycled RAP accepted in 2022 by contractors was around 111,000 tons of RAP (see Figure 4). The average RAP recycled as HMA/WMA was around 84,000 tons. The average RAP amount recycled as a base was around 10,000 tons. No contractor reported recycling any amount of RAP as a warm mix. One contractor reported recycling 25,000 tons of RAP under "other uses." Five contractors reported the amount of RAP accepted and used under all items, and, thus, their excess RAP was calculated. The average excess RAP was around 42,000 tons. To cross-check this number, the average amount of RAP stockpiled in 2021 was around 54,000 tons, which is close to the number calculated previously.

When asked about landfilling, only one contractor reported landfilling 2,500 tons of RAP. The remaining eight contractors reported landfilling zero tons. This finding verifies that significant stockpiles could be 10 to 20 years old, because old RAP tends not to be landfilled.

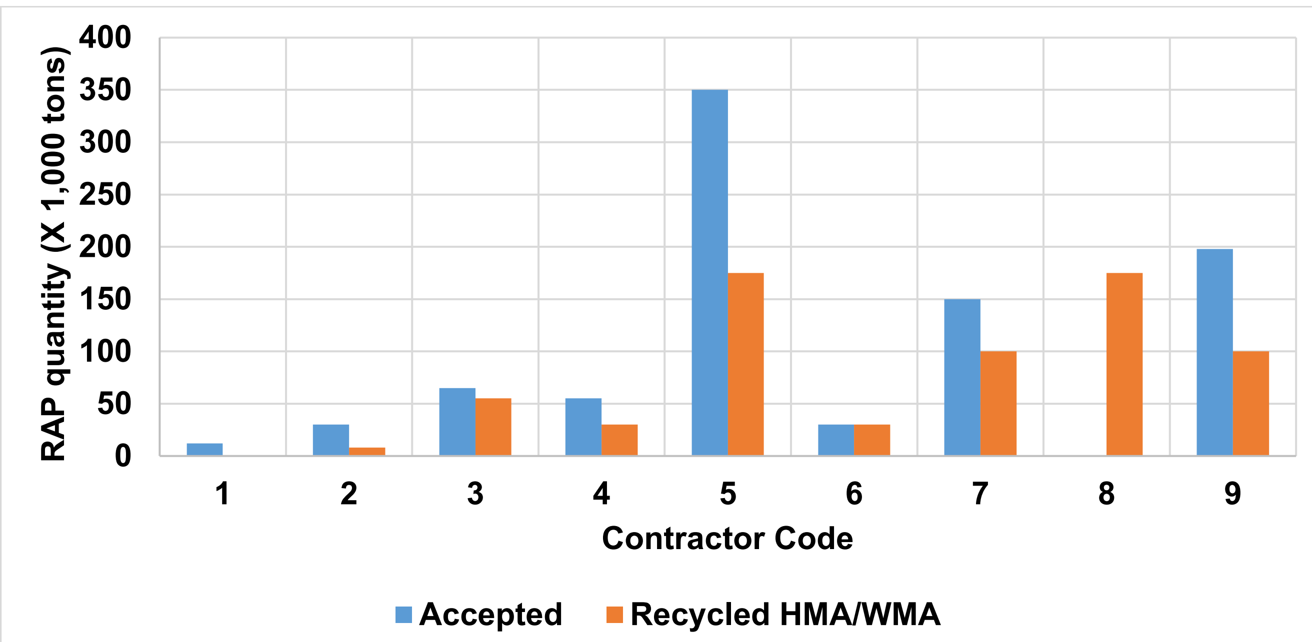

Figure 4. Chart. RAP accepted and recycled by the contractor.

When asked to mark their motivations for using RAP, contractors marked cost reduction as their main motivation (9/9). Other highly ranked motivations included environmental sustainability (8/9) and material availability (5/9). Cost savings are a major motivation in HMA because RAP contains binder that could replace binder needed in the mix. Such savings justified the usually slightly higher RAP prices. In 2023, one ton of binder costs around $600, while a ton of aggregates costs around $15–$20, indicating the importance of using RAP. Material availability is also an important point as sometimes it can be difficult to obtain virgin aggregates at specific locations or specific times. Contractors were asked if they would consider using RAP in preservation treatments even if asphalt binder replacement is not accounted for. Only two out of seven contractors answered with no. Two out of nine contractors abstained from answering.

Contractors were asked to add any other comments regarding actions or concerns related to RAP. Some responses recommended using more RAP.

SURVEY CONCLUSIONS

The following conclusions were drawn from the surveys.

- Contractors are willing to use more RAP. This finding was evident by many questions, such as the question that was directly asked about this matter, or by other questions and comments made by contractors who showed a tendency toward using more RAP in different applications.
- Contractors would use RAP in preservation treatments. Only two out of seven contractors were not willing to use RAP in preservation treatments if it did not count as a replacement for asphalt binder.
- RAP availability does not seem to be an issue, as only two out of seven districts reported not having quality RAP to be reused in HMA construction.
- RAP is seldom landfilled, and contractors usually stockpile it waiting for suitable use.
- RAP is fractionated and processed in most cases, which means additional cost would not be incurred when using RAP in place of virgin aggregates.

Both contractors and districts are interested in using RAP in preservation treatments. However, technical expertise is needed, including labor experience and ease of equipment cleaning. These factors are detailed in the next section (cost-effectiveness analysis).

COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness is a method used to compare two alternatives. The formula is presented in Figure 5.

$$CE = \frac{Cost\ of\ Project\ Alternative\ B - Cost\ of\ Project\ Alternative\ A}{Benefits\ of\ Project\ Alternative\ B - Benefits\ of\ Project\ Alternative\ A}$$

Figure 5. Equation. Cost-effectiveness formula.

where *CE* is cost-effectiveness, which is unitless. *Alternative B* refers to the case where RAP is used in preservation treatments, whereas *Alternative A* refers to the case where virgin aggregates are used.

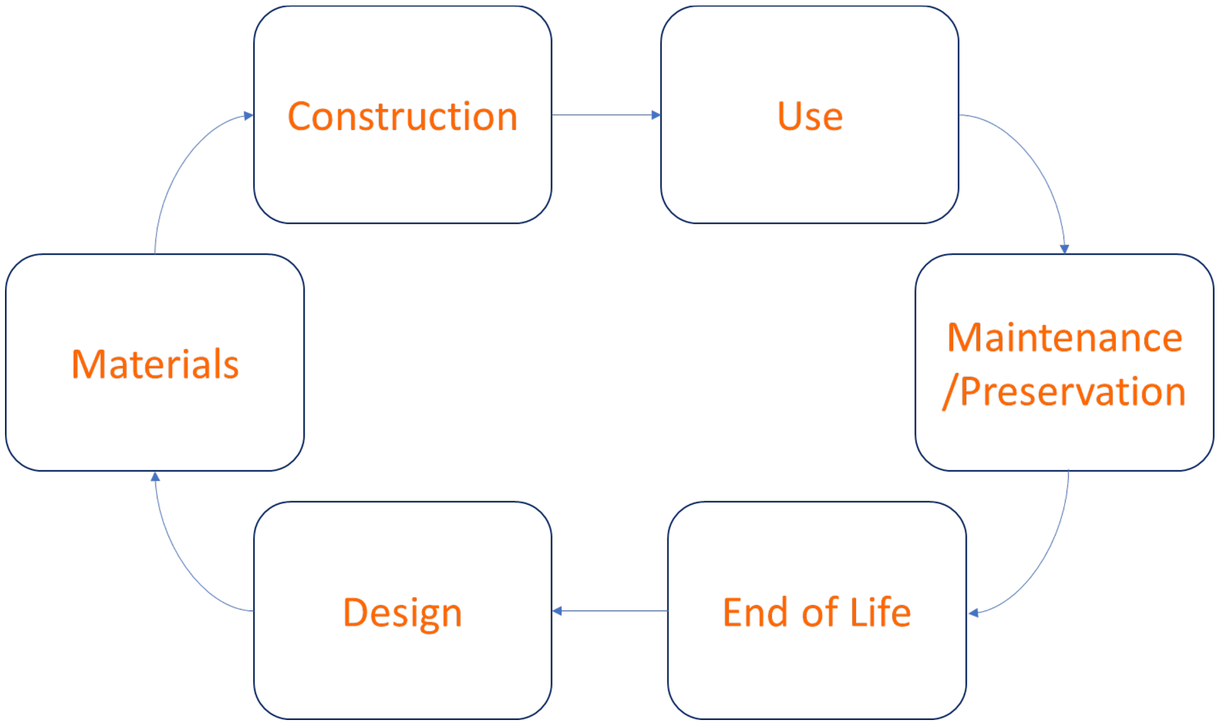

Figure 6. Chart. Pavement life cycle stages (adapted from Harvey et al., 2016).

The functional unit for which the analysis was conducted was a square yard of treatment, as this is conventionally the unit for which prices are reported in bids.

COST ITEMS

To price a bid for a preservation job, the following items contribute to the cost:

- Materials (including aggregates, emulsion, and additives)
- Labor (including surface preparation, material laying, and equipment cleaning)
- Overhead and profit margin
- Mobilization (i.e., transportation)
- Landfilling

Because this analysis method is comparative, more focus is placed on items that differ between one alternative and the other. Generic assumptions are made regarding the remaining items. The item that differed between the two processes was materials (specifically aggregates). Emulsions and additives may differ based on the specific case. Overhead and profit margin are held constant. Other cost effectiveness may arise from cost savings resulting from less RAP disposal.

UNIT PRICE ANALYSIS

As pricing a whole contract is complicated because of the lack of accurate information about many items that contribute toward the unit price (e.g., labor rates, equipment rental/owning costs, profit margin and overhead), unit prices reported in bid lettings in the state of Illinois were utilized. Material costs are more available and less uncertain than other items. As such, bid lettings were used to identify the cost of all items that do not fall under materials.

Bid letting unit prices are reported online and were aggregated to find the average unit price of 1 yd^2 of microsurfacing (the unit used to report microsurfacing prices) and one ton of chip seal (the unit used to report chip seal prices). The distributions are presented in Figure 7 and Figure 8. These prices were for contracts dating back to 2018–2021. Figure 7 presents the unit price distribution of one-pass microsurfacing. The average price was $2.99/$yd^2$. This value checks well with data from other sources. For example, a website for Ergon Asphalt and Emulsions, Inc. reports the average unit price of microsurfacing is $2.75/$yd^2$ (Ergon Asphalt and Emulsions, 2023). Also, Caltrans contract cost data report similar values. The average adjusted per ton price of 65 bids reported in 2022 and 2023 was $417.66. Assuming a weight of 16lb/yd^2, microsurfacing would be around $3.34/$yd^2$ (Caltrans, 2023).

Figure 8 presents the unit price distribution of one ton of seal coat. Note that the horizontal axes (i.e., contract code) in both figures are not related, as these codes are arbitrary. The average price of the 69 reported contracts was $79.33.

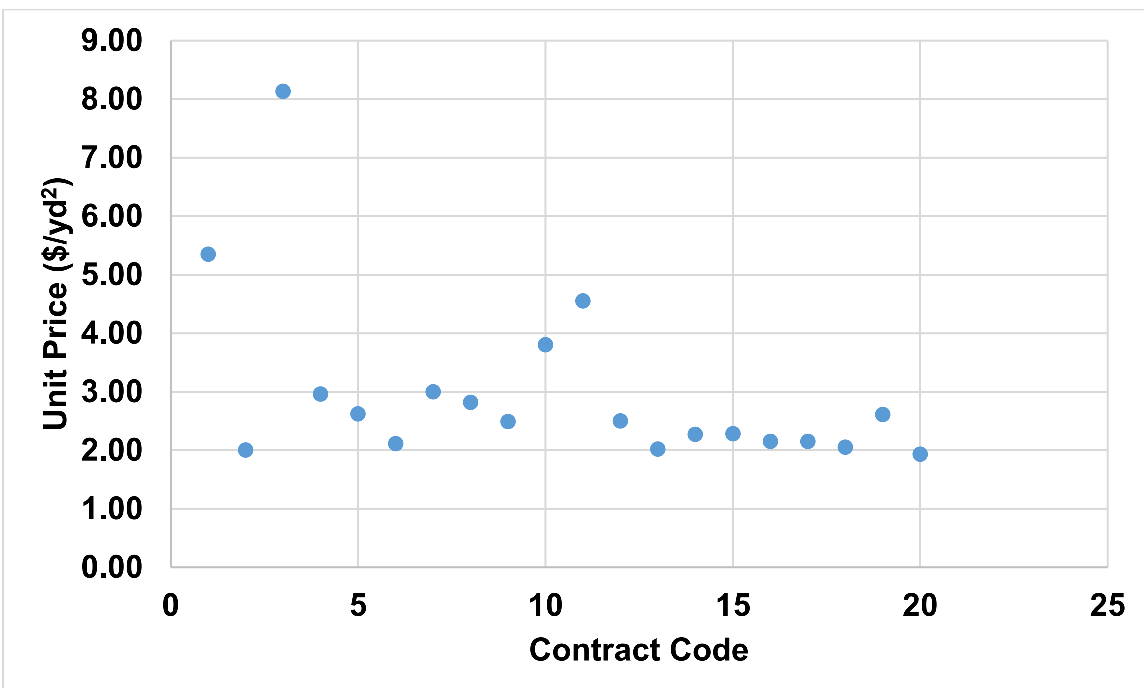

Figure 7. Chart. Distribution of microsurfacing contract unit price.

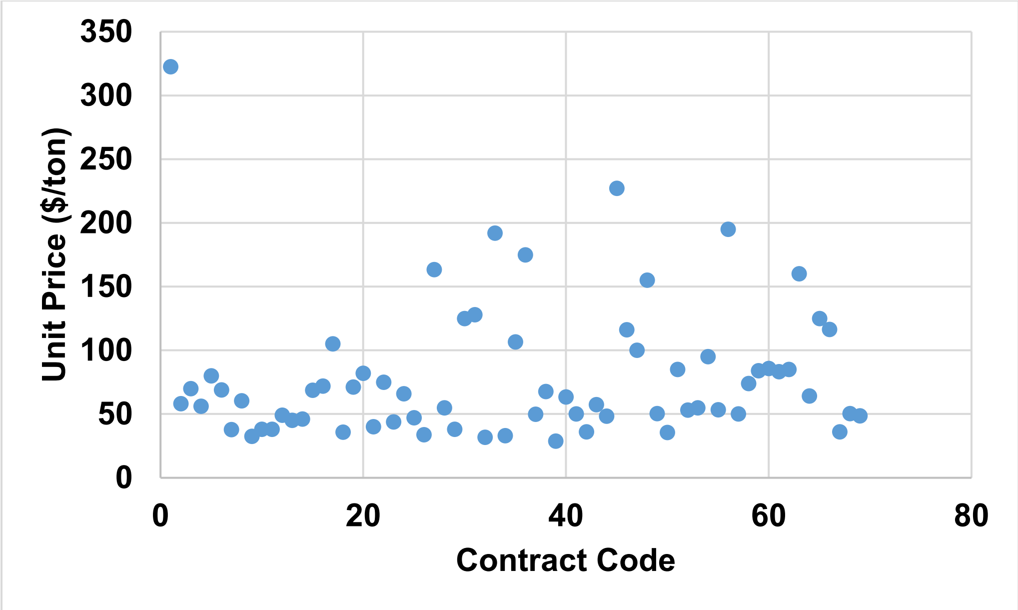

Figure 8.Chart. Distribution of chip seal contract unit price.

Materials

The rate of material application in microsurfacing is around 14–16 lb/yd^2. To analyze the cost of this amount of material, the composition of this material applied to 1 yd^2 must be determined. As such, a generic mix design could be referenced. However, it should be noted that quality assurance (QA) is a major concern in terms of verifying a contractor's RAP mix design for microsurfacing mixes. Future research must include developing a reliable QA procedure for microsurfacing mixes.

The price of one ton of virgin aggregates is around $16. The average price of one ton of RAP is somewhat higher (around $20). This is because RAP includes asphalt binder, albeit worse quality than virgin asphalt binder, which costs around $600 per ton.

Labor

There is no strong evidence of effects on labor when using RAP instead of virgin aggregates in preservation treatments. However, some states pointed out the following differences:

- Equipment cleaning becomes harder when RAP is used because binder sticks to tools and trucks.
- Some workers reported increased productivity and easier mixing of RAP and emulsion in microsurfacing because of the cohesion between binder and emulsion and because RAP aggregates have less dust, which causes the emulsion to stick better to the surface of the aggregates.

Because of the lack of evidence (especially quantitative) and because there are two contradicting effects, the effect on labor and cleaning cost could be reasonably neglected for the purpose of the analysis in this report.

Mobilization

One problem worth considering is aggregate hauling (Tarefder & Ahmad, 2017). Mobilization is the cost incurred by contractors when moving materials or equipment from one site to another. Whether this cost is higher or lower when RAP is used depends on the availability of both virgin aggregates and RAP. The average aggregate hauling distance is believed to be in the vicinity of 50 miles (CalCIMA, n.d.). The unit cost to haul one ton of aggregates for one mile is around $0.20 based on data from the industry.

Overhead and Profit Margin

These factors are believed not to be impacted by whether virgin aggregates or aggregates from RAP are used in construction.

Landfilling

Although minimum landfilling is done in Illinois, the cost of landfilling could be considered in the analysis. This is because RAP cannot be stockpiled forever and in the long run, there must be RAP landfilling when excessive amounts are stockpiled. As such, that cost must be discounted to reflect the fact that contractors would not have to worry about it soon, but the avoided landfilling cost would still be part of the cost savings. Horvath (2003) reported that using one ton of RAP could save upward of $40 of landfilling cost, excluding hauling and other costs. To reflect the conservative nature of the analysis, this cost was neglected.

Obtaining accurate data for most non-material-related items was not straightforward and would need a dedicated database. As such, average unit prices were used to determine how sensitive bid prices would be to material costs. Conservative assumptions were made to provide an upper bound on prices when using RAP and a lower bound on prices when using virgin aggregates.

Average conditions were used (mainly average hauling distance) accompanied with average bid prices to determine average non-material-related cost. As these costs are believed not to be dependent on difference in material cost, they were held constant. As such, bid price of different materials and different hauling distances was estimated. The contribution of non-material-related items to the cost could be calculated using Figure 9.

$$NMR = BP - \sum MR$$

Figure 9. Equation. Non-material-related cost formula.

where, NMR is non-material-related unit cost in dollars per unit, BP is bid price in dollars per unit, and MR is material-related unit cost in dollars per unit.

For the cost of microsurfacing, the equation may be applied as presented in Figure 10.

$$NMR = 2.99 - \left(0.2 * 50 * \frac{33}{2{,}000} + 33 * 0.5 * \frac{16}{2{,}000} + 33 * 0.5 * \frac{20}{2{,}000} + 0.08 * \frac{33}{2{,}000} * 600\right) = \$1.74$$

Figure 10. Equation. Non-material-related cost applied to microsurfacing.

The first term inside the brackets constitutes hauling cost of the aggregates needed for 1 yd^2. The specifications show that the amount that is needed of those aggregates per square yard is around 33 lb (IDOT, 2022). As such, the second and third terms refer to the cost of 16.5 lb of virgin aggregates (price at around $16/ton) and 16.5 lb of steel slag (priced at around $20/ton). The last term represents the emulsion cost. It was assumed that the cost of emulsion is $600/ton. The rate of application was assumed to be 8% by weight of aggregates (last term).

Regarding the proportioning of the mix, if RAP was used, Poursoltani and Hesami (2020) conducted a lab study on using RAP in microsurfacing. In their experiment, the RAP-containing mix used 1% more emulsion than the microsurfacing mix using virgin aggregate. However, they stated that fewer additives were needed for workability and, thus, the overall situation could be saving cost. As such, this factor was overlooked as the approach would still be conservative. NMDOT's District 6 concluded from their experience with chip seals that application rates of aggregate and emulsion did not need to be adjusted (AASHTO, 2020). The percentage of material cost to total bid price was around 40%, indicating that total bid price might not be too sensitive to slight changes in material prices. This value could be used as a constant baseline to be added to material cost from different conditions.

Cost is sensitive to hauling distance. Although material cost may not be a large portion of the total cost, material-related cost could become significant if aggregates must be hauled a long distance. As such, a simple sensitivity analysis was performed. The hauling distance range was between 10 and 100 mi.

Two scenarios were calculated when using RAP: pessimistic and optimistic. In the pessimistic scenario, these assumptions were made: the emulsion needed in the case of RAP would be $100/ton more expensive (i.e., priced at around $700/ton) and the cost of one ton of RAP would be around $20/ton.

The optimistic scenario assumed the same cost of emulsion when using RAP and when using virgin aggregates (i.e., $600/ton). The cost of RAP was marginal (assuming contractors own RAP and that it could cost them as low as $5/ton of handling cost).

Two values were compared against each other in each scenario: The total cost corresponding to 50-mile hauling (typical hauling distance when virgin aggregates are used) vs. the cost corresponding to a 20-mile hauling (believed to be typical hauling distance when RAP aggregates are used) (CalCIMA, n.d.).

The pessimistic scenario showed a 2% increase in cost ($3.06/ton compared to $2.99/ton—Table 4 and Table 3, respectively). The optimistic scenario resulted in a 10% reduction in cost ($2.68/ton compared to $2.99/ton—Table 5 and Table 3, respectively).

Table 3. Unit Price Analysis of Microsurfacing Using Virgin Aggregates

Hauling Cost			Aggregate Cost ($)	Emulsion Cost ($)	Other Costs ($)	Total Cost ($)
Distance (mi)	Unit Cost ($/ton.mi)	Total Cost ($)				
100	0.2	0.33	0.30	0.79	1.74	3.16
90	0.2	0.30	0.30	0.79	1.74	3.13
80	0.2	0.26	0.30	0.79	1.74	3.10
70	0.2	0.23	0.30	0.79	1.74	3.06
60	0.2	0.20	0.30	0.79	1.74	3.03
50	0.2	0.17	0.30	0.79	1.74	2.99
40	0.2	0.13	0.30	0.79	1.74	2.97
30	0.2	0.10	0.30	0.79	1.74	2.93
20	0.2	0.07	0.30	0.79	1.74	2.90
10	0.2	0.03	0.30	0.79	1.74	2.87

Table 4. Unit Price Analysis of Microsurfacing Using RAP—Pessimistic Scenario

Mobilization Cost			Aggregates	Emulsion	Other Costs	Total Cost
Distance (mi)	Unit Cost ($/ton.mi)	Total Cost ($)				
100	0.2	0.33	0.33	0.92	1.74	3.33
90	0.2	0.30	0.33	0.92	1.74	3.30
80	0.2	0.26	0.33	0.92	1.74	3.26
70	0.2	0.23	0.33	0.92	1.74	3.23
60	0.2	0.20	0.33	0.92	1.74	3.20
50	0.2	0.17	0.33	0.92	1.74	3.16
40	0.2	0.13	0.33	0.92	1.74	3.13
30	0.2	0.10	0.33	0.92	1.74	3.10
20	0.2	0.07	0.33	0.92	1.74	3.06
10	0.2	0.03	0.33	0.92	1.74	3.03

Table 5. Unit Price Analysis of Microsurfacing Using Virgin Aggregates—Optimistic Scenario

Hauling Cost			Aggregate Cost ($)	Emulsion Cost ($)	Other Costs ($)	Total Cost ($)
Distance (mi)	Unit Cost ($/ton.mi)	Total Cost ($)				
100	0.2	0.33	0.08	0.79	1.74	2.95
90	0.2	0.30	0.08	0.79	1.74	2.92
80	0.2	0.26	0.08	0.79	1.74	2.88
70	0.2	0.23	0.08	0.79	1.74	2.85
60	0.2	0.20	0.08	0.79	1.74	2.82
50	0.2	0.17	0.08	0.79	1.74	2.78
40	0.2	0.13	0.08	0.79	1.74	2.75
30	0.2	0.10	0.08	0.79	1.74	2.72
20	0.2	0.07	0.08	0.79	1.74	2.68
10	0.2	0.03	0.08	0.79	1.74	2.65

Similar calculations were conducted for chip seal. Table 6 presents cost analysis when virgin aggregates are used; Table 7 and Table 8 show the cost analysis for bad and good scenarios, respectively, when RAP is used. The application rate of aggregates was assumed to be 30 lb/yd^2. Emulsion rate of application was assumed to be 0.425 gal/yd^2, with the assumption that 240 gal of emulsion are in one ton. Other assumptions were made the same as in the case of microsurfacing. A 4% increase ($4.35/ton compared to $4.20/ton) and a 6% ($3.95/ton compared to $4.20/ton) decrease were noticed in cost in the bad and good scenarios, respectively.

Table 6. Unit Price Analysis of Chip Seal Using Virgin Aggregates

Mobilization Cost			Aggregates	Emulsion	Other Costs	Total Cost ($)
Distance (mi)	Unit Cost ($/ton.mi)	Total Cost ($)				
100	0.2	0.3	0.24	1.06	2.75	4.35
90	0.2	0.27	0.24	1.06	2.75	4.32
80	0.2	0.24	0.24	1.06	2.75	4.29
70	0.2	0.21	0.24	1.06	2.75	4.26
60	0.2	0.18	0.24	1.06	2.75	4.23
50	0.2	0.15	0.24	1.06	2.75	4.2
40	0.2	0.12	0.24	1.06	2.75	4.17
30	0.2	0.09	0.24	1.06	2.75	4.14
20	0.2	0.06	0.24	1.06	2.75	4.11
10	0.2	0.03	0.24	1.06	2.75	4.08

Table 7. Unit Price Analysis of Chip Seal Using RAP—Pessimistic Scenario

Mobilization Cost			Aggregates	Emulsion	Other Costs	Total Cost ($)
Distance (mi)	Unit Cost ($/ton.mi)	Total Cost ($)				
100	0.2	0.3	0.3	1.239583	2.75	4.59
90	0.2	0.27	0.3	1.239583	2.75	4.56
80	0.2	0.24	0.3	1.239583	2.75	4.53
70	0.2	0.21	0.3	1.239583	2.75	4.50
60	0.2	0.18	0.3	1.239583	2.75	4.47
50	0.2	0.15	0.3	1.239583	2.75	4.44
40	0.2	0.12	0.3	1.239583	2.75	4.41
30	0.2	0.09	0.3	1.239583	2.75	4.38
20	0.2	0.06	0.3	1.239583	2.75	4.35
10	0.2	0.03	0.3	1.239583	2.75	4.32

Table 8. Unit Price Analysis of Chip Seal Using RAP—Optimistic Scenario

Mobilization Cost			Aggregates	Emulsion	Other Costs	Total Cost ($)
Distance (mi)	Unit Cost ($/ton.mi)	Total Cost ($)				
100	0.2	0.3	0.075	1.0625	2.75	4.19
90	0.2	0.27	0.075	1.0625	2.75	4.16
80	0.2	0.24	0.075	1.0625	2.75	4.13
70	0.2	0.21	0.075	1.0625	2.75	4.10
60	0.2	0.18	0.075	1.0625	2.75	4.07
50	0.2	0.15	0.075	1.0625	2.75	4.04
40	0.2	0.12	0.075	1.0625	2.75	4.01
30	0.2	0.09	0.075	1.0625	2.75	3.98
20	0.2	0.06	0.075	1.0625	2.75	3.95
10	0.2	0.03	0.075	1.0625	2.75	3.92

Another factor to be considered is asphalt binder replacement (ABR). Although most contractors who responded to the survey stated that they would use RAP in preservation treatments even if asphalt binder replacement was not accounted for, it may have to be considered for safety reasons. Not accounting for ABR might cause bleeding, as RAP is coated and would take less emulsion. For example, a 70% embedment of aggregates in chip seal is recommended by some agencies (Caltrans, n.d.; IDOT, 2017). This suggests that ~70% of the volume of the aggregate particle would be submerged in the emulsion. To consider this, the research team used an assumed ABR of 30% for the RAP materials (i.e., conventionally 30% of the binder needed in a mix would be unneeded when RAP is used). Hence, 21% (0.3*0.7) less emulsion would be required, saving in emulsion cost. The total unit price would be $4.22, reduced by $0.64. For microsurfacing, the results could be even better. However, the use of 30% ABR, although the binder is submerged in virgin emulsion, comes with a caveat that the RAP binder may not be mobilized because no heat is used with emulsified asphalt. Therefore, it is likely that full mobilization may not occur. While this number represents a “best case” scenario, future research must determine if bleeding is a concern when RAP is used, assuming 0% ABR.

The analysis was conservative, aimed at setting bounds, and the reality could well be much less pessimistic. As was evident by the cost data, non-material-related costs constituted up to 85% of the total unit price. As such, it is important to solve the logistics of hauling aggregates, especially when aggregates are unavailable.

Statewide Use of RAP

Although it can be unrealistic to assume that all virgin aggregates in preservation treatments would be substituted with aggregates from RAP, this section quantifies the total amount of RAP that could be used in preservation treatments. The total amount of RAP that would be used in preservation treatments may be estimated using Figure 11.

$$TR = LM * RT * CF * TIP$$

Figure 11. Equation. Total RAP used formula.

where, TR is the total amount of RAP that could be used in a preservation treatment, LM is total number of lane-miles preserved by the treatment, RT is rate of application of aggregates in treatment, CF is a conversion factor from square yard to mile, and TIP is a conversion factor from ton to lb.

Figure 12 can be used as follows to calculate the total amount of RAP that could be used in microsurfacing in Illinois. Similarly, the total amount of aggregates needed in chip seal could be estimated as presented in Figure 13. It should be noted that these numbers could be higher if local roads are considered, especially as some preservation treatments are more common for this type of road.

$$TR = 157.25\, mi * 15 \frac{lb}{YD^2} * 7{,}040 \frac{YD^2}{mi} * \frac{1}{2000} \frac{ton}{lb} = 8{,}303\, tons$$

Figure 12. Equation. Total RAP used formula application in microsurfacing.

$$TR = 107.5\, mi * 25 \frac{lb}{YD^2} * 7{,}040 \frac{YD^2}{mi} * \frac{1}{2000} \frac{ton}{lb} = 9{,}460\, tons$$

Figure 13. Equation. Total RAP used formula application in chip seal.

SUMMARY

The following findings were drawn from this chapter:

- Around 250 lane-miles were reported to be preserved using either microsurfacing or chip sealing in all districts annually.
- Contractors are willing to use RAP in preservation treatments. However, technical expertise is needed.
- Based on the district survey, it appears that there is excess RAP in several Illinois districts. Only one district explicitly reported lack of good-quality RAP. Although this application may not solve the problem of RAP stockpiled in Illinois, it will reduce it and could motivate the application of preservation treatments in Illinois.
- Using RAP in preservation treatments could be financially feasible.
- Using RAP in preservation treatments could have an impact by solving a logistical problem when virgin aggregates are not available. In addition, it is expected to reduce the environmental impact, which was not investigated in this study.
- The cost effectiveness of RAP could be increased if a credit is given for RAP binder. The default assumption at this point is no binder is mobilized until proven otherwise.

CHAPTER 4: ENVIRONMENTAL ANALYSES

Life cycle assessment (LCA) is a type of environmental analysis that quantitatively evaluates the environmental impact of the entire life cycle of a system. LCA includes five stages: material acquisition and production, construction, maintenance, use stage, and end of life. Pavement LCA studies started in the late 1990s for both HMA and Portland cement concrete pavements (AzariJafari, 2015). However, in recent years, there has been an influx of pavement LCA studies. This could be due to the high contribution of the transportation sector to the total amount of greenhouse gas emissions. According to the Environmental Protection Agency (EPA), the transportation sector accounted for 29% of greenhouse gas emissions, ranking this sector as the highest contributor.

LIFE CYCLE ASSESSMENT METHODOLOGY

To quantify the environmental benefits of using RAP in chip seal and microsurfacing treatments, a life cycle assessment was carried out and is detailed in this section. The LCA methodology in this study follows the standards proposed by the International Organization for Standardization (ISO 14044), which has four steps: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation, as illustrated in Figure 14.

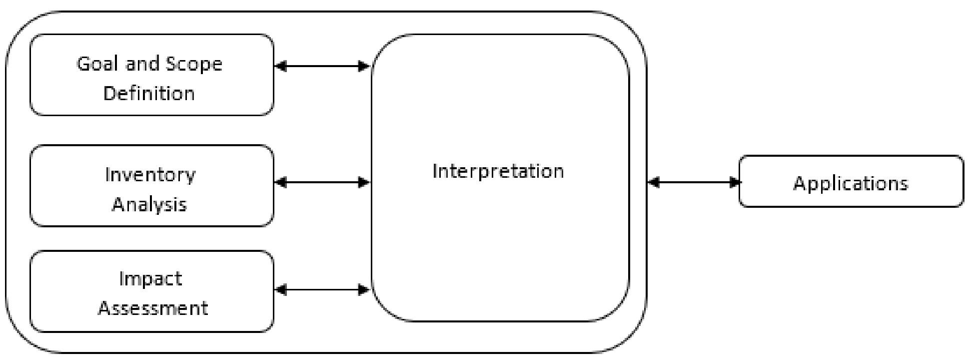

Figure 14. Chart. Framework for conducting life cycle assessment according to ISO 14040.

Goal and Scope Definition

The first step of LCA analysis is to identify the goal of the study. In addition, the inputs and outputs of the system are clearly stated. The primary goal of this LCA was to calculate the environmental impacts of using RAP in microsurfacing and chip seal preservation treatments. To achieve this goal, three specific objectives were considered, as follows:

- Calculate the environmental impacts of using 50% RAP and 100% RAP in microsurfacing and chip seal treatments in Illinois.
- Quantify the environmental performance of using RAP for each treatment, compared with using virgin aggregates only.
- Assess the sensitivity of the conclusions to some of the LCA assumptions: end-of-life considerations and hauling distances.

The functional unit of an LCA is the "quantified performance of a product for use as a reference unit," as defined in ISO (2006). The functional unit used in this LCA is one lane-mile over the analysis period. The system boundary includes the following life cycle stages: material acquisition and production, construction, maintenance, and use stages. The system boundaries of the LCA scope are presented in Figure 15. The assumptions used for each treatment are presented in Table 8.

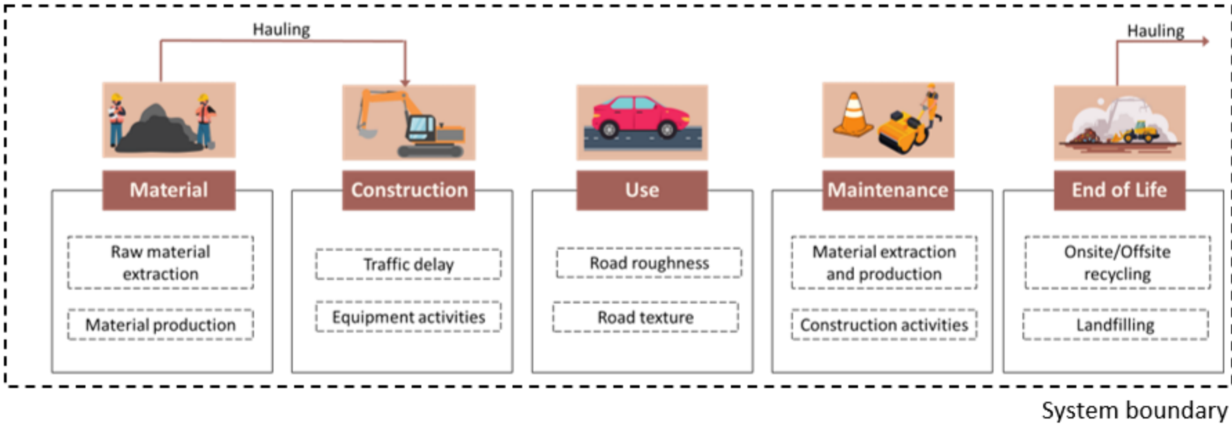

Figure 15. Chart. System boundary of the LCA scope.

Table 8. Assumptions Made for the Life Cycle Assessment

Item	Microsurfacing	Chip Seal
State	Illinois	Illinois
Pavement Width	12 ft	12 ft
Pavement Length	1 mile	1 mile
Asphalt Layer Thickness	4 in	4 in
Aggregate Application Rate	33 lb/yd^2	30 lb/yd^2
Emulsion Application rate	8% by weight of aggregate	0.425 gals/ yd^2
Mineral Filler Application Rate	1.5% by weight of aggregate	–
Virgin Aggregates Hauling Distance	50 miles	50 miles
End-of-Life Considerations	Landfilled 10 miles away	Landfilled 10 miles away

The quantity (in tons) of the materials used per lane-mile of pavement is calculated using the equations in Figure 16 and Figure 17:

$$Q_{material}(tons) = Material\ application\ rate\left(\frac{lb}{yd^2}\right) \times length(mi) \times width(ft) \times \frac{1760}{3 \times 2000}$$

Figure 16. Equation. Material quantity formula when application rate is in pounds per square yards.

$$Q_{material}(tons) = Material\ application\ rate\left(\frac{gal}{yd^2}\right) \times length(mi) \times width(ft) \times \frac{1760}{3 \times 239.65}$$

Figure 17. Equation. Material quantity formula when application rate is in gallons per square yards.

Using the equations in Figure 16 and Figure 17, the quantities for materials used per lane-mile were calculated and are presented in Table 9.

Table 9. Quantities of Materials per Lane-Mile

Material (ton/lane-mile)	Microsurfacing	Chip Seal
Aggregate	116.2	105.6
Emulsion	9.3	12.5
Mineral Filler	1.7	–

The following equipment was used for microsurfacing: microsurfacing/slurry mixing machine, pneumatic tire roller, sweeper, and vibratory roller. The following equipment was used for chip sealing: aggregate spreader, binder distributor, sweeper, and pneumatic tire roller.

Inventory Analysis

The second step of an LCA study is inventory analysis, where the data collection and procedures are described. This section presents the inventory analysis of each inventory item.

Materials

Data for the unit processes of this study were modeled with commercial LCA software SimaPro 9.2.0.1, in which the US-Ecoinvent 2.2 library was used. The unit processes were modified by replacing default electricity models with Illinois electricity models described in Al-Qadi et al. (2015). For aggregates, the unit processes included crushing the rocks multiple times to reach the required size, and for that, the unit process "Gravel, crushed, at mine/US-EI" was used. Asphalt binder is a co-product obtained during petroleum refining processes. Therefore, and to account for the variability of crude oil sources across the US, the inventory model developed by Yang et al. (2016) was used for HMA materials. A combination of unit processes from SimaPro were used to model the impacts of asphalt emulsion, including asphalt binder, emulsifier, water, and electricity.

Plant Operations

Plant operations include the use of electricity to operate mixing drums and conveyor belts, the use of fuel, and the use of diesel for the various operations. Data for these processes were obtained from the literature (Kang et al., 2014).

Equipment

Equipment unit processes were compiled using EPA's MOVES software, as described in Al-Qadi et al. (2015). The simulations run on the software allowed the authors in that work to assess the environmental impacts of on-site equipment. The outputs of the software were then used to calculate the US-EI 2.2-unit processes. A similar procedure was done for hauling trucks.

Life Cycle Impact Assessment

The third step, life cycle impact assessment (LCIA), identifies the impact categories to be considered and consequently calculates the impacts. For this LCA, the impact characterization was done using EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI).

Table 10 presents the impact categories considered in TRACI. The TRACI impact categories may be combined and reported using one unitless number called the Single Score, which is calculated based on normalization and weighting applied to the impacts. The Single Score is reported in "points" and is used to make easy comparisons between LCA alternatives. In addition to TRACI impacts, energy consumption was considered in the LCIA. The Federal Highway Administration recommends reporting two types of energy: energy embodied as fuel, such as natural gas and diesel, and energy embodied as a material (energy with feedstock), such as the energy retained in asphalt binder. A tool developed by Al-Qadi et al. (2020) was used to calculate these impacts for the scenarios considered in this report.

Table 10. TRACI Impact Categories

Impact Category	Unit
Ozone depletion	kg CFC-11 eq
Smog	kg O_3 eq
Acidification	kg SO_2 eq
Fossil fuel depletion	MJ surplus
Eutrophication	kg N eq
Respiratory effects	kg PM2.5 eq
Non-carcinogenic	CTUh
Carcinogenic	CTUh
Ecotoxicity	CTUe
Global Warming	kg CO_2 eq

RESULTS

The results of the LCA showed a decrease in environmental impacts after replacing virgin aggregates with RAP, as presented in Figures 18 and 19 for global warming potential (GWP) and total primary energy, respectively. It is evident that the addition of RAP would reduce the impact on the environment.

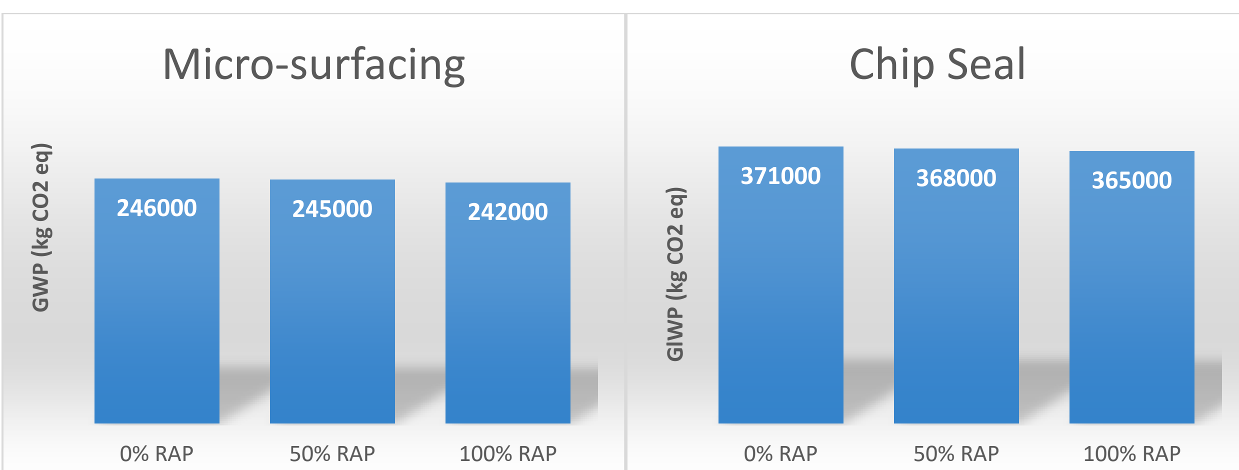

Figure 18. Chart. Global warming potential results of different RAP percentages.

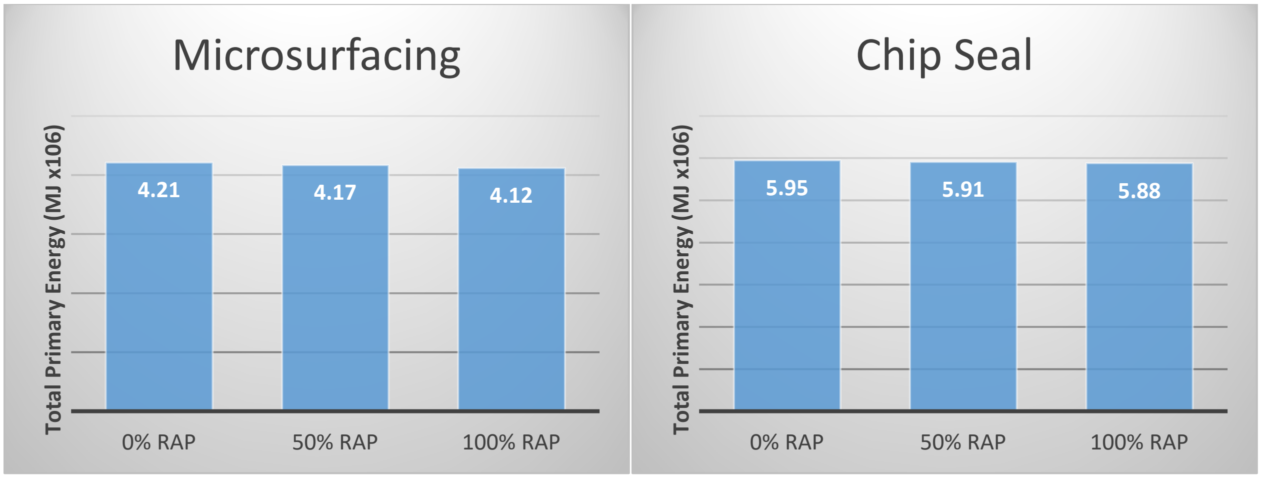

Figure 19. Chart. Total primary energy results for different RAP percentages.

Looking at the material production stage only, Figure 20 presents how the materials used in chip seal treatments contribute to the total GWP of this stage for the three RAP cases. In all cases, asphalt emulsion production produced the highest CO_2 emissions, compared to the aggregate. However, with the introduction of RAP, the contribution of the aggregates to GWP decreased by about 15%.

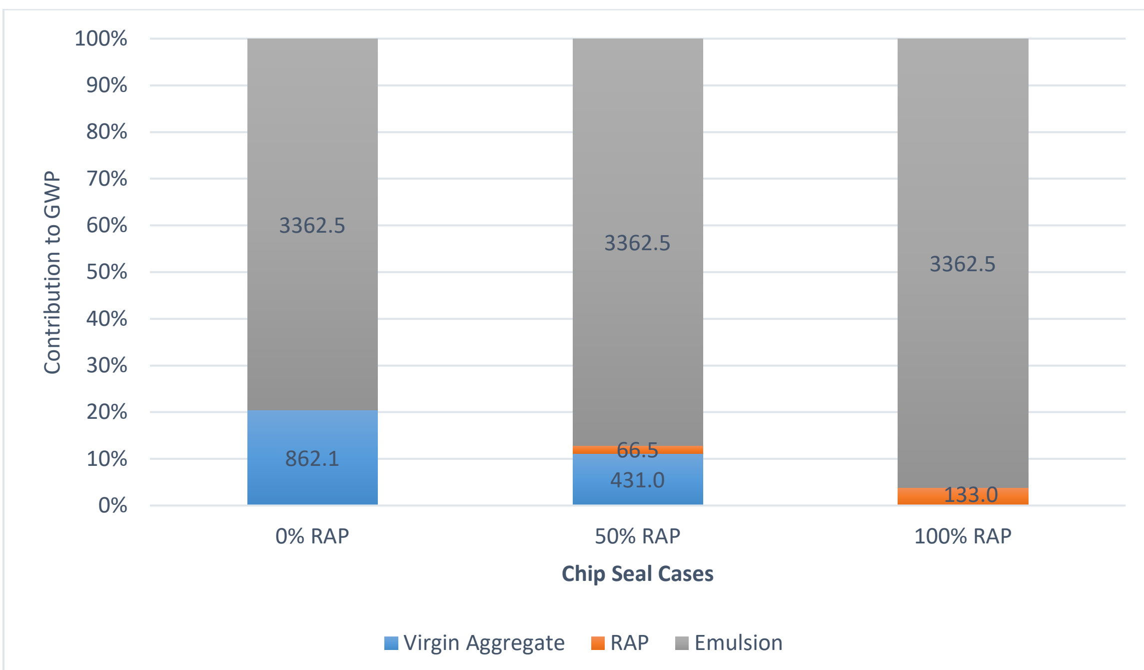

Figure 20. Chart. Percent contribution of the material to GWP of the material production stage.

The LCA results showed that the use of RAP has environmental benefits considering various environmental indicators. This is attributed to the reduction in material production when using RAP.

As noted earlier, crushed virgin aggregates were considered in the aforementioned cases. To consider other aggregate types, two additional cases were considered. In the first case, virgin aggregates were assumed to be 50% crushed aggregate and 50% steel slag. In the second case, virgin aggregates were assumed to comprised 95% crushed aggregate and 5% steel slag. The LCA results are shown only for the 0%RAP for the purpose of evaluating the impact of using steel slag in microsurfacing on the results. The trends are similar for 50%RAP and 100%RAP.

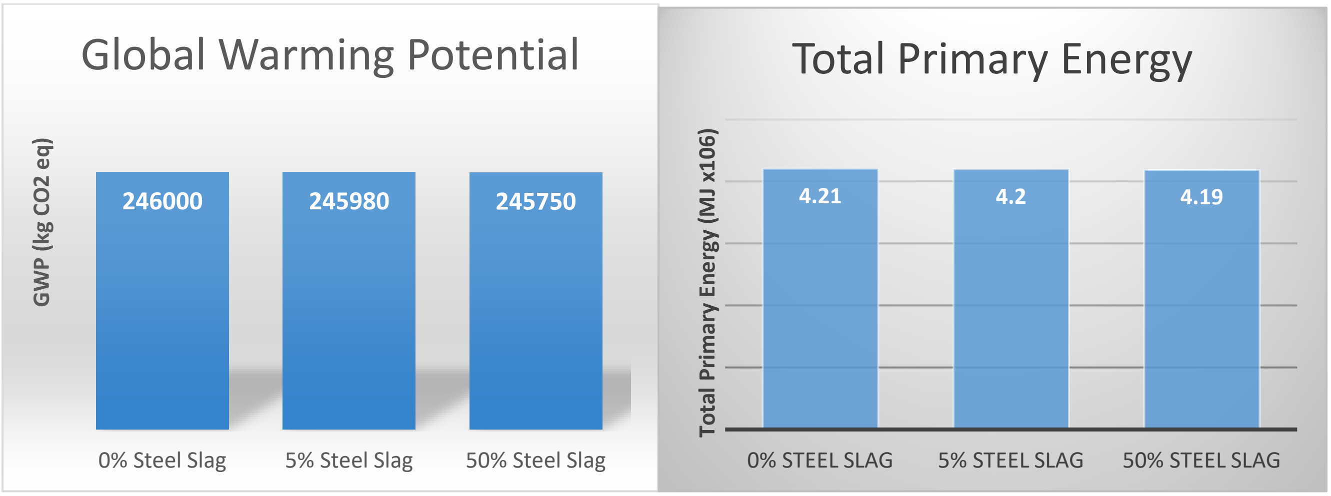

Figure 21. Chart. Global warming potential and total primary energy for different steel slag percentages in microsurfacing.

Using steel slag for microsurfacing had positive environmental impacts, as presented by GWP and total primary energy. However, although steel slag reduced the negative impacts of using virgin aggregates, RAP showed greater environmental benefit. Therefore, using both steel slag and RAP would result in greater environmental benefits than using one of them.

CHAPTER 5: DECISION TOOL

This chapter presents a decision tool used to determine where and how RAP could be used in preservation treatments (mainly in microsurfacing and chip sealing). The tool is based on the data collected throughout the study (both from the literature review and the analysis conducted in this study). The information is related to the current state of practice and knowledge, and any conclusions presented herein may change in the future. For example, information related to RAP availability may change over time due to policies implemented by districts.

While the trade-off between the availability of RAP/virgin aggregates and the benefits of using RAP (e.g., financial benefits) could be evaluated on a case-by-case basis, the fundamental assumption is to use available local RAP and not import it. The following decision tool would help contractors determine the viability of using RAP in a treatment project.

Factors like traffic and climate were not considered. The literature suggested that preservation treatments with RAP have been applied in various environments and on high-volume roads with no issues reported after years of service. Recommendations to use specific materials are based on results from the literature (whether from lab or field experience). Hence, other alternatives may work; however, there is insufficient data at this point. Some lab studies reported types of emulsion that proved to be effectively working with preservation treatments (e.g., CRS-1HP with chip seal [Rahman et al., 2012] and CQS-1HP [Poursoltani, 2020]). However, IDOT may recommend/specify suitable materials for Illinois, including the type of emulsion used when aggregates from RAP are used (Figure 22).

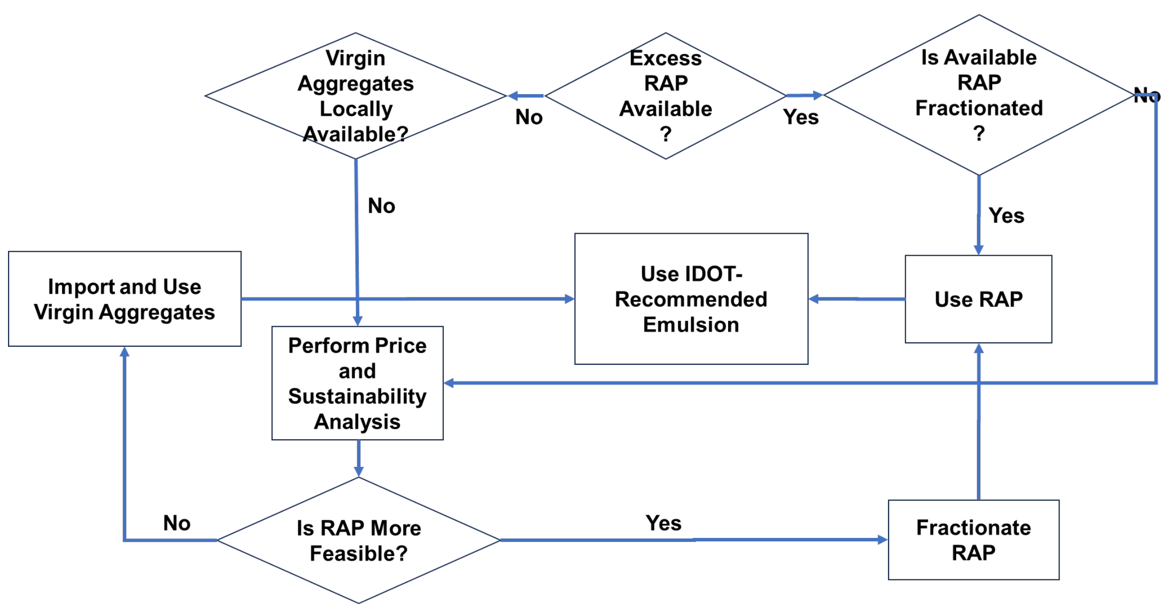

Figure 22. Flowchart. Decision tree framework for using RAP in preservation treatments.

CHAPTER 6: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE WORK

This study investigated the feasibility of using RAP in preventive maintenance treatments (mainly microsurfacing and chip seal). It consisted of a review of the current state of knowledge and practice, a survey aimed at data collection from different IDOT districts measuring overall willingness and preparedness to use RAP in preservation treatments, a generic cost-effectiveness analysis, and a decision tool that summarizes the outcomes of the study.

From the literature, using RAP in preservation treatments has been proven to work both in the lab and field. Field examples from various states with different climates (e.g., California and New Mexico) reported no significant challenges. The survey results demonstrated that both contractors and districts are willing to use RAP in preservation treatments; however, technical expertise may be needed. A data- and literature-based cost effectiveness analysis, using conservative assumptions, demonstrated that using RAP in lieu of virgin aggregate could be effective as well as economically and environmentally efficient. In addition, it could be logistically beneficial when aggregate availability is limited. A flowchart was developed to guide districts in decision-making for using RAP in preservation projects. A preliminary life cycle assessment analysis showed that using RAP in preservation treatments would reduce the impact on the environment by reducing energy, global warming potential, and greenhouse gas emissions.

While using RAP in chip seals has shown to be feasible, a few challenges need to be addressed for using RAP in microsurfacing due to the following: i) lack of cases in the literature; ii) currently, there is no method to perform quality control on microsurfacing materials when RAP is utilized; and the nonexistence of mix designs when using RAP.

The use of RAP in preservation treatments in Illinois is economically and environmentally feasible. Hence, it is recommended that IDOT perform lab testing on Illinois materials in accordance with IDOT guidelines and practice. Upon completion of lab testing, a full life cycle cost analysis and life cycle assessment could be conducted. Each contractor or material supplier must perform its own analysis using available resources and geospatial tools to conduct a financial analysis. IDOT may develop guidelines for the use of RAP in preservation treatments (e.g., specifying RAP gradation and type as well as emulsion type and quantity).

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APPENDIX: QUESTIONNAIRES

DISTRICT SURVEY

General Information

- IDOT District?
- Name of Respondent?
- Position/Title?
- Contact Information (Email/Phone)?

RAP Inventory Data

- Total RAP stockpiled (tons)
- Is RAP fractionated?
- How is RAP typically utilized in your district? (Check all that apply)
    - As a base material (aggregate)
    - As a base material (HMA)
    - As a component in HMA surface mixtures
    - As a component in HMA binder mixtures
    - For shoulder construction(aggregate)
    - For shoulder construction (HMA)
- Is the RAP processed or crushed before reuse? (Yes/no)
- If your answer to the previous question was yes, please provide details of the processing methods.
- Are there any challenges or limitations to utilizing RAP in your district? (Yes/No)
- If your answer to the previous question was yes, please briefly describe the challenges.
- Do you have excess paving quality RAP in your district which cannot be utilized?

- Please specify the tracking and documentation procedures for RAP in your district (i.e., is this part of agencies' responsibilities)?
- What other agencies does your district collaborate with to assure quality of RAP?

Additional Comments

- Please provide any other comments related to RAP/FRAP inventory in your district.

Frequency of Using Pavement Preservation

- How many lane-miles of roadway are chip-sealed annually?
- How many lane-miles of roadway are micro-surfaced annually?
- How many lane-miles of roadway are slurry sealed annually?

CONTRACTOR SURVEY

General Information

- Company name?
- Type of company (e.g., construction contractor)?
- Number of employees?
- Years of experience in the industry?

Practice Information

- Please indicate the extent of RAP usage in your projects
  - Frequently (> 50% of projects)
  - Sometimes (25–50% of projects)
  - Occasionally (< 25% of projects)
  - Never used.
- What are the primary reasons for using RAP in your projects? (Select all that apply.)
  - Cost savings
  - Environmental sustainability

- Regulatory requirements
- Availability of materials
- Enhanced pavement performance.

- What percentage of RAP do you typically incorporate in your asphalt mixes when used? (Please provide an approximate range.)
  - Less than 10%
  - 10–30%
  - 30–50%
  - More than 50%.
- What challenges do you face when incorporating RAP into your projects? (Select all that apply.)
  - Quality control of RAP materials
  - Lack of consistent RAP supply
  - Performance concerns with RAP mixes
  - Regulatory hurdles or restrictions
  - Limited knowledge and technical support.
- Are there any specific topics or areas related to RAP usage that you believe should be addressed in future research or guidelines? Please provide your suggestions.
- Overall, how satisfied are you with the performance and benefits of using RAP in your projects?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied.

- If you have any additional comments or insights regarding the use of RAP, please share them here.
- Would you use RAP for preservation treatments (e.g., chip seal and micro-surfacing) even if asphalt binder replacement was not accounted for?

Practice Information

- How many tons of RAP and asphalt millings were accepted/delivered to your facilities in the state in 2022?
- How many tons of RAP were recycled back into HMA/WMA mixes in 2022?
- How many tons of RAP were recycled back into aggregate base in 2022?
- How many tons of RAP were recycled back into cold mix in 2022?
- How many tons of RAP were recycled back in forms other than the ones mentioned above? (Please specify).
- How many tons of RAP were landfilled in 2022?
- What was the average RAP percentage used in asphalt mixes during 2022?
- At the end of the year 2021, how many tons of RAP did you stockpile? (Use best estimate if data are not available.)
- What percentage of the RAP processed is fractionated into two or more sizes? (Use best estimate if data are not available.)
- What percent of mixes using RAP were produced using a softer grade of asphalt binder? (Use best estimate if data are not available.)
- What percent of mixes using RAP were produced using recycling agents? (Use best estimate if data are not available.)

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