Quo redevivus in quo vadis?
Bitumen stabilised layers = uniformity from variability? True or false?

Kim Jenkins
Sense of Reality
Exploring the Recycling Loop
Technology Challenges
Acquire Knowledge/Gather Data & Info
Technology Development & Innovation
Implement
Conclusions
Closing Technology Loop

Technology Challenges

Step 1
General Transportation Issues

Transport
- Road infrastructure capacity
- Road infrastructure deterioration & maintenance

Available Technology
- Existing tech: Inadequacies with sustainability
- New tech developments:
  - Maintenance capacity
  - Economics
  - Environmental considerations
  - Social issues
- Implementation? Resistance to change

RECYCLING: **THERE IS NO ALTERNATIVE**
Transportation Sector’s Role

Transport's % Contribution Overall (EU Based Stats)

- GDP
- Workforce
- R&D Budget
- CO2 emissions
- Mortalities
- Freight
- Passenger Vehicles

- Economic
- Enviro/Social
- Growth

Transport is a big player (CSIR, 2017)
Example: Indonesia

Increase of 22% veh/yr
Slight decline in kms
Deterioration Trends in Road Infrastructure

Globally, we’re in trouble!

Impact of 3-year reseal program

(W Cape Prov, 2017)
Global Road Infrastructure

- Approximately 65 million km of global roads, with 18 million km surfaced roads
- Assuming average pavement life of 18 years
  - 1 million kms road need rehab per year
  - No allowance for growth

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Road length (km)</th>
<th>Surfaced (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>World</td>
<td>64 285 009</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>United States</td>
<td>6 586 610</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>4 689 842</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>China</td>
<td>4 237 500</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Brazil</td>
<td>1 751 868</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Japan</td>
<td>1 210 251</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Canada</td>
<td>1 042 300</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Russia</td>
<td>982 000</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>France</td>
<td>951 200</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Australia</td>
<td>823 217</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>South Africa</td>
<td>750 000</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Spain</td>
<td>681 298</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Germany</td>
<td>644 480</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Sweden</td>
<td>572 900</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Italy</td>
<td>487 700</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Indonesia</td>
<td>437 759</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Turkey</td>
<td>426 906</td>
<td></td>
</tr>
</tbody>
</table>

...  ...  ...

34  Dem Rep of Congo  153 497
45  Zimbabwe  97 287
54  Zambia  91 440
55  Tanzania  91 049
70  Madagascar  65 663
80  Angola  51 429
72  Namibia  64 189
98  Mozambique  30 331
104  Botswana  25 798
122  Malawi  15 451
148  Lesotho  7 438
161  Swaziland  3 594
173  Mauritius  2 066
193  Seychelles  508

SADC Total  1 449 720

(Wiki, 2016)
Technology Options

![Graph showing technology options with energy consumption and aggregate temperature.](Image)

- **Low Temperature Asphalt LTA**
- **Cold Mix BSM**
- **Half-warm Mix HWM**
- **Warm Mix Asphalt WMA**
- **Hot Mix Asphalt HMA**
- **Heating**
- **Vaporize**
- **Drying**

(Jenkins, AAPT, 2001)
Sustainability: Social, Enviro & Economic

Economics: Material is 70% of HMA cost

(Colas)
Sources of Variability

Challenges to address in Pavement Technology

- **Traffic** (wheel load, tyre pressure, speed, lateral wander, healing etc)
- **Environment** (temperature, moisture, etc)
- **Modelling** (data population, random and systematic error etc)
- **Construction** (compaction, layer thickness, variable binder content, etc)

**Material characteristics**
(strength, stiffness, permeability, etc)
Materials: Allowable RAP % in HMA versus BSM

Awareness: Material = 70% of layer cost!!!

Where does the rest of the 0.5 billion m³ RAP/yr go?
Technology Issues with Recycling

**General**
- Refusal to shift from comfort zone (HMA lobby)
- Resistance to change (risk averse industry)
- Lack of specifications
- Lack of design tools (mix and pavement structure)
- Access to training

**RAP**
- Availability – abundance or dearth (feast or famine)
- Ownership
- Perceived variability (ignorance re processing tools)
- Plant for mixing, paving and compaction (ignorance)
- Access to technology
- Lack of specifications
RAP Usage Issues based on Technology

RAP USAGE ISSUES FOR HMA

Ownership
Lack of tech knowledge
Location of mixing plant

RAP USAGE ISSUES FOR BSM

Ownership
Ownership (BSM Tech)
Ownership (Mobility)
Ownership (KMA)

FHWA Survey, USA

Ownership

(FHWA, 2011)
Step 2

Technology Challenges

Acquire knowledge
Bitumen Stabilisation Agents

BITUMEN EMULSION
Colloidal Mill

- Acid or Caustic Soda
- Surfactants
- Water
- Bitumen
- Mill
- 5 microns

FOAMED BITUMEN
Expansion chamber

- Hot bitumen
- Water
- Air
Acquire Knowledge

Pavement Materials
Long Term Stiffness
FWD Deflection Survey Data - Greece

15% Δ layer thickness
50% Δ layer stiffness

Time after construction (years)

(NTUA, Loizos 2005)
Step 3

Technology Development

Acquire knowledge

Innovate!
**Remember Variability**

**SYSTEM**

- Log N
- Cracked area (%)
- Large variation in life

**COMPONENT**

- tyre-pressure, load etc
- \( \delta_0-\delta_{300} \) gives good insight

**Graph**

- Load Repetitions N
- Effective fatigue
- Strain Ratio \( e/e_b \)
- Number of Load Applications

- Load Repetitions N
- \( \mu e \)
Grading Requirements Update

<table>
<thead>
<tr>
<th></th>
<th>FOAM</th>
<th>EMULSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasticity PI (%)</td>
<td>&lt;6</td>
<td>&lt;6</td>
</tr>
<tr>
<td>Filler Content</td>
<td>&gt;4</td>
<td>&gt;2</td>
</tr>
<tr>
<td>P_{0.075} (%)</td>
<td>&gt;2</td>
<td>&gt;2</td>
</tr>
</tbody>
</table>

**Processing RAP**: Impact crusher with 20mm gap setting

**Hot regions**: Triaxial testing at representative temperature
Sampling asphalt layers

Use a recycler

Normal operating speed of advance (± 8m/min)

Obtain bulk sample (full depth)

Or, a milling machine

Speed of advance (± 3m/min)

Use a recycler

Obtain bulk sample (full depth)

Or, a milling machine

Speed of advance (± 3m/min)
Sampling and processing old asphalt layers

**Typical Grading Curves for Milled Asphalt**

- **RAP**
- **Down-milling**
- **Pulverised**

**Sampling and Processing Old Asphalt Layers**

- **Impact crusher**
- **Cracked asphalt**

**Graph**

- Percentage Passing
- Sieve Size (mm)
- Slow milling
- Fast milling

**Typical Grading Curves for Milled Asphalt**

- Pulverised
- Slow milling
- Fast milling

**Down-milling**

**Pulverised**

**Cracked asphalt**
Achieving the required grading

**Blending of Aggregates to meet spec**

**Problems**
- Gap graded
- Coarse grading

**Solution**
- Add Crusher dust

**TARGET GRADING CURVES FOR BITUMEN STABILISATION**

- **Target Gradings**
  - Less suitable
  - RA
  - Avoid

- **Coarse grading**

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**Achieving the required grading**

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  - Less suitable
  - RA
  - Avoid

- **Coarse grading**
Technology Development

Develop Tools
Innovate!

Vibratory Compaction

Std Test Method

(Stell Univ)
Triaxial Testing

Test Temperature = 25°C
Displacement rate = 3mm/min

Development & Innovation

Std Test Method
Purpose of Bitumen Stabilisation

Shear stress

Cohesion

Speciation BSM1

<table>
<thead>
<tr>
<th>Specification BSM1</th>
<th>C (kPa)</th>
<th>φ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt; 250</td>
<td>&gt; 40</td>
</tr>
</tbody>
</table>

Tech Development

BSM

R² > 0.95

UNBOUND

ϕ Friction angle

Normal stress

Purpose of Bitumen Stabilisation
Triaxial: Analysis of Moisture Damage

Retained Cohesion Spec

Cohesion Loss = 25% max
Retained Cohesion \( C_R = \frac{C_R \times 100}{C_{BSM}} \)

Shear stress

Normal stress

\( \tau \)

\( \phi \) Friction angle

Effect of Moisture

Specification BSM1

\( C_R = \text{Ret.} C \quad >75\% \)
Spin-offs from Vibratory Hammer Compaction and Triaxial Testing

- Representative packing and density
- CT scans showing void distribution
- Interlayer bond

- Direct links between Mix Design and Pavement Design
- Moisture damage insights
  - \( \text{TSR} = \frac{\text{ITS}_{\text{WET}}}{\text{ITS}_{\text{DRY}}} \) has higher COV
  - Direct link of Cohesion Loss to Performance
    (increase in deviator stress ratio)
Spin-offs from Vibratory Hammer Compaction and Triaxial Testing

- Identifying true behaviour of recycled materials
  - Bitumen-Rubber Asphalt RAP (M4 example)

- Soft bitumen in the RAP

Adjust mix to achieve desired shear properties
Permanent deformation (rutting) design for granular material
Structural Design Function for BSM

\[ P_{\text{mod}} = \% \text{ Mod.AASHTO} \]

\[ \log N = A - B \cdot DSR^3 + C \cdot P_{\text{mod}} \cdot \text{RetC} + D \cdot PS \]

- Deviator Stress Ratio
- Plastic Strain % (a/b)
- Retained Cohesion

<table>
<thead>
<tr>
<th>DSR power</th>
<th>Slope</th>
<th>Intercept</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.025</td>
<td>-0.5945</td>
<td>0.819</td>
</tr>
<tr>
<td>3</td>
<td>1.001</td>
<td>1.0572</td>
<td>0.927</td>
</tr>
<tr>
<td>4</td>
<td>1.1296</td>
<td>6.9172</td>
<td>0.355</td>
</tr>
</tbody>
</table>
ME design function for BSMs

**Stellies BSM function**

\[ \log N = A - 57.286(DSR)^3 + 0.0009159(P_{mod} \cdot RetC) + 0.086753(PS) \]

<table>
<thead>
<tr>
<th>Reliability</th>
<th>A</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>1.2044</td>
<td>1.001</td>
</tr>
<tr>
<td>50%</td>
<td>1.1369</td>
<td>0.856</td>
</tr>
<tr>
<td>80%</td>
<td>1.0198</td>
<td>0.656</td>
</tr>
<tr>
<td>90%</td>
<td>0.9312</td>
<td>0.533</td>
</tr>
<tr>
<td>95%</td>
<td>0.8436</td>
<td>0.436</td>
</tr>
</tbody>
</table>

(Stellenbosch Univ: Bierman, 2017)
Design Comparison: Typical Structures

Tech Development

(Stellenbosch Univ: Bierman, 2017)
Step 4
Technology Challenges

Implement
Technology Development

Acquire knowledge

Response
Damage

Technology Challenges

Implement
Technology Development

Acquire knowledge

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Step 4

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Step 4

Technology Challenges

Implement
Technology Development

Acquire knowledge

Response
Damage
Originally constructed early 1970s

Rehabilitation in July 2011
Currently 15,000 heavies/direction/day
Lane Closure 22:00 – 05:00

“EcoPistas” (an EcoRodovias concession since 2009)
Results of Pavement Investigations

- **HMA ± 100mm**
- **SELECTED COARSE GRAVEL (CBR > 25) ± 200mm**
- **EMBANKMENT (RIVER LEEVE) (CBR > 15) ± 200mm**
- **SEMII INFINITE GRADED CRUSHED STONE ± 200mm**
- **CEMENTED CRUSHED STONE ± 250mm**
- **6% CEMENT**
Rehabilitation Options?

350mm BSM

BSM-b

130mm

200mm

HMA

Deviator Stress

50mm

100mm

BSM-a

200mm

?
**Modelling (Rubicon LET)**

"BALANCED PAVEMENT"

<table>
<thead>
<tr>
<th>Material</th>
<th>Modular Ratio</th>
<th>Maximum stiffness (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>5</td>
<td>1000 - 2500</td>
</tr>
<tr>
<td>BSM</td>
<td>2 - 3</td>
<td>500 - 1200</td>
</tr>
<tr>
<td>CTB</td>
<td>2 - 3</td>
<td>300 - 500</td>
</tr>
<tr>
<td>Crushed stone</td>
<td>1.8 - 2.0</td>
<td>300 - 500</td>
</tr>
</tbody>
</table>

Material Modular Ratio Rule

- Crushed stone: 1.8 - 2.0
- Gravel: 1.5 - 1.8
- Soil: 1.2 - 1.6

(Loudon Int)
Pavement Design – Case Study

BSM Modulus Values : FWD back-calcs

Mr (MPa)

Elastic Modulus (MPa)

- BSM Layer
- Remaining Infrastructure

September/2013 (Rehabilitation)  December/2013  October/2014  July/2015

(USP & Copavel, Brazil)
## Analysis of FWD survey – October 2014

### FWD Analysis: From km 15+650 to km 16+250

<table>
<thead>
<tr>
<th>Pavement Layers</th>
<th>Thickness (mm)</th>
<th>Poisson’s ratio</th>
<th>Derived resilient modulus (M_R) (MPa)</th>
<th>Average</th>
<th>80th %ile (high)</th>
<th>80th %ile (low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOW LANE</td>
<td>8 ton axle load, 541 to 607 kPa applied pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt surfacing</td>
<td>50</td>
<td>0.4</td>
<td>3000</td>
<td>3000</td>
<td></td>
<td>3000</td>
</tr>
<tr>
<td>BSM base</td>
<td>100</td>
<td>0.35</td>
<td>1633</td>
<td>1954</td>
<td>1312</td>
<td></td>
</tr>
<tr>
<td>BSM upper subbase</td>
<td>200</td>
<td>0.35</td>
<td>1192</td>
<td>1527</td>
<td>857</td>
<td></td>
</tr>
<tr>
<td>Natural lower subbase</td>
<td>250</td>
<td>0.35</td>
<td>346</td>
<td>459</td>
<td>253</td>
<td></td>
</tr>
<tr>
<td>Subgrade support</td>
<td>Inf</td>
<td>0.35</td>
<td>275</td>
<td>309</td>
<td>204</td>
<td></td>
</tr>
</tbody>
</table>

(Loudon Int, Copavel & USP, Brazil)
DAYTIME OPERATIONS
Processing the RA
Impact crusher (20mm gap setting)
KMA 220 mixing plant
Mix 1: 100% RA + 2% Foamed Bitumen + 1% lime
Mix 2: 85% RA / 15% dust + 2.1% Foamed Bitumen + 1% lime
PROOF ROLLING (27ton PTR)
2nd BSM LAYER (130mm)
...years later

Not yet rehabilitated

REHABILITATED LANE
Close Technology Gap

Implement Technology Challenges

Step 5

Actual RAP performance

Predicted performance

Re-calibrate

RAP

Plastic Strain $\varepsilon_p$ (Rutting)

$\varepsilon_p = aN^b$

Load (Axle) Reps N

Technology

Acquire knowledge

Change text level:
Home // paragraph // increase / reduce list level

Display auxiliary lines: view // show

Check at leading line

Turn slide into original form:
Home // layout // reset

Wechsel des Folienlayouts im Menü über:
Home // slide // layout

Technology Development

Response

Implement Technology Challenges
Conclusions

- Significant **knowledge development** in cold recycling
- New **Mix Design** Procedure
  - New specimen **compaction** (Vib hammer)
  - New test methods (**Triaxial**)
  - System account for **RAP**
  - Testing protocols standardized (TG2)
- Benefits of Triaxial Tests
  - Reliable material evaluation (**less variability**)
  - Direct link to **performance** of BSM
- Mix design New **Structural Design** Function

**Quo vadis?**  **Veni - Vidi - Vici !!**
Russia 2018: it's a level playing field
Break please!