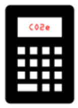
Mix Optimization: Optimizing Mixes for Quality (Performance), Economics and Sustainability

- Shane Buchanan, CRH Americas Materials





SEAUPG

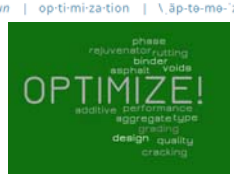
Where We Need to Be?

- **Performance = Quality** for this Discussion.
- **World Class Performance** lies at the intersection of Quality, Sustainability and Economics.
- Can You Have All Three Simultaneously?
  - YES, but it requires desire and attention to detail.

What Exactly is Optimization?

- "Optimization is an act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible."

https://www.merriam-webster.com



QUALITY

What is Quality?

- Quality has many definitions….

1. Meeting or exceeding customer needs or **expectations**
2. How good something is **compared to other similar things**
3. Extent to which products, services, processes, and relationships are **free from defects**.
4. "Performance upon **expectations**" and "fit for functions.
5. Standard of something as **measured against other things** of a similar kind; the degree of excellence of something.
6. Conformance to specifications.
   - Degree to which a product meets the design specifications offering a satisfaction factor that fulfils all the **expectations** that a customer wants.

Quality Expectation

- *Quality is driven by the expectation?*

Pinto Expectations
- Start
- Get you from A to B

You Pay More for the Expectations

Ferrari Expectations
- Start
- Get you from A to B in style!
- ***Acceleration***
- ***Speed***
- ***Handling***
- ***Aesthetics***
- ***Wow Factor***

Quality = $\frac{1}{\text{Variability}}$

Variability (Consistency) is measured by Standard Deviation

Consistency and Quality

- Consistent supply is the No. 1 desire and demand of customers
- Consistency is equated to quality by many
- Customers won't necessarily buy your product because it has quality, but they certainly won't buy it if it does not.
- Quality doesn't start in the quality control department
  - Must be top driven throughout all levels of a company
- "Success is neither magical nor mysterious. Success is the natural consequence of consistently applying the basic fundamentals." (Jim Rohn)

Typical Material Variability Data

Aggregate Blend Grading

Sieve Size	Typical Range for Overall Standard Deviation
19 mm	1.5 to 4.5%
12.5 mm	2.5 to 5.0%
9.5 mm	2.5 to 5.0%
4.75 mm	2.5 to 5.0%
2.36 mm	2.5 to 4.0%
1.18 mm	2.5 to 4.0%
0.60 mm	2.0 to 3.5%
0.30 mm	1.0 to 2.0%
0.15 mm	1.0 to 2.0%
0.075 mm	0.6 to 1.0%

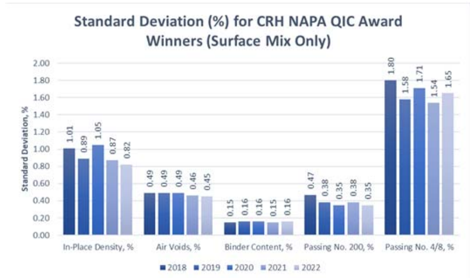
Source: NCHRP Report 673 Manual for the Design of HMA

Mix Volumetrics

Property	Typical Range of Value for Overall Standard Deviation
Asphalt content	0.15 to 0.30%
Air void content, from field cores	1.3 to 1.5%
Laboratory air void content	0.9%
VMA	0.9%
VFA	4.0%

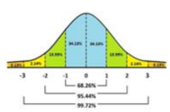
- ***Lower values indicate a more controlled operation and an easier job for the QC personnel!***
- ***As a producer, you MUST know these variabilities for YOUR mixes!***
- ***As an owner, these variabilities should be considered when establishing specifications.***

Target Variability?



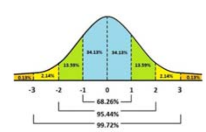
Predicting Compliance Background

- Construction materials and associated processes typically follow a normal distribution, unless bias is introduced into the system.
- Allows easy prediction of future performance based on historical results.
- For example, if a certain average value was obtained with a given variability, future performance (with nothing modified in the process) could be predicted.
- **Value**
  - Estimate probability of success when working under varying specifications.
  - Quantify impact of process changes to improve results (cost/benefit).



Statistical Forecasting

- Statistical forecasting is a way to predict the future based on data from the past.
- We have the data (or we better have it)!
- **So, why not use it?**
  - If I have always done poorly, odds are I will continue to do poorly! (and vice versa).
- Example
  - Plant that makes 50,000 tons of a given mix w/ asphalt binder test every 500 tons
  - 100 asphalt binder tests available
- What do we do with these data? **Put the data to work for you!**

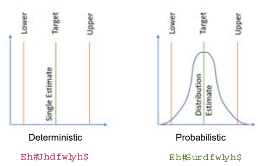


Design and Process Control

Deterministic vs Probabilistic

- Deterministic is blending based on average
- Probabilistic is blending based on average and variability
  - Preferred because it allow the use of statistical methods to predict/evaluate blends versus targets and limits.

Blending w/ averages will give you an average, but blending with averages + variability will give you a distribution!



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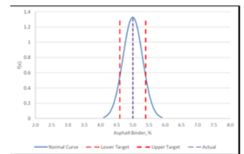
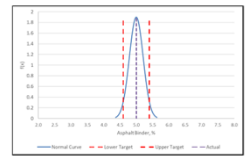
Mix Compliance Scenario 1

- Given
  - Historical mix asphalt binder SD = 0.30%
  - 30% RAP w/ asphalt binder SD = 0.50%
  - RAP contribution to total = 0.30 * 0.50 = 0.15%
  - Actual binder content = 5.0% ± 0.4% w/ n = 1
  - PWS = **81.8%** **(Can do better!)**
- What If
  - **30% RAP w/ asphalt binder SD = 0.20%**
  - RAP contribution to total = 0.30 * 0.20 = 0.06%
  - "New" estimated mix asphalt binder SD = 0.30% - (0.15 – 0.06) = **0.21%**
  - Actual binder content = 5.0% ± 0.4% w/ n = 1
  - PWS = **94.3% Good**

Better RAP Stockpile Management

Assumes Virgin Binder % SD Is Constant





ECONOMICS

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Economics

- Everyone knows how to calculate.
- Economics is NOT about making the "cheapest" mix!
- Mix design economics ≠ in-place economics.
- Everything is **LOCAL…**
  - What binder, aggregates, recycle, additive, plant, laydown operation, etc.
  - Key…Understand your materials and processes, favorable economics will follow.
  - Total economics involves materials, production, transportation, construction, and process control.

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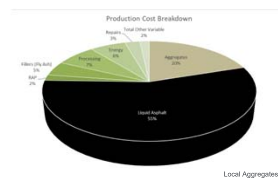

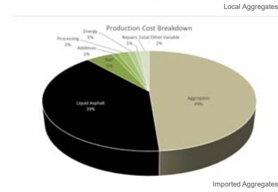

SUSTAINABILITY

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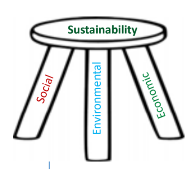
Pavement Sustainability

Pavement Sustainability is the **balance** between Social, Economic, and Environmental impacts.



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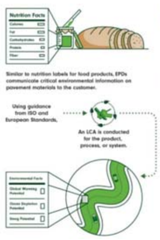
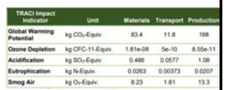
https://www.fhwa.dot.gov/pavement/sustainability/one-pagers/

Environmental Product Declaration (EPD)

Environmental Product Declaration (EPD)

- **Third-party verified document** that publicly discloses the environmental impacts associated with sourcing, manufacturing, use, transportation, and disposal of your product.
- **Provide** verifiable and transparent information on **life-cycle environmental impact data** for materials or products.
- **Allow meaningful comparisons of the environmental performance of materials** (if they were developed using the same product category rules, PCRs, which are industry consensus standards and guidelines used in developing and reporting EPDs).
- **Identify areas** for environmental performance **improvement,** encouraging industry efficiency.





TRACI Impact Indicator	Unit	Materials	Transport	Production
Global Warming Potential	kg CO_2-Equiv.	83.4	11.8	168
Ozone Depletion	kg CFC-11-Equiv.	1.81e-08	5e-10	8.55e-11
Acidification	kg SO_2-Equiv.	0.486	0.0577	1.08
Eutrophication	kg N-Equiv.	0.0263	0.00373	0.0207
Smog Air	kg O_3-Equiv.	8.23	1.81	13.3

EPD Steps…
1. *Develop the PCR*
2. *Conduct the LCA*
3. *Develop the EPD*
4. *Publish the EPD*

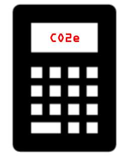
https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/termsandacronyms/search.do
https://www.fhwa.dot.gov/pavement/sustainability/hif19087.pdf

Carbon Dioxide Equivalent (CO2e)

- The unit used to measure the impacts of releasing (or avoiding the release of) different greenhouse gases; it is obtained by multiplying the mass of the greenhouse gas by its global warming potential.
- CO2e puts all GHG emissions in relation to carbon dioxide, which is considered to have a GWP of 1.

https://www.appropedia.org/Glossary_of_sustainability_terms

CO2e = GWP * GHG emission (teqv,



EPD Output

An Environmental Product Declaration for Asphalt Mixtures

TABLE 4. LIFE CYCLE IMPACT INDICATORS

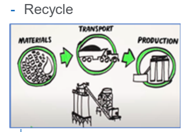
ACRONYM	INDICATOR	UNIT	QUANTITY PER METRIC TONNE ASPHALT MIXTURE (PER SHORT TON ASPHALT MIXTURE)			
			MATERIALS (A1)	TRANSPORT (A2)	PRODUCTION (A3)	TOTAL (A1-A3)
GWP-100	Global warming potential, incl. biogenic CO2	kg CO2 Equiv.	24.85 (22.55)	8.61 (7.81)	27.41 (24.86)	60.87 (55.22)
ODP	Ozone depletion potential	kg CFC-11 Equiv.	1.35e-08 (1.23e-08)	5.21e-08 (4.72e-08)	2.84e-08 (2.58e-08)	9.40e-08 (8.52e-08)
EP	Eutrophication potential	kg N Equiv.	6.74e-03 (6.11e-03)	4.47e-03 (4.06e-03)	2.88e-03 (2.62e-03)	1.41e-02 (1.28e-02)
AP	Acidification potential	kg SO2 Equiv.	7.33e-02 (6.65e-02)	7.40e-02 (6.71e-02)	4.92e-02 (4.46e-02)	1.96e-01 (1.78e-01)
POCP	Photochemical ozone creation potential	kg O3 Equiv.	1.55 (1.41)	2.48 (2.25)	1.55 (1.41)	5.58 (5.07)

Potential CO2e Influencers (EPD)

Materials
- Liquid
  - Total binder content
  - Recycle
- Aggregate
  - Recycle

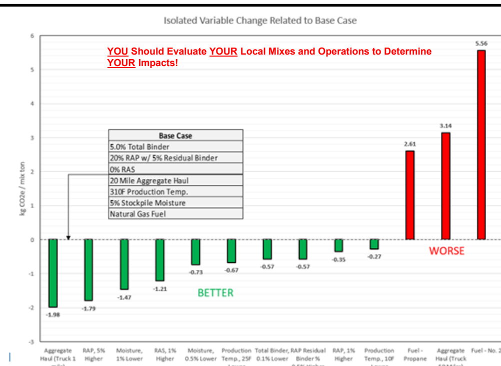
- **Transport**
  - Materials haul distance

- **Production**
  - BTU consumption
    - Moisture
    - Production temperature
  - Burner Fuel



How Do the Factors Influence CO2e?

Factor	How it Helps	EPD Category
Lower Binder %	Lowers the Impact of the Highest CO2 Generator (Binder)	A1
Higher RAP	Lowers Impact of Binder and Virgin Binder + Aggregate Haul	A1, A2
Higher RAS	Lowers Impact of Binder and Virgin Binder Haul	A1, A2
Lower Aggregate Binder Abs.	Lowers the Impact of Binder	A1
Local Aggregate Use	Lowers the Haul Distance	A2
Lower Production Temp. (WMA)	Lowers the Production Energy (BTU), varies on fuel source	A3
Lower Stockpile Moisture	Lowers the Production Energy (BTU), varies on fuel source	A3
Variable Frequency Drives	Lowes the Plant Energy (Electricity)	A3
Plant Piping Insulation	Lowers the Plant Energy	A3
Plant Fuel Type	Significant Impact, NG is lowest impact	A3
Balanced Mix Design	Optimize binder, aggregate, recycle contents	A1
Rejuvenators	Increase Recycle	A1
Additives	Maybe increase recycle, lower binder demand	A1
All Factors Might Also Inluence Service Life and Associated Emissions		



Materials Items

- Asphalt Binder
- Aggregates
- **Recycle**
- Additives

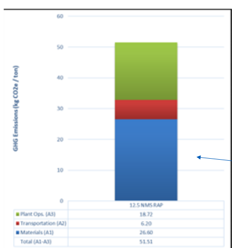


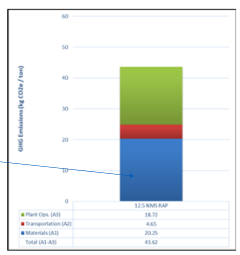

TechBrief
APRIL 2016 FHWA-HIF-16-012
STRATEGIES FOR IMPROVING SUSTAINABILITY OF ASPHALT PAVEMENTS

Page 7: In general, **recycled materials should be used for the "highest use."** Because the asphalt binder in RAP can replace the environmental burden of virgin asphalt production, **the highest use would be first as replacement for virgin asphalt and aggregate in new asphalt concrete**, followed by use in recycled cold-mix materials, followed by use as aggregate base or aggregate in concrete.

SUSTAINABLE PAVEMENTS PROGRAM

RAP 20% vs RAP 40%





1% RAP ~ 0.35 kg CO2e / ton

Recycled Asphalt Pavement (RAP)
- 1% RAP ~ 0.35 kg CO2e / ton

Warm Mix Asphalt (WMA)
- 25F Temp. ~ 0.67 kg CO2e / ton (Natural Gas) / 0.80 (Propane) / 0.95 (RFO)

Liquid Asphalt
- 0.1% liquid = 0.25% VMA = ~ 0.57 kg CO2e / ton

Moisture
- 1% Moisture ~ 1.47 kg CO2e / ton (Natural Gas) / 1.75 (Propane) / 2.06 (RFO)

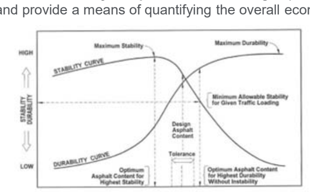
CO2e

General Estimates: Local Conditions Will Drive Actual Data

WHAT IS A GOOD APPROACH TO EVALUATE QUALITY, ECONOMICS, AND SUSTAINABILTY ?

Balanced Mix Design (BMD)

- An **innovative** BMD approach offers the **potential to ensure quality (performance), enhance the sustainability footprint** of mixes through optimization of binder, recycle and aggregate use, and provide a means of quantifying the overall economics.



BMD Checks All the Boxes…
- QUALITY
- SUSTAINABILTY
- ECONOMICS

Source: Randy West, NCAT

….and no way to know if the mix is truly optimized!

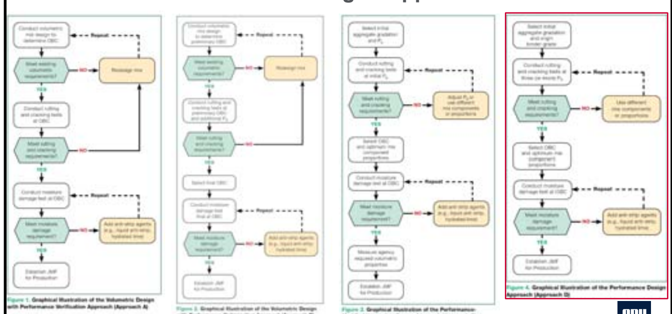
NCAT CRH

Performance Testing and Balanced Mix Design

- Many questions arise during mix design.
  - What is the …
    - Gsb of the aggregate, RAP?
    - Stiffness of the virgin, RAP binder, composite binder?
    - Blending of the virgin and RAP binder?
  - You will **NEVER** know all the answers, all the time!
- ***Avoid the recipe that may not yield the desired product!***
- ***Innovate and engineer the mix for the performance that's required.***

CRH

Balanced Mix Design - Approaches



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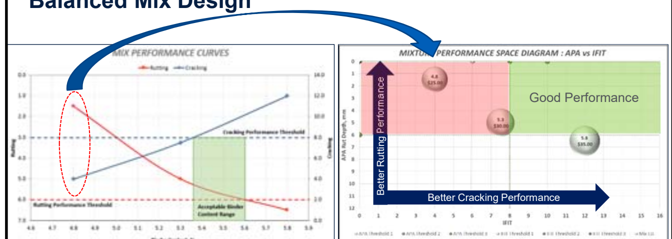
Balanced Mix Design



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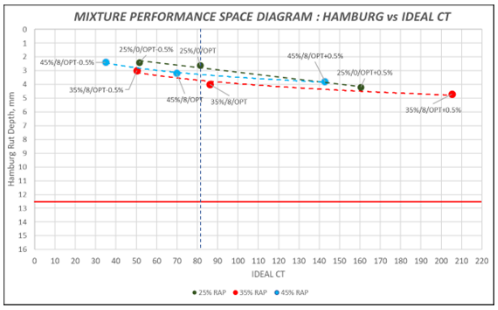
CASE STUDY

Case Study: Quality/Sustainability/Economics

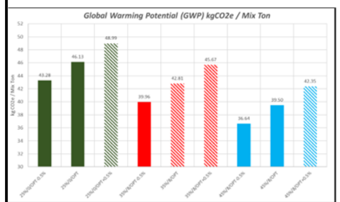
- Control (Baseline) Mix w/ 25% RAP w/o rejuvenator
  - Variables
    - RAP: 25%, 35%, 45%
    - Binder: -0.5%, Opt., +0.5%
    - Rejuvenator: 8% for 35% and 45%
      - By weight of total RAP binder
  - Hamburg
  - IDEAL CT
- Purpose: Generate data for effective decisions on mix utilization.
- Without data you are only guessing!

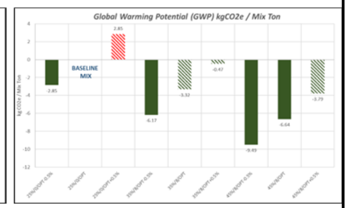
CRH

Case Study: Quality



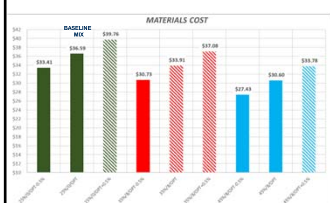
Case Study: Sustainability

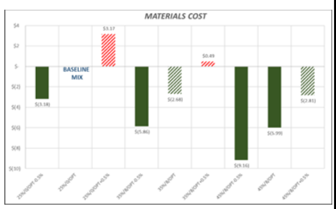




Cross Hatched = Acceptable Mix Performance (Quality)

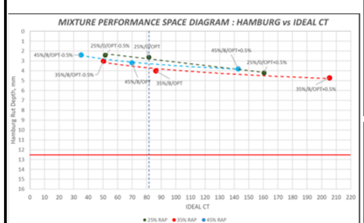
Case Study: Economics

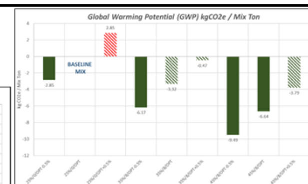


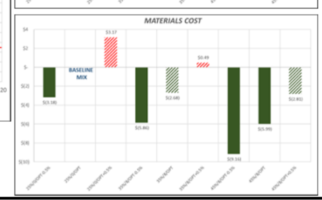


Cross Hatched = Acceptable Mix Performance (Quality)

Case Study: Mix Selection



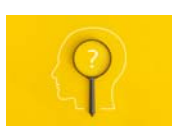




Case Study: Observations

- Sustainability and Economics tend to track together.
- Implementing sustainable approaches almost always lead to favorable economics.

- Which mix would you select?
  - Quality is a MUST.
    - How much above the threshold do you need performance? Variability? Risk?
    - Depends on procurement environment? Low bid, value engineered, etc.
  - Economics drive decisions! Great quality, high sustainable mix might never be used….
  - Sustainability at the present may not be the driver, but that day is coming soon!



Thank You