A Methodology for Sustainable Mechanistic Empirical Pavement Design

Presented by

Neveen Soliman

Louisiana State University, United States

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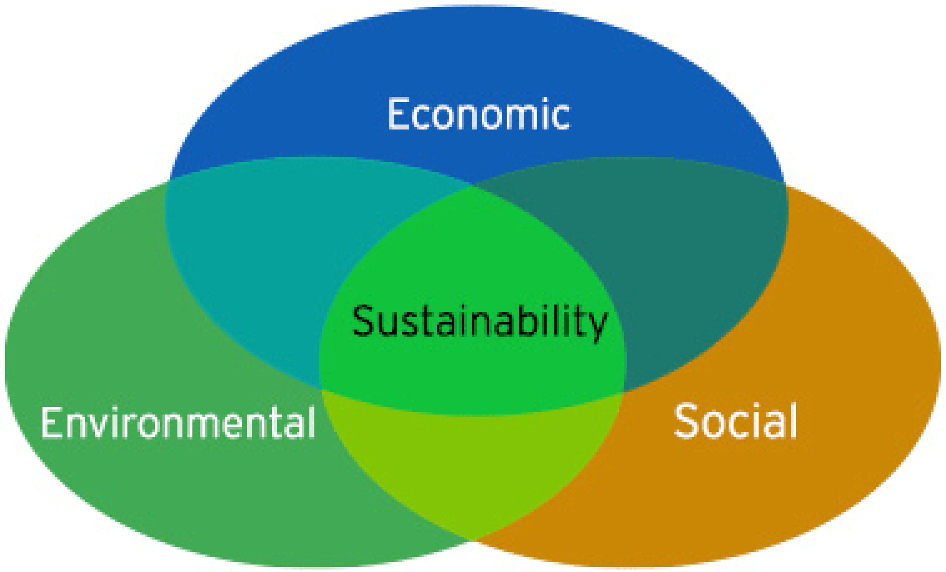
Outline

- 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



http://sustainability.uclahealth.org/images/about/what-is-sustainability.gif

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

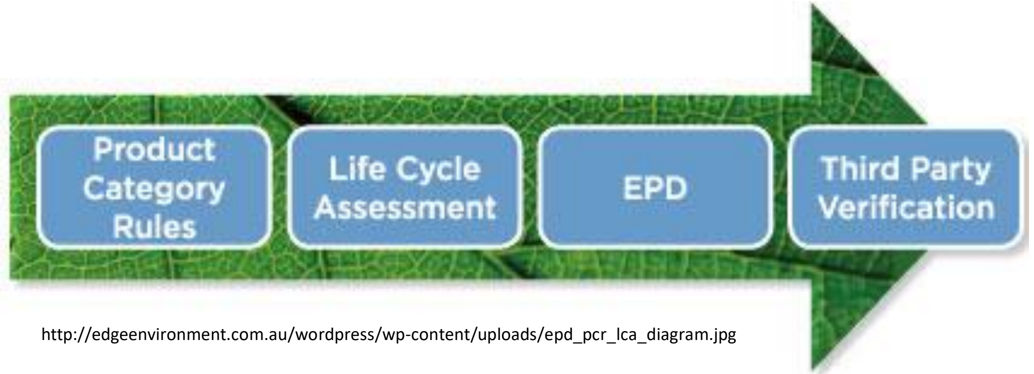
Methods for assessing sustainability

- 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



http://edgeenvironment.com.au/wordpress/wp-content/uploads/epd_pcr_lca_diagram.jpg

GWP	ODP	AP	EP	POCP	PEC	NRE	RE	NRM	RM	CBW	CWW	TW	CHW	CNHW
kg CO2	kg CFC-11	kg SO2	kg N	kg O3	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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

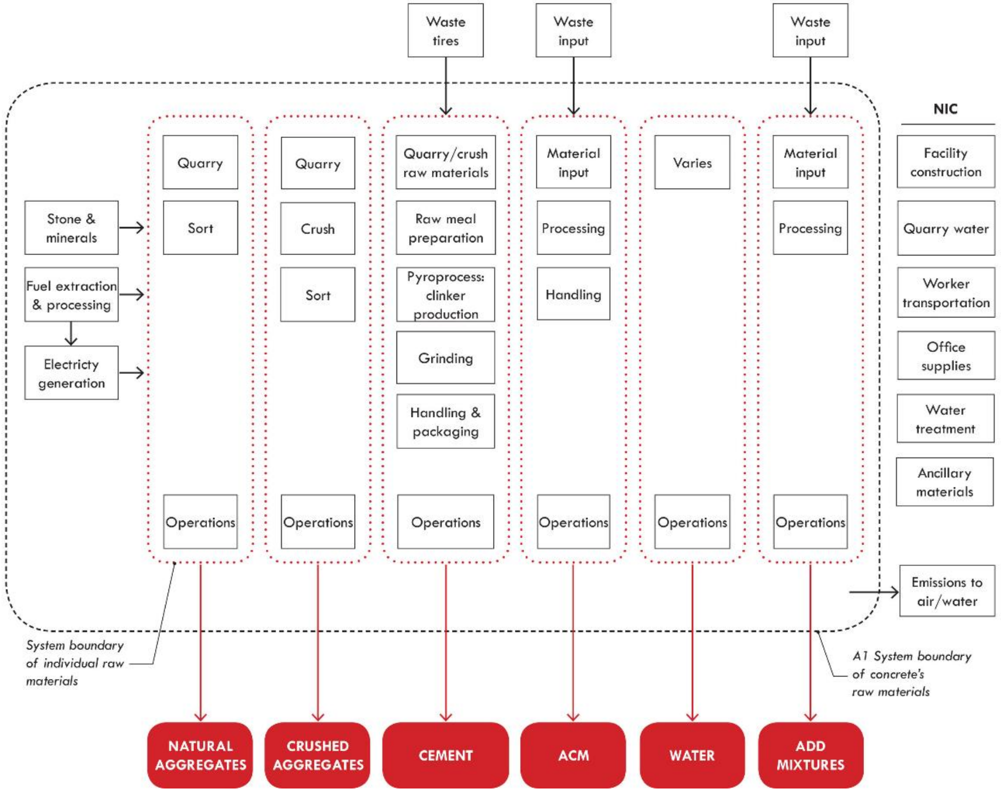
https://www.nrmca.org/sustainability/EPDProgram/Downloads/Graniterock%20EPD_01202015.pdf

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



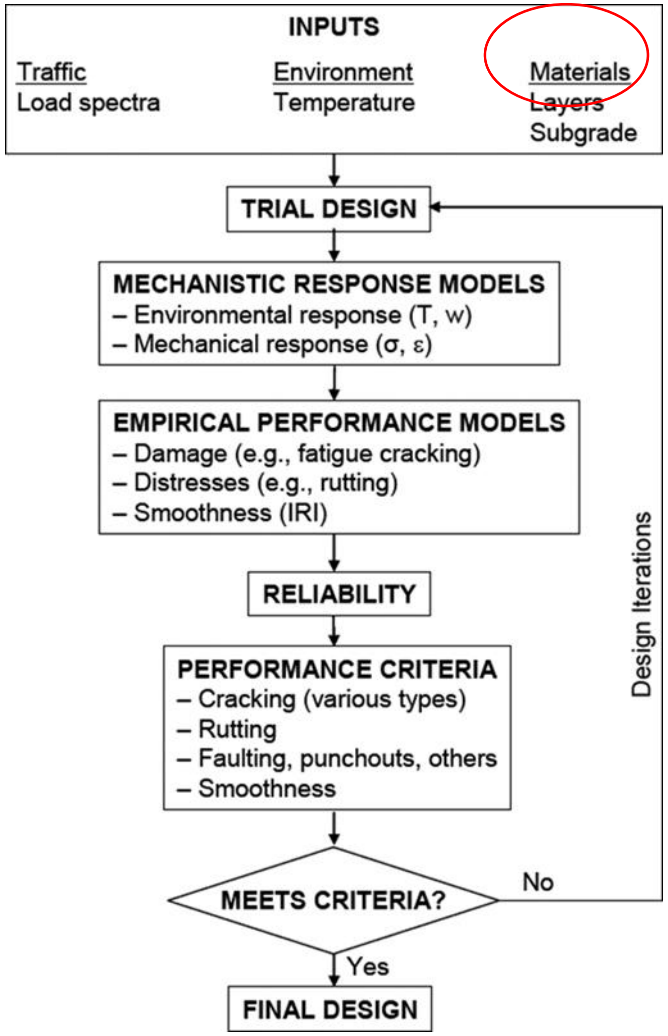
PCR setting system boundaries

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)

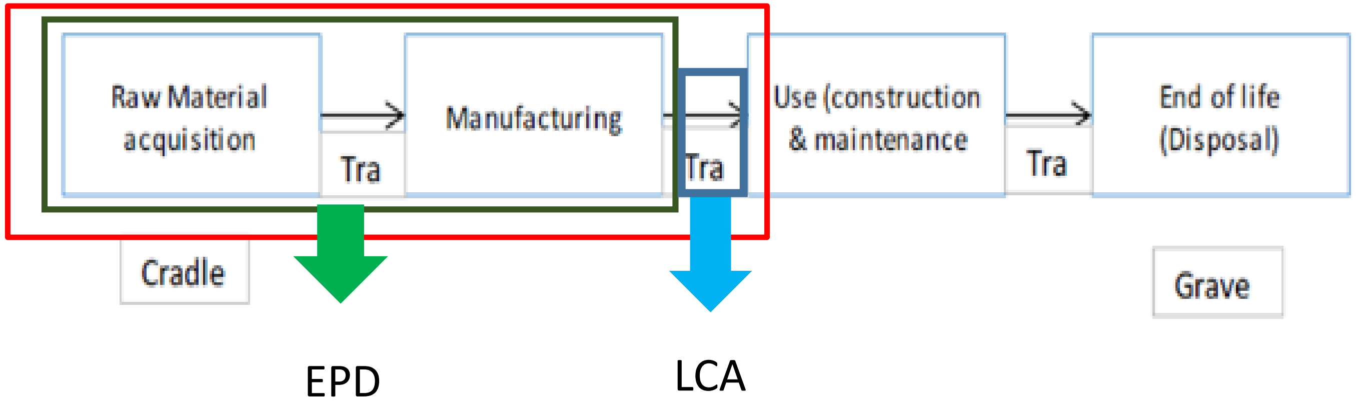


Existing Mechanistic Empirical Pavement design framework

https://www.fhwa.dot.gov/engineering/geotech/pubs/05037/images/f173.gif

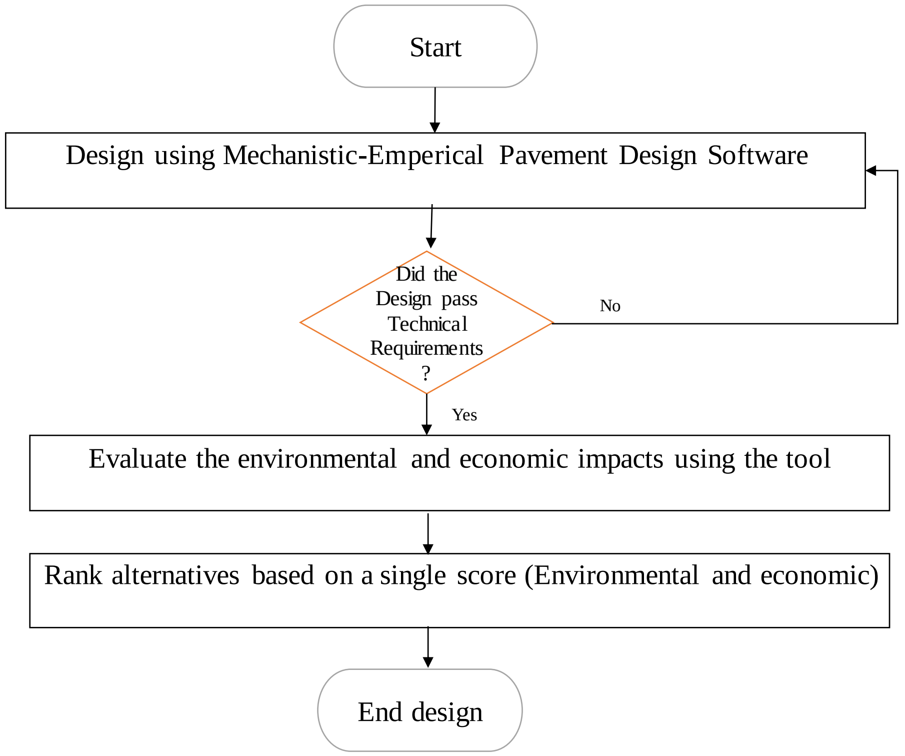
Objective and scope of the study

- 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.



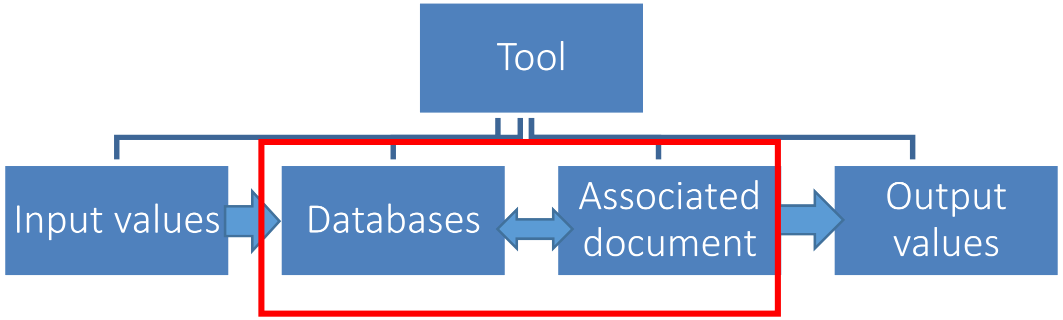
Tool workflow-demonstration

- 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



Tool composition

- 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/



Tool composition

- 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

Units (V)	Compressive_ Strength	pressive strength @	Global_Warming_Potential	e_ Depletion_ Pote	Acidification_ Potential	Eutrophication _ Potentia	chemical_ Ozone_ Cre	Total_ 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	3.091	0.086	42.6	2977	2956

Environmental product declaration

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

Mix design description

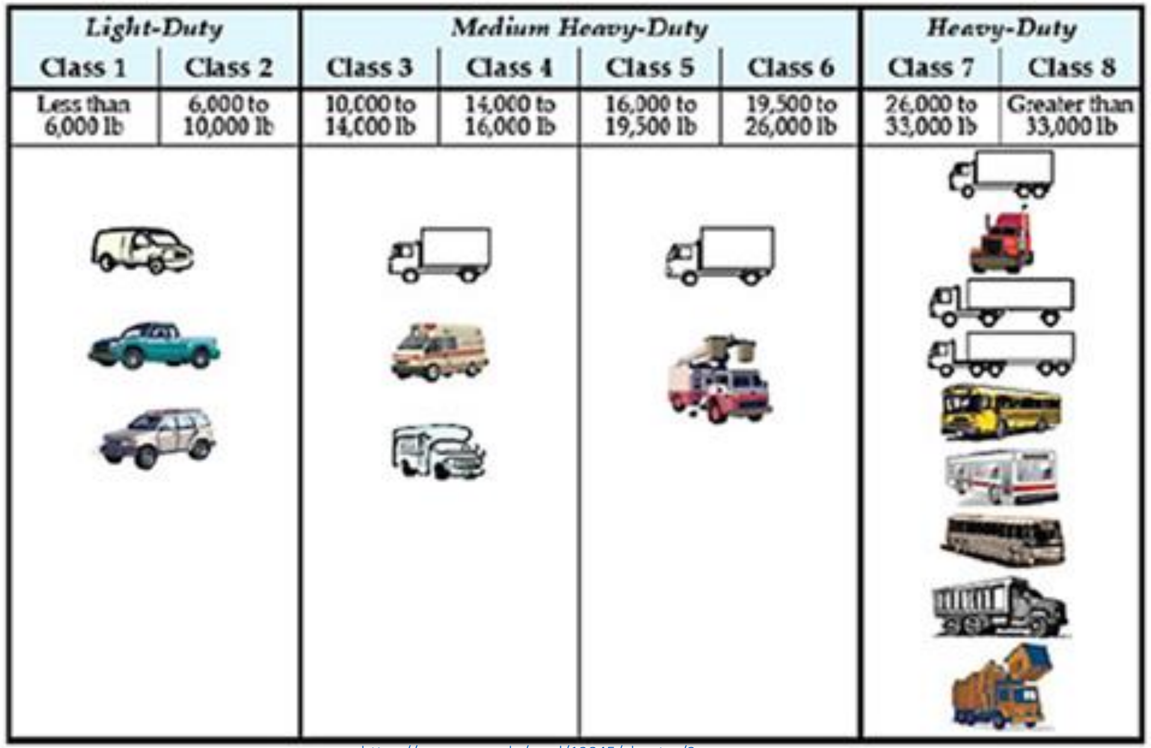
Tool composition

- 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

ITEM_DESCRIPTION	Layer	ement	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 Embankme	Base Course	Rigid	JPCP	Initial	37.8807	SQYD
Class II Base Course (8" Thick) (Asphaltic Concrete Base on Embankme	Base Course	Rigid	CRCP	Initial	38.3538	SQYD
Class II Base Course (8 1/2" Thick) (Asphaltic Concrete Base on Embar	Base Course	Rigid	JPCP	Initial	35.8346	SQYD
Class II Base Course (8 1/2" Thick) (Asphaltic Concrete Base on Embar	Base Course	Rigid	CRCP	Initial	35.8346	SQYD
Class II Base Course (10" Thick) (Asphaltic Concrete Base on Embankn	Base Course	Rigid	JPCP	Initial	31.4114	SQYD
Class II Base Course (10" Thick) (Asphaltic Concrete Base on Embankn	Base Course	Rigid	CRCP	Initial	31.4114	SQYD
Class II Base Course (12" Thick) (Asphaltic Concrete Base on Embankn	Base Course	Rigid	JPCP	Initial	57.9231	SQYD
Class II Base Course (12" Thick) (Asphaltic Concrete Base on Embankn	Base Course	Rigid	CRCP	Initial	57.9231	SQYD
Class II Base Course (16" Thick) (Asphaltic Concrete Base on Embankn	Base Course	Rigid	JPCP	Initial	17.7204	SQYD
Class II Base Course (16" Thick) (Asphaltic Concrete Base on Embankn	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

Tool composition

- 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)

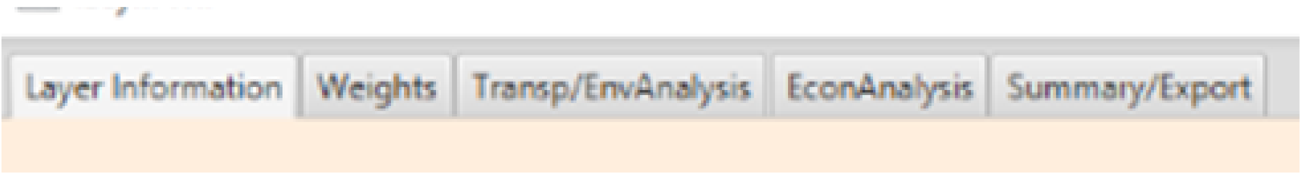


https://www.nap.edu/read/12845/chapter/3

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
	Diesel	1.05	0.0054
Medium	gasoline	1.90	0.0064
	Diesel	2.18	0.0080
Heavy	Gasoline	3.40	0.0080
	Diesel	3.91	0.0163

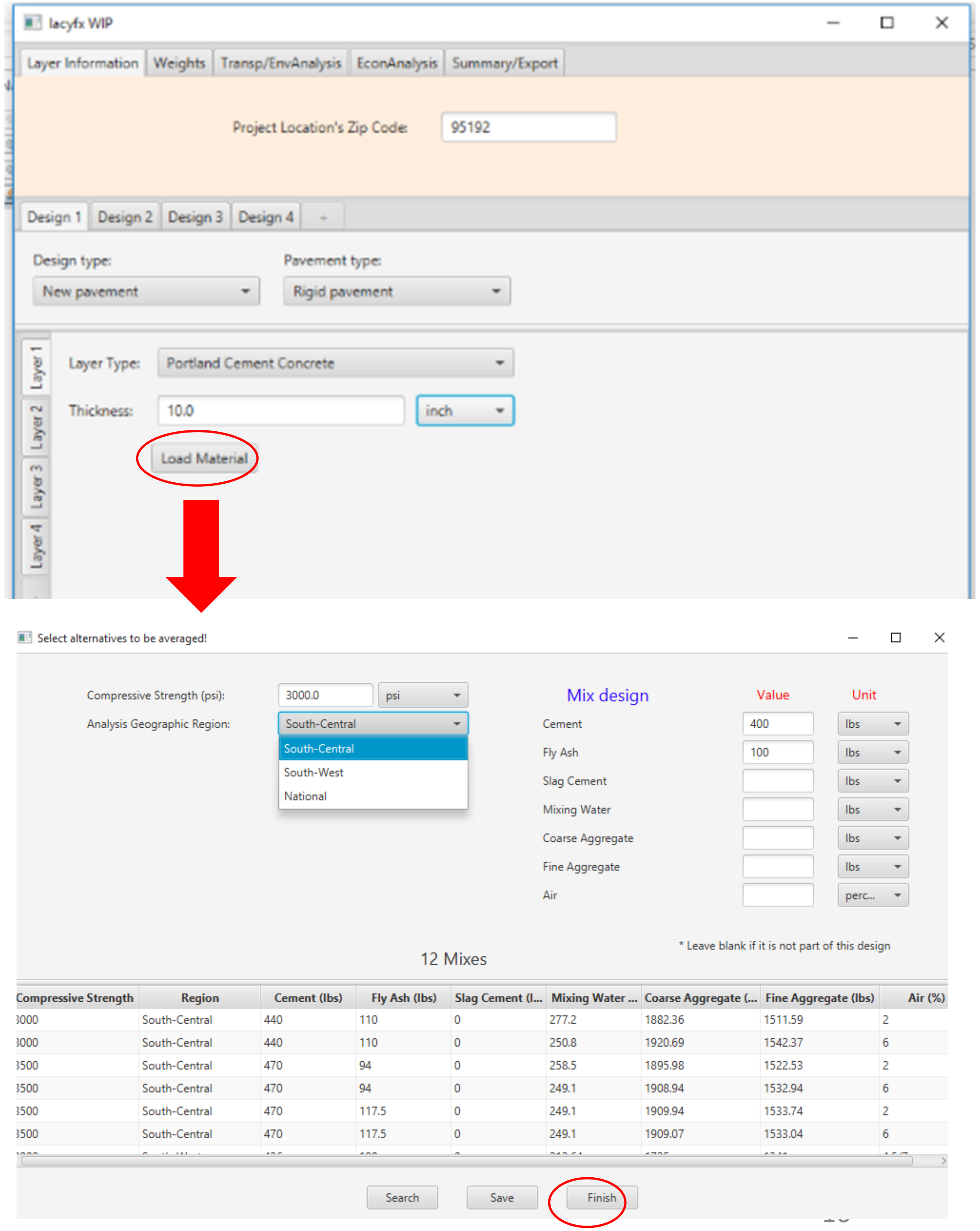
Software description

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



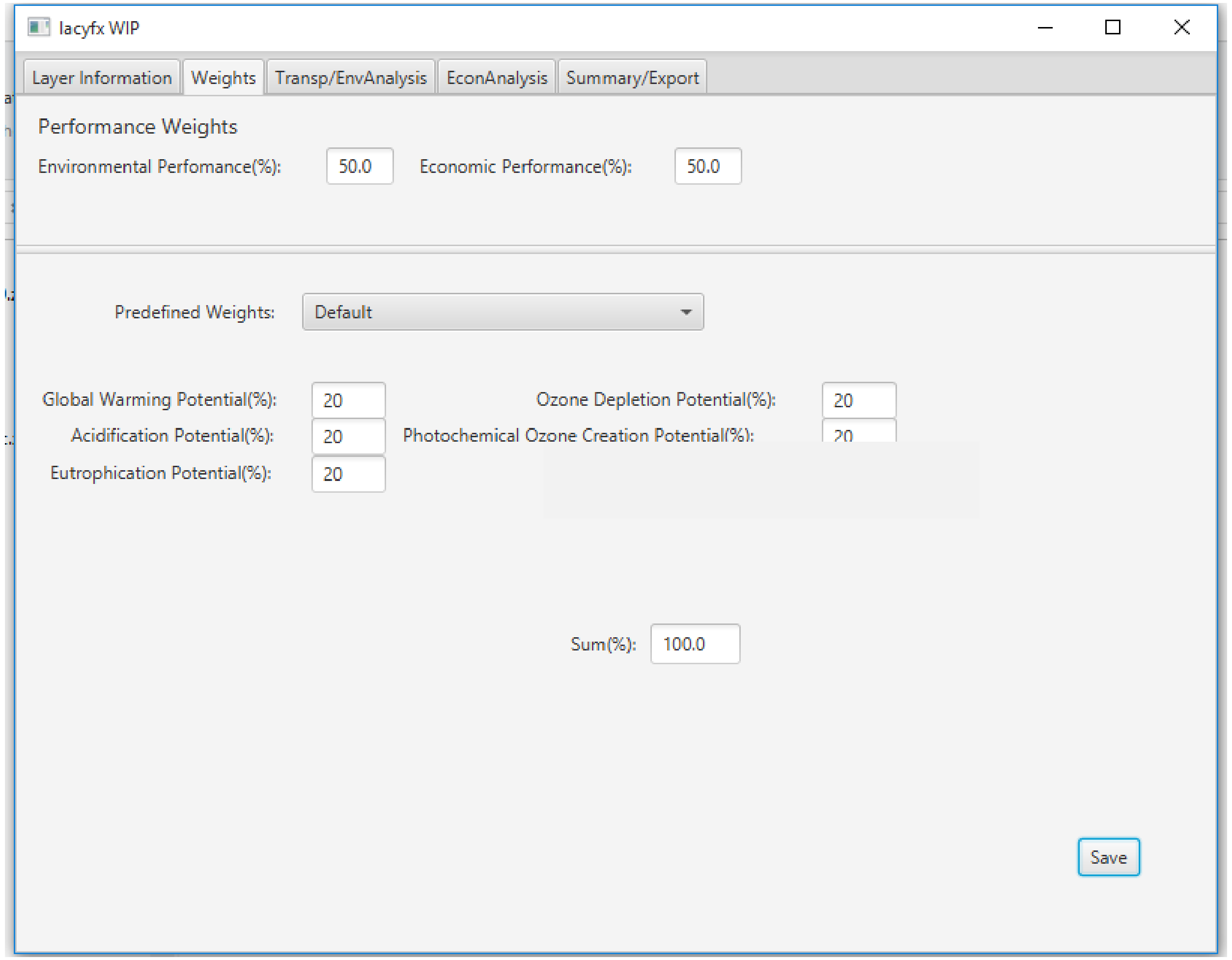
Software description

- 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



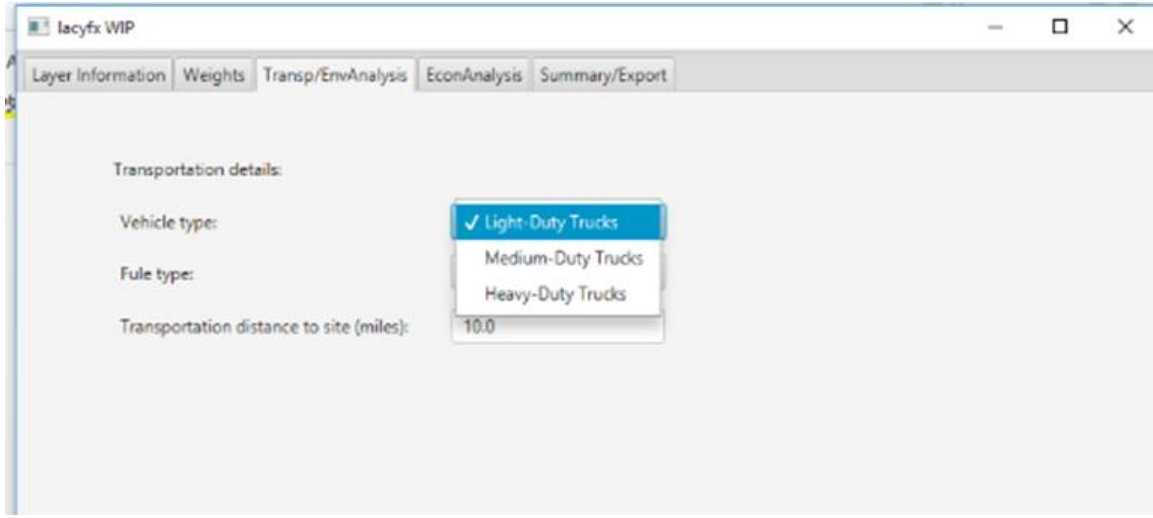
Software description

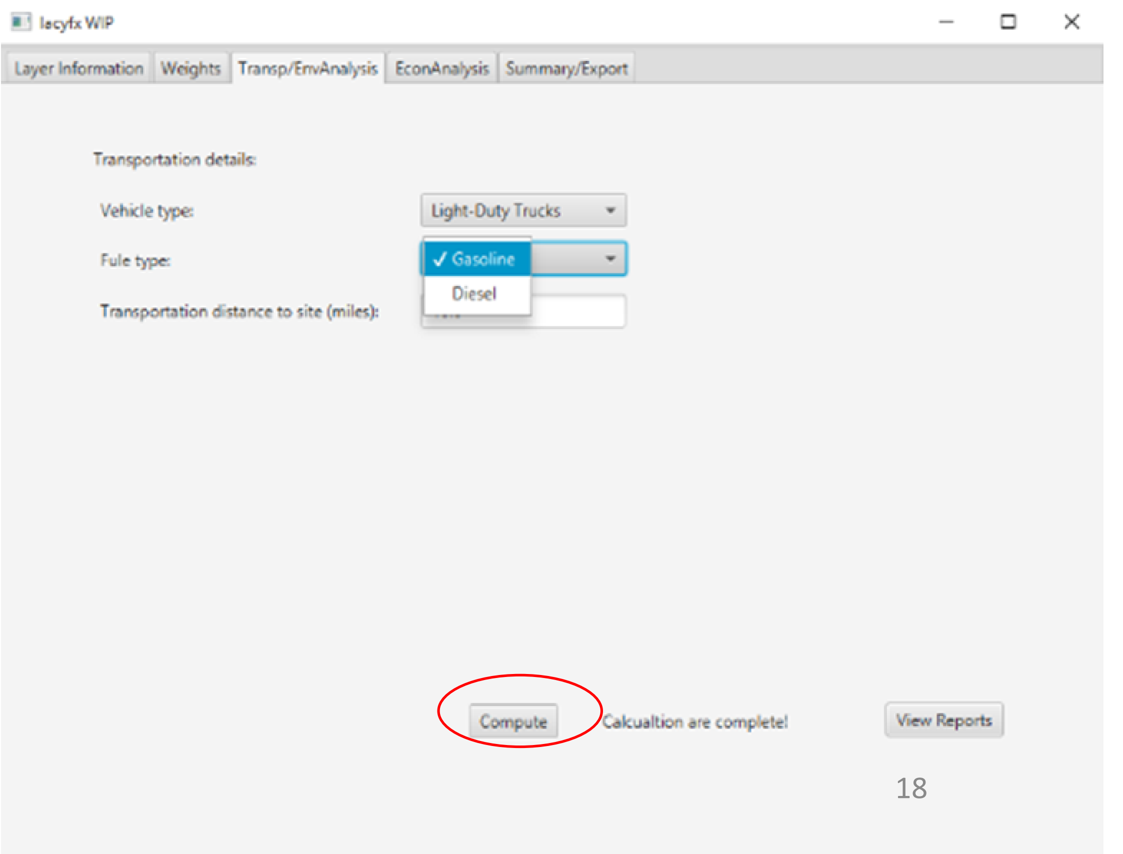
- Tab 2: Weights
  - Environmental vs Economic weights (should sum to 100)
  - Environmental impact weights (should sum to 100)
    - Global warming potential
    - Acidification potential
    - Eutrophication potential
    - Ozone depletion potential
    - Photochemical ozone creation



Software description

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





Software description

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

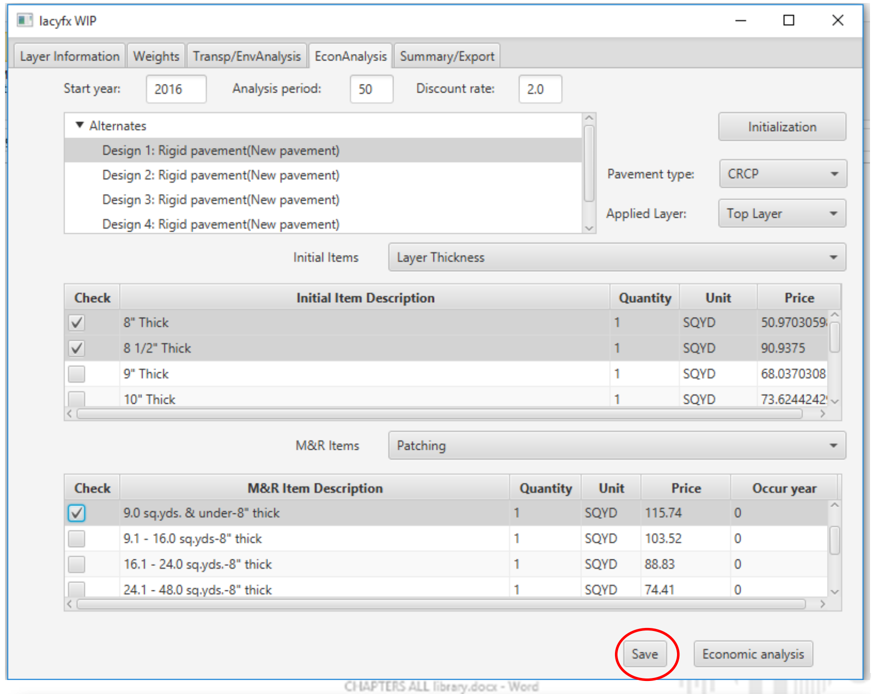
Input

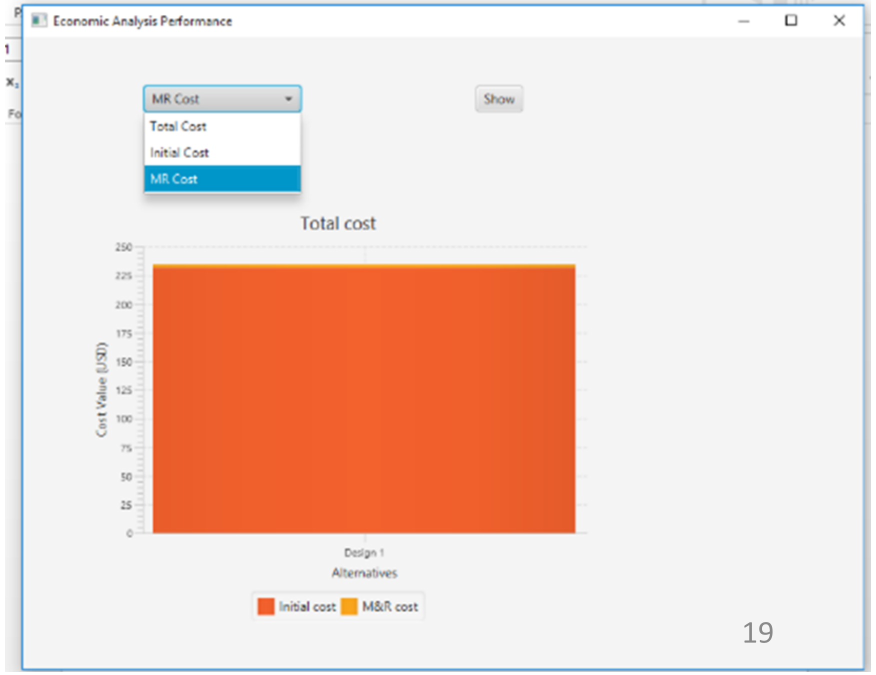
  - Start year of the project
  - Analysis period (years)
  - Discount rate

Select

  - Pavement type (previously selected)
  - Applied layer (Top layer, base, subbase)
  - Initial cost items
  - Maintenance and rehabilitation cost items

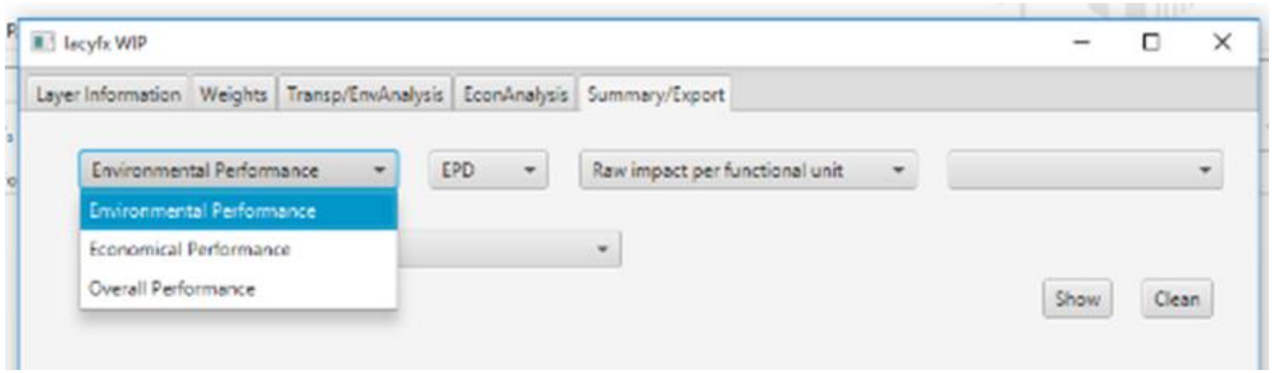
- Output/ comparison between various layers/designs
  - Initial cost
  - Maintenance and rehabilitation cost
  - Total cost

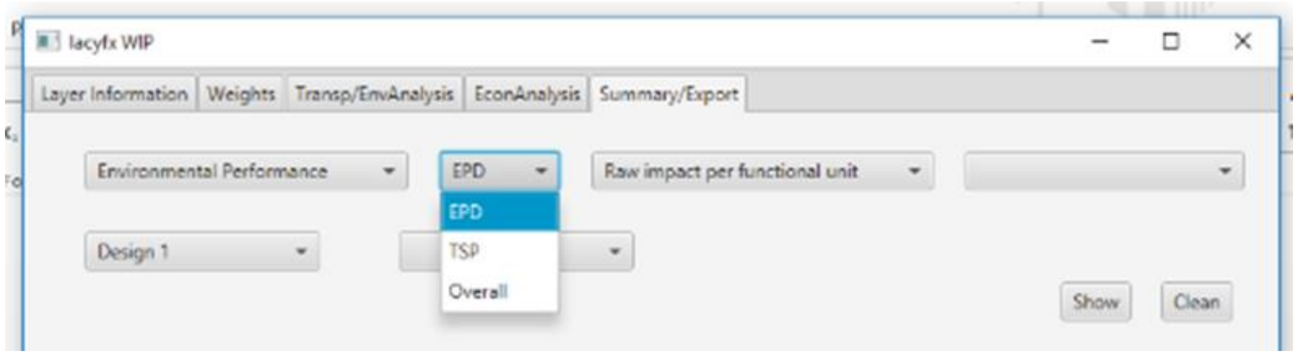


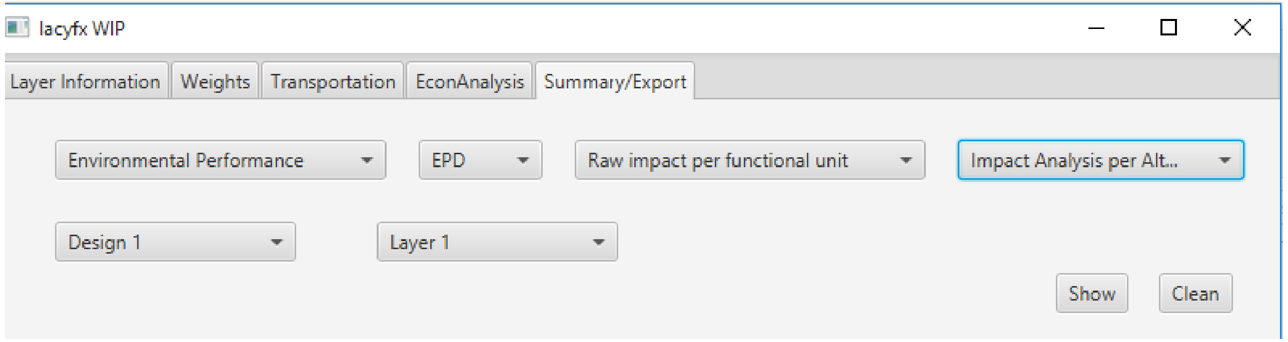


Software description

- 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

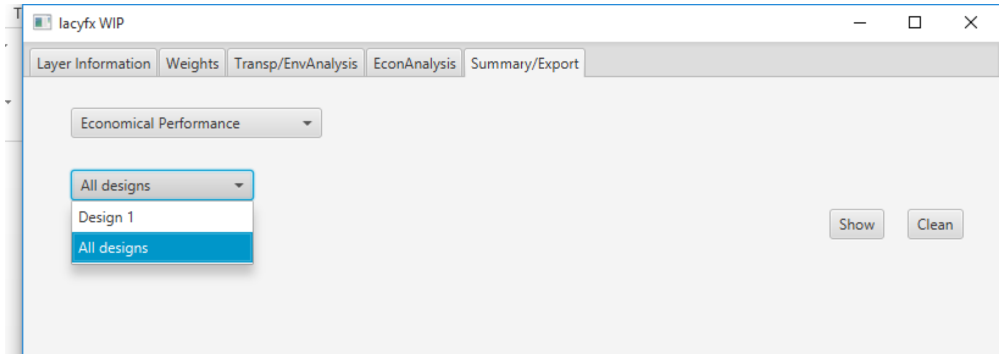


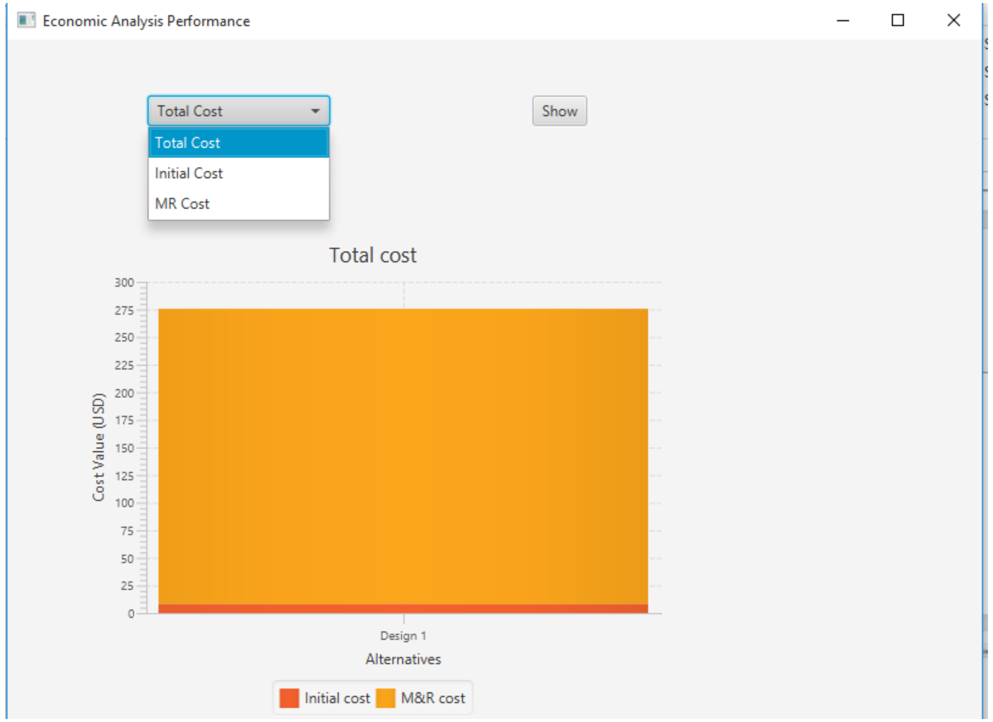


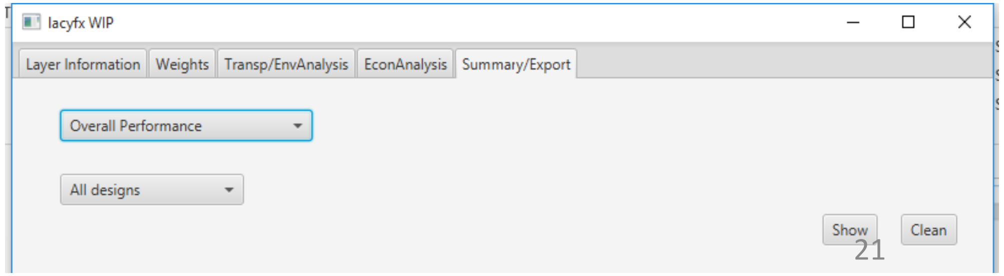


Software description

- 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

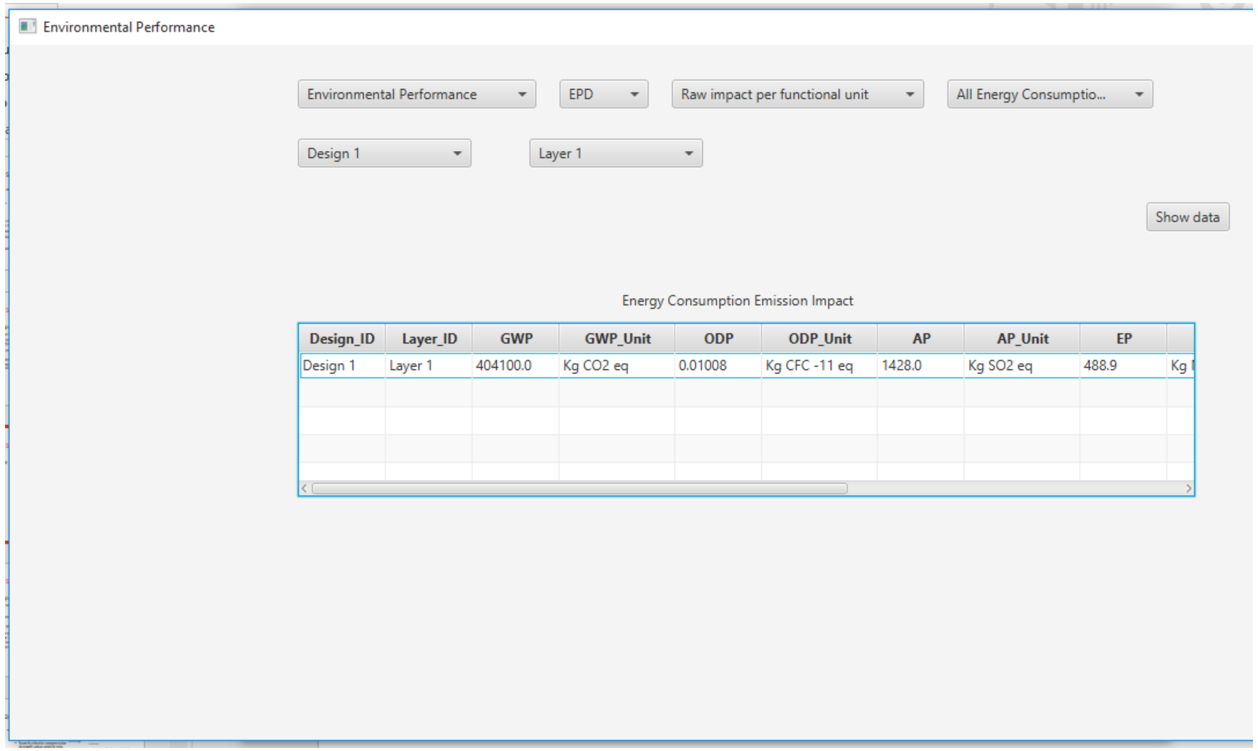






Software description

- All values can also be displayed in a table format



Calculation algorithm summary

- Layer thickness

- EPD database: calculate the corresponding layer volume based on layer thickness
  - Search criteria: compressive strength value and/or mix design breakdown

Equation

Layer volume × declared unit in EPD .

- 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 conversion

Calculation algorithm summary

- Project start year, analysis period, discount rate → Economic analysis database → Net present value equation

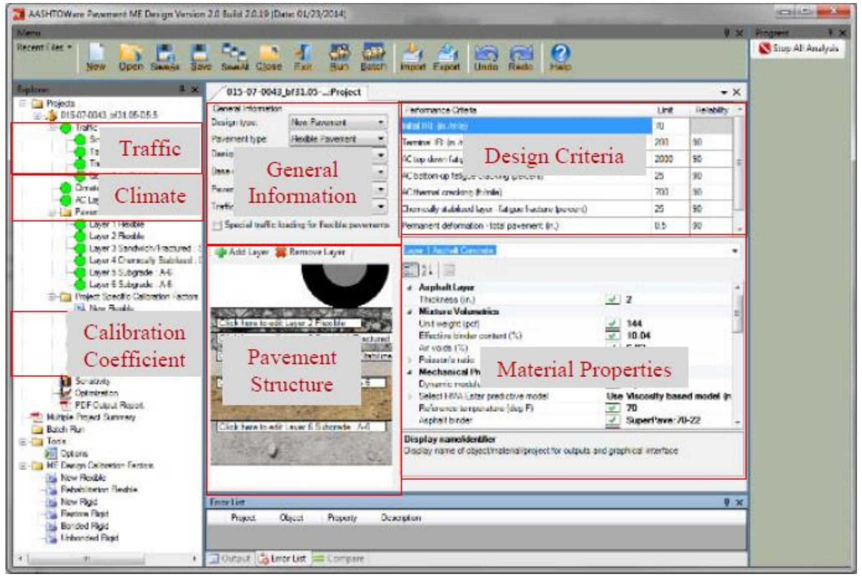
- Total impacts → Weighted Environmental + weighted Economic score → Total impacts

A case study

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



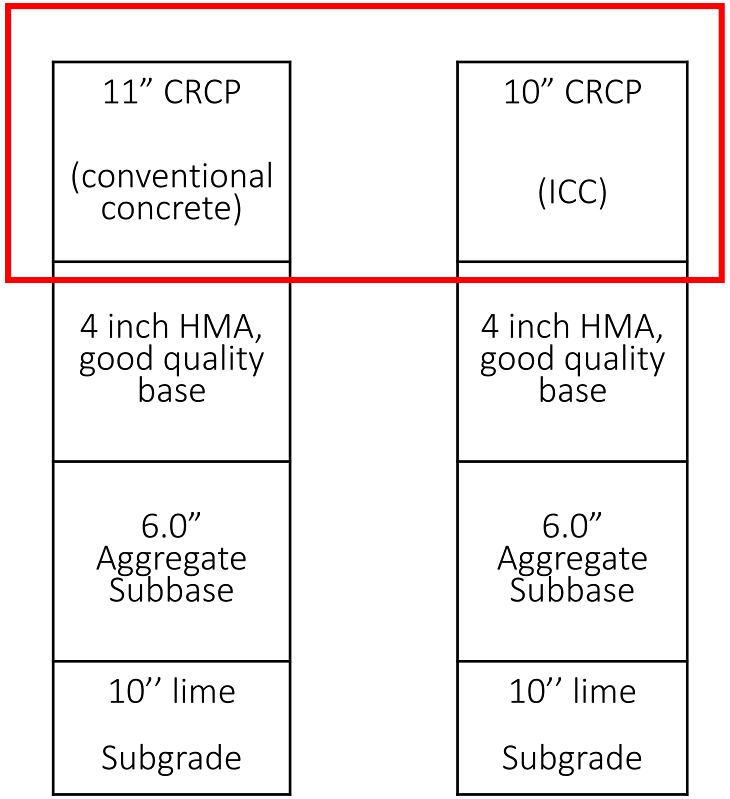
http://www.ltrc.lsu.edu/pdf/2016/FR_551.pdf

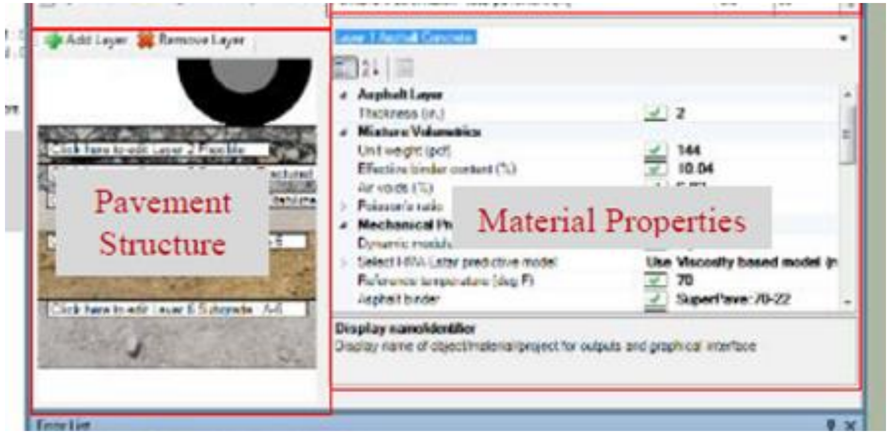
A case study

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

Alternative #	Type	Compressive strength (psi)	Layer Thickness (inch)
1	Conventional	6000	11
2	Internally cured concrete	5500	10





A case study

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

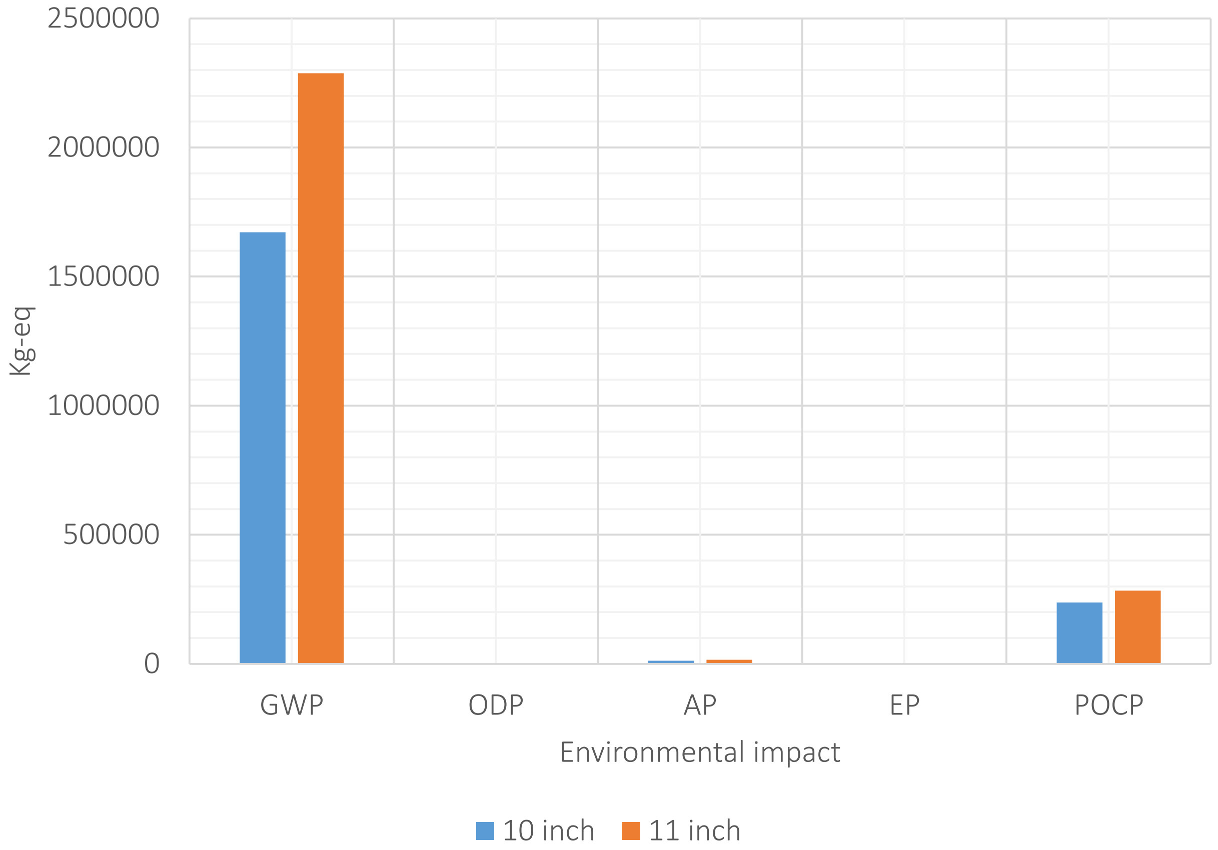
Alternative	Compressive strength (psi)	GWP	ODP	AP	EP	POCP
1	6000	642	0.00000491	4.29	0.162	79.6
2	5500	516	0.0000041	3.72	0.151	73.4

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

impact	weight
Environmental impact	0.5
Economic impact	0.5

A case study

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



A case study

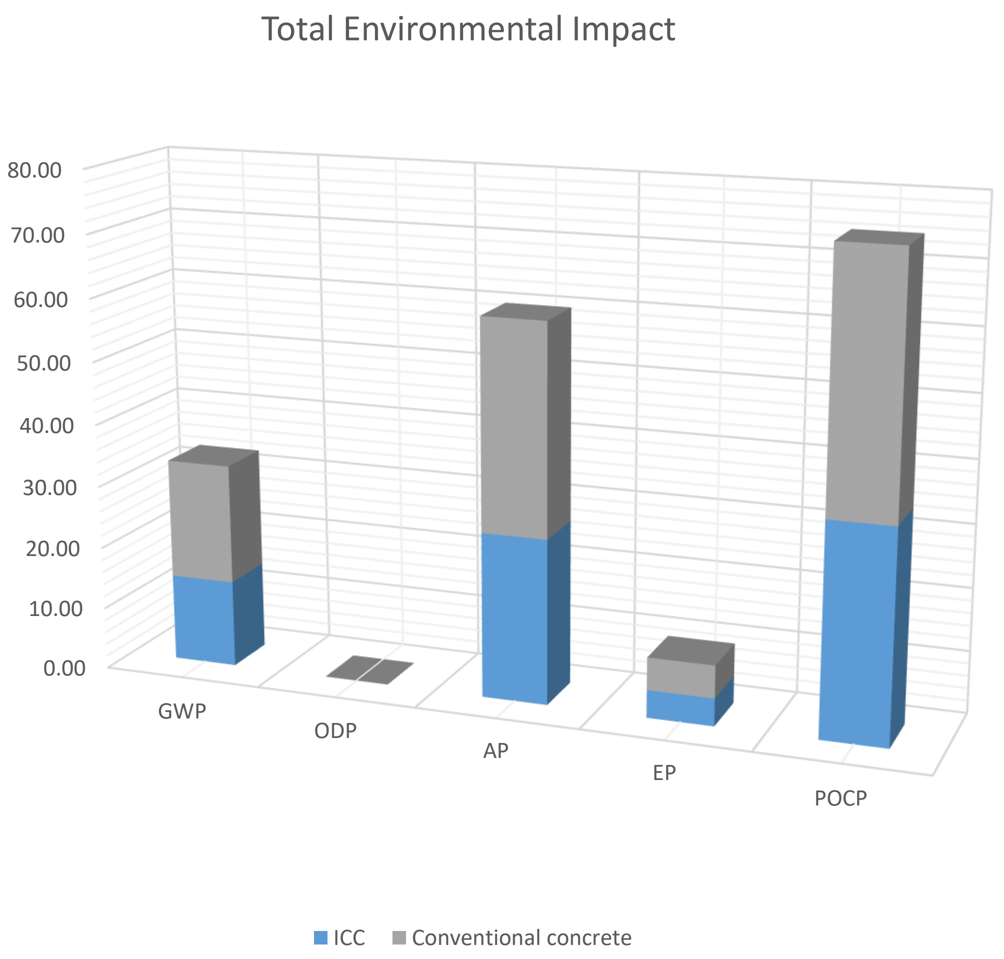
- Environmental impact of transportation
  - Based on calculated distance from projects location to the manufacturer

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

A case study

Total Environmental impacts per alternative

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



A case study

- 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

A case study

- 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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