



Sustainability and Training Materials for In-Place Recycling

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16. ABSTRACT <p>Hot and cold in-place recycling techniques recycle 100 percent of a hot mix asphalt (HMA) pavement, in place, during the maintenance/rehabilitation process. Numerous studies have shown in-place recycling to be a sustainable, cost-effective procedure for rehabilitation of HMA pavements. However, many states do not use these viable, environmentally friendly procedures for pavement rehabilitation. The three most common agency reported drawbacks to in-place recycling usage are: 1) lack of data on performance benefits, 2) lack of familiarity with or lack of guidelines on construction procedures (training materials), and 3) limited information on input parameters for pavement thickness design. There is a need to provide pavement design professionals and highway agencies with the knowledge and tools necessary to use in-place pavement recycling and reclaiming as a feasible, sustainable, competitive alternative to traditional pavement maintenance and rehabilitation strategies.</p> <p>The intent of this proposed project is to develop a sustainability calculator that would document the sustainability benefits of in-place recycling compared to traditional maintenance and rehabilitation techniques and to develop interactive training materials that will serve as a Basic Recycling Primer for in-place recycling. The sustainability calculator will be made available for local agencies and the training materials developed through this project will be provided to the Transportation Curriculum Coordination Council (TCCC) where they will develop an interactive web based training course.</p> <p>When the web based training course is complete by the TCCC the course should be available for free and will be hosted on the National Highway Institute's web site and the TCCC web page. The sustainability calculator will be provided to the Asphalt Recycling & Reclaiming Association (ARRA) for possible hosting on their web page. The target audience for these materials includes students, local government agencies, state DOTs, engineering consultant technicians/inspectors, engineering and construction management students and any other individuals who need an awareness or basic understanding of in-place recycling.</p>			
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Approximate Conversions to SI Units					Approximate Conversions from SI Units				
Symbol	When you know	Multiply by	To Find	Symbol	Symbol	When you know	Multiply by	To Find	Symbol
LENGTH					LENGTH				
in	inches	25.40	millimeters	mm	mm	millimeters	0.0394	inches	in
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yd
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
AREA					AREA				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	square millimeters	0.00155	square inches	in ²
ft ²	square feet	0.0929	square meters	m ²	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.8361	square meters	m ²	m ²	square meters	1.196	square yards	yd ²
ac	acres	0.4047	hectares	ha	ha	hectares	2.471	acres	ac
mi ²	square miles	2.590	square kilometers	km ²	km ²	square kilometers	0.3861	square miles	mi ²
VOLUME					VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.2642	gallons	gal
ft ³	cubic feet	0.0283	cubic meters	m ³	m ³	cubic meters	35.315	cubic feet	ft ³
yd ³	cubic yards	0.7645	cubic meters	m ³	m ³	cubic meters	1.308	cubic yards	yd ³
MASS					MASS				
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000 lb)	T
TEMPERATURE (exact)					TEMPERATURE (exact)				
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C	°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS				
lbf	poundforce	4.448	Newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in ²	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in ²

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SUSTAINABILITY AND TRAINING MATERIALS FOR IN-PLACE RECYCLING

Final Report

April 22, 2016

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EXECUTIVE SUMMARY

In-place recycling techniques recycle 100 percent of an asphalt pavement in place during the maintenance and rehabilitation process. Numerous studies have shown in-place recycling to be a cost-effective procedure for rehabilitation of asphalt pavements. However, many states do not use these viable, environmentally friendly procedures for pavement rehabilitation. The three most common agency-reported drawbacks to in-place recycling usage are: 1) lack of long term performance data; 2) lack of familiarity with, or lack of guidelines on, construction procedures; and 3) limited information on input parameters for pavement thickness design. There is a need to provide pavement design professionals and highway agencies with the knowledge and tools necessary to use in-place pavement recycling and reclaiming as a feasible and competitive alternative to traditional pavement maintenance and rehabilitation strategies.

The principal investigators (PIs) for this project were provided with a unique opportunity to partner with the Transportation Curriculum Coordination Council (TC3). They were approached by the TC3 to assist with developing two additional web-based training courses for in-place asphalt recycling. The two requested courses were on Hot In-place Recycling (HIR) and Full Depth Reclamation (FDR). The partnership allowed the TC3 access to the latest technology on in-place recycling through use of the second edition of the BARM and guide specifications. This provided the PIs with expertise in developing web-based training and provided a nationally recognized platform to host the final product.

When the web-based training courses are completed, they will be available free of charge and can be accessed on the TC3 web page at [Transportation Curriculum Coordination Council \(TC3\)](#). The web-based training was designed to answer the following questions:

- What are HIR and FDR and the benefits to using these methods of pavement maintenance and rehabilitation?
- What is the overall process for completing an HIR and FDR project?
- What is involved in the pre-production inspection?

- What is the purpose of a control strip and what does it tell us about the roller pattern to be used to compact the HIR and FDR mix?
- How is the mix/mix design handled on an HIR and FDR project?
- What is the process for placing and compacting HIR and FDR mixes?
- What are the considerations for curing compacted HIR and FDR mixes?
- How are the HIR and FDR surfaces maintained?
- What are the methods for acceptance of HIR and FDR construction and materials?
- How are the HIR and FDR materials measured and paid for?

Nonroad heavy duty diesel (HDD) equipment plays an important role in building and maintaining surface transportation infrastructure, including asphalt paving and recycling. Not only does HDD equipment have substantial ownership and operating costs but it also has a significant impact on national energy consumption in the form of diesel fuel, and an impact on the environment in the form of greenhouse gases and hazardous air pollutants. In order to manage these impacts, they must first be quantified. The PIs developed a fuel use and emissions calculator for HDD equipment used in asphalt paving activities. The calculator estimates the quantities of fuel used and pollutants emitted to various types of HDD equipment used in asphalt paving operations. The pollutants include nitrogen oxides, hydrocarbons, carbon monoxide, particulate matter, sulfur oxides, and carbon dioxide. The calculator also serves a useful purpose for comparing the energy and environmental impacts for alternative equipment.

INTRODUCTION

Background

Hot and cold in-place recycling techniques recycle 100 percent of an asphalt pavement in place during the maintenance/rehabilitation process. Numerous studies have shown in-place recycling to be a cost-effective procedure for rehabilitation of asphalt pavements (1). However, many states do not use these viable and environmentally friendly procedures for pavement rehabilitation. The three most common agency reported drawbacks to hot and cold in-place recycling usage are:

1. Lack of long term performance data;
2. Lack of familiarity with, or lack of guidelines on, construction procedures; and
3. Limited information on input parameters for pavement thickness design (2).

Transportation infrastructure includes massive areas of pavement, most of which form the wearing surface for streets, roads, and highways. These pavements represent the single largest capital asset for most cities, counties, and states, as well as a significant capital asset for many private landowners. In addition, the initial construction of these pavements requires consumption of substantial natural resources (cement, asphalt, aggregate, energy, etc.) and poor asset management practices can result in consumption of significant additional natural resources to maintain and replace these pavements. The associated material volumes are large, so even modest improvements in design, construction, and maintenance practices can translate to significant material and energy savings.

Fortunately, a number of sustainable technologies are being developed to address these concerns. For example, the traditional means of rebuilding an asphalt pavement has been to remove the pavement, haul the debris to a landfill, and replace it with a new pavement constructed of newly-mined aggregate and new asphalt cement. This wasteful practice can be replaced with various in-place recycling technologies that process the old materials on-site and mix them with a much lesser volume of new asphalt to form a new pavement.

Pavement recycling and reclaiming has been around for many years. However, compared to other pavement maintenance and rehabilitation strategies, recycling has been used much less frequently than other technologies (2). Lately, more and more agencies are seeing the value in recycling and are interested in using this technology on their pavement network. Unfortunately, only a few agencies have the experience and know-how to deliver successful in-place pavement recycling projects. In addition, because of the lack of effective technology dissemination activities, these technologies are often misapplied which results in much less effective results and discourages their use by public and private agencies (2). There is a need to provide pavement design professionals and highway agencies with the knowledge and tools necessary to use in-place pavement recycling and reclaiming as a feasible and competitive alternative to traditional pavement maintenance and rehabilitation strategies.

In 2002 the Asphalt Recycling and Reclaiming Association (ARRA), a trade association of hot and cold in-place recycling contractors, published the *Basic Asphalt Recycling Manual*, or BARM, as it is better known (3). BARM has received wide acceptance, having been published in two additional languages, and is one of the texts for the National Highway Institute's Course FHWA-NHI-131050, *Asphalt Pavement In-place Recycling Techniques*. There have been numerous advances in hot and cold in-place recycling techniques since 2002. PI Cross worked with ARRA and FHWA to develop a second edition of BARM which was published in 2014 (4). In addition, the PI Cross and ARRA are developing construction guidelines, mix design procedures, best practices and guide specifications for the ARRA disciplines of cold in-place recycling (CIR) and full depth reclamation (FDR).

In order to make the information in the second edition of BARM and ARRA's guide specifications more readily available and more of an educational tool, the intent of this project is to take this material and develop materials for web-based training courses on HIR and FDR to complement the previously developed course on Cold In-place Recycling developed through OTCREOS11.1-15 (5). As with the OTCREOS11.1-15 (5)

project, the PIs were again provided with a unique opportunity to partner with the Transportation Curriculum Coordination Council (TC3) to assist with developing the web-based training courses for HIR and FDR.

Transportation Curriculum Coordination Council (TC3)

The TC3 was developed in 2002 as a partnership among State Departments of Transportation (DOTs), Federal Highway Administration (FHWA) and its National Highway Institute (NHI), the American Association of State Highway and Transportation Officials (AASHTO), industry associations and institutes, and academia. TC3's goal is to create and maintain a fully optimized curriculum to respond to the changing needs of the transportation technical workforce. The mission of TC3 is to develop, maintain, and provide effective access for a quality training curriculum to enhance the competency of the nation's transportation technical workforce, with the focus on construction, maintenance, and materials (6).

TC3 combines resources and knowledge to develop standardized technical training materials for all stakeholders. The Council's goals included developing a core curriculum to support national priorities that could be used by any agency to improve the skills and qualifications of the transportation technical workforce (6).

TC3 has a library of more than 100 on-line training modules covering a variety of topics in the three primary disciplines. As a national resource, TC3 helps states, local government, and industry save money at a critical time of infrastructure investment through course development, web-based trainings, information, and resource sharing that is available at substantially reduced cost. All 50 state DOTs have used the TC3 web-based training resources, which are also being used by local governments, universities, consultants, contractors, industry, contractor organizations, and international groups (6).

The Committee for Course Development/Course Sharing of TC3 was tasked by their member partners to develop web-based training courses for asphalt recycling, specifically, CIR, HIR and FDR. The Committee decided to begin with CIR and the web-

based course was developed as described in OTCREOS11.1-15 (5). The plan was completed with funds from this project.

Benefits

Development of the web-based training courses for HIR and FDR will provide transportation officials with general information on HIR and FDR techniques as well as guidance on best practices for construction, construction specifications and inspection. The interactive website will serve as an education and outreach tool to provide students, pavement design professionals and transportation agencies with the knowledge and tools necessary to use HIR and FDR as a feasible and competitive alternative to traditional pavement maintenance and rehabilitation strategies.

SURVEY OF AVAILABLE RESOURCES

Internet Sites

A search of internet sites for asphalt recycling contractors was carried out by Harvey as a part of her Master of Science in Civil Engineering at OSU (7). The purpose of the search was to research the websites of various asphalt recycling contractors and determine what information they provide about their recycling processes. A list of asphalt recycling contractors was obtained from ARRA (8). If a website had good descriptions, videos, and graphics pertaining to in-place recycling, the available resource was noted and listed in Tables 1 – 3 for CIR, FDR and HIR, respectively. The websites were reviewed for videos and pictures showing differences between types of recycling techniques and how their company handles the various processes. Frequently asked questions (FAQ), power point presentations, diagrams, and other useful learning tools were available on a few of the websites and were noted. If a website contained a certain item it was marked accordingly with an “X” in the tables. Descriptions were evaluated to assess ability to explain processes and benefits of recycling to someone with little knowledge of the subject. Each video or presentation was viewed with the same goal in mind, and evaluated on how well it engaged the viewer.

A total of 56 contractors were listed as providing asphalt recycling services. Of those contractors, 29 claimed to specialize in CIR. Of those, 15 also utilized FDR as an

alternative recycling method. The remaining 27 were listed as recycling asphalt by either HIR or FDR. Five of those contractors used HIR, eight used FDR, and the others had little-to-no useable resources available on their websites.

Table 1 Results from CIR Contractor Websites

Contractor	Website (http://www.)	Photos	Text	FAQ	Video
Arizona Pavement Profiling	nesbitts.com	X			
Ballou Pavement Solutions	ballousolutions.com	X	X		
E.J. Breneman Inc.	ejbreneman.com		X		X
Coughlin Company, Inc.	coughlincompany.com/	X	X		X
Cruickshank Construction	cruickshankgroup.com/		X		
Donegal Construction Corp.	donegalconstruction.com	X			
Dunn Company	dunnco.com	X	X	X	
Flex-Tech Resources Ltd.	flectechresources.com		X		
Fonseca McElroy Grinding Co. Inc	fmgrinding.com	X	X		X
Koss Construction Company	kossconstruction.com				X
Lavis Contracting Company Ltd.	lavis.ca		X		
Midland Asphalt Materials Inc.	midlandasphalt.com		X		
Midstate Reclamation Inc.	midstatecompanies.com		X		
The Miller Group Inc.	millergroupusa.com	X	X		
Miller Paving Limited	millergroup.ca		X		
Pavement Recycling Systems, Inc.	pavementrecycling.com		X		X
Reclamation Inc. of Kingston	reclamationllc.net	X	X		
Roadway Management Inc.	roadwaymanagement.com		X		
Seeley and Arnill Construction	seeleyandarnill.com	X	X		X

Table 2 Results from FDR Contractor Websites

Contractor	Website (http://www.)	Photos	Text	FAQ	Video
All States Asphalt Inc.	allstatesasphalt.com		X		
American Road Reclaimers	americanroadreclaimers.com		X		
Base Construction Technologies, Inc.	baseconstructiontechnology.com		X		
Blout Construction Co. Inc.	bloutconstruction.com	X	X		X
E.J. Breneman Inc.	ejbreneman.com		X		X
Coughlin Company, Inc.	coughlincompany.com	X			
Dunn Company	dunnco.com	X	X		
Garrity Asphalt Reclaiming	garrityasphalt.com/	X			
Midland Asphalt Materials Inc.	midlandasphalt.com		X		
Midstate Reclamation Inc.	midstatecompanies.com		X	X	
The Miller Group Inc.	millergroupusa.com	X	X		
Miller Paving Limited	millergroup.ca		X		
Mt. Carmel Stabilization Group, Inc.	mtcsg.com		X		
Pavement Recycling Systems, Inc.	pavementrecycling.com		X		X
Payne and Dolan Inc.	payneanddolan.com			X	
Reclamation Inc. of Kingston	reclamationllc.net	X	X		
Recon Construction Services	reconconstruction.com	X			
Roadway Management Inc.	roadwaymanagement.com		X		
Ruston Paving Co., Inc.	rustonpaving.com	X	X		X
Slurry Pavers Inc.	slurrypavers.com	X	X		
Specialties Company, LLC	specialtiescompany.com		X		
Wadel Stabilization	wadelstabilization.com	X	X		

Table 3 Results from HIR Contractor Websites

Contractor	Website (http://www.)	Photos	Text	FAQ	Video
Cutler Repaving Inc.	cutlerrepaving.com		X		X
Dustrol Inc.	dustrol.com	X	X		X
Gallagher Asphalt Corporation	gallagherasphalt.com		X		
Green Roads Recycling Ltd.	greenroadsrecycling.com			X	X
Manatt's Inc.	manatts.com		X		
Paveover, Inc.	paveover.com			X	

A total of 13 videos were found during the website investigations. Three websites provided a FAQ page regarding asphalt recycling. Descriptions and brochures of the various types of recycling were the most common resources with 38 of these found. There were 20 websites with good quality pictures/images. Contractor websites that contained high quality materials were selected for review and possible inclusion in the web-based training courses.

COURSE OUTLINE

The selected titles of the web-based courses for HIR and FDR are *Hot In-Place Recycling (HIR)* and *Full Depth Reclamation (FDR)*. The intent of the courses is to provide an overview of HIR and FDR, including an explanation of the pre-production inspection procedures, completion of the control strip, full production of the mixtures, mix placement and compaction, mixture curing and maintenance, acceptance testing and measurement and payment. The target audiences for the courses include state DOT and/or engineering consultant technicians/inspectors; engineering and construction management students; and any other individuals who need an awareness or basic understanding of HIR or FDR.

The course outlines were developed by members of the TC3 technical panel and the PIs to meet the intended course outcomes. The TC3 technical panel expressed an

interest to use the second edition of BARM and ARRA's guide specifications for HIR and FDR as a guide to the course outline and content.

The documents used to develop the course outline and content were the second edition of BARM (4); *Recommended Construction Guidelines For Full Depth Reclamation (FDR) Using Bituminous Stabilizing Agents, FDR101 (9)*; *Recommended Construction Guidelines For Full Depth Reclamation (FDR) Using Cementitious Stabilizing Agents, FDR102 (10)*; *Recommended Preconstruction Sampling and Mix Design Guidelines For Full Depth Reclamation (FDR) Using Bituminous Stabilizing Agents, FDR201 (11)*; and *Recommended Preconstruction Sampling and Mix Design Guidelines For Full Depth Reclamation (FDR) Using Cementitious Stabilizing Agents (12)*.

The draft course outlines for the HIR and FDR web-based training courses are provided below. Once the draft outlines were established, the TC3 technical panel and the PIs developed PowerPoint presentations that covered the intended course content. The presentations were then reviewed and modified or supplemented as necessary to develop the course content. Once complete, the presentations were delivered to the consultant secured by the TC3 to develop the interactive web-based training courses.

Hot In-place Recycling

1. Module 1 Introduction and Background
 - 1.1. Lesson 1 Introduction to Hot In-place Recycling
 - 1.1.1. Purpose, benefits, and use of HIR
 - 1.1.2. Types of HIR
 - 1.1.2.1. Surface recycling
 - 1.1.2.2. Remixing
 - 1.1.2.3. Repaving
 - 1.2. Lesson 2 HIR Equipment
 - 1.2.1. Common to all HIR
 - 1.2.1.1. Pre-heater units
 - 1.2.1.2. Heater scarification/milling units
 - 1.2.1.3. Compaction equipment

- 1.2.1.4. Other (rejuvenating agent and additive tankers)
 - 1.2.2. Surface recycling equipment
 - 1.2.3. Remixing equipment
 - 1.2.4. Repaving equipment
 - 1.3. Lesson 3 Mix Design, Rejuvenating Agents, and Additives
- 2. Module 2 HIR Pre-Production Inspection
 - 2.1. Lesson 1 Pre-production Meeting
 - 2.1.1. Traffic control set-up
 - 2.1.2. Utilities
 - 2.1.3. Equipment requirements
 - 2.1.4. Sequence of operations
 - 2.1.5. Quality control plan
 - 2.1.6. Weather limitations
 - 2.1.7. Other specification topics
 - 2.2. Lesson 2 Roadway Preparation
 - 2.2.1. Examine pavement cores
 - 2.2.2. Weak area / soft spots
 - 2.2.3. Surface prep
 - 2.2.3.1. Clean and dry surface
 - 2.2.3.2. Crack sealing materials
 - 2.2.3.3. Paving fabrics
 - 2.2.3.4. Remove grass & soil
 - 2.2.4. Geometric Corrections and Utilities
 - 2.2.4.1. Pre-milling
 - 2.2.4.2. Manholes and valves
 - 2.2.4.3. Improved pavement smoothness
 - 2.3. Lesson 3 Equipment Checks
 - 2.3.1. Pre-heaters
 - 2.3.2. Heater/Scarification Unit
 - 2.3.3. Mixing
 - 2.3.4. Spreaders

2.3.5. Rollers

3. Module 3 Pavement Recycling (Full Production)

3.1. Lesson 1 Compacting and Finishing

3.1.1. Monitor treatment depth

3.1.2. Monitoring pavement temperature

3.1.3. Incorporation and application rate of rejuvenating agent

3.1.4. Incorporation and application rate of additives

3.1.5. Mixing & spreading

3.1.6. Joints

3.2. Lesson 2 Compaction

3.2.1. Same procedure as conventional HMA

3.2.2. Use/size of rollers

3.2.3. Compaction standards

3.2.4. Weather

3.2.5. Smoothness

3.3. Lesson 3 Acceptance, Measurement and Payment

3.3.1. Either by certification, QPL, or testing for conformance

3.3.2. Sampling rate and location

3.3.3. Rejuvenating agents and additive

3.3.4. Mix design approval

3.3.5. Percent compaction

3.3.6. Yield checks

3.3.7. Surface tolerance/smoothness

3.3.8. Measurement & payment

Full Depth Reclamation

1. Introduction and Background

1.1. Purpose, benefits, and use of:

1.1.1. FDR pulverization

1.1.2. FDR mechanical

1.1.3. FDR chemical

1.1.4. FDR bituminous

- 1.2. Mix Design, Stabilizers, and Additives
 - 1.2.1. FDR pulverization/mechanical
 - 1.2.2. FDR chemical
 - 1.2.3. FDR bituminous
- 2. Pre-production Inspection
 - 2.1. Pre-production Meeting
 - 2.1.1. Traffic control plan
 - 2.1.2. Utilities and obstacles
 - 2.1.3. Sequence and schedule of operations
 - 2.1.4. Quality control plan
 - 2.1.5. Maintenance of FDR prior to placement of surfacing
 - 2.1.6. Weather limitations
 - 2.1.7. Other specification topics
 - 2.2. Roadway preparation
 - 2.2.1. Weak area, soft spots, and drainage problems
 - 2.2.2. Surface preparation
 - 2.2.2.1. Patching and crack sealing materials
 - 2.2.2.2. Old asphalt curb and concrete curb
 - 2.2.2.3. Pavement markings
 - 2.2.2.4. Paving fabrics
 - 2.2.2.5. Grass and topsoil
 - 2.2.3. Geometric corrections and utilities
 - 2.2.3.1. Pre-milling
 - 2.2.3.2. Roadway widening
 - 2.2.3.3. Lowering manholes & valves
 - 2.2.3.4. Walls adjacent to pavement (or curbs without gutters)
 - 2.3. Equipment Needs
 - 2.3.1. Self-propelled reclaimer
 - 2.3.2. Water tanker
 - 2.3.3. Stabilizer supply vehicles
 - 2.3.4. Motor grader

- 2.3.5. Rollers
 - 2.3.6. Other
- 3. Control Strip
 - 3.1. Purpose
 - 3.2. Methods and Details of Completing a Control Strip
- 4. Mixing and Reclaiming the Pavement and Portion of Underlying Material (Full Production)
 - 4.1. Daily Start-up Process, Calibration, and Checks
 - 4.2. Monitor Reclaiming Depth
 - 4.3. Monitoring and Sampling Gradation
 - 4.3.1. Gradation effects on stabilizing additives
 - 4.4. Incorporation and Application Rate of Stabilizing Additives
 - 4.4.1. Aggregates
 - 4.4.2. Chemical additives
 - 4.4.3. Bituminous additives
 - 4.4.4. Monitoring (automation and manual checks)
 - 4.5. Mixing
 - 4.5.1. Combining reclaimed material, water, stabilizing additives and time limits
 - 4.5.2. Temperature range of additives - monitor
 - 4.5.3. Additive application rate – monitor metering system and manual checks
 - 4.5.4. Addition of water and moisture control
 - 4.5.5. End result: well dispersed and uniformly coated mixture - monitor
 - 4.5.6. Adjusting application rates based on field conditions
 - 4.5.7. Two pass operations, breakdown/sizing & mixing
- 5. Spreading, Compacting, and Finishing
 - 5.1. Spread Material with Grader to Meet Required Line and Grade
 - 5.1.1. Rough grading
 - 5.1.2. Shaping
 - 5.2. Compaction (Breakdown, Intermediate, and Final)
 - 5.2.1. Start time – including time limits for start and completion
 - 5.2.2. Use/size of pad foot rollers (vibratory)

- 5.2.3. Use/size of pneumatic rollers
- 5.2.4. Use/size of steel wheel rollers (vibratory or non-vibratory)
- 5.2.5. Compaction standards
 - 5.2.5.1. Checking density based on target value using NDG
 - 5.2.5.2. Method spec based on roller passes
 - 5.2.5.3. Other
- 5.3. Construction Joints
 - 5.3.1. Longitudinal
 - 5.3.2. Transverse
- 5.4. Finishing and Surface Tolerance
 - 5.4.1. Final trimming (tight blading)
 - 5.4.2. Straightedge checks
- 5.5. Fog Sealing and Curing Membrane with Blotter
 - 5.5.1. Purpose
 - 5.5.2. Application rate
 - 5.5.3. Sand Blotter
- 5.6. Micro-cracking (for cementitious FDR)
 - 5.6.1. Purpose
 - 5.6.2. Method
- 6. Curing and Maintenance
 - 6.1. Opening to Traffic
 - 6.2. Follow-up Rolling to Maintain a Dense Surface
 - 6.3. Restoration of Damaged Areas
 - 6.4. Brooming Loose Material
 - 6.5. Need and Placement of Final Riding Surface
 - 6.5.1. Time limits
 - 6.5.2. Tack coat
- 7. Acceptance Testing
 - 7.1. Stabilizing Additives
 - 7.2. Mix
 - 7.2.1. Mix design approval

- 7.2.2. Interpretation/use of strength tests in the field
- 7.3. Gradation
- 7.4. Density
- 7.5. Surface tolerance
- 7.6. Other
- 8. Measurement and Payment
 - 8.1. Certification
 - 8.2. Qualified Products List
 - 8.3. Testing for Conformance

INTERACTIVE WEBSITE

Project Overview

The actual web-based training (WBT) course will be developed by a subcontractor, selected and compensated by TC3, from the outline and presentations developed by the PIs and the TC3 technical panel. When completed, the course will be hosted on the TC3 web site (<https://tc3.transportation.org>).

As with the previous web-based training course on CIR (5), the WBT will use audio to narrate the training. The audio will be generated by a pre-approved narrator. Audio integrates smoothly with WBT. In the design of the training, PowerPoint functionality will be used to emphasize points and allow for interactivity. The WBT will use pictures and graphics where appropriate to illustrate concepts and relationships, and create visual interest. Pictures will be as high resolution as possible while maintaining a course that loads in a reasonable amount of time given a high-speed connection. Animation may be used to enhance learning or where applicable and beneficial to illustrate a learning point. Animation will not be used simply to create visual interest (as it can distract from learning when used in this way and does not accommodate all learning styles).

Interactivity will be used throughout the training to engage participants and allow learners to practice applying information whenever possible and where applicable. The

WBT will be designed and developed at Interactivity Level II – Limited Interaction, where the learner makes simple responses to instructional cues. The responses may include answering multiple choice or true-false questions. This level of interactivity allows for highly engaging and interactive content while meeting the content requirements for this course at the comprehension, awareness, and information level (13).

Training Goals

As with the previous course on CIR (13), the two WBT courses will be designed to answer the following questions:

- What are HIR and FDR and the benefits to using these methods of pavement maintenance and rehabilitation?
- What is the overall process for completing an HIR and FDR project?
- What is involved in the pre-production inspection?
- What is the purpose of a control strip and what does it tell us about the roller pattern to be used to compact the HIR or FDR mixture?
- How is the mix/mix design handled on an HIR or FDR project?
- What is the process for placing and compacting HIR and FDR mixtures?
- What are the considerations for curing compacted HIR and FDR?
- How are the HIR and FDR surfaces maintained?
- What are the methods for acceptance of HIR and FDR construction and materials?
- How are HIR and FDR materials measured and paid for?

FUEL USE AND EMISSIONS CALCULATOR

Nonroad heavy duty diesel (HDD) equipment plays an important role in building and maintaining surface transportation infrastructure, including asphalt paving and recycling. Not only does HDD equipment have substantial ownership and operating costs but it also has a significant impact on national energy consumption in the form of diesel fuel, and an impact on the environment in the form of greenhouse gases and hazardous air pollutants. In order to manage these impacts, they must first be quantified. The Pls

developed a methodology for estimating fuel use and emissions quantities for HDD equipment used in asphalt paving activities.

HDD equipment consumes large quantities of diesel fuel and consequently emits air pollutants including nitrogen oxides (NO_x), particulate matter (PM), hydrocarbons (HC), and carbon monoxide (CO), as well as greenhouse gases such as carbon dioxide (CO₂). In order to estimate the quantities of fuel consumed and pollutants emitted, fuel use and emission factors were needed. These factors are approximations of the amount of fuel consumed and pollutants emitted by a particular type of equipment during a unit of use. These factors were based on calculations and the methodology employed by the EPA NONROAD model (14).

Methodology

For fuel use, NONROAD uses brake specific fuel consumption (BSFC) reported in pounds per horsepower-hour (lb/hp-hr); for pollutants, emission factors are reported in grams per horsepower-hour (g/hp-hr). The factors used by NONROAD are based on engine dynamometer test data and adjusted accordingly to account for in-use operation that differs from the typical test conditions. For NO_x, HC, and CO, the emission factor for a specific type of nonroad equipment with a particular model year and age is calculated as follows:

$$EF_{adj} (NO_x, HC, CO,) = EF_{ss} \times TAF \times DF \quad (1)$$

where:

EF_{adj} = final emission factor used in NONROAD, after adjustments for transient operation and deterioration (g/hp-hr)

EF_{ss} = zero-hour, steady-state emission factor (g/hp-hr)

TAF = transient adjustment factor (unitless)

DF = deterioration factor (unitless)

The zero-hour, steady-state emission factor (EF_{ss}) is a function of the engine's model year and horsepower rating, which defines the EPA Engine Tier category (Tier 1-4). Nonroad engines are typically monitored based on steady-state tests; however, this approach does not always accurately reflect fuel use and emissions activity for nonroad

equipment applications. Some differences are due to load or engine speed whereas some are due to transient demands. Transient adjustment factors are applied to Tier 0, 1, 2, and 3 engines but are not applied to Tier 4 engines because transient emission controls will be a part of all Tier 4 engine design considerations. Transient adjustment factors are calculated as the ratio of the transient emission factor to the corresponding steady-state emission factor and may be greater than or less than 1.0.

Deterioration factors are used to account for increases in emissions over time above a new engines base emission level. Emissions may increase over time for numerous reasons including engine wear, poor maintenance, or modification of emission control systems. Emissions performance typically deteriorates at a slow rate for well-maintained engines but rapidly for poorly-maintained engines. The deterioration factors used by the NONROAD model are based on well-maintained engines and are a linear function based on engine age. The transient adjustment and deterioration factors used for the inventory computations were found in *Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression-Ignition (15)*.

Since PM emissions are dependent on the sulfur content of the fuel consumed by the engine, the equation for the PM emission factor is modified from Equation 1 as follows:

$$EF_{adj (PM)} = EF_{ss} \times TAF \times DF - S_{PMadj} \quad (2)$$

where:

S_{PMadj} = adjustment to PM emission factor for variations in fuel sulfur content (g/hp-hr)

For BSFC (or fuel use factor), deterioration factors are not applied, thus, the equation is simplified as follows:

$$EF_{adj (BSFC)} = EF_{ss} \times TAF \quad (3)$$

NONROAD computes CO₂ emissions directly by using in-use adjusted BSFC, as shown in Equation 4. The carbon that goes into exhaust HC emissions is subtracted in order to correct the equation for unburned fuel.

$$EF_{adj(CO_2)} = (BSFC \times 453.6 - HC) \times 0.87 \times (44/12) \quad (4)$$

where:

BSFC = in-use adjusted fuel consumption factor (lb/hp-hr)

453.6 = conversion factor from pounds to grams

HC = in-use adjusted hydrocarbon emissions (g/hp-hr)

0.87 = carbon mass fraction of diesel

44/12 = ratio of CO₂ mass to carbon mass

Individual fuel use and emissions values for an item of equipment are computed according to the methodology presented in *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling (16)* and Equation 5:

$$Emissions_{(NO_x, HC, CO, PM, CO_2, BSFC)} = Power \times LF \times A \times EF_{adj (NO_x, HC, CO, PM, CO_2, BSFC)} \quad (5)$$

where:

NO_x, HC, CO, CO₂ = total annual emissions for the specified pollutant (g/yr)

BSFC = total annual fuel consumption (lb/yr)

Pop = equipment population

Power = engine rated horsepower (hp)

LF = engine load factor (fraction of available power)

A = equipment average annual activity (hr/yr)

EF_{adj (NO_x, HC, CO, PM, CO₂, BSFC)} = engine emission factor (g/hp-hr) or BSFC factor (lb/hp-hr)

The engine rated horsepower is the maximum level of power that an engine is designed to produce at its rated engine speed. HDD equipment seldom operates at its rated power for extended periods and frequently operates at a variety of speeds and loads. NONROAD uses a load factor (*LF*) to indicate the average proportion of rated power used to account for the effects of operation at idle and partial load conditions. For example, a 100 hp engine with a load factor of 0.3 (or 30%) will produce an average of 30 hp over the course of normal operation. Depending on equipment usage patterns, load factors may vary widely for nonroad engines and can be difficult to quantify. If equipment usage patterns are not known, NONROAD model default load factors from

Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling may be used (16).

Results

In order to simplify these calculations and provide an implementable and useful tool, the PIs developed an interactive spreadsheet calculator based on the above methodology. The purpose of the fuel use and emissions calculator is provide accurate diesel fuel use and emissions factors for a variety of HDD equipment, including those that are used for asphalt paving and recycling activities. The interactive spreadsheet responds to inputs from the user and provides the fuel use and emissions factors as outputs. The user selects the type of equipment from a dropdown menu and then enters the engine size (horsepower), engine model year, engine age (years), and estimated hours of use per year (hr/yr). Based on these inputs, the fuel use and emissions calculator provides estimated fuel use and emissions factors. The fuel use factors are reported in units of pounds per horsepower-hour (lb/hp-hr) and emissions factors are reported in units of grams per horsepower-hour (g/hp-hr). Emissions factors are provided for NO_x, HC, CO, PM, CO₂, and SO₂.

For example, consider a model year 2010 construction equipment paver with a 150 hp engine. The age is six years (2016 – 2010 = 6) and it is estimated that the paver is used 1000 hours per year. For this paver, the fuel use factor is 0.4 lb/hp-hr. The emissions factors are: NO_x = 2.6 g/hp-hr; HC = 0.2 g/hp-hr; CO = 1.5 g/hp-hr; PM = 0.4 g/hp-hr; SO₂ = 0.8 g/hp-hr; and CO₂ = 536 g/hp-hr. On an annual basis, this paver would consume approximately 60,000 pounds of fuel (8,600 gallons). It would emit approximately 390,000 grams (0.4 tons) of NO_x; 30,000 grams (0.03 tons) of HC; 225,000 grams (0.25 tons) of CO; 60,000 grams (0.07 tons) of PM; 120,000 grams (0.13 tons) of SO₂; and 80,000,000 grams (90 tons) of CO₂.

The fuel use and emissions calculator may be used to estimate a baseline of fuel consumption and pollutant emissions for as many items of equipment as necessary. It can help determine what the energy and environmental footprint is for a fleet of equipment or for a particular activity, such as a paving operation. Furthermore, the

calculator is a useful tool for evaluating alternative equipment selection to reduce the environmental impact of the activity.

IMPLEMENTATION AND TECHNOLOGY TRANSFER

The two WBT courses are completed and they will join the previously completed WBT course on CIR. This permits greater access to the training and greater publicity and advertisement of the class through FHWA, NHI and the TC3. ARRA and the National Center for Pavement Preservation will provide links to these WBT courses on their respective websites. The courses are available free-of-charge on the TC3 web page at:

- Hot In-Place Recycling (HIR) (2.5 Hours)
https://training.transportation.org/item_details.aspx?ID=2590.
- Full Depth Reclamation (FDR) (4.5 Hours)
https://training.transportation.org/item_details.aspx?ID=2593.
- Inspector Training for Cold In-Place Recycling (CIR) (4 Hours)
https://training.transportation.org/item_details.aspx?ID=2509.

The fuel use and emissions calculator is currently in the prototype stage. Although the technical components of the calculator are complete, the final formatting of the model is still being reviewed by the PIs and potential users in the asphalt industry. When the final formatting of the calculator is complete, it will be made available free of charge on the above mentioned websites along with the training materials.

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