A Methodology for Sustainable Mechanistic Empirical Pavement Design

Presented by

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Presented to: Pavement Lifecycle Assessment

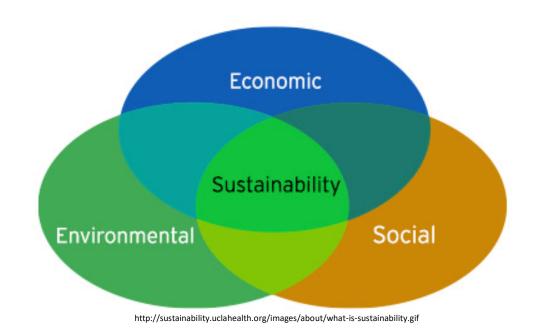
Champaign, Illinois, April 2017

Outline

- What is sustainability?
- How is pavements sustainability currently assessed ?
- The Mechanistic Empirical Pavement design and sustainability
 - Current tools to assess sustainability and associated problems
- Environmental Product Declarations (EPDs)
- The development of a tool using EPDs as a quantification method
- Validation in a case study
- Conclusion

What is sustainability?

- "Meeting the needs of the present without compromising the ability of future generations to meet their own needs" United Nation commission on Environment and Development
- Three pillars
 - Environmental
 - Social
 - Economic



Environmental	Economic	Social
 Making decisions that minimize the degradation of our planet. 	• The use of available resources in an efficient and responsible manner	 Concerned with the interests of stakeholders

Reasons for quantifying the environmental impact

- Becoming more environmentally conscious
- Transparency
- Increasing demand on sustainability
 - Consumers tend to purchase environmentally friendly products
- Making more informed choices for consumers
- Green/Environmental claims
 - Claims made by firms about the environmental qualities of their goods
- The need for benchmarking



http://greenliving4live.com/wp-content/uploads/2013/05/eco-friendly.jpg

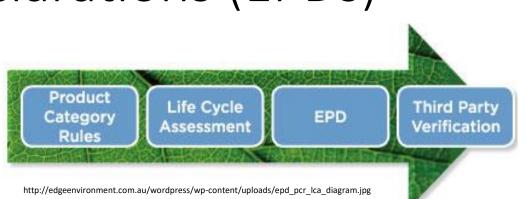
Methods for assessing sustainability

- One of the tools is: Lifecycle assessment (LCA)
 - Limited lifecycle inventory databases
 - Data acquisition problems
 - Time consuming
- LCA can be implemented in diverse ways
 - Incomparable results
- Environmental labels and declarations intend to address these problems
 - Type III environnemental déclarations (Environmental Product Declaration (EPDs)

Category	Problem
Data source	Some sources can be using literatures, while others can be using measurements
Technological representation	Laboratory vs. plant data
Temporal representation	Old vs. new data
Geographical representation	One source can be using U.S. data, while the other can be using European data
System boundaries	100 years vs. 500 years timeline

Environmental Product Declarations (EPDs)

- "Quantified environmental data for a product with pre-set categories of parameters"
- LCA-based tool to communicate the environmental performance of a product
- The information provided is verifiable and accurate / not misleading
- Provide the basis of a fair comparison of products with identical functions
 - Cradle to gate



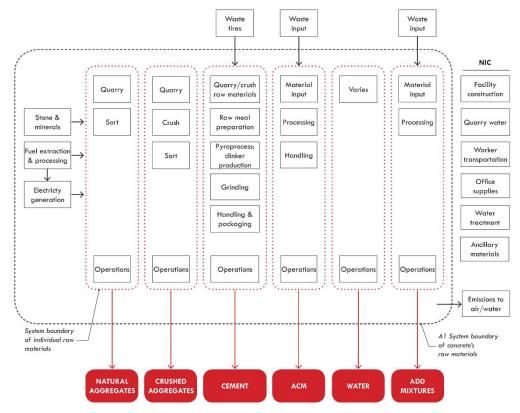
GWP	ODP	AP	EP	POCP	PEC	NRE	RE	NRM	RM	CBW	CWW	TW	CHW	CNHW
kg CO2	kg CFC-11	kg 502	kg N	kg 03	MJ	MJ	MJ	kg	kg	m3	m3	m3	kg	kg
285.51	4.25E-6	1.16	0.13	13.30	2,345.66	2,285.55	38.78	2,312.50	0.51	0.18	0.15	0.33	0.00	0.06
291.80	4.31E-6	1.18	0.13	13.52	2,371.97	2,312.72	39.77	2,161.83	0.50	0.20	0.15	0.35	0.00	0.06
292.25	4.35E-6	1.19	0.13	13.51	2,385.35	2,324.76	39.77	2,279.08	0.51	0.19	0.15	0.34	0.00	0.06
184.82	2.73E-6	0.94	0.10	11.87	1,734.89	1,688.61	24.33	2,211.19	0.39	0.18	0.15	0.33	0.00	0.06
183.93	2.71E-6	0.93	0.10	11.82	1,725.88	1,679.93	24.25	2,190.36	0.39	0.18	0.15	0.33	0.00	0.06
320.75	4.75E-6	1.30	0.14	14.56	2,578.83	2,514.78	43.63	2,288.95	0.54	0.18	0.15	0.33	0.00	0.06
324.83	4.81E-6	1.31	0.14	14.52	2,585.60	2,521.94	44.45	2,185.46	0.54	0.20	0.15	0.35	0.00	0.06
294.58	4.36E-6	1.20	0.13	13.76	2,408.32	2,347.80	39.93	2,263.94	0.51	0.17	0.15	0.33	0.00	0.06
301.93	4.49E-6	1.23	0.14	13.91	2,457.79	2,395.62	41.00	2,324.48	0.52	0.17	0.15	0.32	0.00	0.06
199.71	2.93E-6	1.00	0.11	12.60	1,840.97	1,792.95	26.30	2,211.44	0.41	0.17	0.15	0.33	0.00	0.06
289.18	4.28E-6	1.18	0.13	13.76	2,388.90	2,328.40	38.94	2,333.62	0.51	0.16	0.15	0.31	0.00	0.06
171 00	4 045 4	1 11	0.12	12.04	2 256 16	2 109 20	26.01	2 269 74	0.40	0.17	0.15	0.22	0.00	0.04

https://www.nrmca.org/sustainability/EPDProgram/Downloads/Graniterock%20EPD_01202015.pdf

Environmental Product Declarations (EPDs)

- Based on Product Category Rules (PCRs):
 - A document establishing criteria for preparing an EPD
 - Setting boundaries
 - Identifies impact categories

Achieve comparability in results



CARBON LEADERSHIP FORUM

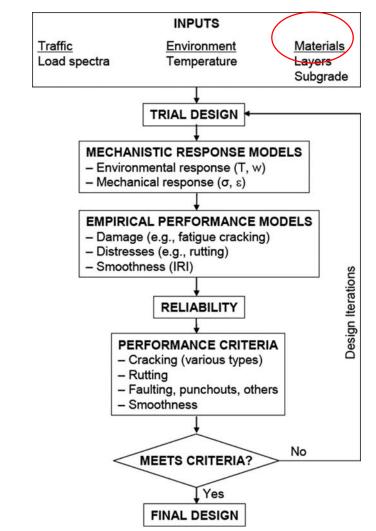
PCR setting system boundaries

Objective and scope of the study

Develop a methodology for sustainable Mechanistic Empirical Pavement design using EPD as a quantification tool.

Environmental impacts of materials

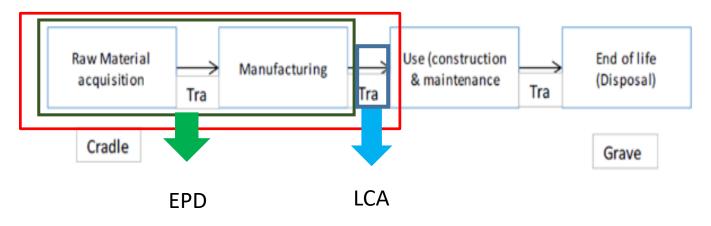
- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Ozone Depletion Potential (ODP)
- Photochemical Ozone Creation (POCP)



Existing Mechanistic Empirical Pavement design framework

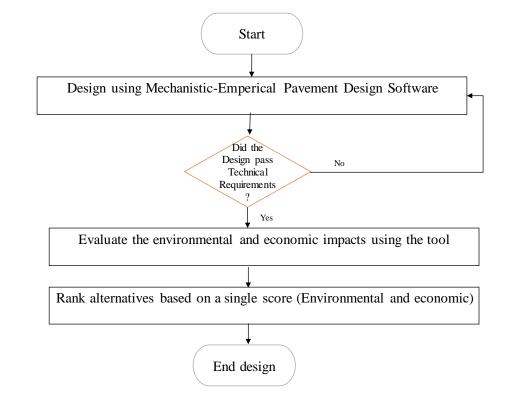
Objective and scope of the study

- Quantify the Environmental impact of materials used (Cradle to gate analysis) for rigid pavement
- Evaluate the Environmental impact of the transportation stage from the manufacturer to the project location.

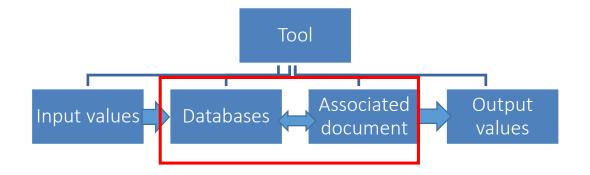


Tool workflow-demonstration

- The design should technically pass the analysis in Mechanistic Empirical Pavement design
- Analyze the Environmental and Economic impacts respectively
- Rank alternatives based on a single score



- The software/tool is composed of :
 - Input values
 - User inputs:
 - Design/project information
 - layer information / thickness
 - Databases
 - Environmental database
 - Economic/ cost analysis database
 - Transportation database
 - Associated documents
 - Product category rule for comparability
 - Output values
 - Environmental impact of the design
 - Economic impact of the design
 - Total single score (Environmental+ Economic)
 - It is expandable/easy to use/



- Environmental database
 - A compilation of Environmental product declarations
 - Search criteria:
 - Mix design description
 - Cement
 - Fly ash
 - Slag
 - Water
 - Fine aggregate
 - Coarse aggregate
 - Compressive strength value
 - Region

its (V) Co	mpressive_Strengt	h pressive strength @	Global_Warming_Potential	e_ Depletion_	Pote Acidification_ Potential	Eutrophication _	Potentia chemical_Ozone_Crefotal	_ Primary_ Energy_ Consumption	_ Non_Renewable
m3	4000	28	3.41E+02	3.97E-06	1.918	0.058	2.77E+01	1919	1905
m3	3000	28	3.71E+02	4.30E-06	2.075	0.063	2.99E+01	2066	2051
m3	4500	28	4.02E+02	4.63E-06	2.233	0.066	3.18E+01	2205	2189
m3	4000	28	3.94E+02	4.56E-06	2.19	0.065	3.13E+01	2175	2158
m3	4400	28	3.34E+02	3.89E-06	1.894	0.058	2.78E+01	1889	1875
m3	4500	28	4.33E+02	4.95E-06	2.393	0.07	3.38E+01	2347	2330
m3	4500	28	4.64E+02	5.29E-06	2.549	0.073	3.58E+01	2491	2473
m3	5000	28	3.41E+02	3.99E-06	1.921	0.059	2.78E+01	1929	1914
m3	3000	28	2.60E+02	3.10E-06	1.525	0.05	2.34E+01	1557	1546
m3	4500	28	2.98E+02	3.51E-06	1.724	0.055	2.60E+01	1733	1721
m3	6000	28	554	6.38E-06	3.018	0.085	4.17E+01	2945	2924
m3	9000	28	410	4.76E-06	2.28	0.067	3.25E+01	2252	2235
m3	3600	28	496	5.79E-06	2.72	0.078	3.79E+01	2675	2656
m3	6000	28	464	5.32E-06	2.547	0.073	3.57E+01	2500	2482
m3	5000	28	527	6.10E-06	2.877	0.082	3.99E+01	2817	2796
m3	8000	28	493	5.74E-06	2.711	0.078	3.80E+01	2660	2641
m3	9000	56	520	5.99E-06	2.853	0.082	3.98E+01	2785	2765
m3	9000	56	522	6.05E-06	2.857	0.081	3.98E+01	2793	2774
m3	4000	28	348	4.04E-06	1.952	0.058	28.1	1912	1897
m3	3000	28	378	4.38E-06	2.115	0.063	30.3	2065	2049
m3	4500	28	411	4.72E-06	2.279	0.066	32.2	2209	2193
m3	4000	28	402	4.65E-06	2.234	0.065	31.7	2177	2160
m3	4400	28	341	3.95E-06	1.929	0.058	28.1	1885	1871
m3	4500	28	443	5.05E-06	2.445	0.07	34.4	2358	2340
m3	4500	28	475	5.40E-06	2.607	0.074	36.4	2507	2488
m3	5000	28	348	4.06E-06	1.954	0.058	28.1	1920	1905
m3	3000	28	264	3.14E-06	1.547	0.05	23.6	1540	1528
m3	4500	28	303	3.56E-06	1.754	0.055	26.3	1725	1712
m3	6000	28	568	6 53E-06	3.001	0.086	12.6	2077	2056

Environmental product declaration

1.00	****						1.54			55				
	Water_Cement_Ratio	Water		Slag_Weight		Coarse_Aggregate			_	US dollar	-	State	Validity	Air (%)
376	0.5	246	118	0	1309	1875	3924	1 Y3	201.25	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
411	0.45	262	176	0	1346	1840	4035	1 Y3	206.25	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
451	0.43	257	141	0	1193	1875	3917	1 Y3	206.3	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
441	0.44	261	147	0	1353	1840	4042	1 Y3	206.25	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
367	0.42	254	244	0	1202	1840	3906	1 Y3	207.5	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
489	0.41	263	153	0	1108	1900	3913	1 Y3	208.8	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
526	0.39	267	165	0	1079	1875	3912	1 Y3	211.35	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
376	0.53	249	94	0	1433	1900	4052	1 Y3	198.75	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
276	0.43	242	288	0	1340	1900	4045	1 Y3	208.00	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
322	0.36	240	336	0	1256	1900	4045	1 Y3	212.00	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
635	0.31	260	212	0	1256	1750	4073	1 Y3	229.00	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
461	0.42	275	197	0	1248	1840	4021	1 Y3	213.00	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
564	0.35	250	141	0	1285	1840	4080	1 Y3	222.5	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
526	0.42	275	132	0	1200	1900	4033	1 Y3	213.00	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
602	0.33	251	150	0	1241	1840	4084	1 Y3	227.50	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
559	0.32	259	240	0	1204	1800	4062	1 Y3	224	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
592	0.31	262	254	0	1840	1840	4062	1 Y3	229	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
595	0.32	273	255	0	1172	1750	4044	1 Y3	229.25	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
376	0.5	246	118	0	1309	1875	3924	1 Y3	201.25	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
411	0.45	262	176	0	1346	1840	4035	1 Y3	206.25	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
451	0.43	257	141	0	1193	1875	3917	1 Y3	206.3	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
441	0.44	261	147	0	1353	1840	4042	1 Y3	206.25	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
367	0.42	254	244	0	1202	1840	3906	1 Y3	207.5	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
489	0.41	263	153	0	1108	1900	3913	1 Y3	208.8	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
526	0.39	267	165	0	1079	1875	3912	1 Y3	211.35	Y3	South-Central	Texas	August 26th, 2019	4.50 +/- 1.5
376	0.53	249	94	0	1433	1900	4052	1 Y3	198.75	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
276	0.43	242	288	0	1340	1900	4045	1 Y3	208.00	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
322	0.36	240	336	0	1256	1900	4045	1 Y3	212.00	Y3	South-Central	Texas	August 26th, 2019	1.50 +/- 1.5
635	0.31	260	212	0	1256	1750	4073	1 V3	220.00	¥3	South-Central	Tevas	August 26th 2010	1 50 +/- 1 5

- Cost analysis database
- Classification
 - Rigid pavement design (Continuously Reinforced Concrete Pavement (CRCP vs Jointed Plain Concrete Pavement (JPCP)
 - Layers (Top layer, base, subbase)
 - Initial vs. maintenance and rehabilitation cost items

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ITEM_DESCRIPTION	Layer	r jement 🖅	esign 🕆	tem_T -	averag -	UNI -
Subgrade Layer (8" Thick) (Asphaltic Concrete)	Subgrade	Rigid	JPCP	Initial	53.5	SQYD
Subgrade Layer (8" Thick) (Asphaltic Concrete)	Subgrade	Rigid	CRCP	Initial	53.5	SQYD
Class I Base Course (6" Thick)	Base Course	Rigid	JPCP	Initial	32.875	SQYD
Class I Base Course (6" Thick)	Base Course	Rigid	CRCP	Initial	32.875	SQYD
Class II Base Course	Base Course	Rigid	JPCP	Initial	78.2196	CUYD
Class II Base Course	Base Course	Rigid	CRCP	Initial	78.2196	CUYD
Class II Base Course (4" Thick)	Base Course	Rigid	JPCP	Initial	17.7204	SQYD
Class II Base Course (4" Thick)	Base Course	Rigid	CRCP	Initial	17.7204	SQYD
Class II Base Course (8" Thick)	Base Course	Rigid	JPCP	Initial	21.1079	SQYD
Class II Base Course (8" Thick)	Base Course	Rigid	CRCP	Initial	21.1079	SQYD
Class II Base Course (8 1/2" Thick)	Base Course	Rigid	JPCP	Initial	19.219	SQYD
Class II Base Course (8 1/2" Thick)	Base Course	Rigid	CRCP	Initial	19.219	SQYD
Class II Base Course (Asphaltic Concrete Base on Embankment Layer)	Base Course	Rigid	JPCP	Initial	189.193	CUYD
Class II Base Course (Asphaltic Concrete Base on Embankment Layer)	Base Course	Rigid	CRCP	Initial	189.193	CUYD
Class II Base Course (8" Thick) (Asphaltic Concrete Base on Embankm	Base Course	Rigid	JPCP	Initial	37.8807	SQYD
Class II Base Course (8" Thick) (Asphaltic Concrete Base on Embankm	Base Course	Rigid	CRCP	Initial	38.3538	SQYD
Class II Base Course (8 1/2" Thick) (Asphaltic Concrete Base on Emba	Base Course	Rigid	JPCP	Initial	35.8346	SQYD
Class II Base Course (8 1/2" Thick) (Asphaltic Concrete Base on Emba	Base Course	Rigid	CRCP	Initial	35.8346	SQYD
Class II Base Course (10" Thick) (Asphaltic Concrete Base on Embanki	Base Course	Rigid	JPCP	Initial	31.4114	SQYD
Class II Base Course (10" Thick) (Asphaltic Concrete Base on Embanki	Base Course	Rigid	CRCP	Initial	31.4114	SQYD
Class II Base Course (12" Thick) (Asphaltic Concrete Base on Embanki	Base Course	Rigid	JPCP	Initial	57.9231	SQYD
Class II Base Course (12" Thick) (Asphaltic Concrete Base on Embanki	Base Course	Rigid	CRCP	Initial	57.9231	SQYD
Class II Base Course (16" Thick) (Asphaltic Concrete Base on Embanki	Base Course	Rigid	JPCP	Initial	17.7204	SQYD
Class II Base Course (16" Thick) (Asphaltic Concrete Base on Embanki	Base Course	Rigid	CRCP	Initial	17.7204	SQYD
Class II Base Course (6" Thick) (Soil Cement)	Base Course	Rigid	JPCP	Initial	6.93325	SQYD
Class II Base Course (6" Thick) (Soil Cement)	Base Course	Rigid	CRCP	Initial	6.93325	SQYD

- Transportation analysis
 - Vehicle types based on weight (light duty-medium duty-heavy duty)
 - Fuel consumption factor based on vehicle type
 - Fuel types (gasoline vs. diesel)

Light	-Duty		Medium H	eavy-Duty		Heav	y-Duty
Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Less than 6,000 lb	6,000 to 10,000 lb	10,000 to 14,000 lb	14,000 to 16,000 lb	16,000 to 19,500 lb	19,500 to 26,000 lb	26,000 to 33,000 lb	Greater than 33,000 lb
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Vehicle type	Fuel type	Global Warming Air (kg CO2 eq / kg substance)	Acidification Air (kg SO2 eq / kg substance)
light	gasoline	0.92	0.0045
Light	Diesel	1.05	0.0054
Medium	gasoline	1.90	0.0064
Medium	Diesel	2.18	0.0080
Цории	Gasoline	3.40	0.0080
Heavy	Diesel	3.91	0.0163

- The program includes 5 tabs:
  - Layer/design information
  - Weights
  - Environmental impact of transportation
  - Economic analysis
  - Summary/report

Layer Information	Weights	Transp/EnvAnalysis	EconAnalysis	Summary/Export
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- Tab 1: Layer information
  - Input project zip code
  - Select number of designs/layers to analyze/compare
  - Design type: New pavement
  - Pavement type: rigid pavement
  - Layer type: Portland cement concrete
  - Layer thickness
  - load material
  - Selection/filtering criteria
    - Compressive strength value and/or
    - Mix design description and/or
    - Region

	Imerical									
Layer Information	Weights	Transp/EnvAnalysis	EconAnalysis	Summary/Exp	ort					
		Project Location's 2	Zip Code:	95192						
		ala a al d								
Design 1 Design	n 2   Design	3 Design 4 +								
Design type:		Pavement	type:							
New pavement		<ul> <li>Rigid pav</li> </ul>	ement	*						
										-
र्ट् हे Layer Type	Portlan	d Cement Concrete		-						
Se cojertype	. Forear	d cement concrete								
Layer Type Layer Type Thickness:	10.0		inc	h v						
ayer		<u> </u>								
-	Load Ma	terial								
e 3										
Lay										
4										
syer										
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Select alternatives to	be averaged!							_		
								_		
	b be averaged! ive Strength (p:	si): 3000.0	psi	•	Mix desig	jn	Value	Unit		
Compress					Mix desig	jn	Value 400	Unit		
Compress	ive Strength (p:		al	~		jn [				
Compress	ive Strength (p:	ion: South-Centra	al	•	Cement Fly Ash	<b>jn</b> ( (	400	lbs lbs	•	
Compress	ive Strength (p:	ion: South-Centra South-Centra	al	•	Cement Fly Ash Slag Cement	<b>jn</b> ( (	400	lbs lbs lbs	*	
Compress	ive Strength (p:	ion: South-Centra South-Centra South-West	al	•	Cement Fly Ash Slag Cement Mixing Water	<b>jn</b> ( (	400	lbs lbs lbs	•	
Compress	ive Strength (p:	ion: South-Centra South-Centra South-West	al	·	Cement Fly Ash Slag Cement Mixing Water Coarse Aggregate	<b>jn</b> ( ( ( (	400	lbs lbs lbs lbs		
Compress	ive Strength (p:	ion: South-Centra South-Centra South-West	al	·	Cement Fly Ash Slag Cement Mixing Water	<b>jn</b> ( ( ( (	400	lbs lbs lbs	•	
Compress	ive Strength (p:	ion: South-Centra South-Centra South-West	al	Y	Cement Fly Ash Slag Cement Mixing Water Coarse Aggregate	<b>jn</b> ( ( ( ( (	400	lbs lbs lbs lbs		
Compress	ive Strength (p:	ion: South-Centra South-Centra South-West	al	Y	Cement Fly Ash Slag Cement Mixing Water Coarse Aggregate Fine Aggregate	<b>jn</b> ( ( ( ( ( (	400	lbs lbs lbs lbs lbs		
Compress	ive Strength (p:	ion: South-Centra South-Centra South-West	1	×	Cement Fly Ash Slag Cement Mixing Water Coarse Aggregate Fine Aggregate		400	lbs lbs lbs lbs lbs perc		
Compress	ive Strength (p:	ion: South-Centra South-Centra South-West	1	Y	Cement Fly Ash Slag Cement Mixing Water Coarse Aggregate Fine Aggregate		400	lbs lbs lbs lbs lbs perc		
Compress Analysis G	ive Strength (p:	ion: South-Centra South-Centra South-West National	12 Fly Ash (lbs)	• Mixes Slag Cement (I	Cement Fly Ash Slag Cement Mixing Water Coarse Aggregate Fine Aggregate Air		400	Ibs Ibs Ibs Ibs Ibs Ibs Ibs Ibs	ign	
Compress Analysis G mpressive Strength 00	ive Strength (p ieographic Reg P Regio South-Central	ion: South-Centra South-Centra South-Ventra South-West National	12 Fly Ash (lbs)	Mixes Slag Cement (I 0	Cement Fly Ash Slag Cement Mixing Water Coarse Aggregate Fine Aggregate Air Mixing Water 277.2	* Leave blank	400 100 if it is not part of Fine Aggreg 1511.59	Ibs Ibs Ibs Ibs Ibs Ibs Ibs Ibs	: • • • • • • • • • • • • • • • • • • •	
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- Tab 2: Weights
  - Environmental vs Economic weights (should sum to 100)
  - Environmental impact weights (should sum to 100)
    - Global warming potential
    - Acidification potential
    - Eutrophication potential
    - Ozone depletion potential
    - Photochemical ozone creation

ayer Information Weigh	ts Transp/EnvAnalys	is EconAnalysis	Summary/Export		
Performance Weights		Economic Perforr			
Predefined Wei	ghts: Default		•		
Global Warming Potentia	l(%): 20	Oz	one Depletion Potential(%):	20	
Acidification Potentia	I(%): 20 P	hotochemical Ozo	ne Creation Potential(%):	20	
Eutrophication Potentia	(%): 20				
			Sum(%): 100.0		
					Save

- Tab 3: Transportation impact
  - Vehicle type (light duty, medium duty, heavy duty)
  - Fuel type (diesel vs. gasoline)

acyfx WIP						-		
ayer Information Weights	Transp/EnvAnalysis	EconAnalysis	Summary/Ex	port				
Transportation detail	ls.							
Vehicle type:		<b>√</b> light∙	Duty Trucks					
Fule type:			im-Duty Truck -Duty Trucks	5				
Transportation dist	ance to site (miles):	10.0	buly nood	-				
💽 lacyfx WIP						_	0	~
lecyfx WIP Layer Information Weights	Transp/EnvAnalysis	EconAnalysis	Summary/Exp	ort		-	0	×
-	Transp/ErrvAnalysis [	EconAnalysis	Summary/Exp	DIT		_	0	×
-		EconAnalysis	Summary/Exp	ort		_		×
Layer Information Weights		EconAnalysis Light-Dut		Tro		-		×
Layer Information Weights			y Trucks	The second secon		-		×
Layer Information Weights Transportation deta Vehicle type: Fule type:		Light-Dut	y Trucks	ort •		-	•	×



View Reports

• Tab 4: Economic impact analysis (uses the net present value)

Input

- Start year of the project
- Analysis period (years)
- Discount rate

#### Select

- Pavement type (previously selected)
- Applied layer (Top layer, base, subbase)
- Initial cost items
- Maintenance and rehabilitation cost items
- Output/ comparison between various layers/designs
  - Initial cost
  - Maintenance and rehabilitation cost
  - Total cost

syfx WIP								_	- 🗆
	Weights Trans	sp/EnvAnalysis	EconAnalysis	Summary/Export					_
Start year		Analysis per		Discount rate:	2.0				
		Analysis per	JU. 30	Discount rate.	2.0	A			
▼ Alter						â			Initialization
	sign 1: Rigid paver					Davia	ment type	: CR	CD
	sign 2: Rigid paver sign 3: Rigid paver					Fave	ment type		CF
	sign 4: Rigid paver					Appli ~	ied Layer:	Тор	p Layer
		Ir	nitial Items	Layer Thickness					
Check			nitial Item Des	cription		Qu	antity	Unit	Price
$\checkmark$	8" Thick					1	S	QYD	50.9703059
$\checkmark$	8 1/2" Thick					1	S	QYD	90.9375
	9" Thick					1	S	QYD	68.0370308
	10" Thick					1	S	QYD	73.6244242
		P	A&R Items	Patching					
Check		M&R Ite	m Description		Quantity	Unit	Pri	ce	Occur year
	9.0 sq.yds. & und				1	SQYD	115.74	0	
	9.1 - 16.0 sq.yds-8	8" thick			1	SQYD	103.52	0	
	16.1 - 24.0 sq.yds	8" thick			1	SQYD	88.83	0	
	24.1 - 48.0 sq.yds	8" thick			1	SQYD	74.41	0	
Economic A	Analysis Performane	ce						-	- 0
	MR Cost			Sho	w.				
	Total Cost								
	Initial Cost MR Cost								
	MIK COst								
			Total cost						
2	250								
1	225								
	200								
	175								
1									
1	150								
1	150								
Value (USD)	150								
1	150								
1	150								
1	150 125 75 50 25								
1	150 125 75		Decian 1						
1	150 125 75 50 25		Design 1 Alternativ						
1	150 125 75 50 25	Initi		es					

- Tab 5: Output/ report
  - Environmental performance
    - Environmental impact of the material (from EPD)
    - Environmental impact of transportation
    - Overall: The sum of Environmental impact of the materials and the transportation stage

Iscyl	fx WIP					-		×
Løyer In	formation W	eights	Transp/EnvAnaly	sis EconAnalysis	Summary/Export			
E	invironmental.	Perform	ance *	EPD +	Raw impact per functional unit *			•
E	mironmental 8	Perform	ance					
E	conomical Per	formani	ce		-			
0	Verall Perform	ance				Show	Clean	3

lacyfx WIP					-	
Layer Informatio	n Weights	Transp/EnvAnalysis	EconAnalysis	Summary/Export		
Environm	ental Perform	nance 💌	EPD 👻	Raw impact per functional unit *		-
			IPD			
Design 1		- 1	rsp	*		
		(	Overall		Show	Clean

Iacyfx WIP	_	
Layer Information Weights Transportation EconAnalysis Summary/Export		
Environmental Performance	Impact Analysis per	Alt 👻
Design 1 - Layer 1 -		
	Show	Clean

- Tab 5: Output/ report
  - Economic performance
    - Initial items
    - Maintenance and rehabilitation items
    - Total Economic performance (Initial items+ maintenance and rehabilitation item per design)
  - Total performance
    - A total score for Economic + Environmental impacts
    - Rank alternatives based on total score

			-
Layer Information         Weights         Transp/EnvAnalysis         EconAnalysis         Summary/Export			
Economical Performance			
All designs 👻			
Design 1	Show	Clea	in
All designs			
Economic Analysis Performance	-		>
Total Cost 👻			
Total Cost			
Initial Cost			
MR Cost			
Total cost			
300 =			
275			
250			
Cost And Cos			
8 100 100 100 100 100 100 100 100 100 10			
75			
50			
25			
Design 1			
Alternatives			
Initial cost M&R cost			
🔲 lacyfx WIP	_		;
Layer Information Weights Transp/EnvAnalysis EconAnalysis Summary/Export			
Overall Performance 👻			
All designs 👻			

• All values can also be displayed in a table format

Environmen	tal Performanc	e 💌	EPD -	Raw impac	t per functional unit	-	All Energy Consur	nptio 💌	
Design 1	-	La	iyer 1	-					
									Show o
			Energy	Concumption	Emission Impact				
					n Emission Impact				
Design_ID	Layer_ID	GWP	GWP_Unit	ODP	ODP_Unit	AP	AP_Unit	EP	
Design_ID Design 1	Layer_ID Layer 1	<b>GWP</b> 404100.0				AP 1428.0	AP_Unit Kg SO2 eq	EP 488.9	Kg I
_			GWP_Unit	ODP	ODP_Unit		_		
_			GWP_Unit	ODP	ODP_Unit		_		
_			GWP_Unit	ODP	ODP_Unit		_		

### Calculation algorithm summary

- Layer thickness
- EPD database: calculate the corresponding layer volume based on layer thickness

Equation

Layer volume × declared unit in EPD .

 Search criteria: compressive strength value and/or mix design breakdown

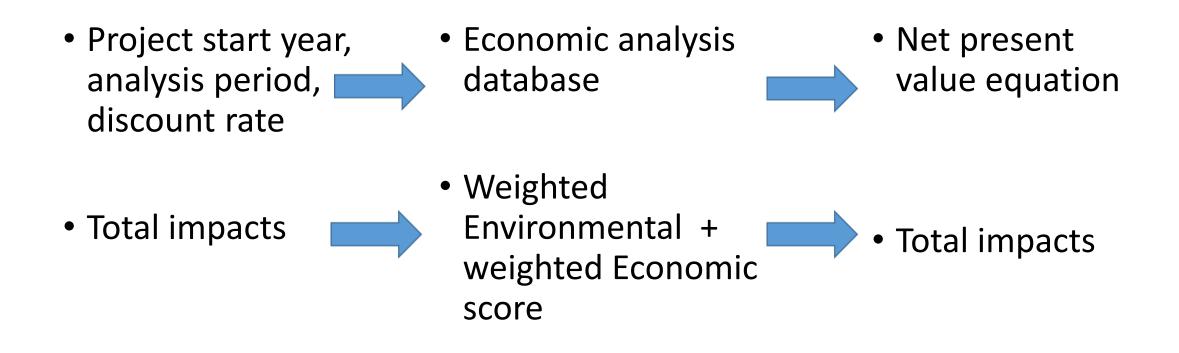
- Project location
- Calculate the total transportation distance and the corresponding environmental impacts



Equation:

- Emissions of substance= 2× (VKT × FC × substance content × Factor)
- VKT: Vehicle kilometers traveled.
- FC: fuel consumption factor (depending on truck weight)
- Substance content: weight of the material per liter of fuel recommended by EPA
- Factor: molecular weight 23

### Calculation algorithm summary

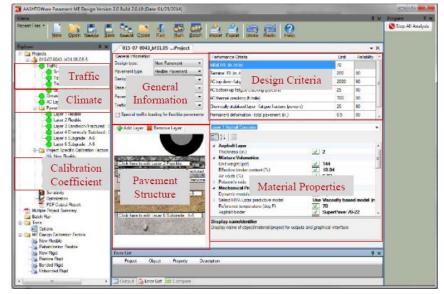


**Project information** 

- Located in SH 121 west of I-75 and east of the Dallas North Tollway
- The Dallas-Fort Worth weather station
- Moderate traffic volume with an average annual daily traffic (AADT) of 23,400
- Linear traffic growth of 4%
- Compare internally cure concrete with conventional concrete



http://www.escsi.org/uploadedFiles/Technical_Docs/Internal_Curing/Eval%20of%20ICC%20for%20Paving%20Apps%20Report.pdf

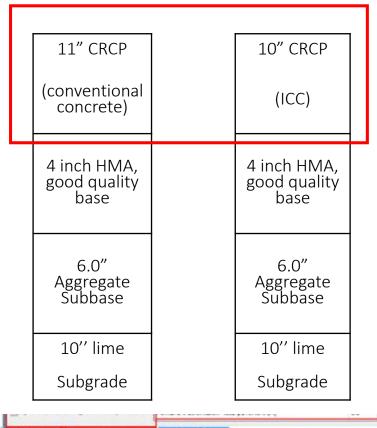


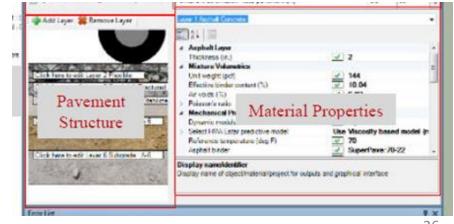
http://www.ltrc.lsu.edu/pdf/2016/FR_551.pdf

Step 1: Analyze using Mechanistic Empirical Pavement design

- Compare 2 design alternatives
  - Continuously Reinforced Concrete Pavement (CRCP)
  - Same overall design /different top layer
    - The design was successful, proceed to the Environmental and economic analysis

Alterna tive #	Туре	Compressive strength (psi)	Layer Thickness (inch)	
1	Conventional	6000	11	
2	Internally cured	5500	10	
	concrete			





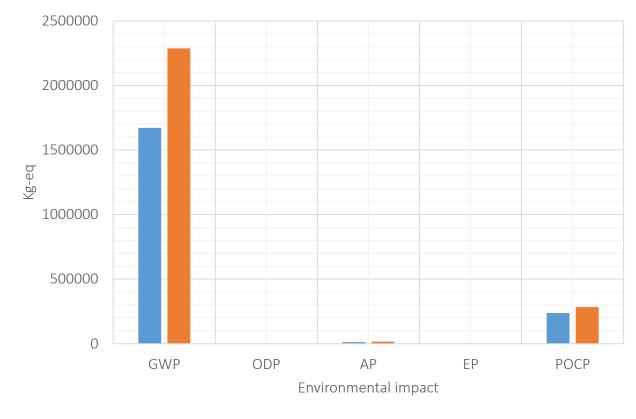
- Environmental impact (Extracted from EPD)
  - Search criteria: compressive strength value and/or mix design breakdown/location
  - Adjust to
    - Layer volume
    - Weights assigned

Alternative	Compressive strength (psi)	GWP	ODP	АР	EP	РОСР
1	6000	642	0.00000491	4.29	0.162	79.6
2	5500	516	0.0000041	3.72	0.151	73.4

Environmental impact	Assigned weight
GWP	0.2
ODP	0.2
AP	0.2
EP	0.2
РОСР	0.2

impact	weight
Environmental impact	0.5
Economic impact	0.5

- Environmental impact (Extracted from EPD)
  - Search criteria: compressive strength value and/or mix design breakdown
  - Adjust to volume
  - Total impacts



■ 10 inch ■ 11 inch

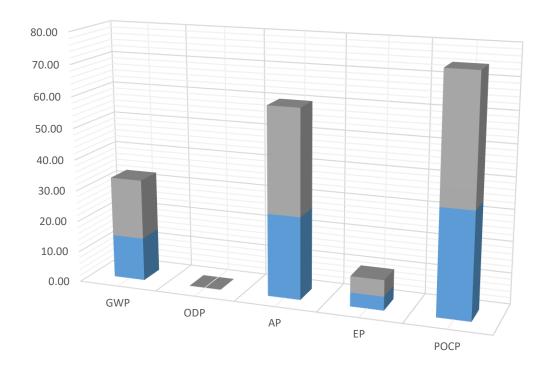
- Environmental impact of transportation
  - Based on calculated distance from projects location to the manufacturer

Alternative	Distance (km)	Fuel consumption factor (L/100 km)	GWP (kg CO2 eq)	AP (kg S eq)
1	5	12.8	3.00	0.0768
2	6	12.8	3.60	0.09216

### Total Environmental impacts per alternative

- (Environmental impact from EPD and from transportation state)
- Normalization

#### **Total Environmental Impact**



■ ICC ■ Conventional concrete

- Economic analysis database
  - Select corresponding initial and maintenance and rehabilitation alternatives
  - Uses net present value
    - Lower initial cost for ICC
    - Lower maintenance and rehabilitation cost due to its durability
    - Higher salvage value

Alternative (1)- Conventional Concrete	Alternative 2 - ICC			
Description (year)	Total NPV (\$)	Description (year)	Total NPV (\$)	
Initial cost	3,727,390	Initial cost	3,281,530	
Full-depth repair (15)	4108	Full-depth repair (15)	4,108	
Diamond Grind Existing Surface (25)	59,626	Diamond Grind Existing Surface (25)	59,626	
Full-depth pavement repairs (25)	382	Full-depth pavement repairs (25)	459	
Full-depth pavement repair (42)	1,156	Full-depth pavement repairs (40)	245	
Full-depth pavement repairs (50)	18,066	Full-depth pavement repairs (60)	4,685	
Place asphalt tack coat (9 sy/gal)	961	Place asphalt tack coat (9 sy/gal) (60)	715	
2.0-in HMAC binder	36,690	2.0-in HMAC binder (60)	27,301	
2.0-in HMAC surface	36,690	2.0-in HMAC surface (60)	27,301	
Salvage value	-57,754	Salvage value	-75,002	
Total (NPV) (\$)	3,827,315	Total (NPV) (\$)	3,330,968	

- Total score for each alternative
  - ICC alternative has lower : Environmental, economic and total score

Alternative	Thickness (inch)	Environmental impact	Environmental Impact (0.5)	Economic impact	Economic impact (0.5)	Total Weight
ICC	10	0.44	0.22	0.48	0.24	0.46
Conventional	11	0.56	0.28	0.52	0.26	0.54

### Conclusion and future work

- Limitations of existing tool for quantifying the Environmental impact of pavement
- The use of EPDs to quantify the environmental impact
  - Verifiable, accurate information, not misleading.
  - The data is based on a pre-set category of parameters
  - Comparable
  - Same system boundary
  - benchmarking
- Demonstration in a case study
- Future work
  - Expand the Environmental database
  - Evaluate sustainability of other materials once their EPDs become available
  - Expand the type of fuel used

THANK YOU Questions?

### References

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