9th National Conference on Transportation Asset Management

Making Asset Management Work in Your Organization

Multi-Approach Life Cycle Assessment Optimization to Incorporate Environmental Impacts into PMS

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Outline

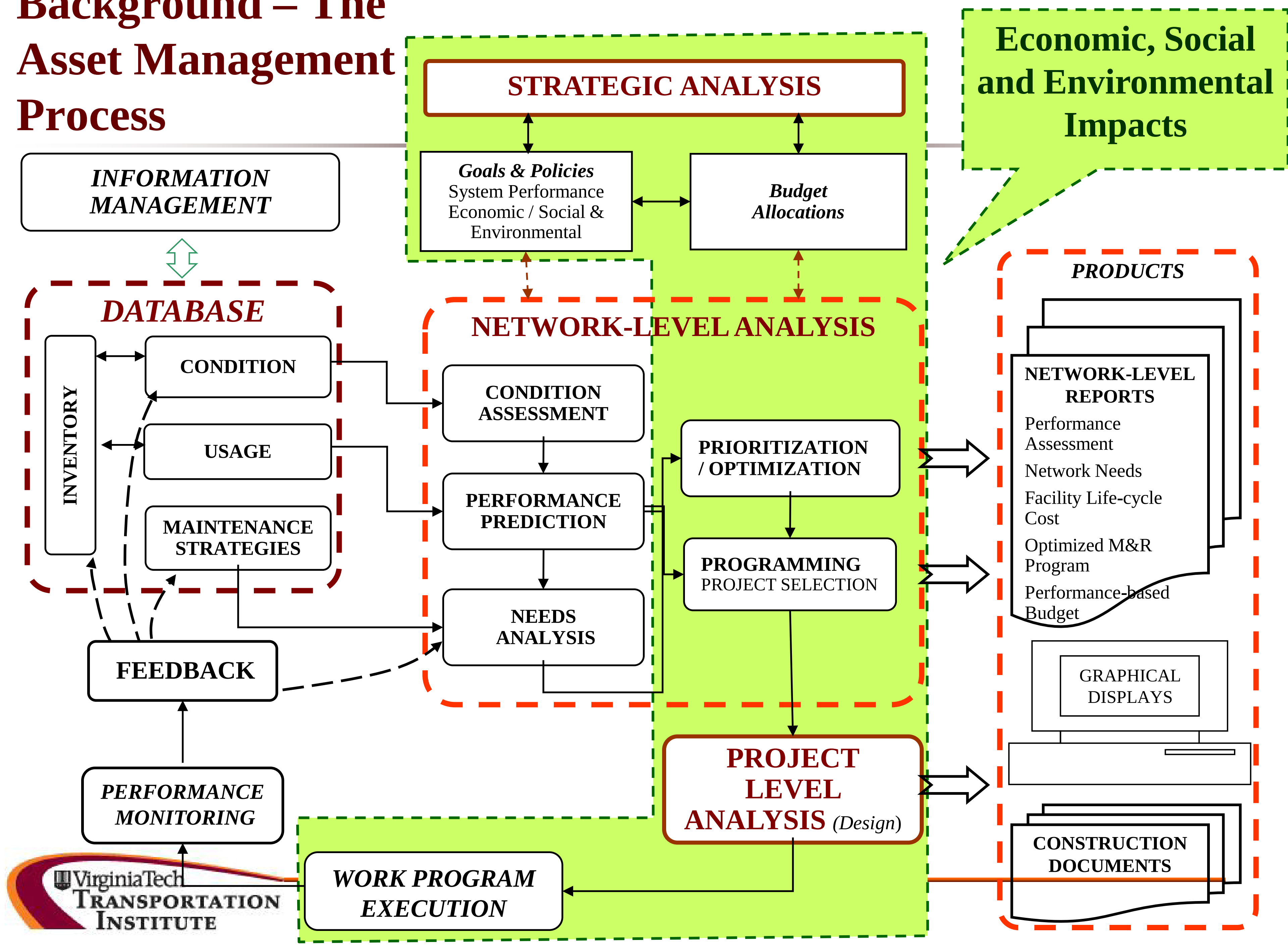
- Introduction
- Addressing Sustainability on Pavements
- Sustainable Management of Pavement Asset
  - ✓ PMS Impacts
  - ✓ Multi-attribute Approach to PMS
- Conclusions & Recommendations

Introduction

Background

- **Concern for the environment has been increasing for decades**
- **Balancing the avoidance and mitigation of environmental degradation with economic growth and the well-being of society is understood as *sustainability***
  - ✓ European Union (EU) has a sustainable development strategy that includes transportation
  - ✓ New Zealand and the UK have specifically designed sustainable transportation strategies
- **Need new set of decision support tools**

Background – The Asset Management Process



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Managing Pavement Assets: Goals

- Minimize COSTS (both agency and user costs)
- Maximize BENEFITS (better pavement performance, higher safety, …, etc.)
- What about the ENVIRONMENTAL IMPACTS of asset management strategies?

Sustainability Triple Bottom Line

Costs

Economic Development

- Meet financial and economic needs of current and future generations

Performance

Social Equity

- Improve the quality of life for all people
- Promote equity between societies, groups, and generations

Environmental Impacts

Environmental Stewardship

- Clean environment for current and future generations
- Use resources sparingly.

Addressing Sustainability in Pavements

Challenges

- **Research is still on-going and many questions are still unanswered:**
  - ✓ **What is a “sustainable” pavement?**
  - ✓ **How to define a sustainable management strategy?**
  - ✓ **How to include sustainability considerations into a comprehensive PMS?**
- **However, sustainability practices and environmental assessments are already implemented in several other fields**

Including Sustainability Considerations

Examples from other fields

DER BLAUE ENGEL
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Eco LABEL

energy
EPA DOE
Money Isn't All You're Saving

BUILDING GREENHOUSE RATING

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U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

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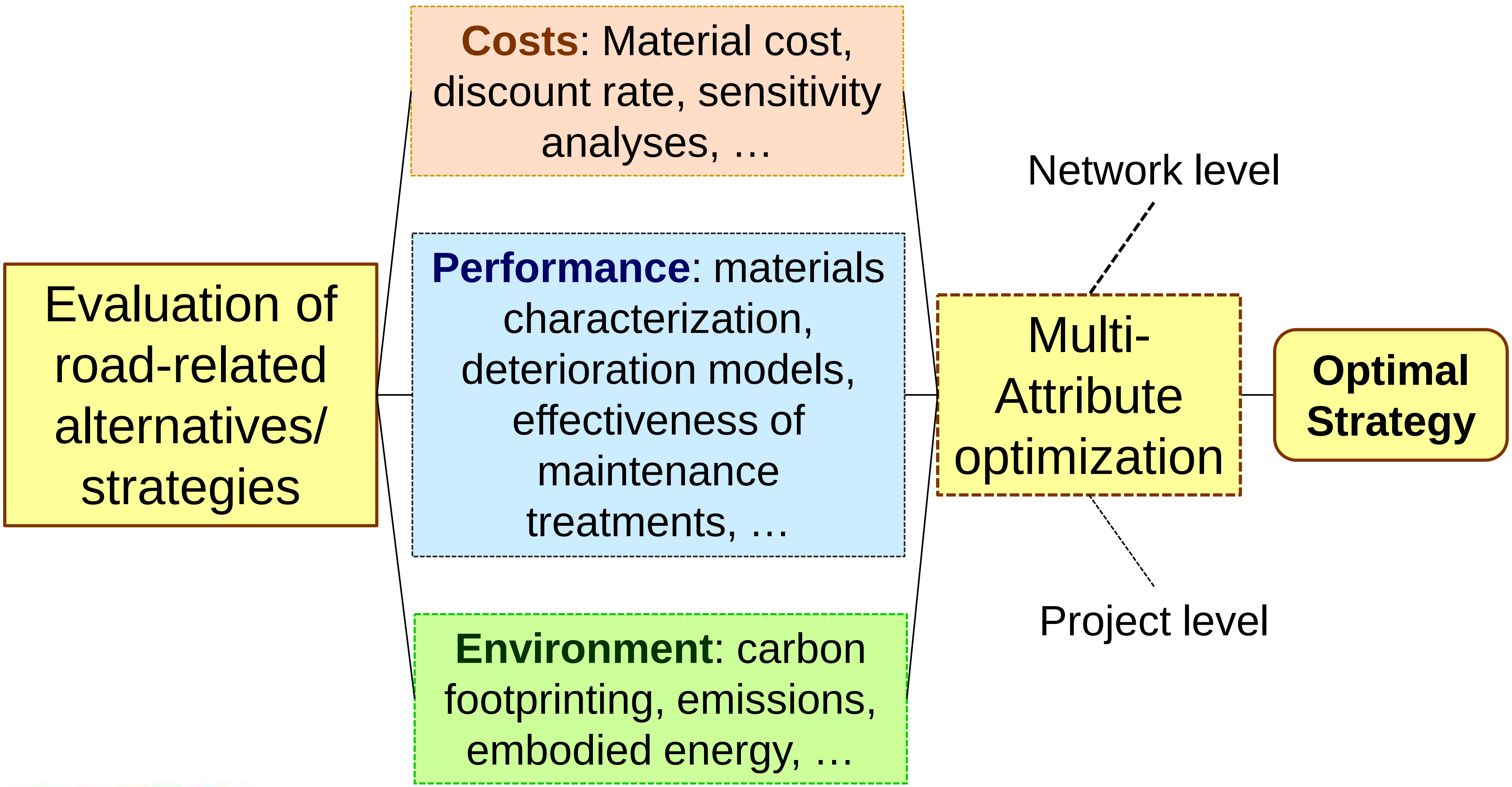
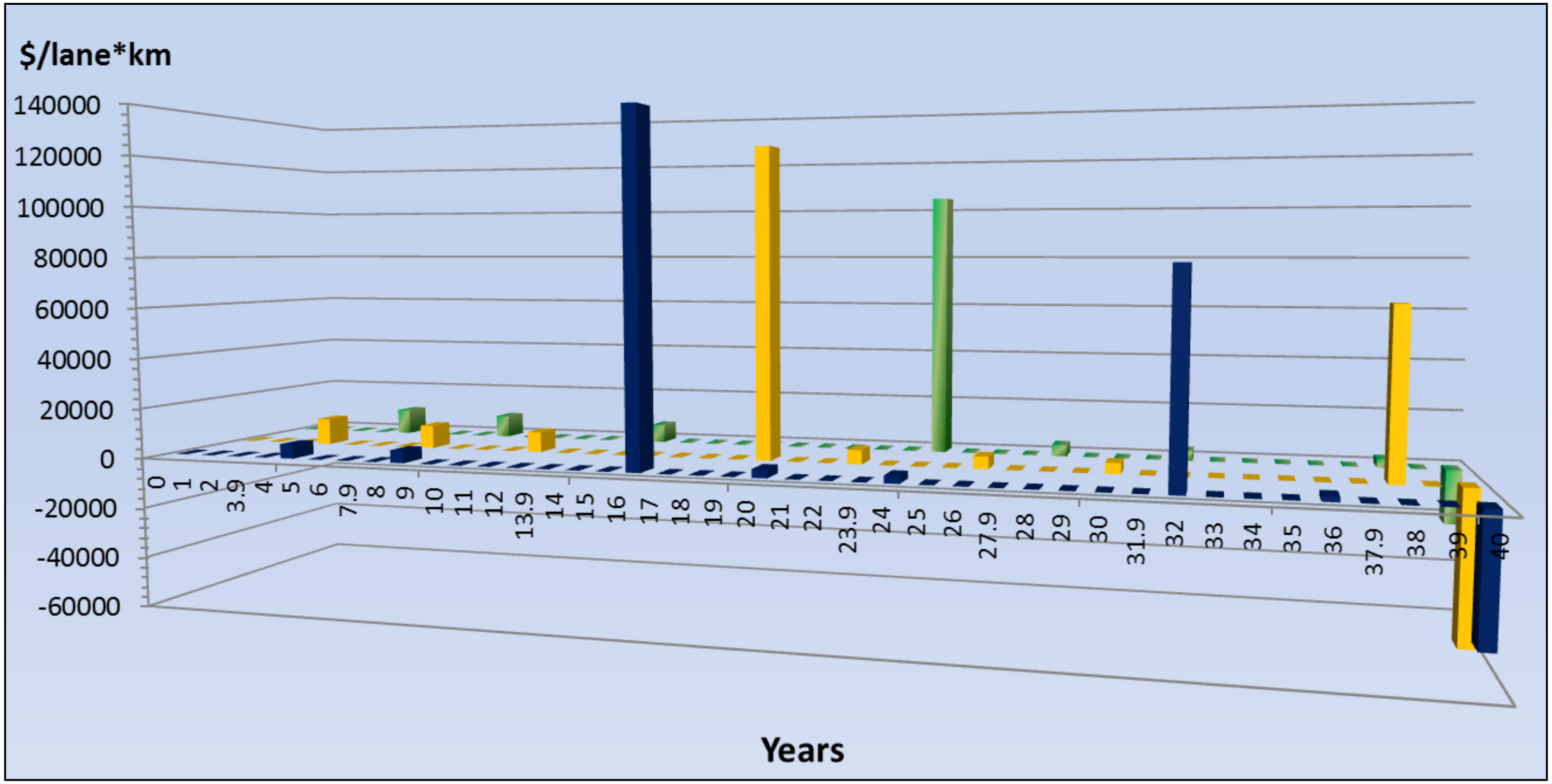
Federal Highway Administration, U.S. Department of Transportation
Sustainable Highways Self-Evaluation Tool

Including Sustainability Considerations

Framework

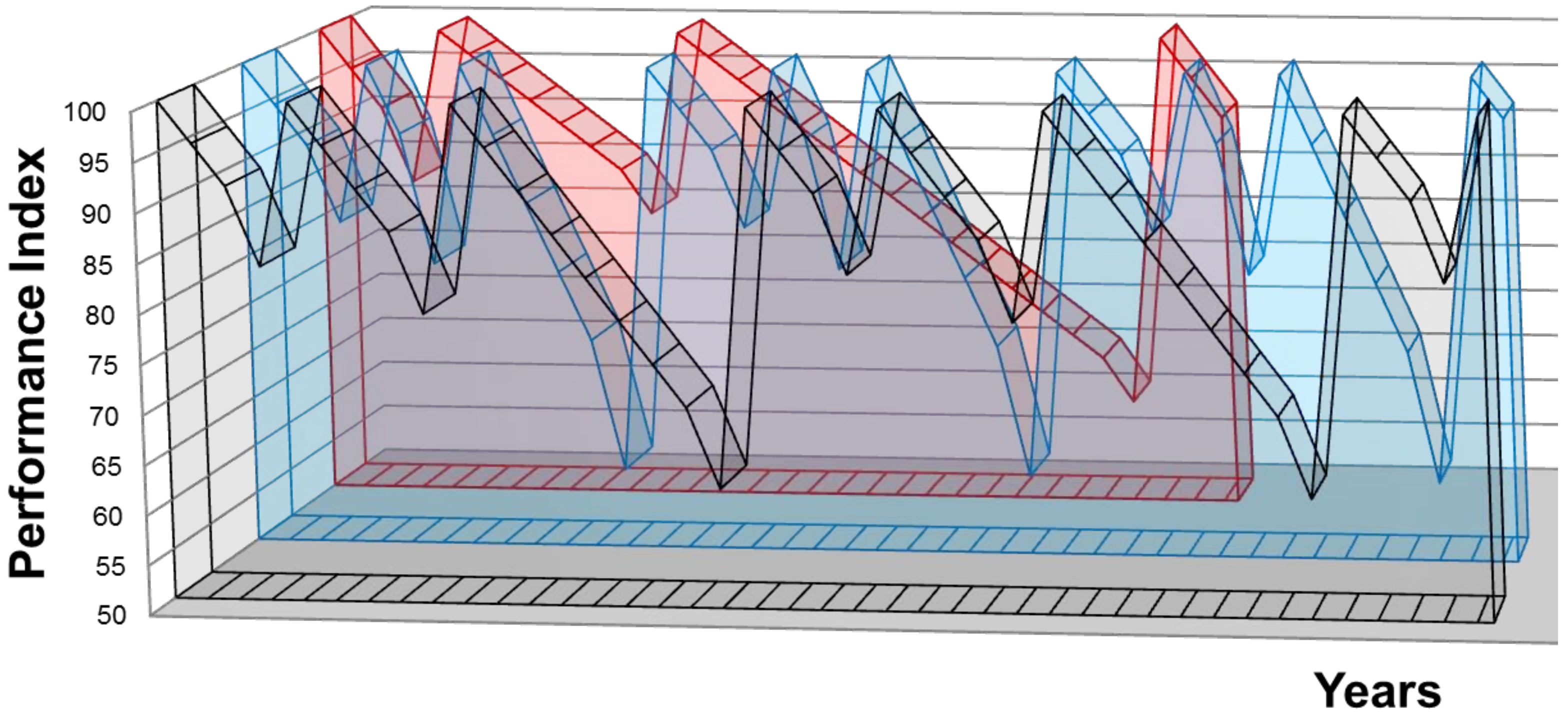


PMS Part #1: Life Cycle Cost Analysis



EUAC, PWC, etc.

PMS Part #2: Life Cycle Performance Analysis



AuC, etc.

PMS Part #3: Life Cycle Assessment

1 • Materials

2 • Transportation

3 • Construction, Maintenance

4 • Equipment

5 • Usage Phase

6 • Recycling, Disposal, Landfill

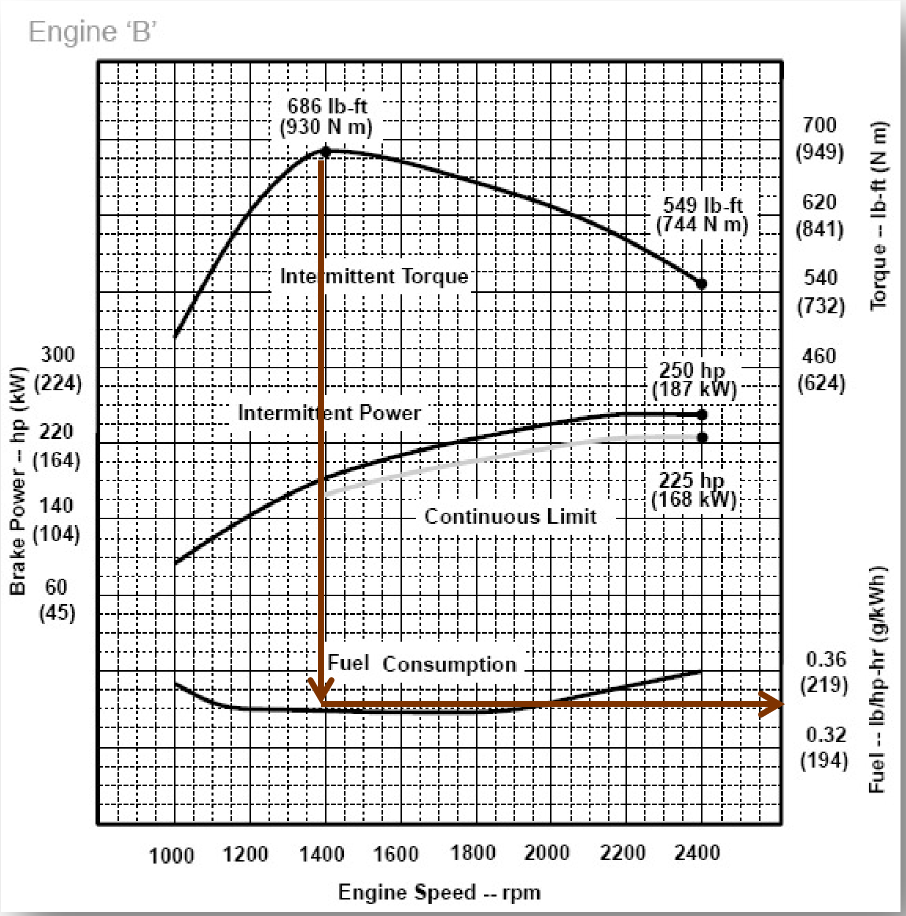
Carbon Footprinting

PMS Part #3: Life Cycle Assessment (cont.)
Road Materials: Literature Review

Material	Emission – CO_{2eq} [kg/ton material]	Standard Dev.	Embodied energy [MJ/ton material]	Standard Dev.
Bitumen	256.5	118.2	4603	2226.0
Bitumen emulsion [60%]	221.0	21.9	3490	428.8
Crushed aggregates	7.5	9.9	38.9	2.7
Pit-run aggregates	5.3	2.2	19.4	11.4
Cement	1079.6	311.5	5900	847.1
Quicklime	2500	-	9240	-
Water	0.29	-	10	-
Polymers – elastomers	3000	543.4	91440	36753.5
Polymers – plastomers	1400	424.3	44667.3	51087.7
Emulsifiers	600	52.4	63250	6010.4

PMS Part #3: Life Cycle Assessment (cont.)

Road Construction/Maintenance Equipment



PMS Part #3: Life Cycle Assessment (cont.)

Emissions Calculations

$$F\,[l] = BSFC\left[\frac{g}{kW \cdot h}\right] \cdot P[kW] \cdot T[h] \cdot 1/\gamma \left[\frac{l}{g}\right]$$

Where: F = *fuel consumed*, T = *usage time*, BSFC = *brake specific fuel consumption*, P = *engine power when the rotation speed provides the maximum torque*, γ = *density of the fuel (diesel density = 0.832 kg/l)*

$$\alpha = 2778g \cdot 0.99 \cdot \frac{44}{12} = 10084\,\frac{g}{gallon} = 2.6639\,\frac{kg}{l}$$

[EPA report 420-F-05-001]

Where: α = *specific amount of CO_2 emitted during the combustion of a liter of diesel*

2778 g = *carbon content per gallon of diesel fuel [U.S. EPA]*

0.99 = *oxidation factor*

44/12 = *ratio of the molecular weight of CO_2 to the molecular weight of carbon*

PMS Part #3: Life Cycle Assessment (cont.)

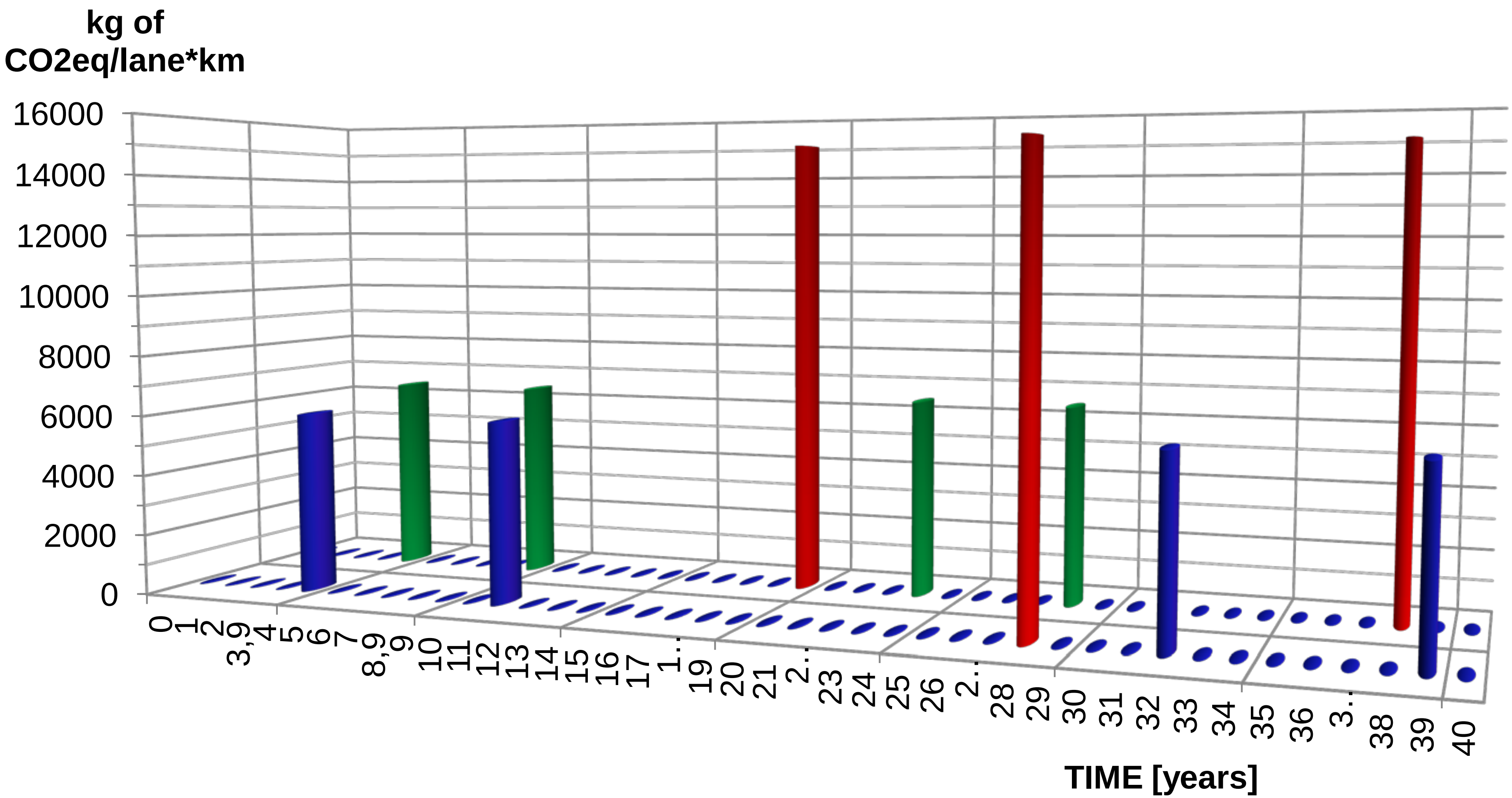
Road Construction/Maintenance Equipment Emissions

Models	**Prod.** [m^2/h]	**P_engine** [KW]		**F** [l/h]	F_{sqm} [l/m^2]	CO_2e [g/m^2]	**Energy** [MJ/m^2]
MILLERS							
PL2000S	2448.98	447		105	0.043	113.62	1.544
PL2100S	4320.00	447		105	0.024	64.41	0.875
W120F	1020.41	227		61	0.060	158.42	2.152
W200	2040.82	380		62	0.030	80.51	1.094
PAVERS							
AP1000D	4082	166		41.0	0.010	26.63	0.362
AP600D	2449	122		31.3	0.013	33.91	0.461
DF145C	3673	153		38.2	0.010	27.53	0.374
F121C	2449	120		30.9	0.013	33.44	0.454
Super1603	2449	100		26.5	0.011	28.68	0.390
Super1803	2857	130		33.1	0.012	30.70	0.417
SLURRY MACHINERIES		**mixer engine** [KW]	**truck engine** [KW]				
M206	3600	74	186	41.7	0.0116	30.70	0.417
M210	3600	74	224	42.4	0.0118	31.25	0.424

	Quantity [ton/m²]	Emission – CO_2e [kg/ton material]	Embodied energy [MJ/ton material]	Total CO_2e [kg/m²]	Total Energy [MJ/m²]
ASPHALT OVERLAY: 3 cm					
Materials					
Bitumen	0.00294	256.5	4603	0.75	13.5
Tack coat emulsion	0.001	221.0	3490	0.22	3.49
Crushed Aggregates	0.037	7.5	38.9	0.28	1.44
Pit-run Aggregates	0.016	5.3	19.4	0.10	0.31
HMA production	0.0735	22	314.2	1.62	23.1
RAP processing	0.0147	8.7	42	0.13	0.62
Equipment	**Fuel consumption** [L/h]				
Tack coat sprayer	6			0.036	0.491
Paver	35.3			0.03	0.341
Roller	24.5			0.056	0.763
Hauling (20 Km)	3.0 L/km			0.088	1.32
			SUM	**3.30**	**45.39**

PMS Part #3: Life Cycle Assessment (cont.)

Evaluating Impacts from Road M&R Strategies



Multi-Attribute Evaluation of Alternatives

Overall Approach (Preliminary)

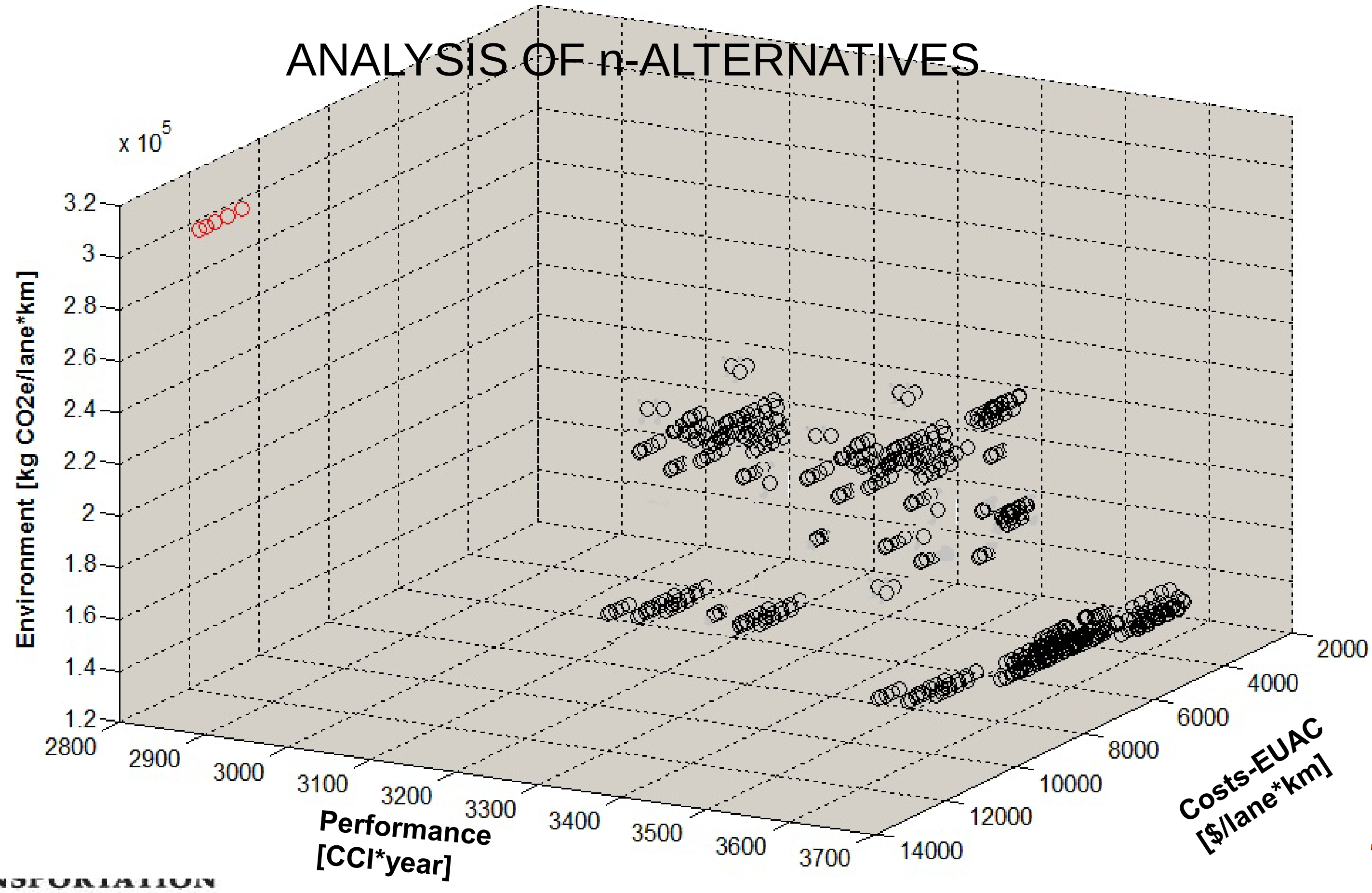
1. Identify feasible alternatives in terms of costs, performance, & environmental impacts over life cycle
2. Normalize and rescale values (0-1, 0-100, etc.)
3. Find the Pareto efficiency frontier coupling normalized parameters (i.e.; costs-performance, costs-environment, environment-performance)
4. Plot points of the Pareto efficiency fronts in a 3D space (cost-performance-environment)
5. Interpolate Pareto points to find out a Pareto efficiency surface
6. Choose the optimal alternative

Multi-Attribute Evaluation of Alternatives (cont.)

1. **Identify feasible alternatives in terms of costs, performance, and environmental impacts over life cycle**
   - ✓ **Run the analysis several times changing:**
     - **analysis period;**
     - **discount rate;**
     - **M&R timing (year of application)**
     - **number of M&R applications (i.e.; 1 treatment per life cycle, 2 treatments per life cycle; etc.)**
     - **type of maintenance (i.e.; preventive approach, corrective approach, etc.)**
     - **maintenance treatment (i.e.; thin overlay, microsurfacing, etc.)**
     - **level of traffic**

Multi-Attribute Evaluation of Alternatives (cont.)

1. **Identify feasible alternatives in terms of costs, performance, and environmental impacts over the life cycle**



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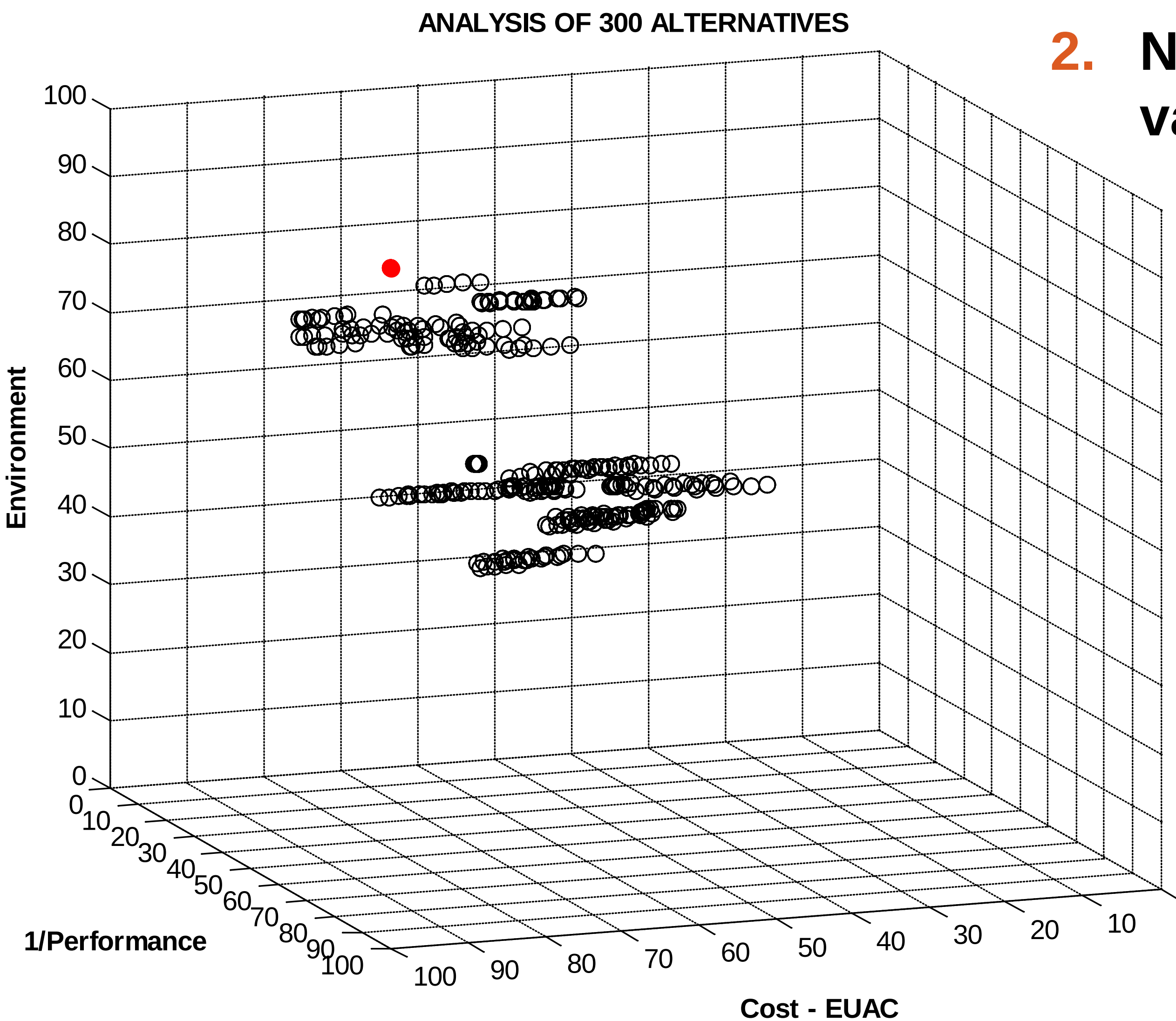
Multi-Attribute Evaluation of Alternatives (cont.)

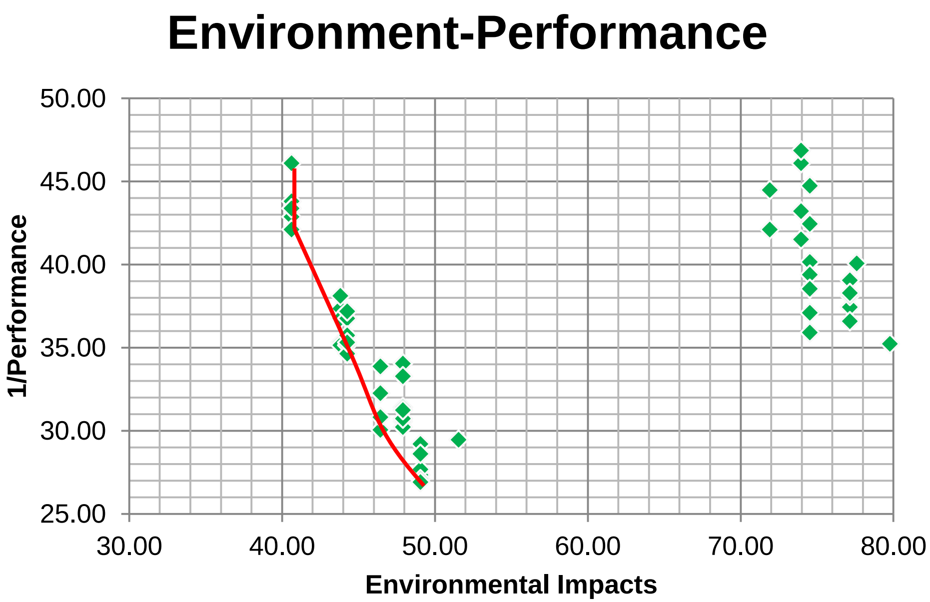


2. **Normalize and rescale values**

Costs, Performance, and Environmental impacts have different unit measures; rescaling is therefore needed for comparing alternatives.

Multi-Attribute Evaluation of Alternatives

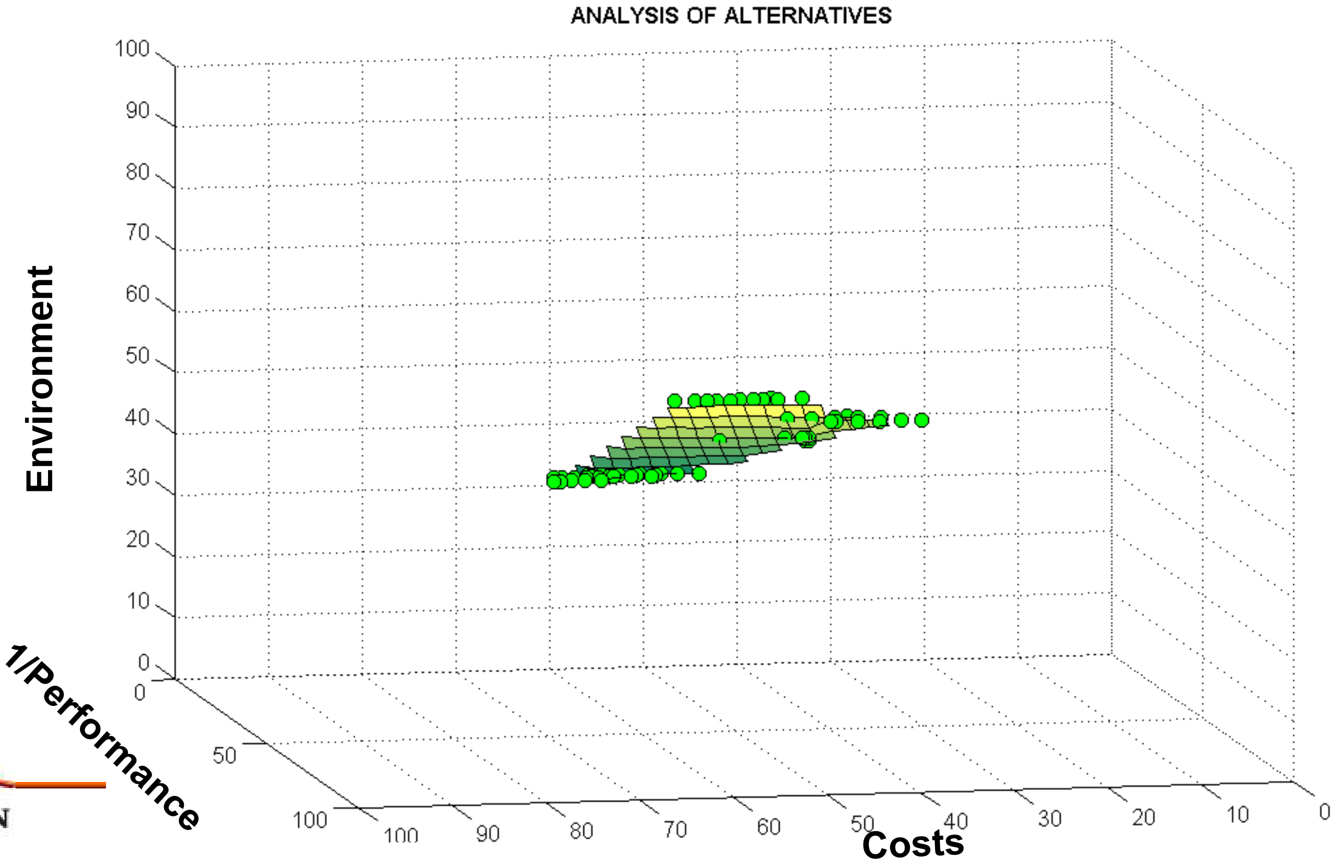
3. **Find the Pareto efficiency front coupling normalized parameters (i.e.; costs-performance, costs-environment, environment-performance)**



Multi-Attribute Evaluation of Alternatives

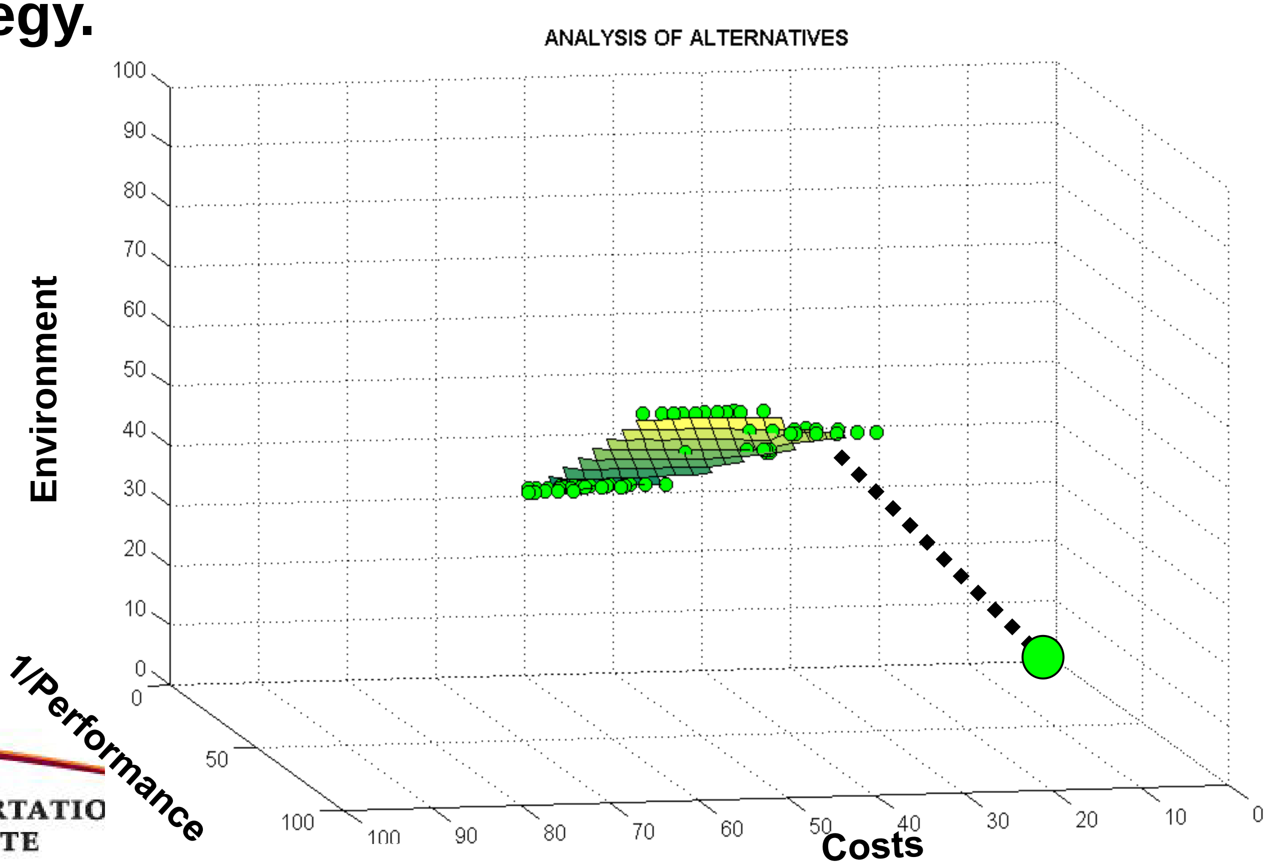
4. **Plot points of all Pareto efficiency fronts in a 3D space (cost-performance-environment)**

5. **Interpolate Pareto points to find out a 3D Pareto efficiency surface**



Multi-Attribute Evaluation of Alternatives

6. **Weight the alternatives according to specific needs (i.e.; 70% importance to costs, 20% to the performance, and 10% to the environmental impacts). The point having the minimum distance from the (0,0,0) point finally represents the optimal strategy.**



Conclusions & Recommendations

- PMS should include a more comprehensive evaluation of strategies
  - ✓ Incorporating environmental impacts can represent a step forward for assessing road pavements sustainability
- Computing emissions for road-related activities is still at an early stage.
  - ✓ Uncertainty on what to account for and how to evaluate the parameters involved

Conclusions & Recommendations (cont.)

- **The proposed methodology can help road authorities and municipalities incorporate several performance measures into a single multi-attribute analysis**
  - ✓ **Parameters involved can also be weighted according to needs**

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