GSFM – An Integrated Approach to Mine Haul Road Design

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Aim of Presentation

- GSFM – four components of mine road design
- GSFM and rolling resistance interactions
- What does road design and construction involve?
  - Geometric
  - Structural
  - Functional
  - Maintenance... Design components
Introduction

- Poor road design impacts safety, traffic management, & cost per tonne hauled.

- Ideally, SHMS /SOP specifications should include a formal approach to road design.

- But...what should design consider and;
  - How is it specified?
  - How is conformance monitored?
Rolling Resistance

- Primary measure of mine road ‘performance’ is often based on ‘rolling resistance’
- Frequently the basis of a cost benefit evaluation, but...
- ... what is rolling resistance and how is it generated?
Rolling Resistance

- Rolling resistance is the resistance to truck motion due mostly to:
  - Road deformation under the tyre,
  - Tyre penetration into the road,
  - Tyre deformation effects on the road surface.
Road deformation under tyre pressure

Tyre penetration into the road surface

Tyre deformation effects on the road surface
Rolling Resistance

Total resistance% = RR% ± GR%

GR% (+ve against the load) (-ve with the load)
Practical Application

- Ramps
  - $\uparrow 1\% RR$ $\downarrow 10\% KPH$

- Surface roads
  - $\uparrow 1\% RR$ $\downarrow 26\% KPH$
Practical Application

- Ramps
  - $\uparrow 1\%$ RR $\downarrow 10\%$ KPH
- Surface roads
  - $\uparrow 1\%$ RR $\downarrow 26\%$ KPH

![Graph showing the effect of rolling resistance on truck speed.](image)

**Effect of rolling resistance on truck speed**

- Base case rolling resistance (RR) = 2%
- 2% to 3% RR
- 3% to 4% RR
- 4% to 5% RR

![Performance Chart](image)

Rear dump truck (electric drive) with 4.27kW/t GVM

Effective grade (UPHILL) % = Grade % + rolling resistance%

Effective grade (DOWNHILL) % = Grade % – rolling resistance%
Haul Road Design

- How do we develop a road design which:
  - Maximises safety
  - Maximises utility of environment (materials and equipment), and
  - Minimises rolling resistance and total-road users costs?
Haul Road Design

- From a safety perspective;
  - Geometric design – Excessive shear forces and truck instability.
  - Structural Design – Damage to tyre and chassis, truck instability, miss-alignment.
  - Functional Design – wet slipperiness, traction and skid resistance, dust.
  - Maintenance Design – running surface.
Haul Road Design

- From a rolling resistance perspective, minimise;
  - deformation under tyre - Structural Design
  - penetration and tyre deformation - Functional Design –
  - road deterioration rate - Maintenance Design –
Improving Mine Haul Roads

Unsprung mass acceleration due to two 100mm road defects

374t GVM RDT

Arbitrary time (s)

Acceleration (m/s²)

Road defect height (m)

Measured truck response

Actual road defect
First, you need to know what is wrong before you can decide to fix it.

Real-time monitoring can be used to record the truck and tyre response to the road, and when linked with GPS, gives the first indication of WHERE and WHAT the haul road problems are.
Improving Mine Haul Roads

- The cure is not necessarily just ‘more frequent’ maintenance.
- No amount of maintenance will fix a poorly-designed road. Each component of the road infrastructure must be correctly addressed at the design stage.
Improving Mine Haul Roads

- Investigate the root-cause of the under – performance before deciding on a remediation strategy.
- Follow an ‘integrated’ approach to road design, examine each design ‘component’.
HAUL ROAD DESIGN PHASE

- BASIC HAUL ROAD DESIGN DATA
- GEOMETRIC DESIGN GUIDELINES
- STRUCTURAL DESIGN GUIDELINES
- FUNCTIONAL DESIGN GUIDELINES
- MAINTENANCE MANAGEMENT GUIDELINES

HAUL ROAD OPERATION PHASE

- IS PERFORMANCE OPTIMUM AND DELIVERING MINIMUM TOTAL ROAD-USER COSTS?
- MODIFY WEARING COURSE MATERIAL
- CHEMICAL PALLIATION OR WATER-BASED SPRAYING

MOST COST EFFICIENT SOLUTION TO HAUL ROAD DESIGN AND OPERATION
Integrated Road Haul Design

BASIC HAUL ROAD DESIGN DATA

GEOMETRIC DESIGN GUIDELINES

STRUCTURAL DESIGN GUIDELINES

FUNCTIONAL DESIGN GUIDELINES

MAINTENANCE MANAGEMENT GUIDELINES

MODIFY WEARING COURSE MATERIAL

CHEMICAL PALLIATION OR WATER-BASED SPRAYING

IS PERFORMANCE OPTIMUM AND DELIVERING MINIMUM TOTAL ROAD-USER COSTS?

MOST COST EFFICIENT SOLUTION TO HAUL ROAD DESIGN AND OPERATION
Geometric Design
Integrated Haul Road Design

- Basic Haul Road Design Data
- Geometric Design Guidelines
- Structural Design Guidelines
- Functional Design Guidelines
- Maintenance Management Guidelines
- Is performance optimum and delivering minimum total road-user costs?
- Chemical palliation or water-based spraying

Most cost efficient solution to haul road design and operation
Structural Design
Integrated Road Haul Design

BASIC HAUL ROAD DESIGN DATA

GEOMETRIC DESIGN GUIDELINES

STRUCTURAL DESIGN GUIDELINES

FUNCTIONAL DESIGN GUIDELINES

MAINTENANCE MANAGEMENT GUIDELINES

IS PERFORMANCE OPTIMUM AND DELIVERING MINIMUM TOTAL ROAD-USER COSTS?

MODIFY WEARING COURSE MATERIAL

CHEMICAL PALLIATION OR WATER-BASED SPRAYING

MOST COST EFFICIENT SOLUTION TO HAUL ROAD DESIGN AND OPERATION

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Functional Design
Integrated Haul Road Design

- **Haul Road Design Phase**
  - Basic Haul Road Design Data
  - Geometric Design Guidelines
  - Structural Design Guidelines
  - Functional Design Guidelines
  - Maintenance Management Guidelines

- **Haul Road Operation Phase**
  - Is Performance Optimum and Delivering Minimum Total Road-User Costs?
  - Chemical Palliation or Water-Based Spraying

**Maintenance Management**

**Most Cost Efficient Solution to Haul Road Design and Operation**
Maintenance frequency

Rolling resistance

Costs

Maximum total cost solution

Minimum total cost solution

Max

Maintenance frequency

Min

Rolling resistance

Min

Max

Costs
Geometric Design

- Geometric design;
- Determines the road layout – or alignment, both horizontally and vertically.
- Practically, we often need to compromise between an ideal layout and what mine geometry and hauling economics will allow.
Establish start and end points of road.

Establish feasible (mine plan) and economic route (topography) selection.

Optimise truck performance against route grades and speeds and construction costs.

Check additional road geometric requirements against ALL road-user vehicles.

Design horizontal and vertical alignments. Check sight distances throughout.

Check drainage requirements with topographic contours in vicinity of route.

Survey and peg the route centre lines. Test soil properties for Structural Design phase.

Assess junction and intersection layouts and associated safety components.
Geometric Design Vertical Alignment

- Alignment of the road in;
- The *vertical* plane – here we design for safe and efficient;
- Stopping and sight distances (how reliably can we determine these values??),
- Optimum ramp gradients and vertical curve transitions.
Geometric Design Vertical Alignment

- Stopping distances;
- Truck manufacturers and site testing should confirm the distances required to bring a truck to a stop under various conditions of load (NB empty), speed, grade and traction - wet, dry, wearing course(s).
Geometric Design Vertical Alignment

- Sight distances; precautions should be applied when sight distance falls below stopping distance;
  - Bench edge obstructions require lay-backs or batter,
  - Vertical curves – crests often require flattening to improve sight distances,
  - Use a minimum vertical curve length of 150m and radius of 1500m for design work.
  - Apply speed limits.
Geometric Design Vertical Alignment

- Sight distances and machine factors;
- In addition to sight distances – also consider driver blind spots – where the driver has limited or no sight of parts of the road.

Geometric Design Horizontal Alignment

- Alignment of the road in the *horizontal* plane – here we design for safe and efficient;
  - Road width,
  - Curvature and super-elevations,
  - Crown or cross-fall.
Geometric Design Horizontal Alignment

Ramp W 3
Ramp W 4
Ramp W 5

50m
Geometric Design Horizontal Alignment

Ramp W1 (W)  Ramp W1 (E)

Main haul road

50m 50m 50m
Geometric Design Horizontal Alignment

- Width of road;
- Sufficient for the required number of lanes (pavement width), and shoulders (carriageway width) and all the associated safety and drainage features (formation width).
Geometric Design Horizontal Alignment

- The widest vehicles proposed determine the pavement width.
- The Table summarizes these design roadway widths.

<table>
<thead>
<tr>
<th>Number of lanes</th>
<th>Factor Width of largest truck on road</th>
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<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>3.5</td>
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<td>3</td>
<td>5</td>
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<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

NOTES
- For switchbacks or other sharp curves and/or roads with high traffic volumes or limited visibility, a safe roadway width would be designed with an additional 0.5 m vehicle width.
- A four-lane road is recommended where trolley assist systems are in use.

Truck images courtesy Caterpillar Inc
Curves and switchbacks;
- Designed with the maximum radius possible and be kept smooth and consistent.
- Changes in curve radii (compound curves) should be avoided. A larger curve radius allows a higher safe road speed and increased truck stability - >200m minimum radius ideal.
Geometric Design Horizontal Alignment

- Super-elevation;
  - Banking applied on the outside of a curve to allow the truck to maintain stability in the curve at speed.
- Should not exceed 5% -7%, unless high-speed haulage is maintained and the possibility of sliding minimized by using median berms to split super-elevations. Refer Table.
Geometric Design Horizontal Alignment

- Cross-fall (use with extreme caution), crown or camber;
- **Critical** to the design and successful operation of mine roads.
- Ensures water does not gather on and penetrate into the road surface.
Geometric Design Horizontal Alignment

- Cross-slope should be used with caution, possibility of collision increases or run-off bench edge.
- Large deflection berms should be placed at the road center and edge.
- Cross-slope easier to maintain.
Geometric Design

- Safety berms;
  - A 'crest' or road-edge berm will not effectively stop trucks (especially high speed laden or unladen trucks) from leaving the road.
  - At best, they will provide limited deflection and warning to the driver that the truck path needs correcting.
Berm slope should be as steep as possible (1.5V:1H ideally), but ensure stability and maintenance of height.

For large haul trucks, the berm height should be **at least** 50%-66% of the truck wheel diameter.

Steep berm side aids deflection. Flatter berms allow the truck to 'climb' and overturn.

Median berms – consider traffic management implications.
Geometric Design

- Also included in the geometric design is drainage;
- No matter how good the design, water will always damage a mine road. *Keep water OFF the roads* – or at the very least lead water off the road as soon as possible.
- Investigate geometry AND local topographic drainage patterns.
Structural Design

- Structural design refers to the load carrying capacity of the road;
- Better pavement response to applied loads,
- Reduced deflection on surface, better wearing course performance
- Eliminate deformation in sub-grade or in-situ.
Structural Design

- Two approaches;
  - Mechanistic design approach using pavement layer limiting vertical strain criteria &
  - CBR cover-curve approach using pavement layer CBR values.
Structural Design - Mechanistic

- Mechanistic design approach using pavement layer limiting vertical strain criteria;
- Limiting strain criteria tailored to traffic volumes, type and life of mine road (ramp, pit or main haul).
The strains resulting from the truck wheel loads decrease with depth – except where these strain fields overlap. Here, higher strains are found – and if more than 2000 microstrains – the in-situ material is liable to ‘collapse’ leading to structural failure.
Maximum permissible vertical strains can also be determined from \((kt/day \times \text{performance index})\).

Where performance index is defined as:

1. Adequate but fairly maintenance intensive,
2. Good with normal maintenance interventions,
3. Outstanding with low maintenance requirements.
Structural Design - Mechanistic

- When a base layer of selected blasted waste rock is used in the structure, a mechanistic approach is more appropriate.

- The selected waste rock layer is located under the wearing course,
  - Road performance is significantly improved, primarily due to the load carrying capacity of the waste rock layer.
Design chart (examples) are based on a fully laden haul truck, at maximum GVM, (tons) with standard radial tyres, inflated to 800kPa.

The road design incorporates 200mm of sheeting with CBR=80%, a selected blasted waste rock base layer, built on 3m of in-situ material with the indicated E-modulus shown on the charts.
CAT789C Base Layer Thickness Design
800kPa tyre pressure, fully laden truck at OEM GVM

For limiting strains of 2000 με

Category I
Category II
Category III

Wearing course
200mm
E = 350MPa

Base layer thickness
E = 3000MPa

In-situ Thickness
3000mm
CBR cover-curve design approach uses pavement layer CBR values;

- Thickness of successive layers based on CBR (strength) of underlying layer and truck wheel load (tonnes).
In-situ CBR 7%
Sub-base CBR 30%
Base CBR 55%
Compacted In-situ CBR 13%
Wearing course CBR 80%
In-situ CBR 7%

Truck GVM (t) | Truck wheel load (t) |
-------------|---------------------|
 90          | 15                  |
 150         | 25                  |
 240         | 40                  |
 320         | 55                  |
 390         | 65                  |
 450         | 75                  |
 510         | 85                  |
 570         | 105                 |
 630         |                     |
Integrated Road Haul Design

Basic Haul Road Design Data

Geometric Design Guidelines

Structural Design Guidelines

Functional Design Guidelines

Is performance optimum and delivering minimum total road-user costs?

Modify Wearing Course Material

Chemical Palliation or Water-Based Spraying

Most cost efficient solution to haul road design and operation
Functional Design

- Wearing course material selection. Design for;
  - Improved traction, skid resistance, reduced dust,
  - Reduced rolling resistance – through reduced wearing course ‘defects’,
  - Reduced deterioration rates and maintenance frequency.
Here, the stones in the mix – or ‘aggregate’ is too big – this can’t easily be graded and if it is, the large stones will come loose ‘seeding’ potholes and damaging truck tyres.

In this case – the wearing course has too much fine material and it forms a slippery soft layer on the road. Carry-over?
Functional Design

- This is probably a good mix of crushed rock to use, everything smaller than 40mm in size and not too much fine material (<20% smaller than 2mm).
- Watch out for smooth round alluvial aggregate in the mix.
  - This will not easily interlock and will ravel out of the wearing course.
Functional Design

- A small jaw crusher can be used to prepare blasted rock as a wearing course aggregate, often in a mix of one or more other materials to form the final product.

- It is also useful for creating a fine aggregate from waste rock to be placed as a dressing in loading areas – to reduce tyre damage in these areas.
Correct wearing course material selection will;

- Reduce road rolling resistance – through reduced wearing course ‘defects’ &
- Reduce road deterioration rates and maintenance frequency.
Functional Design

Wearing Course Selection

Grading Coefficient

Shrinkage Product

Recommended (1)

Recommended (2)

- Dustiness
- Slippery when wet
- Loose stones
- Tyre damage
- Corrugates
- Loose material
Practical Application

Grading coefficient

Shrinkage product

Wet skid resistance

Dustiness

Loose stoniness

Corrugations

Dry skid resistance

Loose material
Practical Application

- Shrinkage product
- Grading coefficient
- Dustiness
- Loose stoniness
- Dry skid resistance
Dust Palliatives

- Dust is caused through loss of fines, so consider specifically;
  - Wearing course material selection;
    - Size distribution, clay content,
    - Restraint of fines,
  - Traffic volumes,
  - Climatic conditions.
Dust Palliatives

- All suppression systems aim to minimise erosivity of the wearing course. Options include:
  - Improved wearing course material,
  - Regular watering,
  - Use of chemical suppressants.
Dust Palliatives

- Chemical palliatives available include;
  - Water/wetting agents,
  - Hygroscopic salts,
  - Lignosulphonates,
  - Modified waxes,
  - Polymers,
  - Tar/bitumen products,
  - Sulphonated oils,
  - Enzymes.
Dust Palliatives

- Use of chemical dust suppressants;
- Should be considered only as an adjunct to other methods,
- Chemical dust suppressants have a limited life and will require regular applications,
- Various generic types to choose from, based mainly on climatic conditions and wearing surface material.
Dust Palliatives

- Trial a chemical dust suppressant first before making a firm commitment,
- Careful attention should be given to whole-of-life costing before using a chemical dust suppressant.

<table>
<thead>
<tr>
<th>Wetting Agents</th>
<th>High PR (≥10)</th>
<th>Medium PR (2–10)</th>
<th>Sand</th>
<th>Very Weather Instability</th>
<th>Ramp roads</th>
<th>Heavy traffic</th>
<th>Short terms</th>
<th>Long terms</th>
<th>Smart</th>
<th>Plan-in</th>
<th>Maintainable</th>
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<tbody>
<tr>
<td>Hygroscopic Salts</td>
<td>✔️</td>
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<td>✔️</td>
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<td>Ligno- sulphonates</td>
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<td>✔️</td>
<td>✔️</td>
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<td>Petroleum Emulsions</td>
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<tr>
<td>Tar / Bitumen Emulsions</td>
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<td>✔️</td>
<td>✔️</td>
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</tbody>
</table>

**Notes:**
- PR: Particle size.
- ✔️: Effective.
- ✓: Moderate effectiveness.
- ✗: Not effective.
- R: Reapply after 1–2 days.
- M: Maintain when moist, lightly watered.
- SK: Maintain with spray-on re-application.
- SR: Maintain with spray-replacement.
Dust Palliatives

- The most appropriate selection and management strategy should consider:
  - Safety and health benefits,
  - Road management philosophy,
  - Improved cost-efficiency.
Locality Data
- Road, Climate, Wearing course parameters
- Hours per day of dust control required

Equipment Data
- Productivity and operating costs of road (re)-construction, maintenance and (spraying) equipment

Set Maximum Dust Defect Allowable

Palliative Data
- Cost ($/litre) and application rates (establishment and rejuvenation)

Determine Cost of Establishment

Determine Cost of Rejuvenation (re-application) and Interval

Determine Wearing Course Maintenance Interval and Cost with Palliative Applied

Determine Wearing Course Maintenance Interval and Cost with Water-based Spraying

Water Data
- Cost ($/kilo-liter) and application rates (l/m²)

Determine Cost of Water-based Spraying

Summarise Annual Costs (Application and Road Maintenance)

Method selection
Integrated Haul Road Design

- Basic Haul Road Design Data
- Geometric Design Guidelines
- Structural Design Guidelines
- Functional Design Guidelines
- Maintenance Management Guidelines

- Modify Wearing Course Material
  - Chemical Palliation or Water-Based Spraying

Is performance optimum and delivering minimum total road-user costs?

Most cost efficient solution to haul road design and operation
Maintenance Management

- Maintenance design and management;
- Routine road maintenance as a result of progressive wearing course deterioration.
  - A satisfactory road design will require minimum maintenance.
Maintenance Management

Minimum total cost solution
LOW VOLUME SURFACE ROADS

Minimum total cost solution
RAMPS

Maintenance frequency
Rolling resistance

Costs

Max
Min
Max
Min
Max
Min
Percentage increase in total road-user costs with maintenance interval

Days between maintenance

Percent change

- B02
- B03
- B04
- B05
- S Ramp
Why is the segment maintenance intensive?
- Poor design and/or build specs;
  - Geometrics,
  - Structure (layer works and materials),
  - Functional (wearing course – surfacing materials).
Benchmarking Rolling Resistance

- Road performance evaluation,
- Use defect degree and extent to determine RR%.

<table>
<thead>
<tr>
<th>DEFECT</th>
<th>RDS (Rolling resistance)</th>
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<tbody>
<tr>
<td>Date</td>
<td>EVALUATOR</td>
</tr>
<tr>
<td>ROAD</td>
<td>VEHICLE SPEED km/hr (V)</td>
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<tr>
<td>CHAINAGE</td>
<td>TRAFFIC/km</td>
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<tr>
<td>DEFECT</td>
<td>DEGREE (1-5)</td>
</tr>
<tr>
<td>Potholes</td>
<td>x</td>
</tr>
<tr>
<td>Corrugations</td>
<td>x</td>
</tr>
<tr>
<td>Rutting</td>
<td>x</td>
</tr>
<tr>
<td>Loose material</td>
<td>x</td>
</tr>
<tr>
<td>Stainless - fixed</td>
<td>x</td>
</tr>
<tr>
<td>TOTAL ROUGHNESS SCORE (RDS)</td>
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</tbody>
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ESTIMATED ROLLING RESISTANCE (%)
Refer to graph for rolling resistance percentages

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<table>
<thead>
<tr>
<th>Defect extent</th>
<th>% road area effected</th>
<th>Extent score</th>
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<tbody>
<tr>
<td>Not seen or isolated only</td>
<td>&lt;5</td>
<td>1</td>
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<tr>
<td>Intermittent</td>
<td>6-15</td>
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<tr>
<td></td>
<td>Degree 1</td>
<td>Degree 3</td>
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<tr>
<td>Potholes</td>
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<tr>
<td>Corrugations</td>
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<td>![Image]</td>
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<tr>
<td>Rutting</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Loose material</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Stoniness - fixed in wearing course</td>
<td>![Image]</td>
<td>![Image]</td>
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## Practical Application

<table>
<thead>
<tr>
<th>Defect</th>
<th>Degree (1-5)</th>
<th>Extent (1-5)</th>
<th>Degree x Extent</th>
<th>Extent</th>
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<tr>
<td>Potholes</td>
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<td>1</td>
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<td>Corrugations</td>
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<td>Rutting</td>
<td>3</td>
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<tr>
<td>Loose material</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Stones - fixed</td>
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<td>2</td>
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<tr>
<td><strong>Total score</strong></td>
<td><strong>49</strong></td>
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Practical Application

3.25%
Percentage increase in total road-user costs with maintenance interval

<table>
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<th>Days between maintenance</th>
<th>Percent change</th>
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Resources

- For more information on issued raised today;
  - [http://mining.curtin.edu.au/people](http://mining.curtin.edu.au/people) click on RJT for further links to haul road publications
Resources

- [www.cdc.gov/niosh/mining/pubs](http://www.cdc.gov/niosh/mining/pubs) search for ‘IC8758.pdf’ 1977 USBM haul road design guidelines
- Copy of presentation and full supporting notes available through DEEDI Mines Safety and Health web-site....