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?
  - **G**eometric
  - **S**tructural
  - **F**unctional
  - **M**aintenance…. 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?

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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

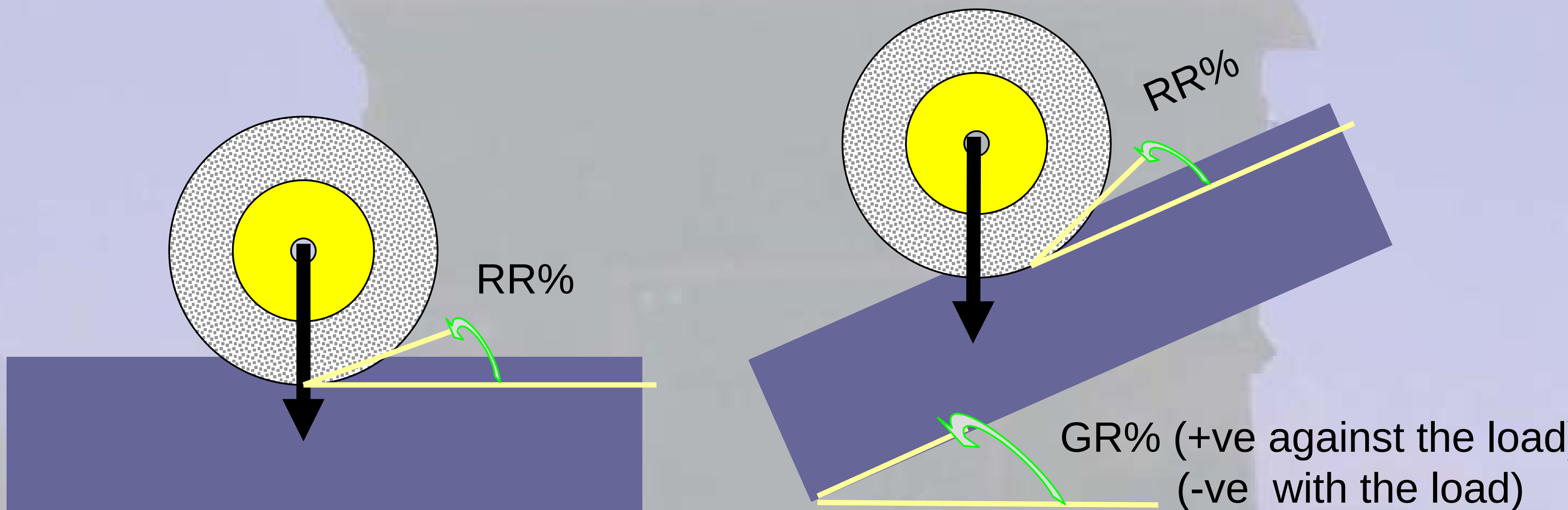
- Rolling resistance is the resistance *to truck motion* due mostly to:
  - Road deformation under the tyre,
  - Tyre penetration into the road,
  - Tyre deformation effects on the road surface.

Road deformation under tyre pressure

Tyre penetration into the road surface

Tyre deformation effects on the road surface

Rolling Resistance



Total resistance% = RR% ± GR%

Practical Application

- Ramps
  - ↑1%RR ↓10%KPH
- Surface roads
  - ↑1%RR ↓26%KPH

Practical Application

- Ramps
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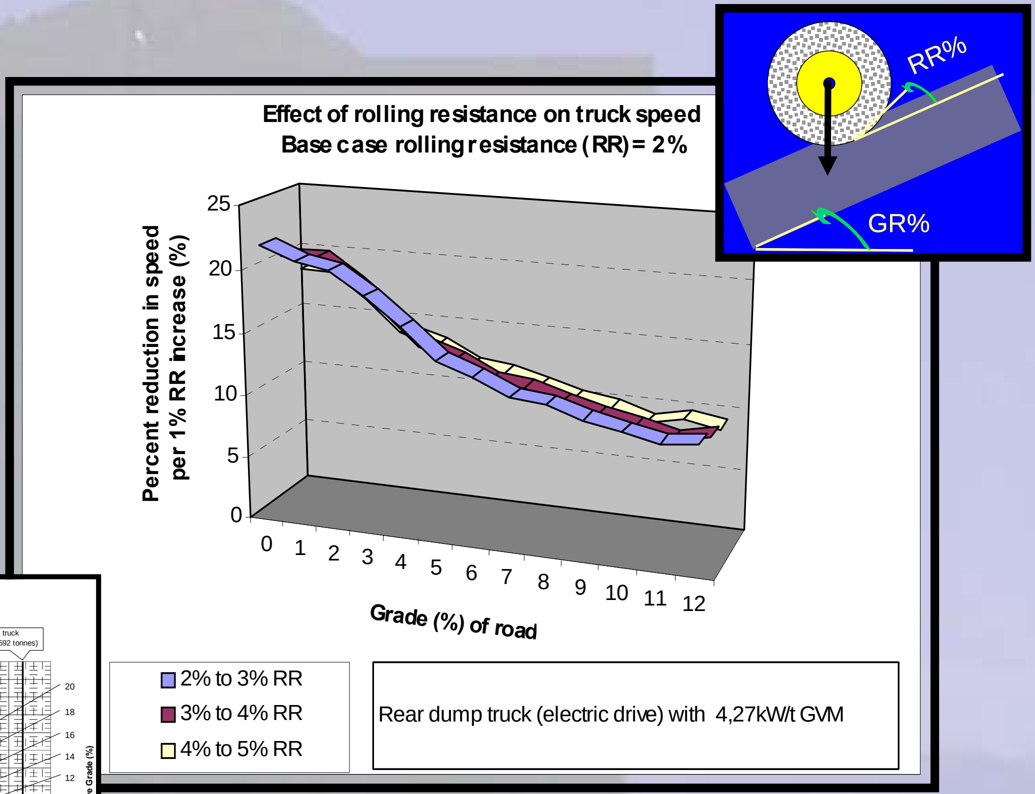
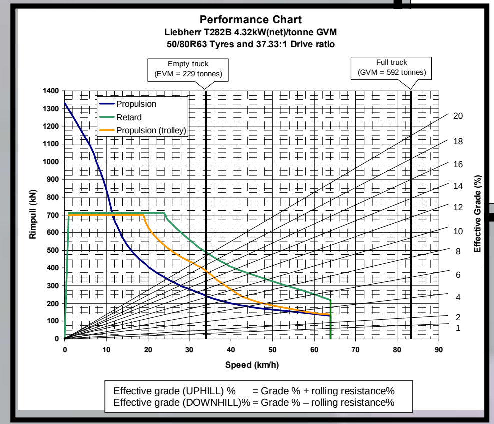
- Surface roads
  - ↑1%RR ↓26%KPH





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?

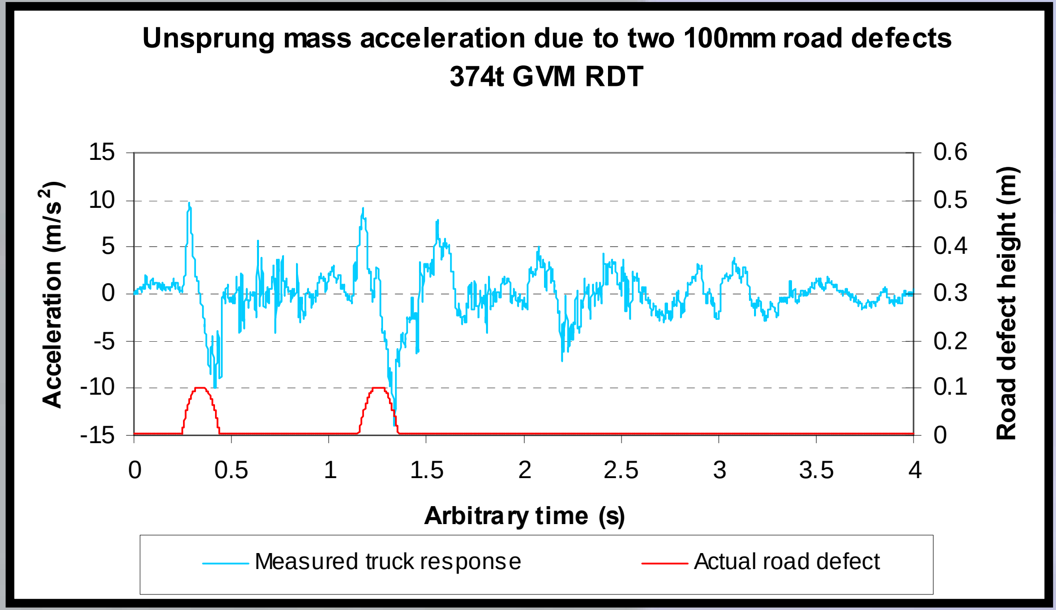
Haul Road Design

- 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



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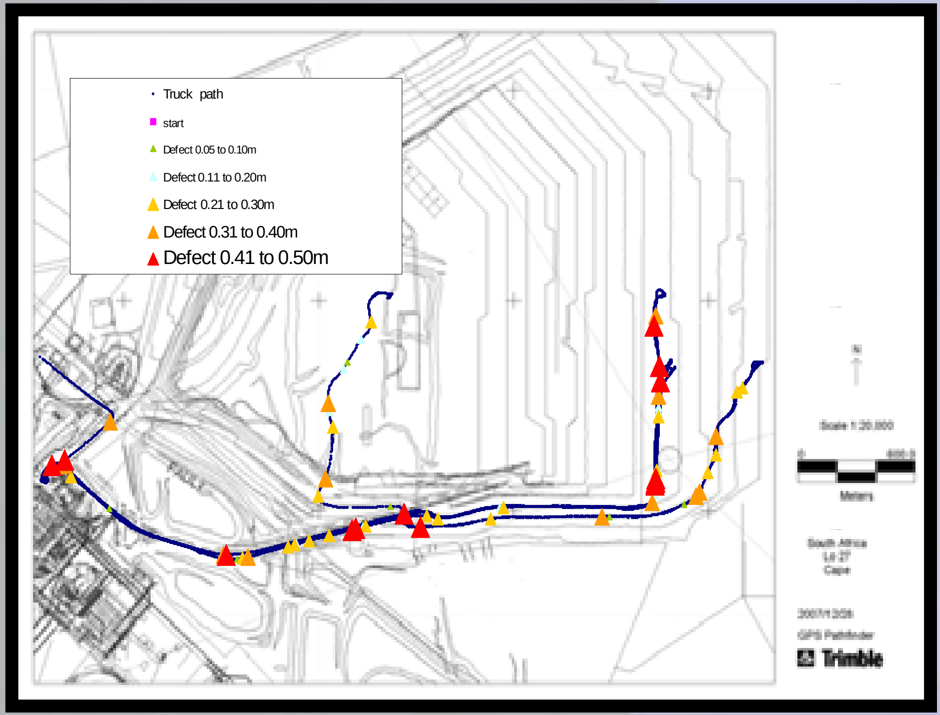
Improving Mine Haul Roads

- First, you need to know what is wrong before you can decided 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.



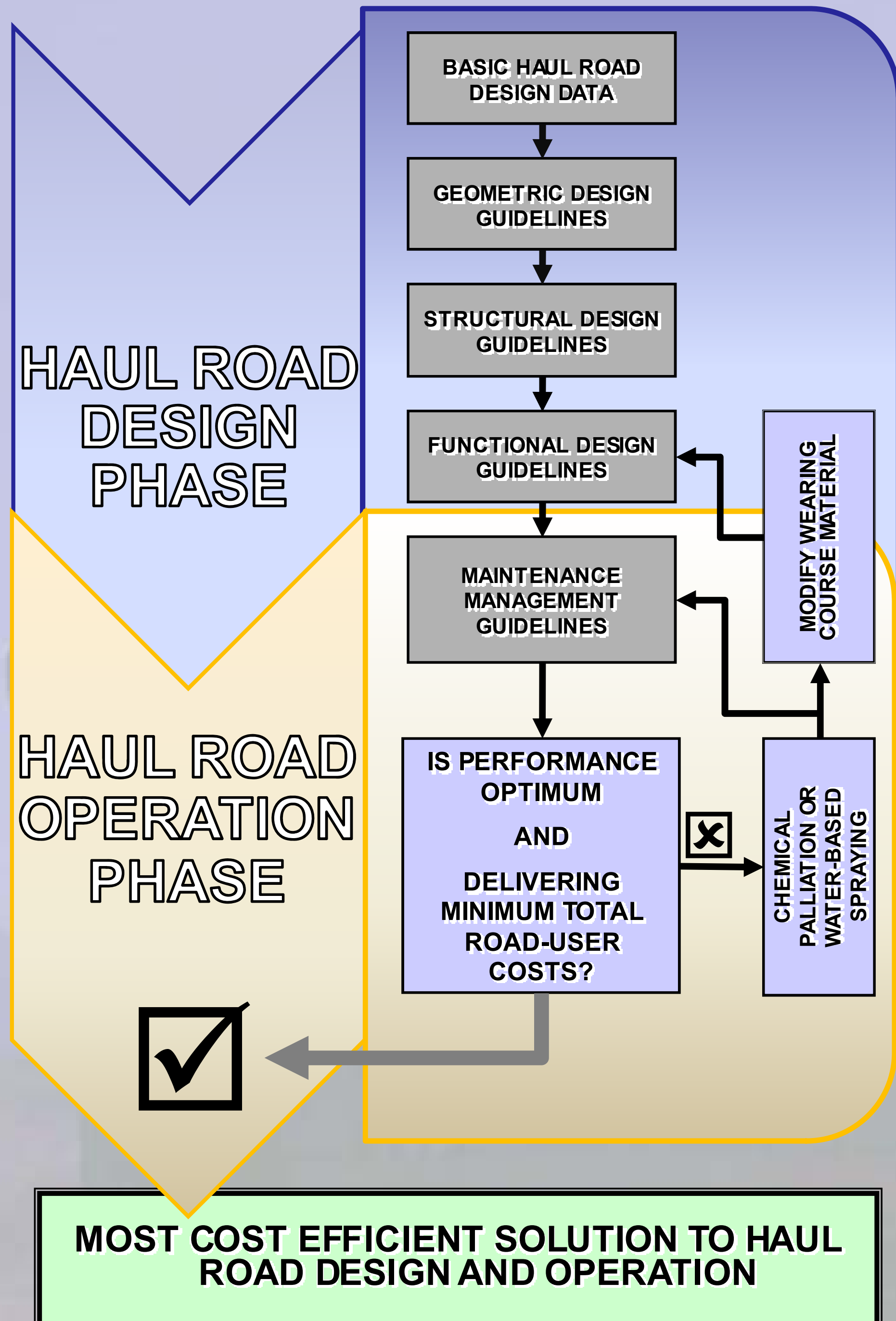
Improving Mine Haul Roads

- 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.

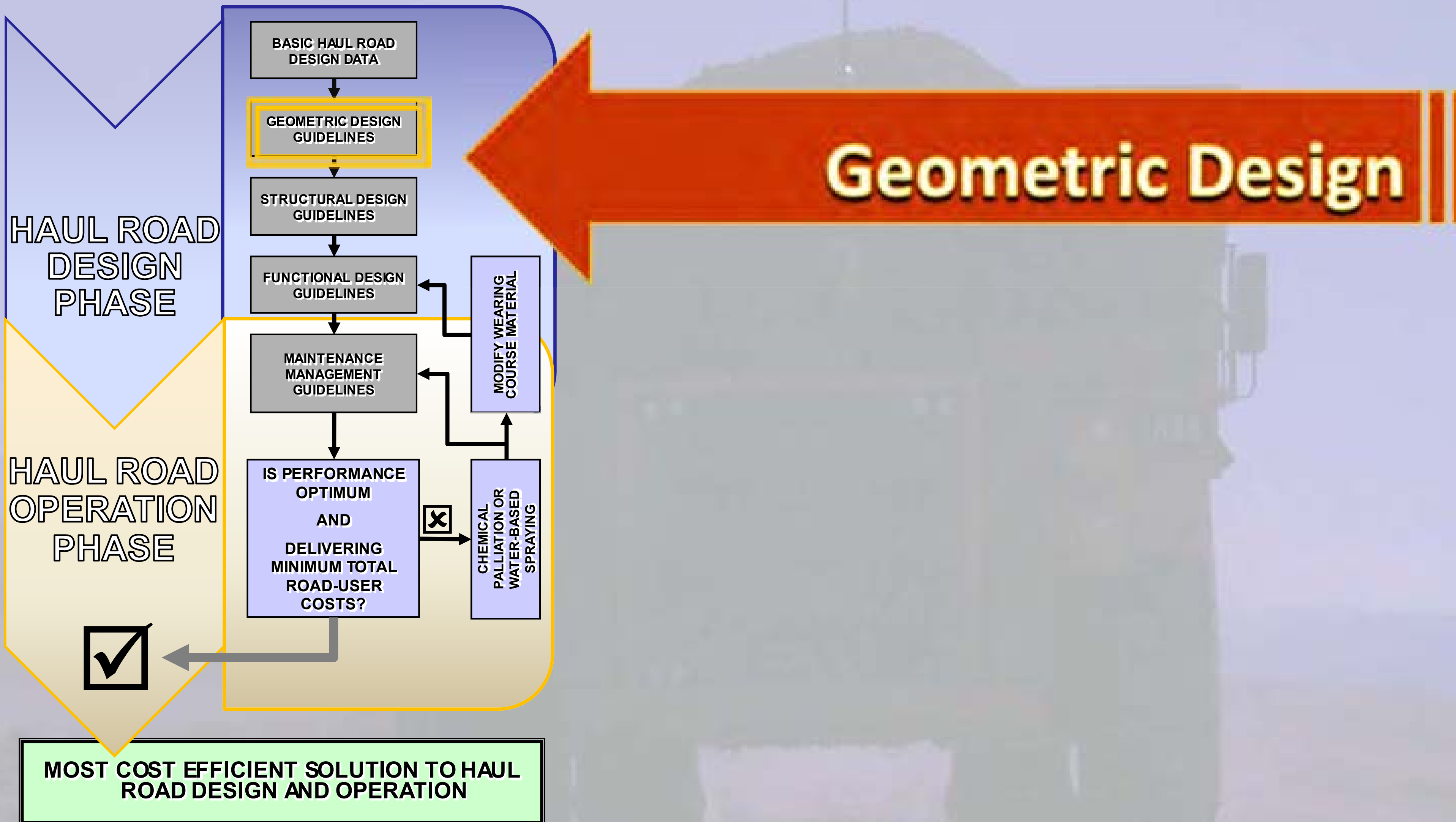
Improving Mine Haul Roads

- 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’.



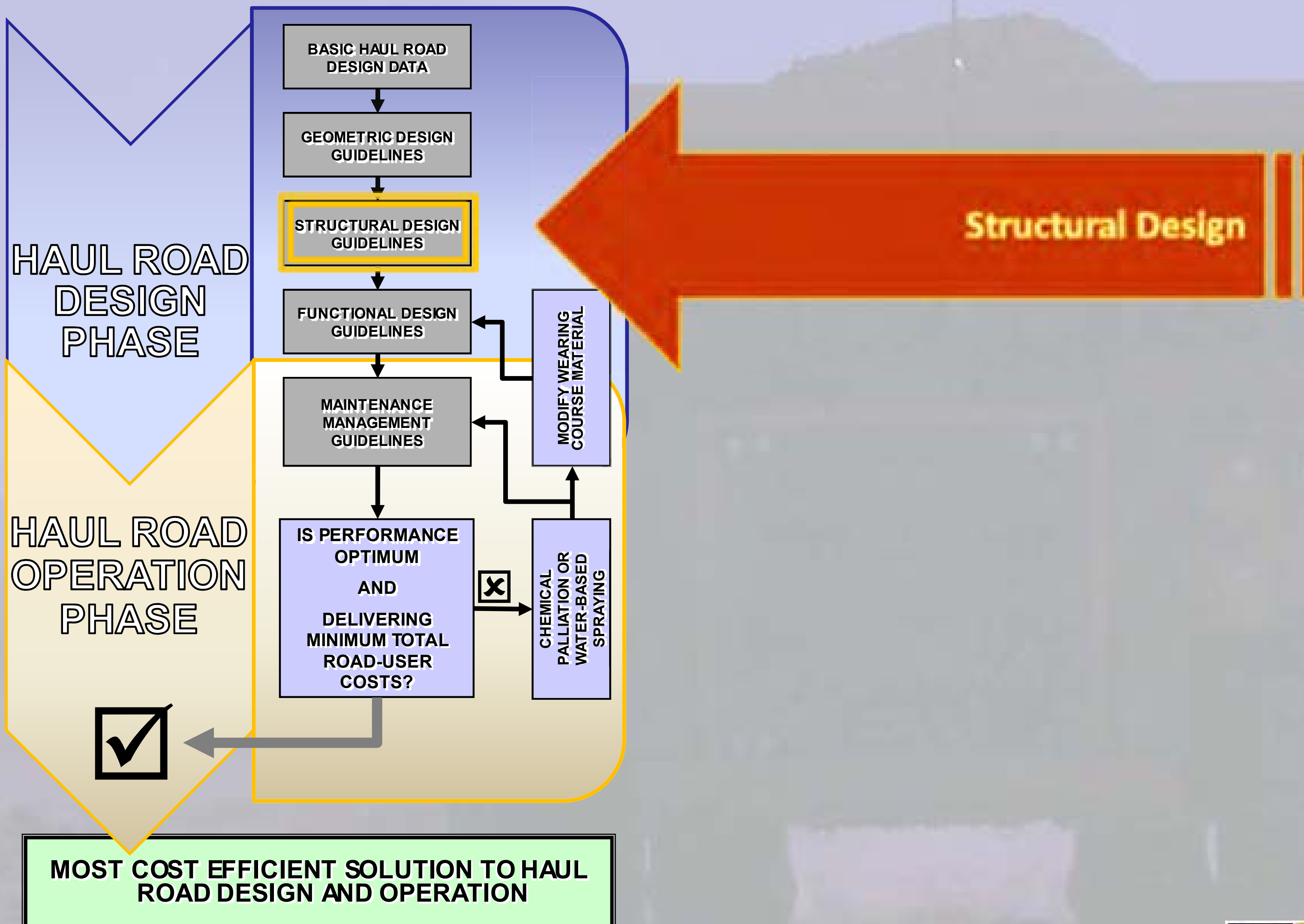
HAUL ROAD DESIGN PHASE
HAUL ROAD OPERATION PHASE
BASIC HAUL ROAD DESIGN DATA
GEOMETRIC DESIGN GUIDELINES
STRUCTURAL DESIGN GUIDELINES
FUNCTIONAL DESIGN GUIDELINES
MAINTENANCE MANAGEMENT GUIDELINES
IS PERFORMANCE OPTIMUM AND DELIVERING MINIMUM TOTAL ROAD-USER COSTS?
MODIFY WEARING COURSE MATERIAL
CHEMICAL PALLIATION OR WATER-BASED SPRAYING
MOST COST EFFICIENT SOLUTION TO HAUL ROAD DESIGN AND OPERATION

Integrated Road Haul Design

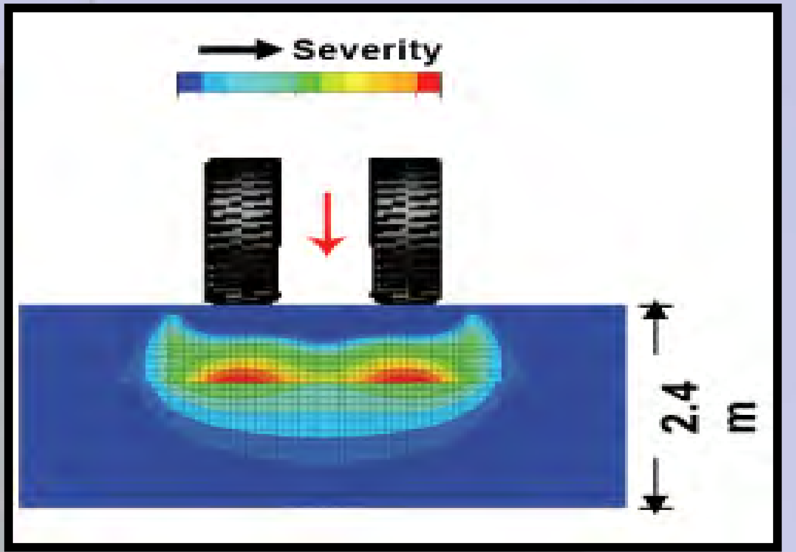


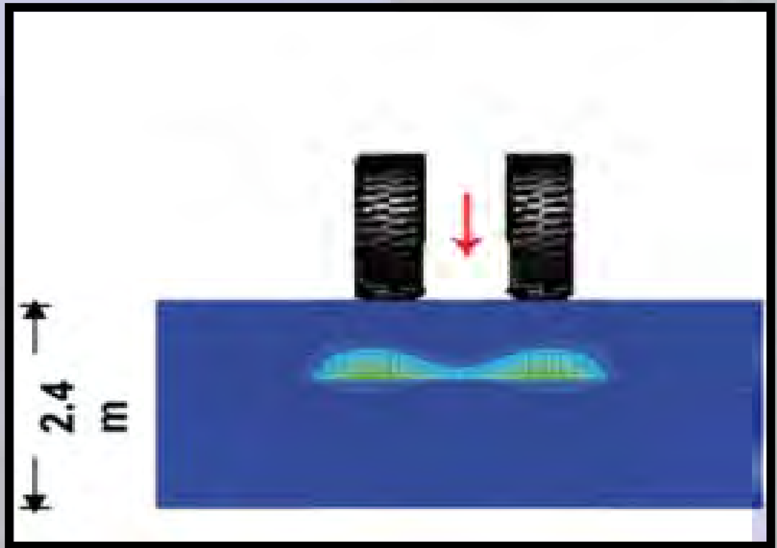
Geometric Design

Integrated Haul Road Design

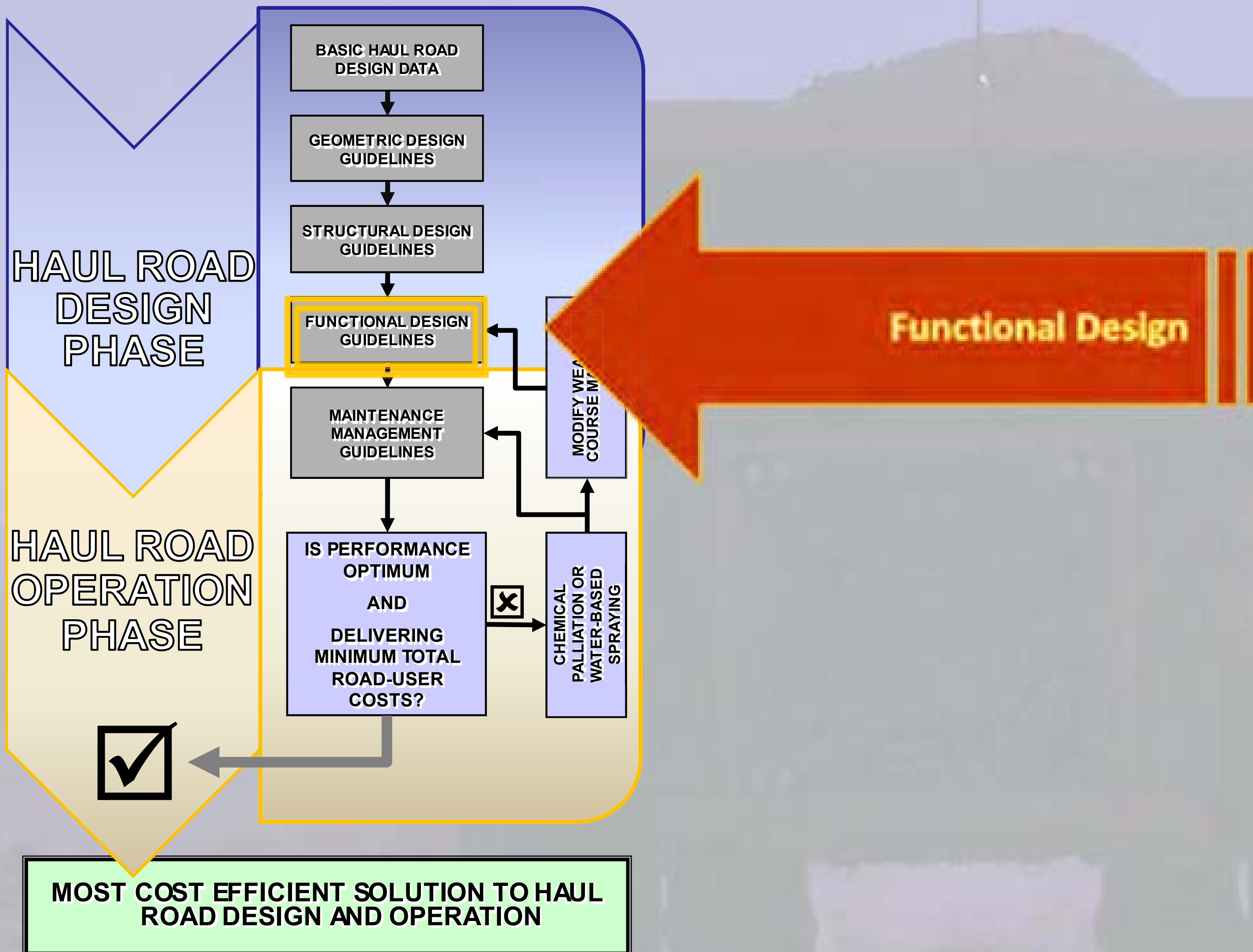


Structural Design





Integrated Road Haul Design



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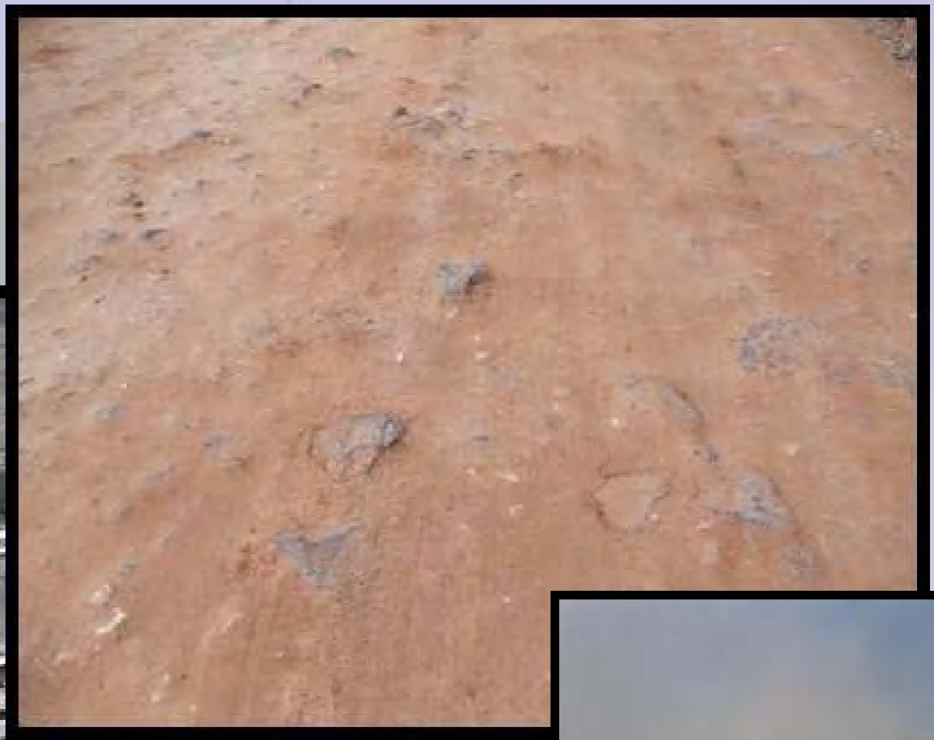
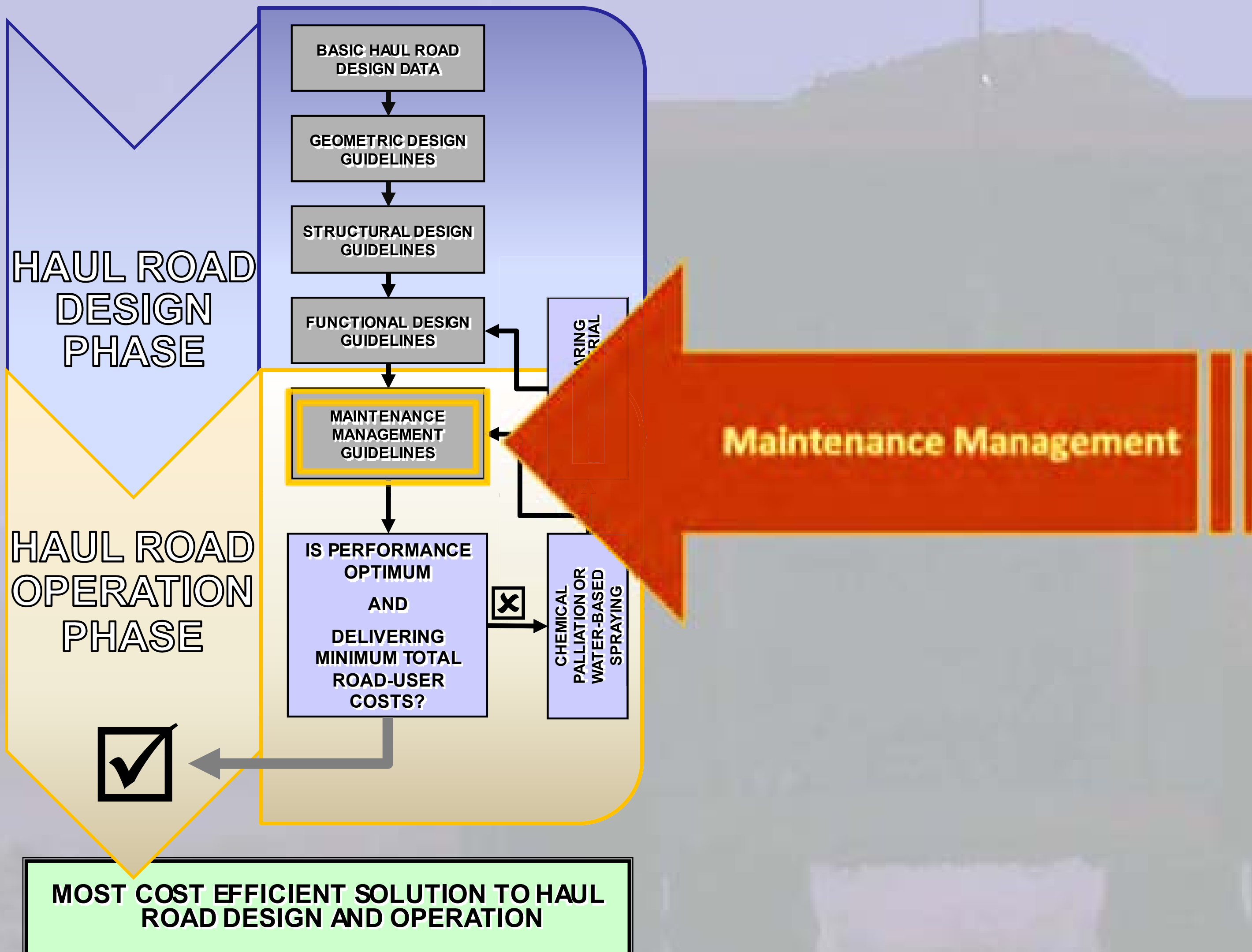
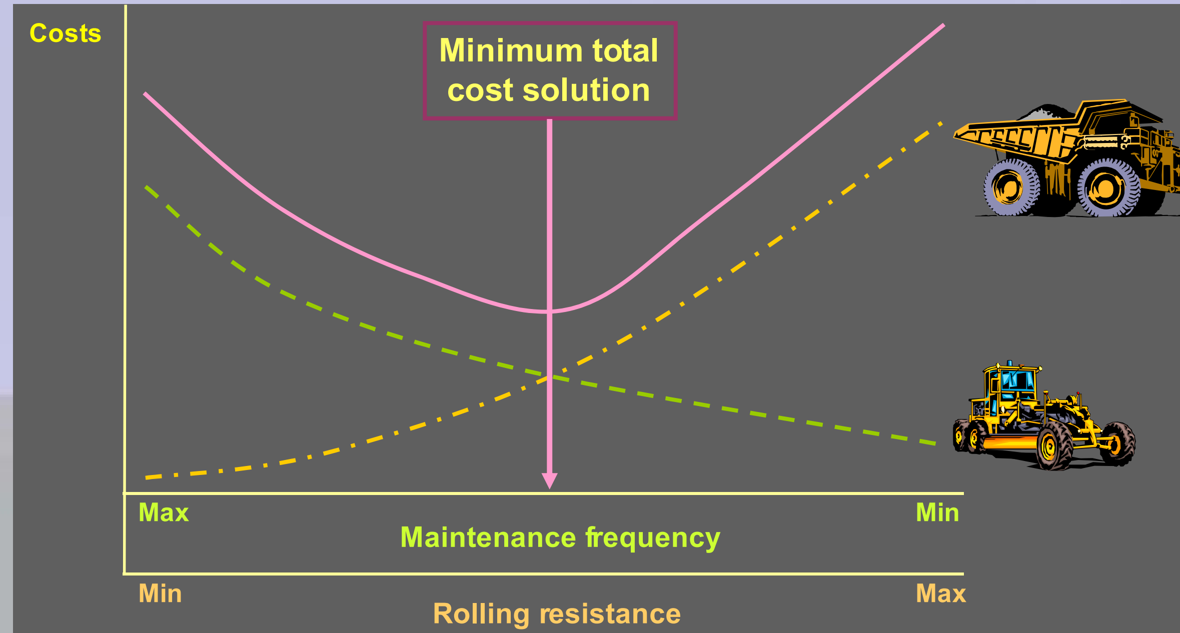
Functional Design



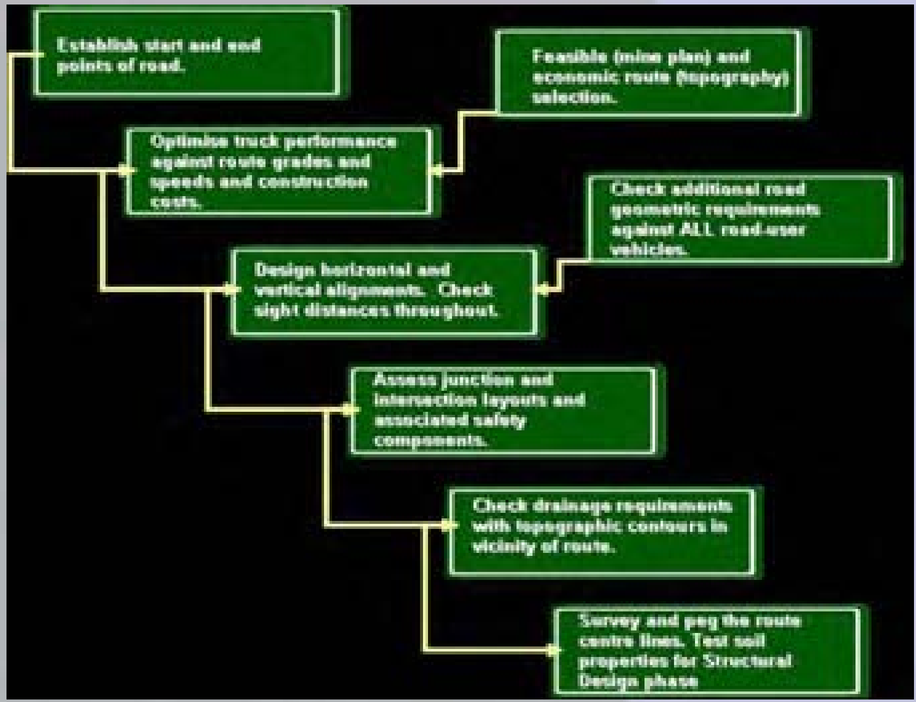
Integrated Haul Road Design




Costs
Minimum total cost solution
Max
Min
Maintenance frequency
Min
Max
Rolling resistance

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.

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.

Assess junction and intersection layouts and associated safety components.

Check drainage requirements with topographic contours in vicinity of route.

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

Geometric Design Vertical Alignment

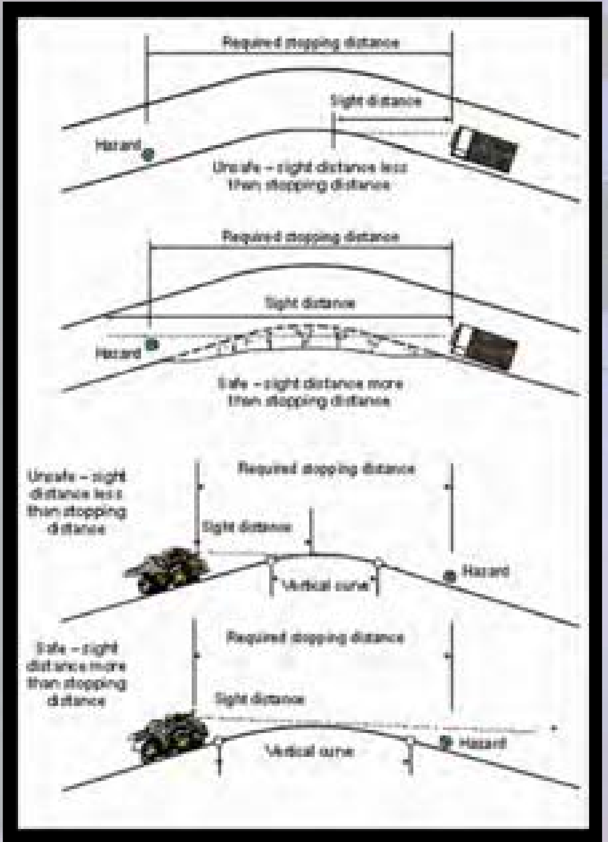
- Alignment of the road in;
  - The ***vertical*** plane – here we design for safe and efficient;
    - Stopping and sight distances (how reliably can we determine these values??),
    - Optimum ramp gradients and vertical curve transitions.

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).

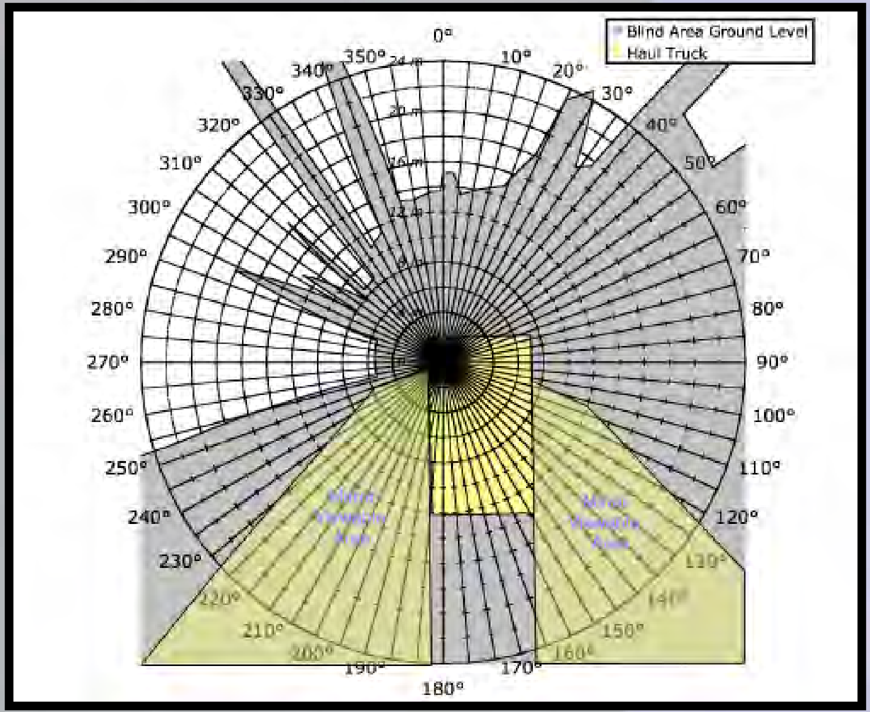
Geometric Design Vertical Alignment

- 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.

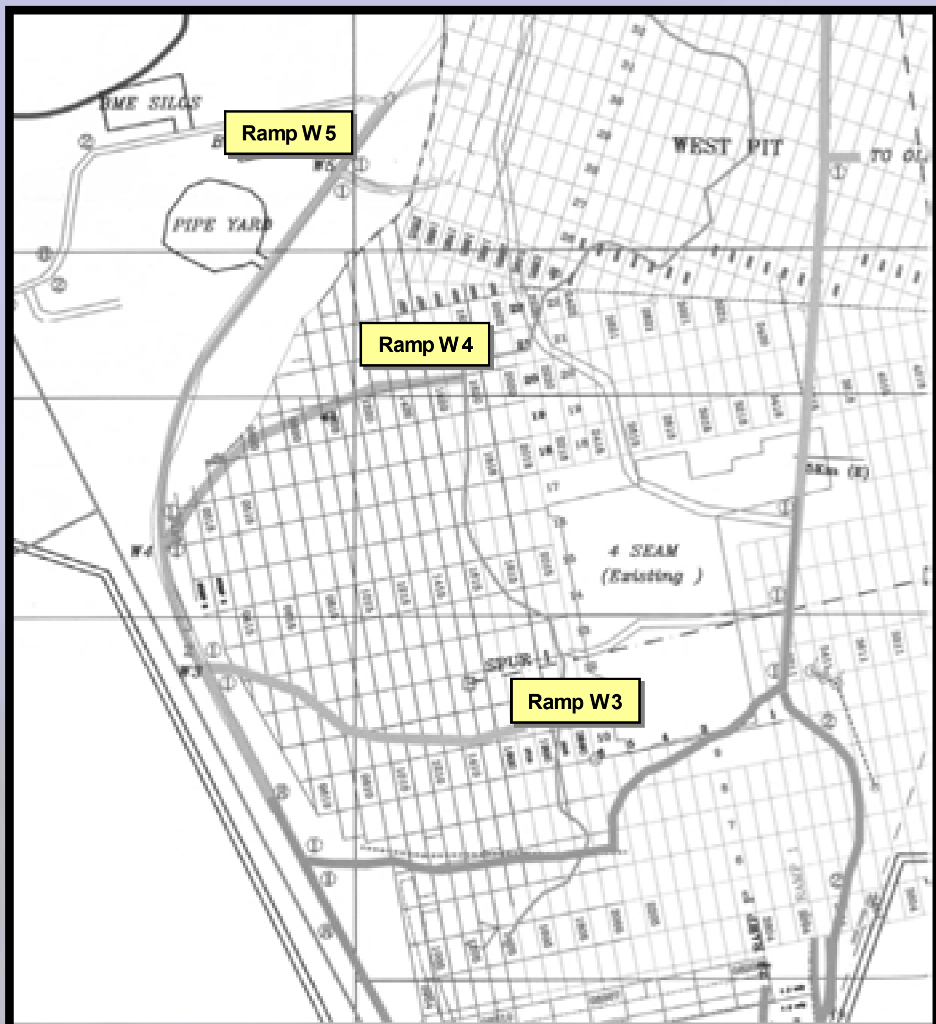


Final Report Blind Area Study Large Mining Equipment, Contract Report 200-2005-M-12695, CDC/NIOSH, USA, 2006.

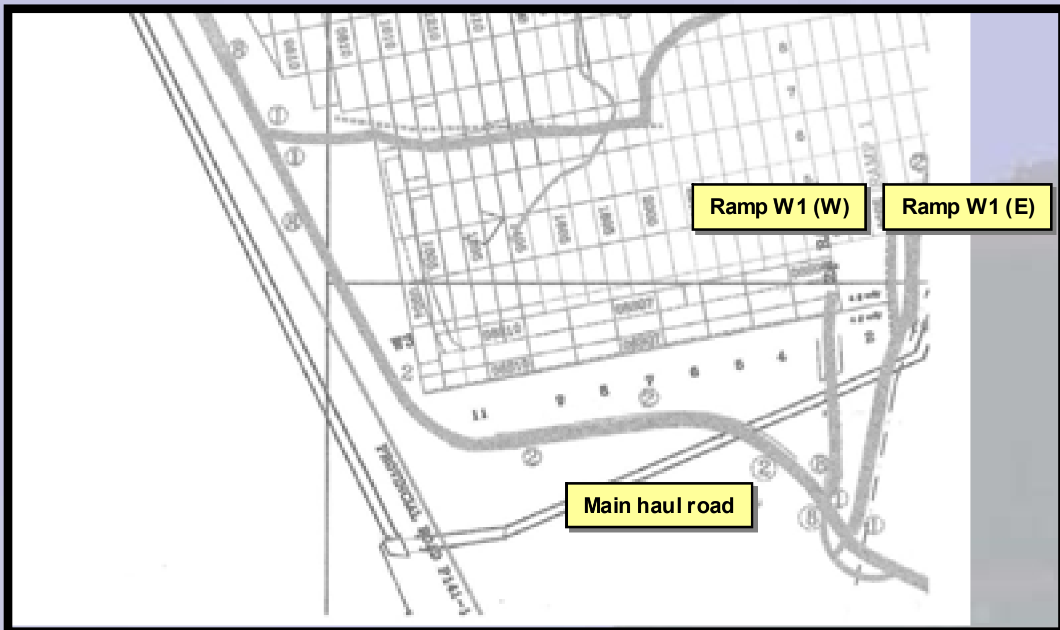
Geometric Design Horizontal Alignment

- 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



Geometric Design Horizontal Alignment

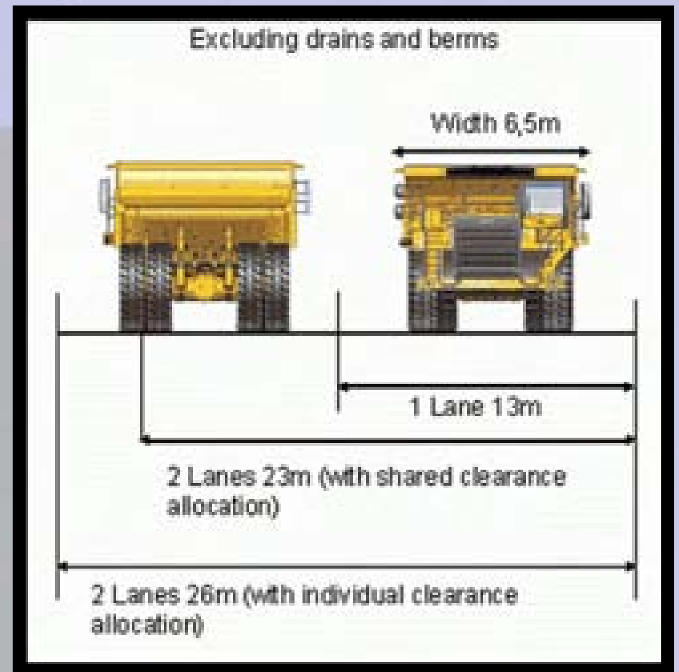


Geometric Design Horizontal Alignment

- 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).
  - 3.5W – why? Effect of larger vehicles.

Geometric Design Horizontal Alignment

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



Number of lanes	Factor x Width of largest truck on road
1	2
2	3,5
3	5
4	6

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 x vehicle width.

A four-lane road is recommended where trolley assist systems are in use.

Truck images courtesy Caterpillar Inc

Geometric Design Horizontal Alignment

- 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

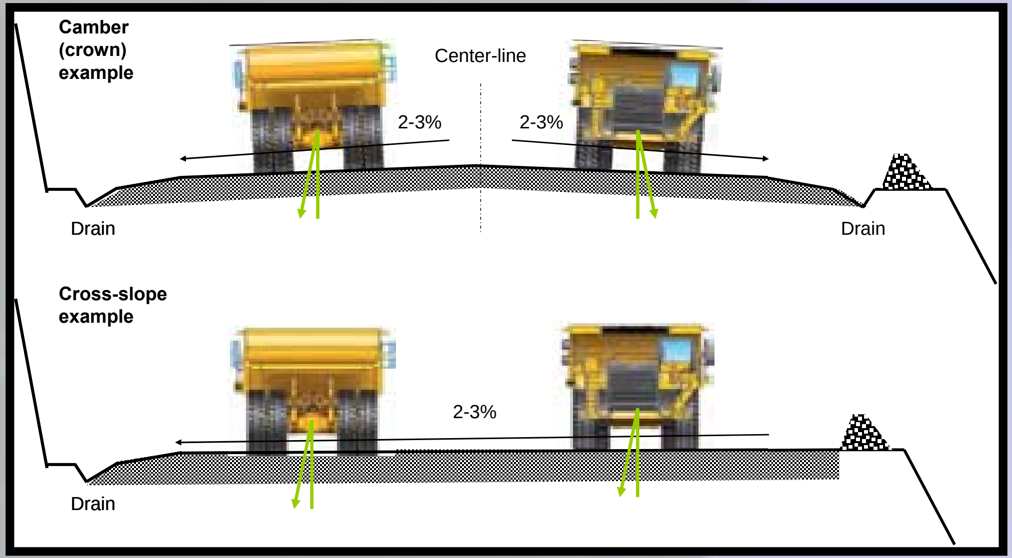
- Super-elevation;
  - Banking applied on the outside of a curve to allow the truck to maintain stability in the curve at speed.
  - Should not exceed 5% -7%, unless high-speed haulage is maintained and the possibility of sliding minimized by using median berms to split super-elevations. Refer Table.

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.

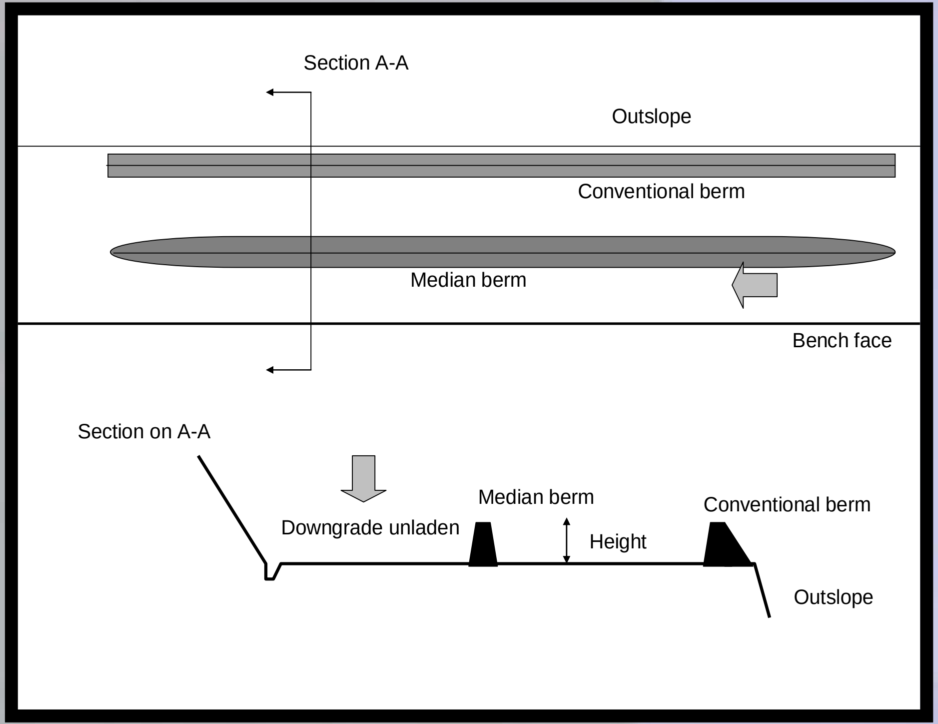
Geometric Design

- 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.



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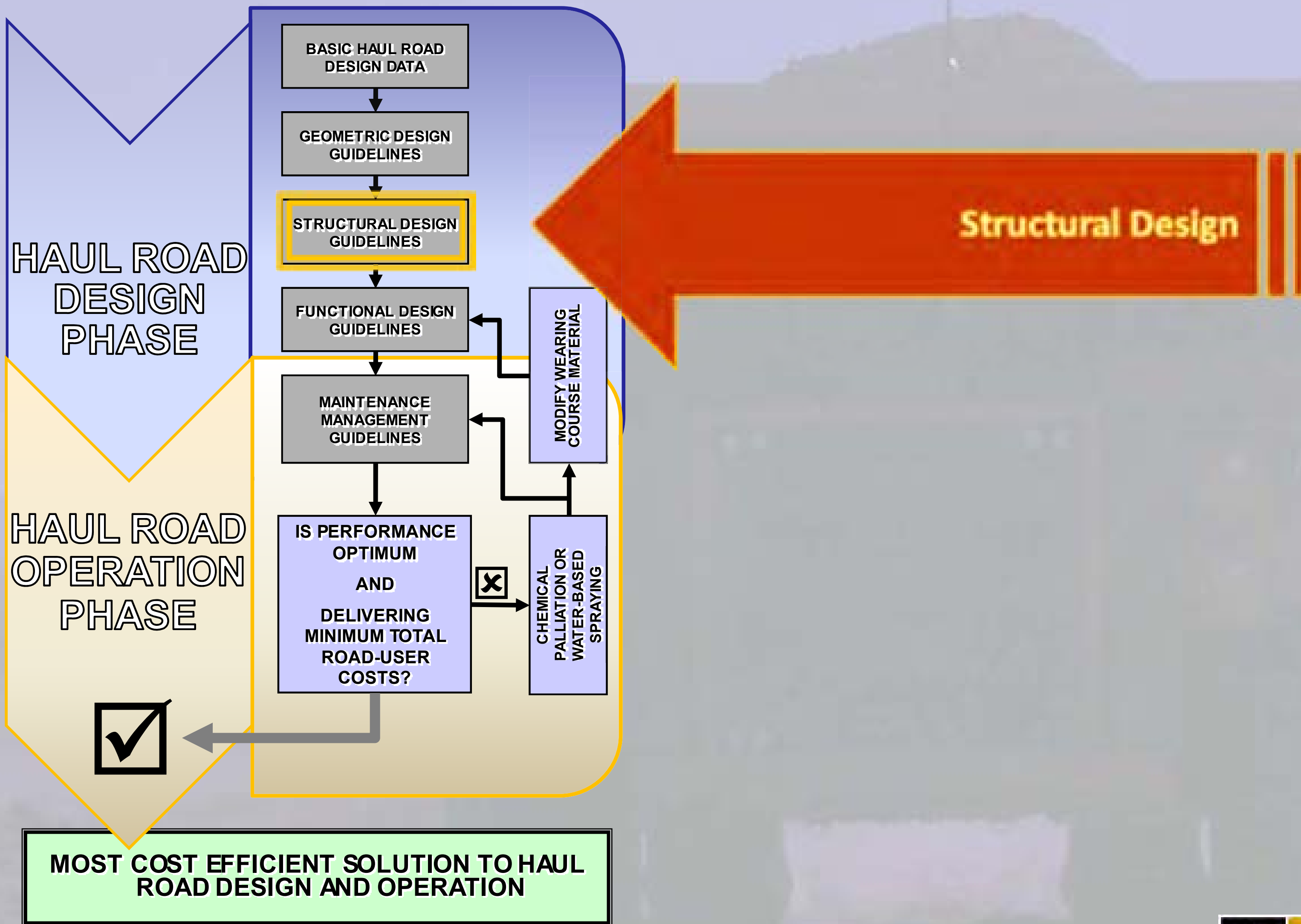
Geometric Design

- 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 <u>geometry</u> AND local topographic <u>drainage</u> patterns.

Integrated Haul Road Design



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.

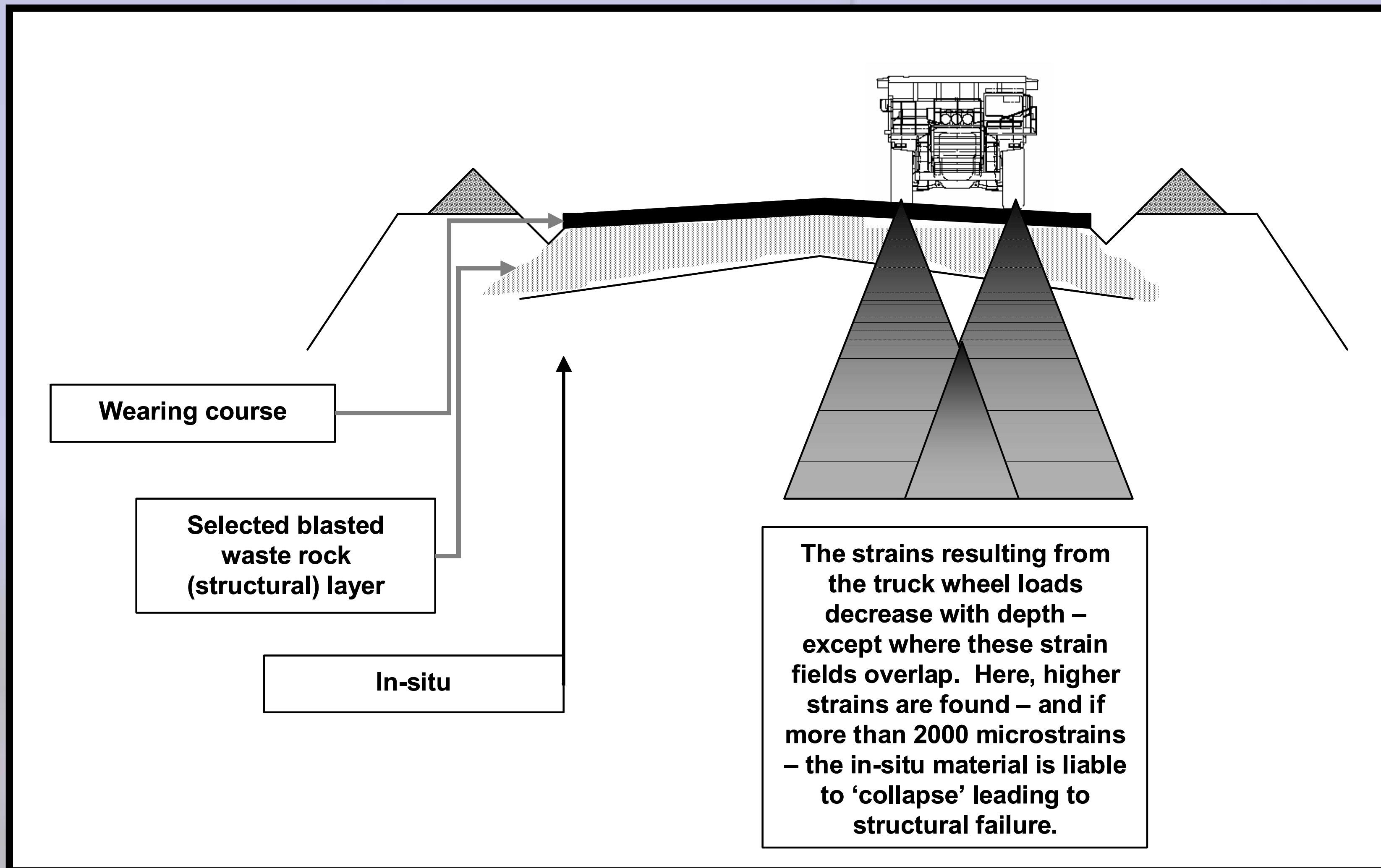
Structural Design

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

Structural Design - Mechanistic

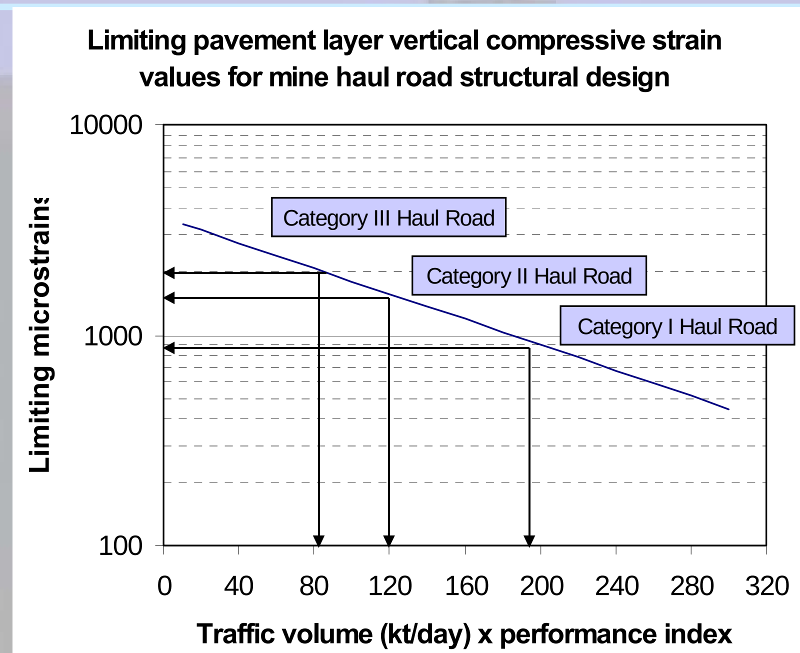
- Mechanistic design approach using pavement layer limiting vertical strain criteria;
  - Limiting strain criteria tailored to traffic volumes, type and life of mine road (ramp, pit or main haul).

Structural Design - Mechanistic



Structural Design - Mechanistic

Haul Road Category
Category I Permanent life-of-mine high volume main hauling roads and ramps in- and ex-pit. Operating life >20 years
Category II Semi-permanent high volume ramp roads in-pit. Operating life >10 years
Category III Semi-permanent medium- to low-volume in-pit bench access, ex-pit dump, or ramp roads. Operating life <5 years (>50kt/day) or <10 years (<50kt/day)



Maximum permissible vertical strains can also be determined from (*kt/day x performance index*).

Where performance index is defined as;

1 Adequate but fairly maintenance intensive,

2 Good with normal maintenance interventions,

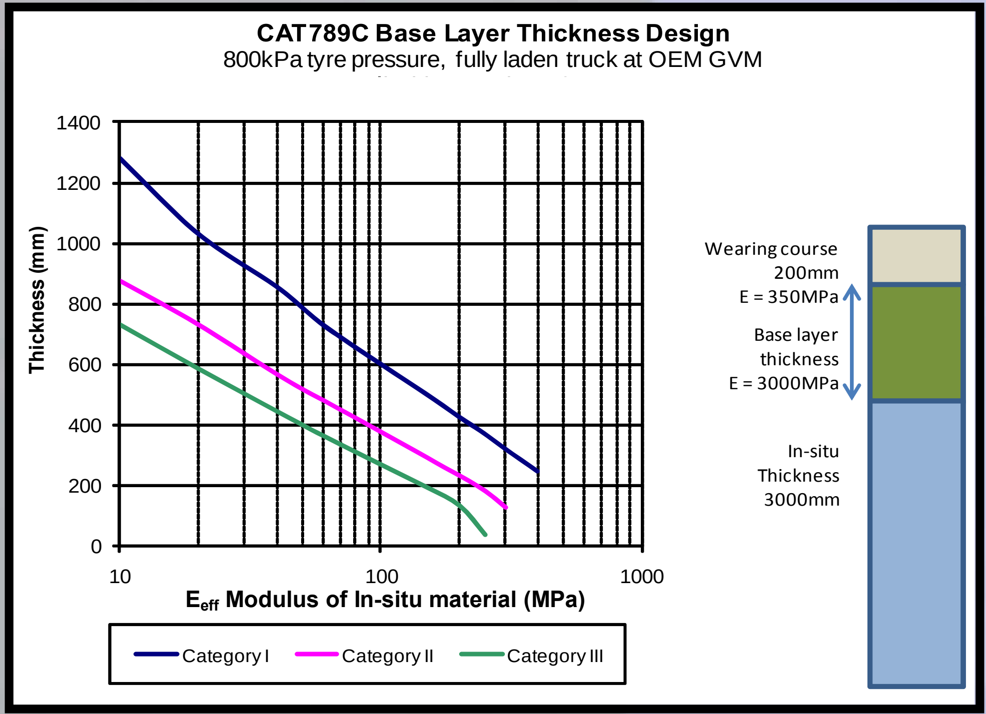
3 Outstanding with low maintenance requirements .

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.

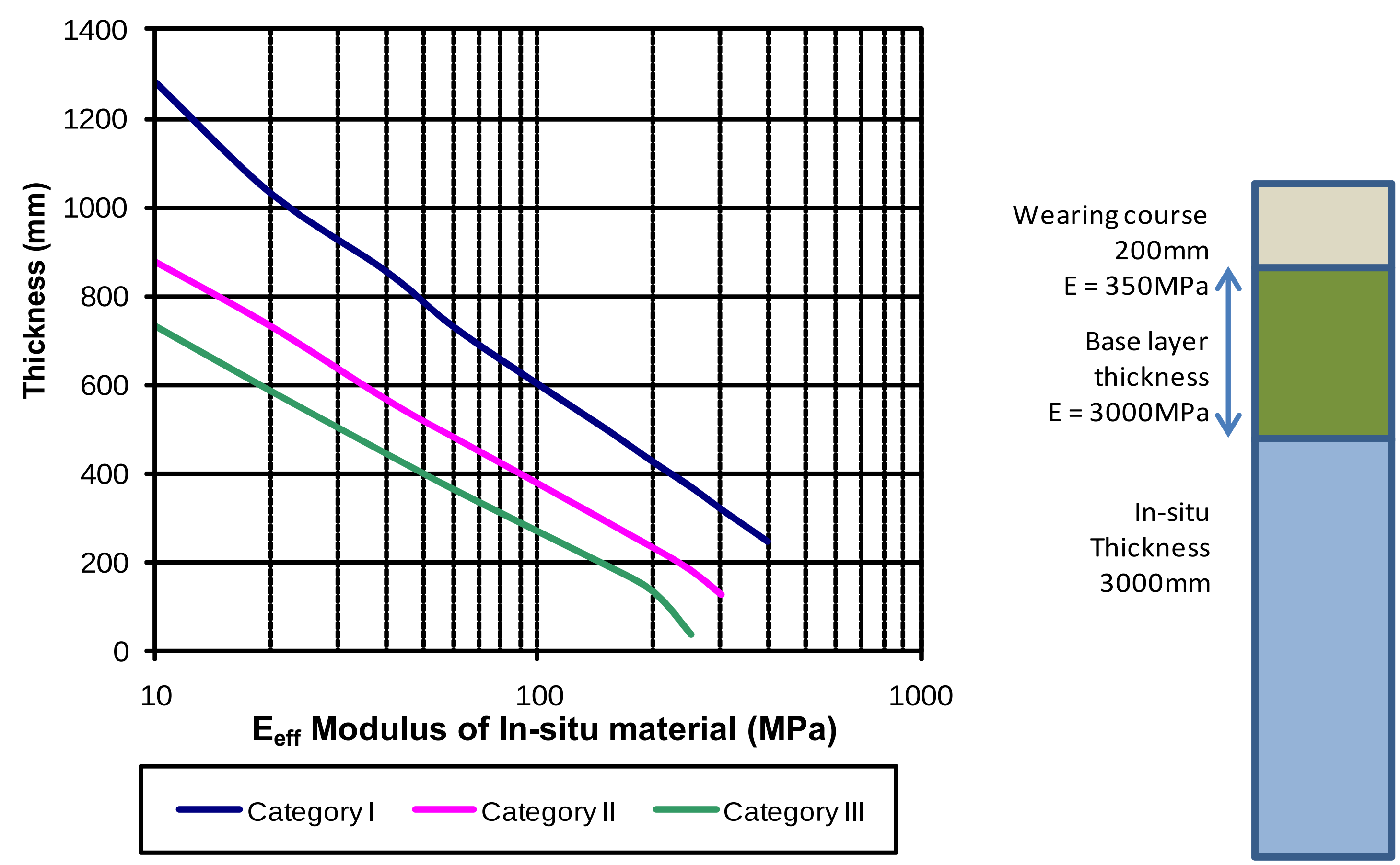
Practical Application Mechanistic

- 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.



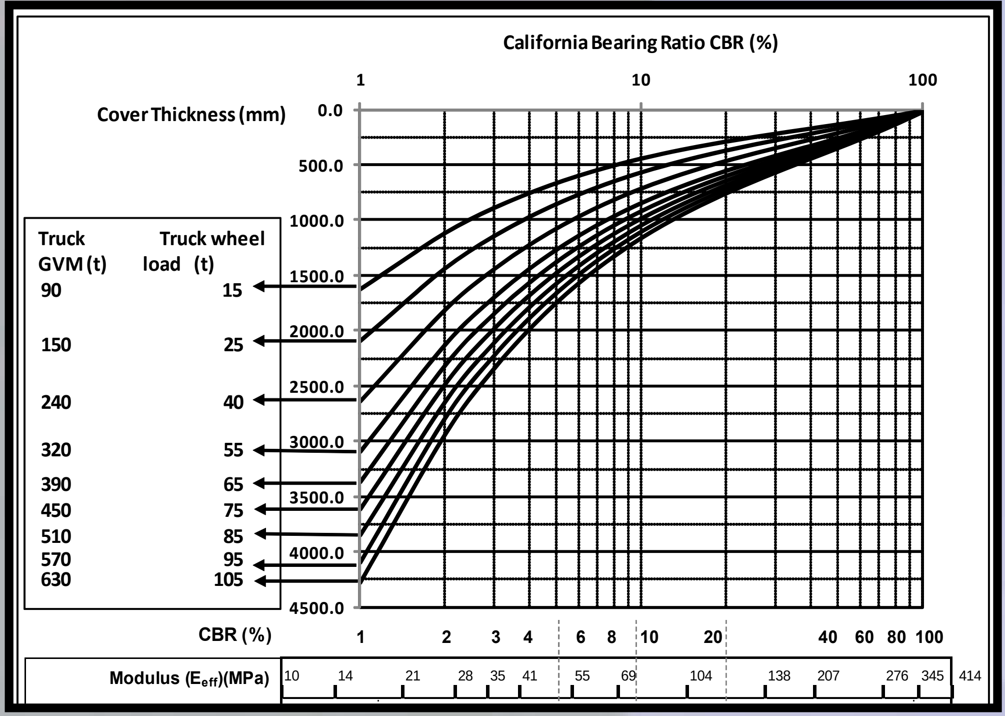
CAT789C Base Layer Thickness Design

800kPa tyre pressure, fully laden truck at OEM GVM



Structural Design
CBR Cover Curve

- 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).



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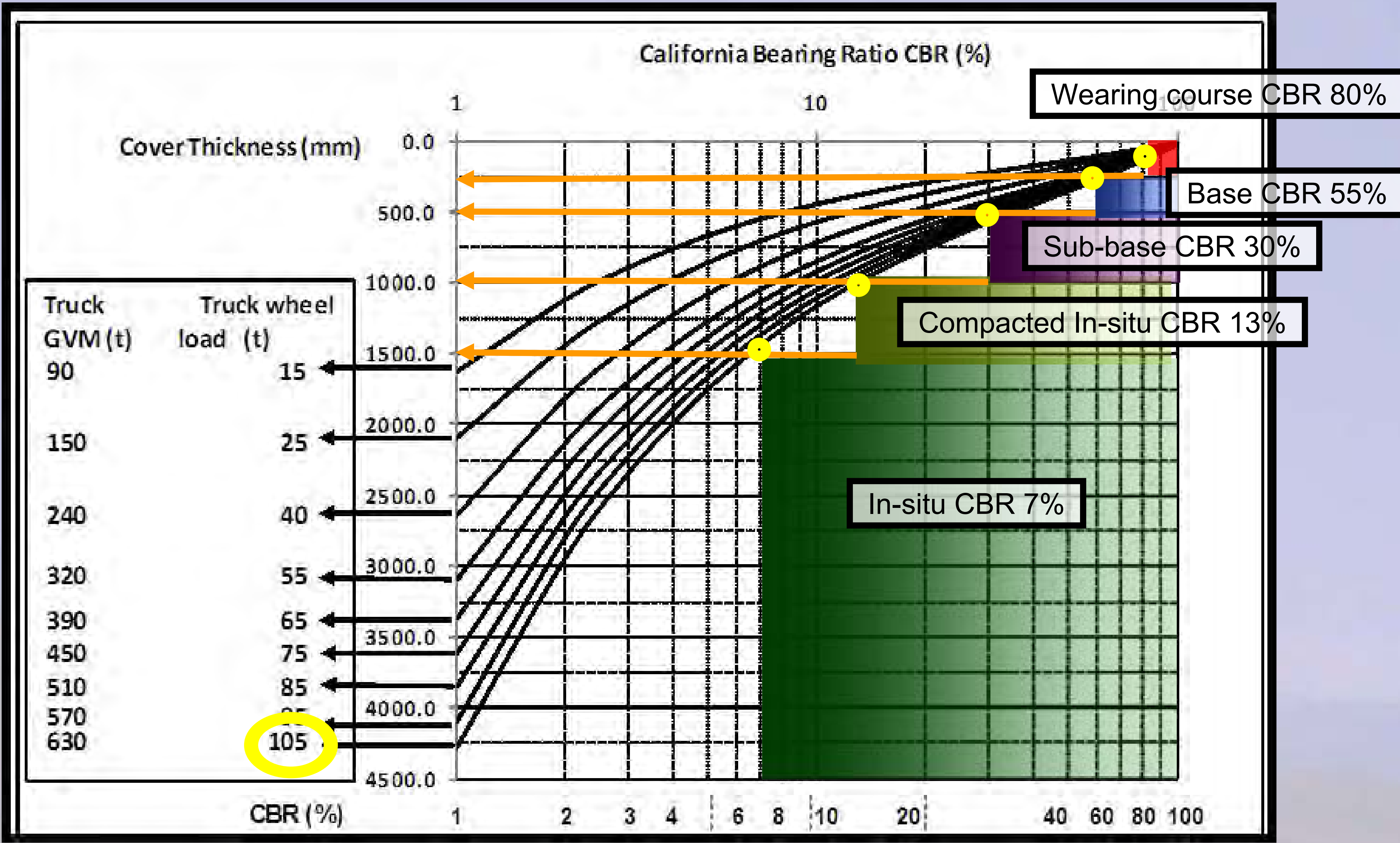
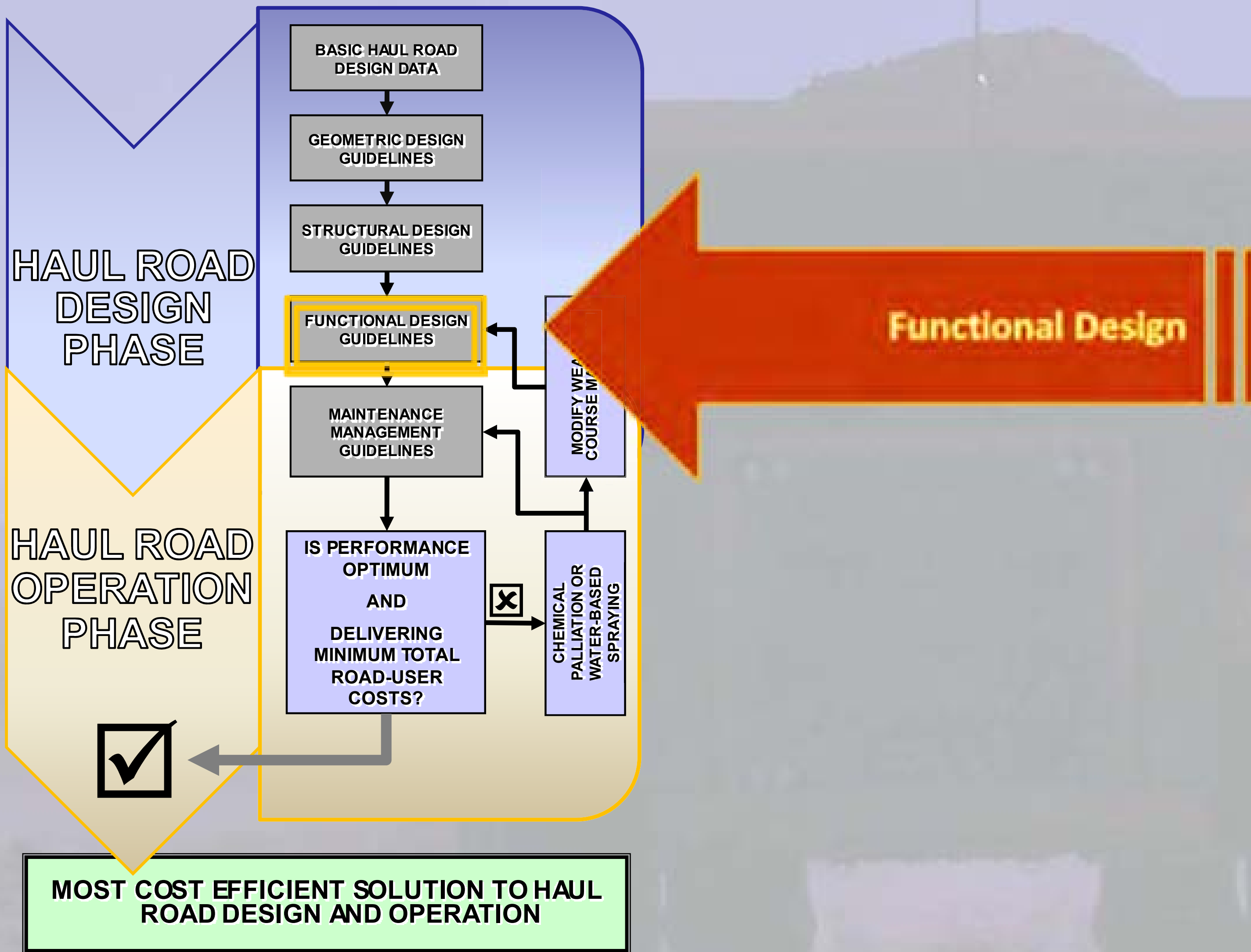

California Bearing Ratio CBR (%)
Cover Thickness (mm)
Wearing course CBR 80%
Base CBR 55%
Sub-base CBR 30%
Compacted In-situ CBR 13%
In-situ CBR 7%
Truck GVM (t)
Truck wheel load (t)
90 15
150 25
240 40
320 55
390 65
450 75
510 85
570
630 105
0.0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
CBR (%)
1 2 3 4 6 8 10 20 40 60 80 100

Integrated Road Haul Design



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.

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

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.

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.

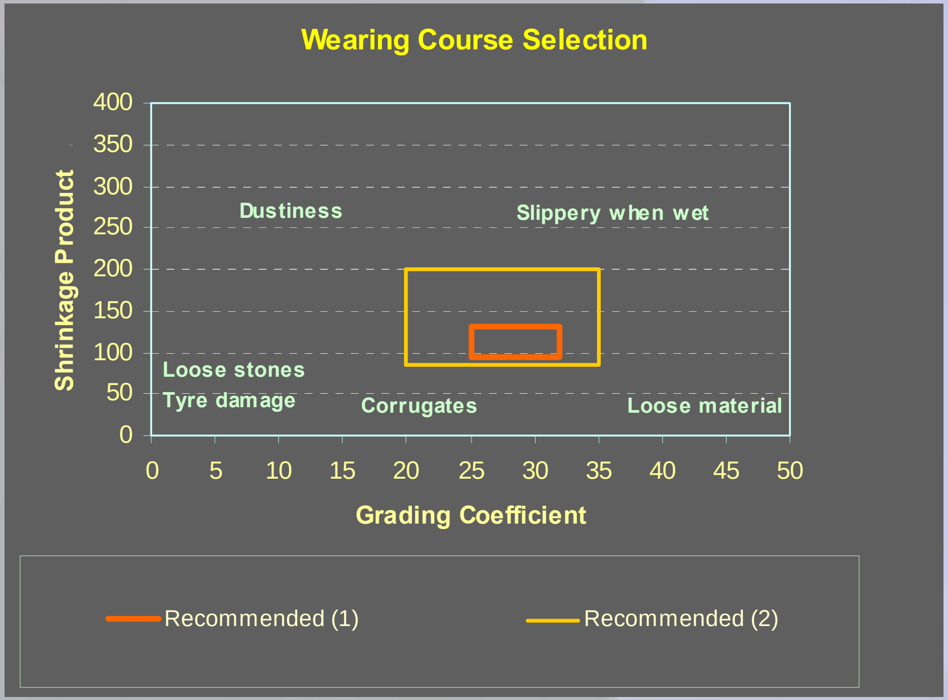
Functional Design

- 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.

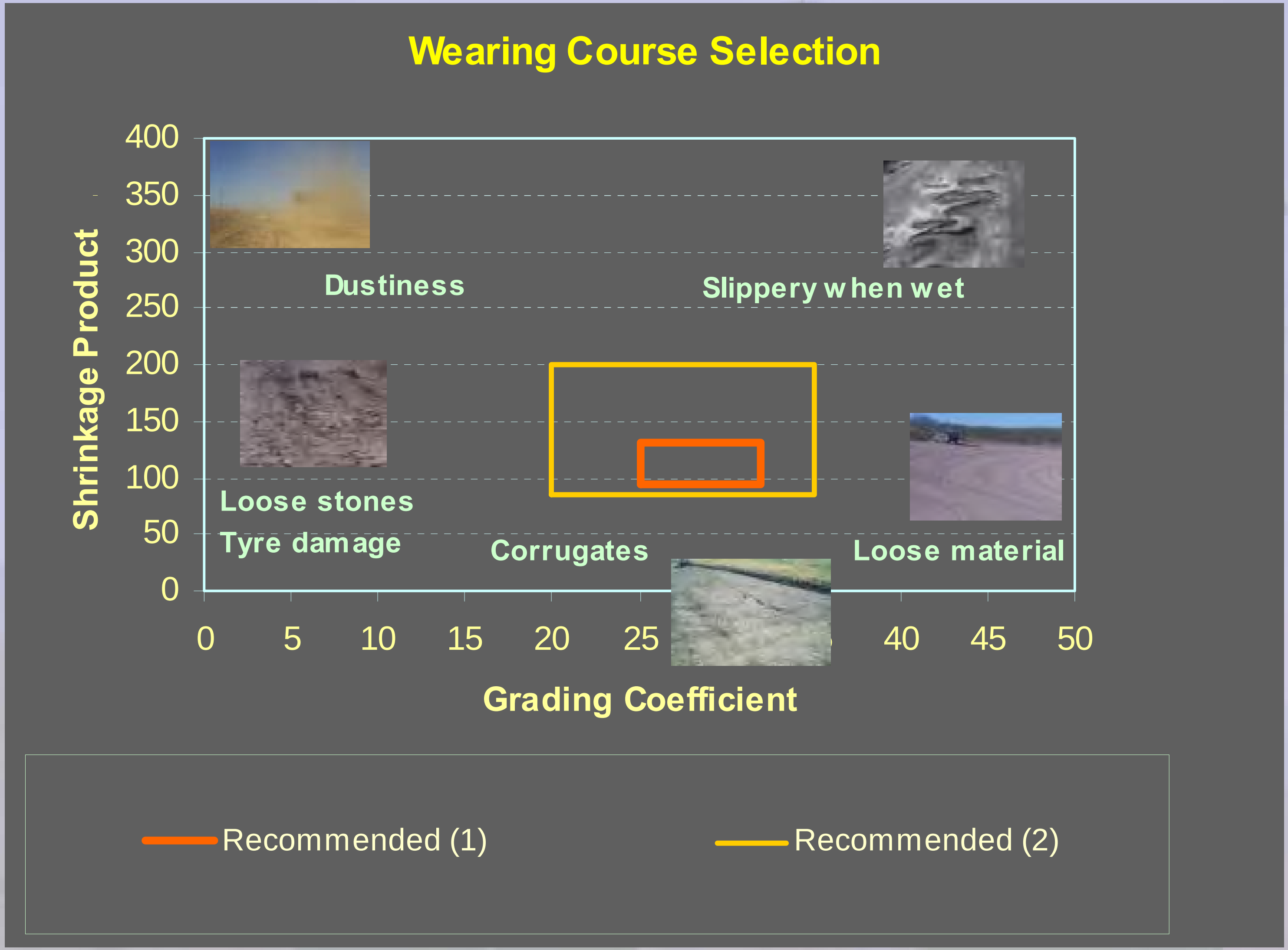
- It is also useful for creating a fine aggregate from waste rock to be placed as a dressing in loading areas – to reduce tyre damage in these areas.

Functional Design

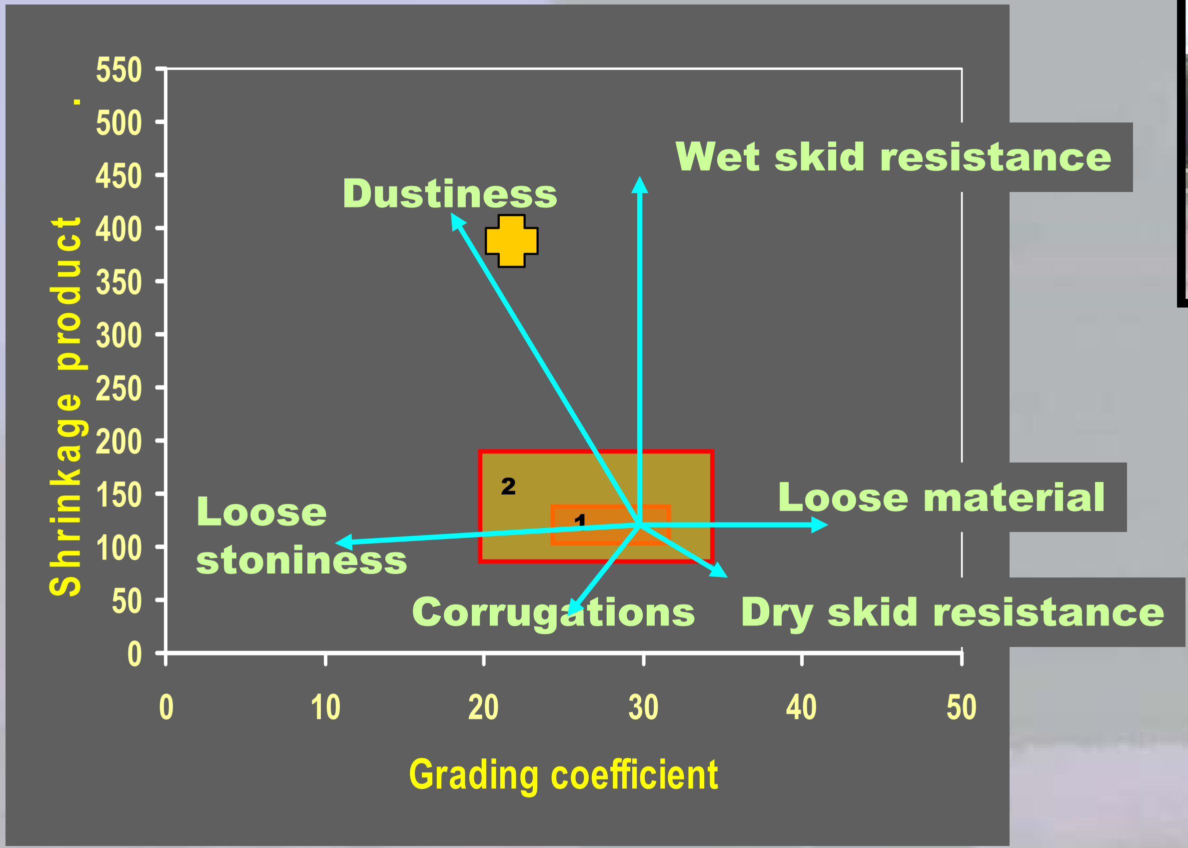
- Correct wearing course material selection will;
  - Reduce road rolling resistance – through reduced wearing course 'defects' &
  - Reduce road deterioration rates and maintenance frequency.



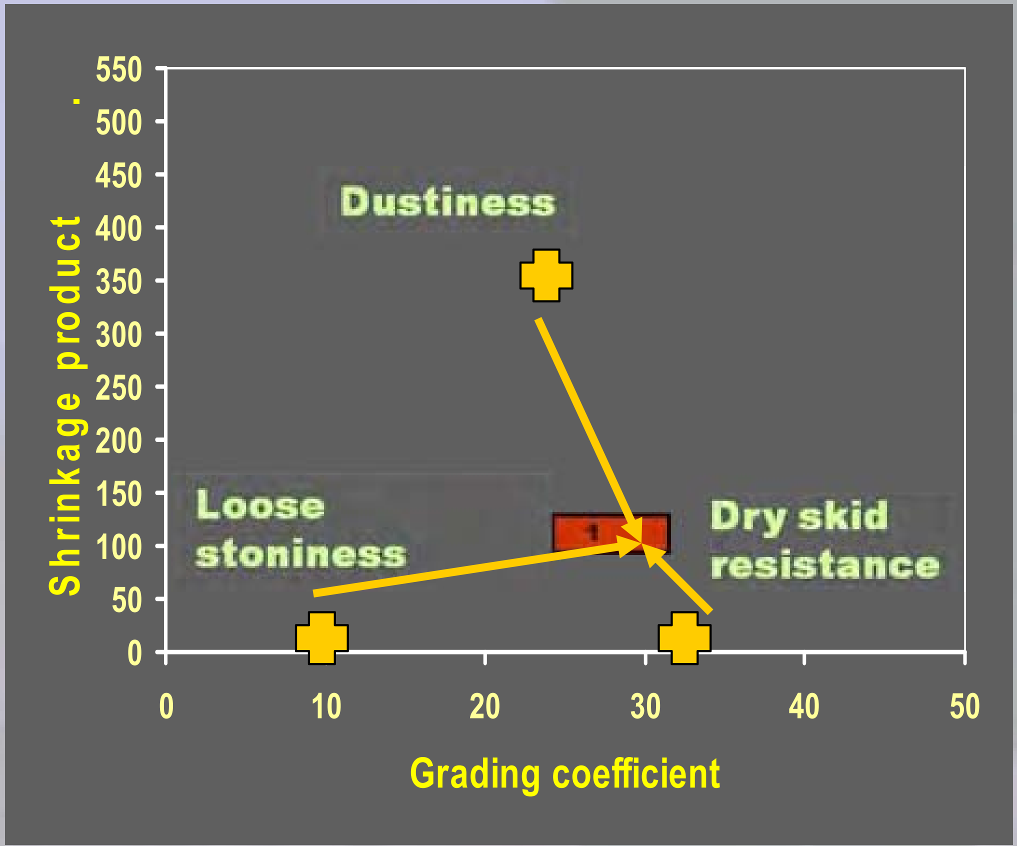
Functional Design



Practical Application



Practical Application



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.

	High PI (>10)	Medium PI (>10)	Sand	Wet weather trafficability	Ramp roads	Heavy traffic	Short term	Long term	Spray-on	Mix-in	Maintainable
Wetting Agents		✓			✓		✓		✓I/R		✓
Hygroscopic Salts		✓				✓	✓		✓R	✓I	✓M
Ligno-sulphonates	✓	✓	✓				✓	✓		✓I/R	✓SO
Petroleum Emulsions	✓	✓	✓	✓	✓	✓	✓		✓I	✓I	
Polymer Emulsions	✓	✓		✓	✓	✓		✓		✓I	✓SO
Tar/ Bitumen Emulsions		✓		✓	✓	✓		✓	✓R	✓I	✓SR

Notes
I - Initial establishment application
R - Follow-on rejuvenation applications
M - Maintain when moist or lightly watered
SO - Maintain with spray-on re-application
SR - Maintain with spot repairs

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.

	High PI (>10)	Medium PI (>10)	Sand	Wet weather trafficability	Ramp roads	Heavy traffic	Short term	Long term	Spray-on	Mix-in	Maintainable
Wetting Agents		✓			✓		✓		✓I/R		✓
Hygroscopic Salts		✓				✓	✓		✓R	✓I	✓M
Ligno-sulphonates	✓	✓	✓				✓	✓		✓I/R	✓SO
Petroleum Emulsions	✓	✓	✓	✓	✓	✓	✓		✓I	✓I	
Polymer Emulsions	✓	✓		✓	✓	✓		✓		✓I	✓SO
Tar/ Bitumen Emulsions		✓		✓	✓	✓		✓	✓R	✓I	✓SR

Notes
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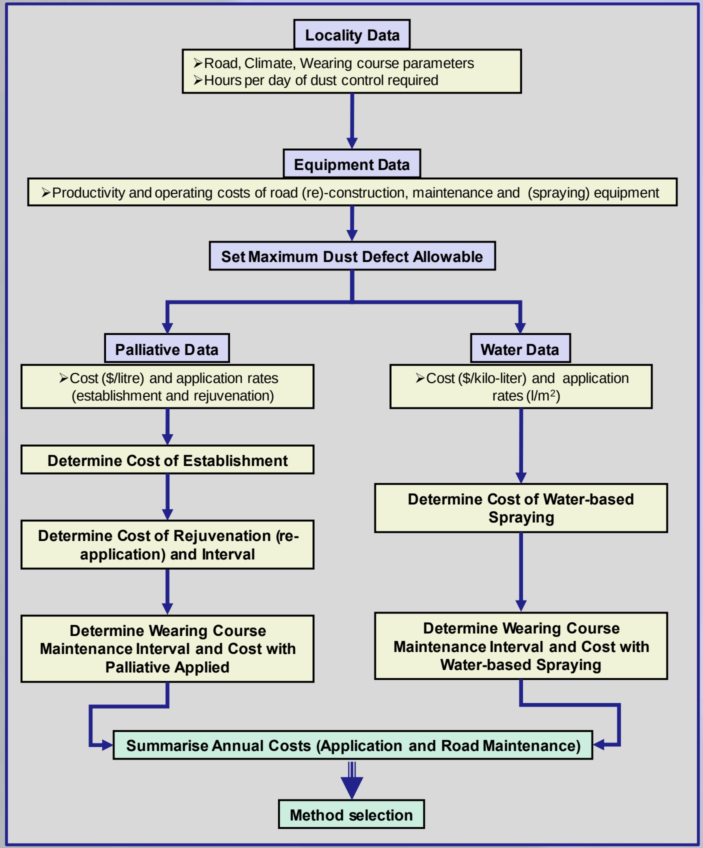
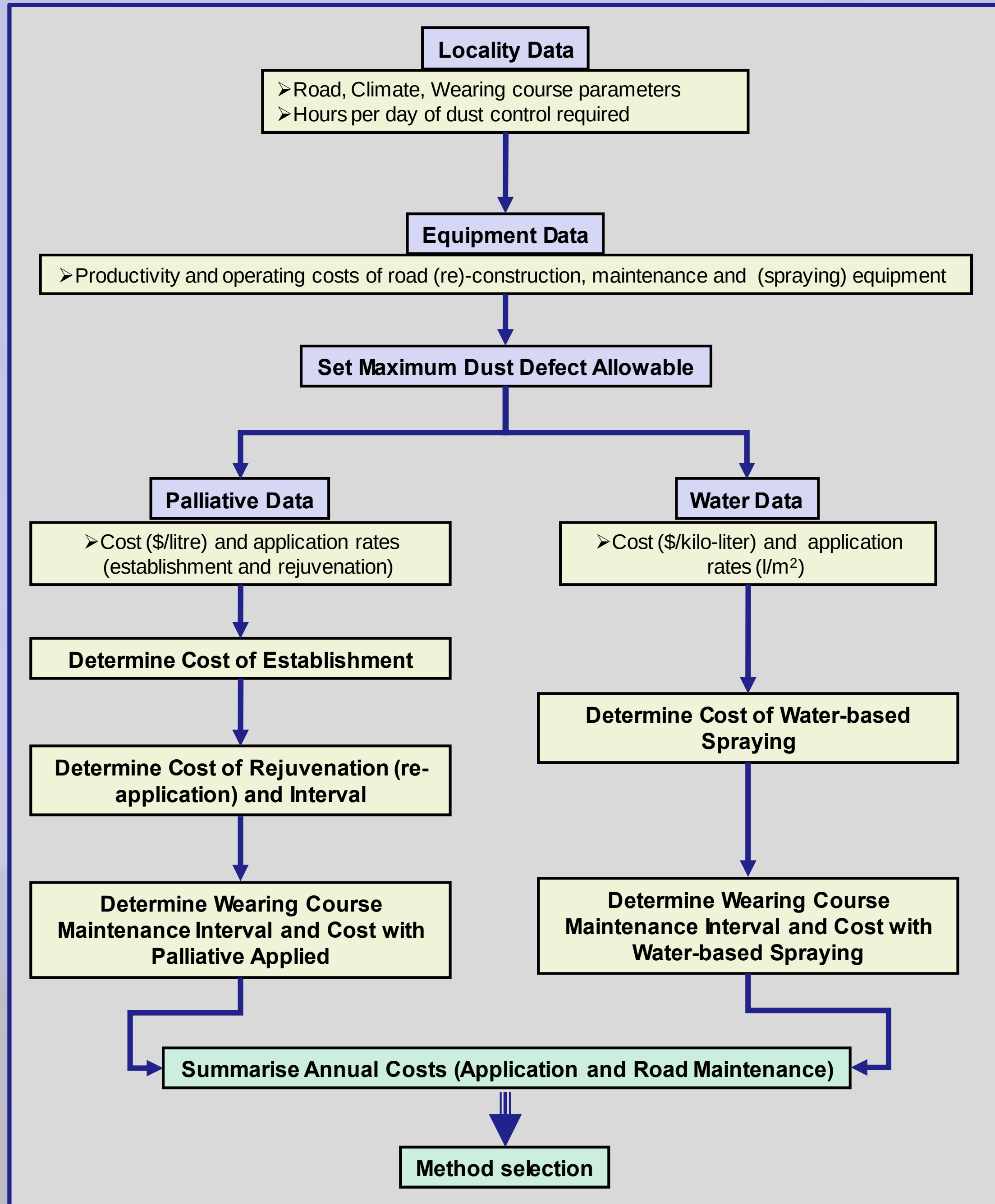
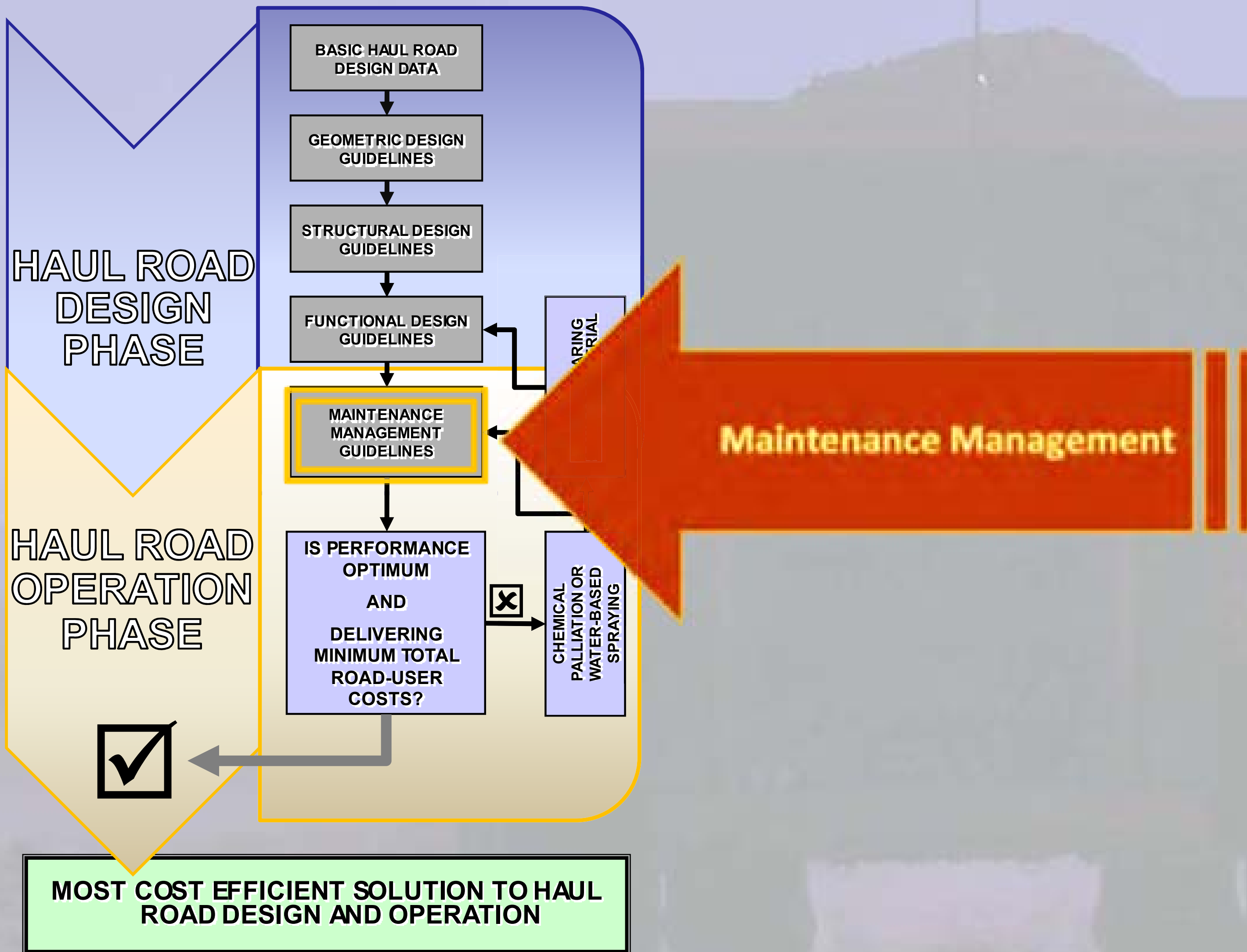
Dust Palliatives

- 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 ($/litre) and application rates (establishment and rejuvenation)
Water Data
➢Cost ($/kilo-liter) and application rates (l/m^2)
Determine Cost of Establishment
Determine Cost of Rejuvenation (re-application) and Interval
Determine Wearing Course Maintenance Interval and Cost with Palliative Applied
Determine Cost of Water-based Spraying
Determine Wearing Course Maintenance Interval and Cost with Water-based Spraying
Summarise Annual Costs (Application and Road Maintenance)
Method selection

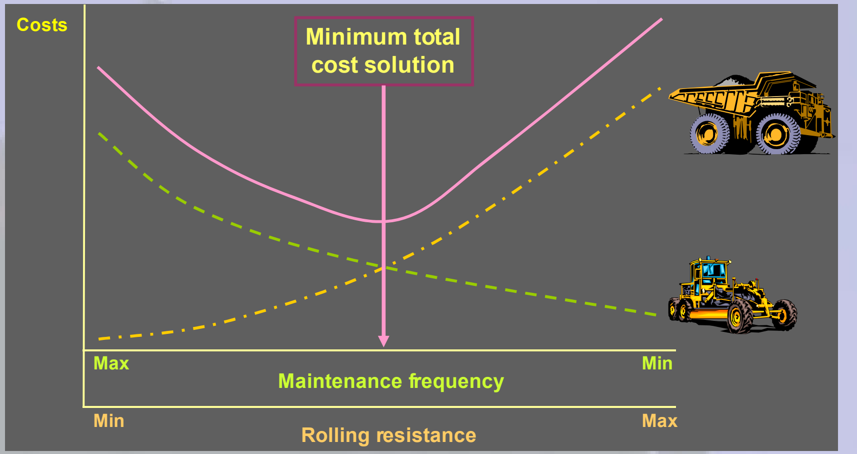
Integrated Haul Road Design

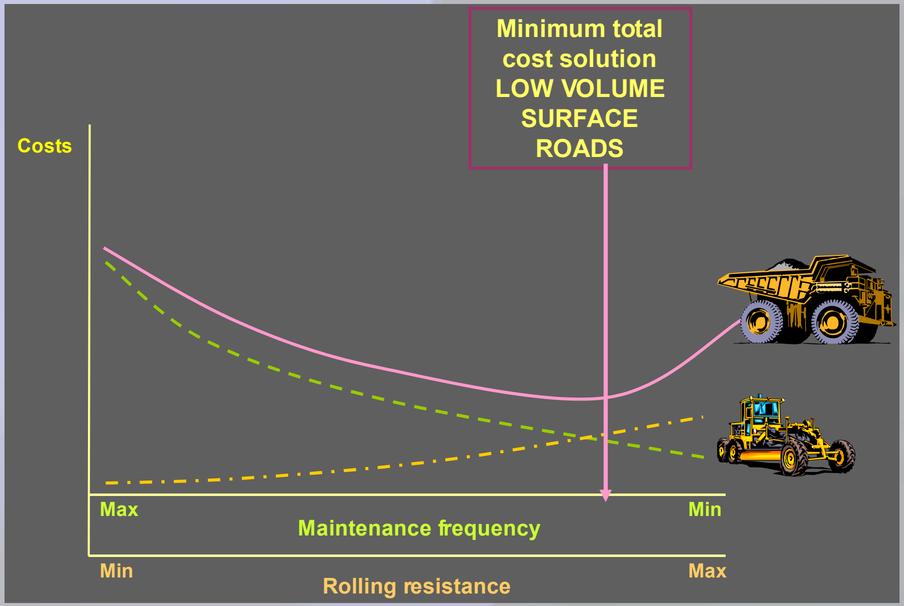


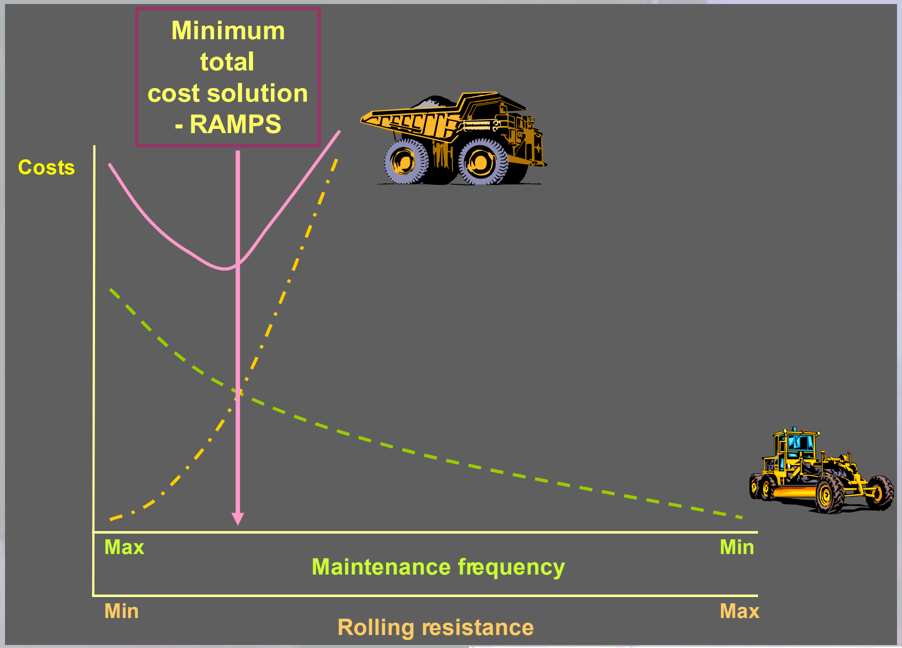
Maintenance Management

- Maintenance design and management;
  - Routine road maintenance as a result of progressive wearing course deterioration.
    - A satisfactory road design will require minimum maintenance.
    - Too frequent maintenance? Review design data to find root of problem.

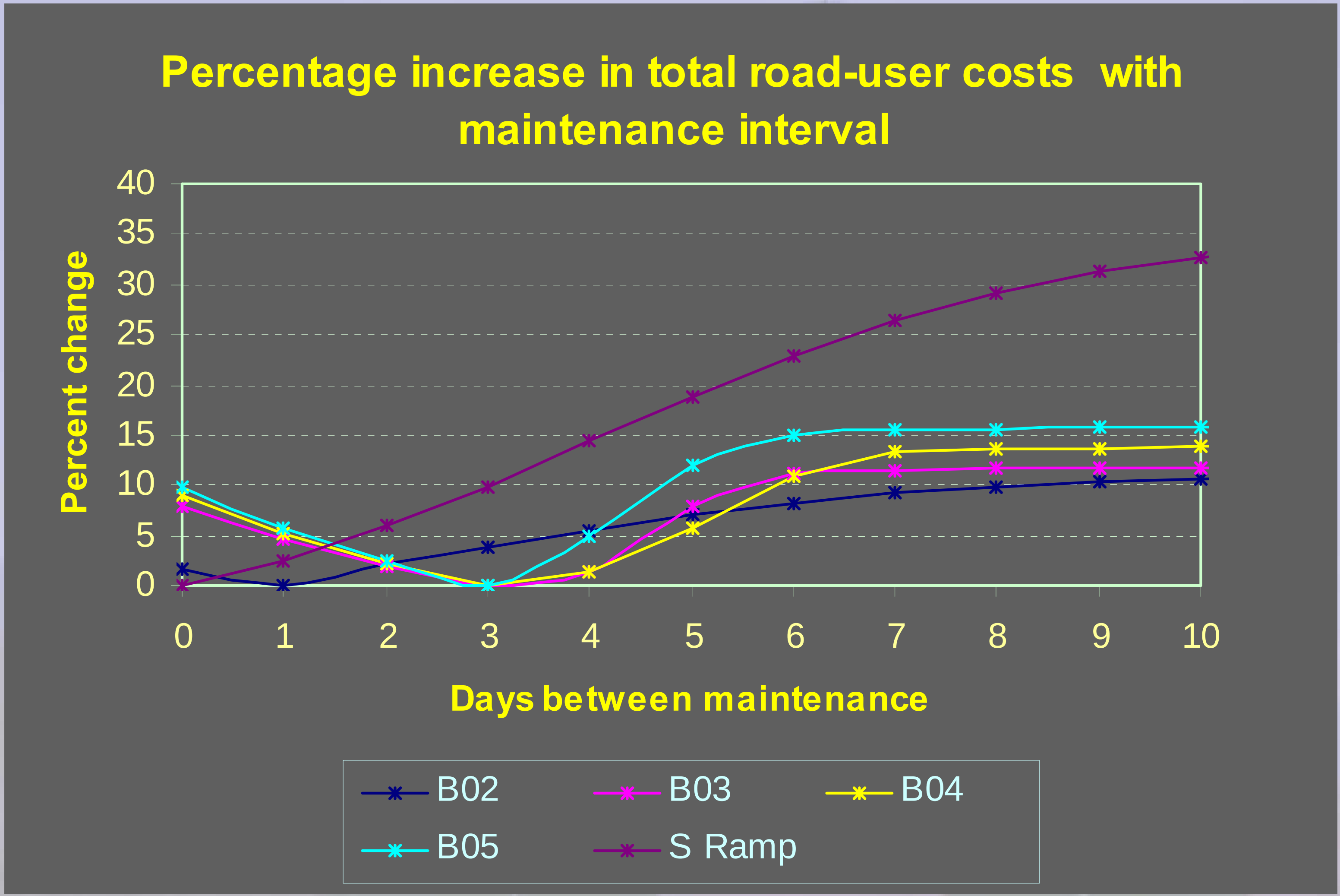
Maintenance Management







Maintenance Management



Practical Applications

- 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%.

MINE HAUL ROAD ROLLING RESISTANCE VISUAL EVALUATION					
DATE		EVALUATOR			
ROAD		VEHICLE SPEED km/hr (V)			
CHAINAGE		TRAFFIC kt/day			
DEFECT	RDS (Rolling resistance)				
	DEGREE (1-5)		EXTENT (1-5)		DEFECT SCORE
Potholes		x		=	
Corrugations		x		=	
Rutting		x		=	
Loose material		x		=	
Stoniness - fixed		x		=	
TOTAL ROUGHNESS SCORE (RDS)					
ESTIMATED ROLLING RESISTANCE (%) Refer to graph for rolling resistance percentages					

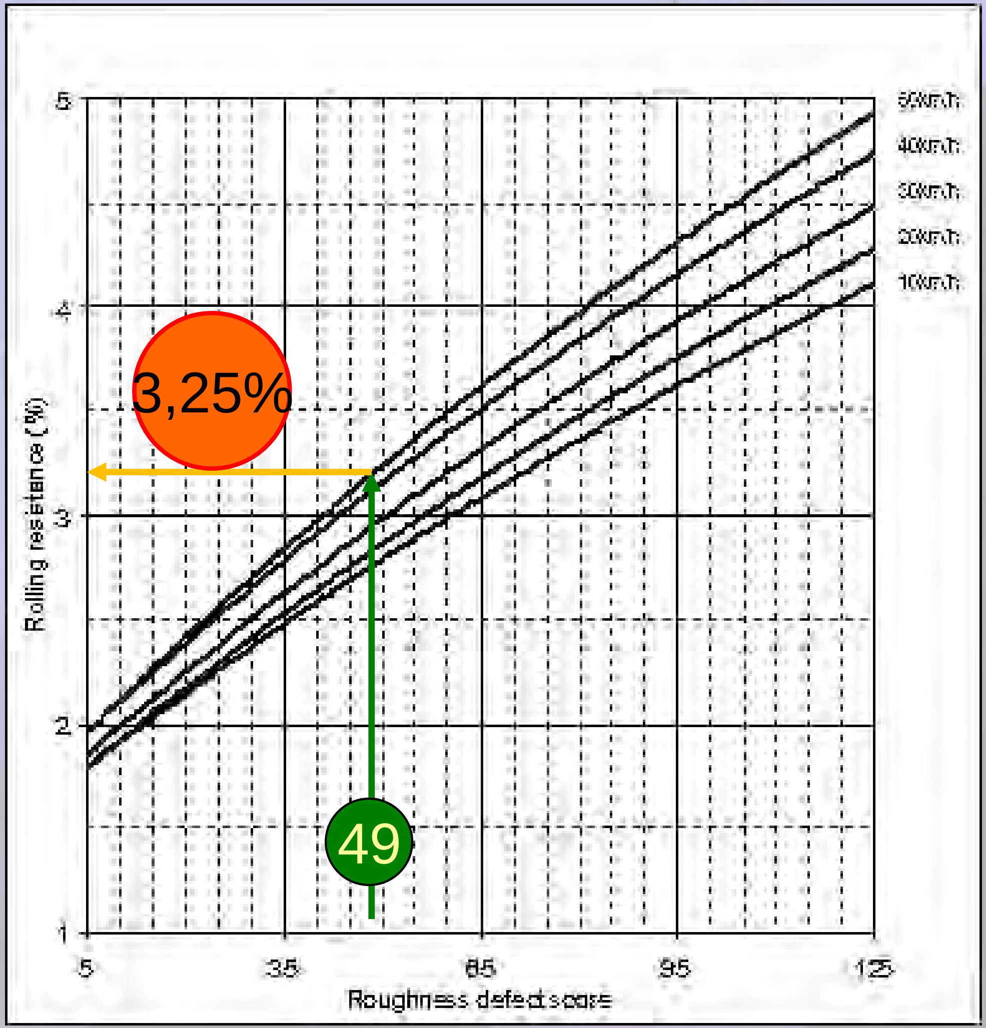
Defect extent	% road area effected	Extent score
Not seen or isolated only	<5	1
Intermittent	6-15	2
Regular	16-30	3
Frequent	31-60	4
Extensive	>60	5

DEFECT	VISUAL DESCRIPTION		
	Degree 1	Degree 3	Degree 5
Potholes			
Corrugations			
Rutting			
Loose material			
Stoniness - fixed in wearing course			

Practical Application

Defect	Degree (1-5)	Extent (1-5)	Degree x Extent
Potholes	5	1	5
Corrugations	3	3	9
Rutting	3	5	15
Loose material	5	2	10
Stones - fixed	5	2	10
		Total score	49

Practical Application



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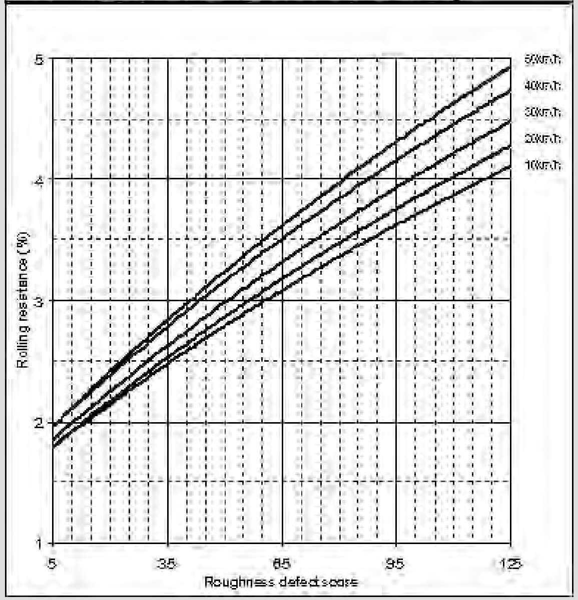
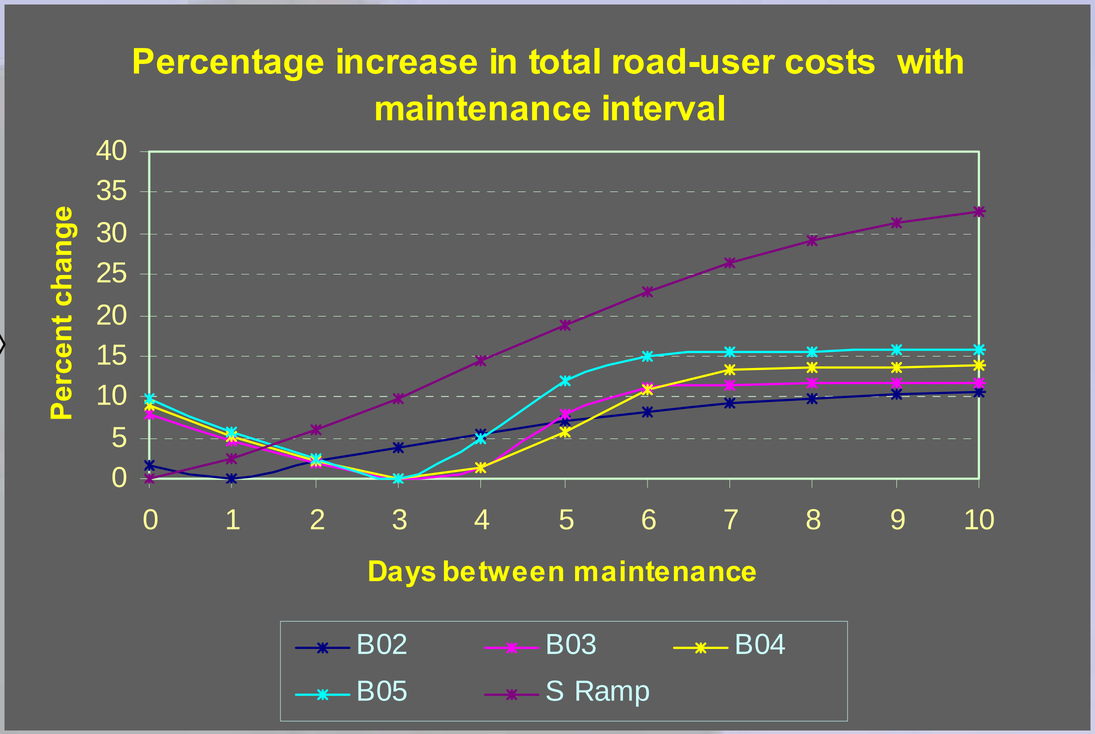
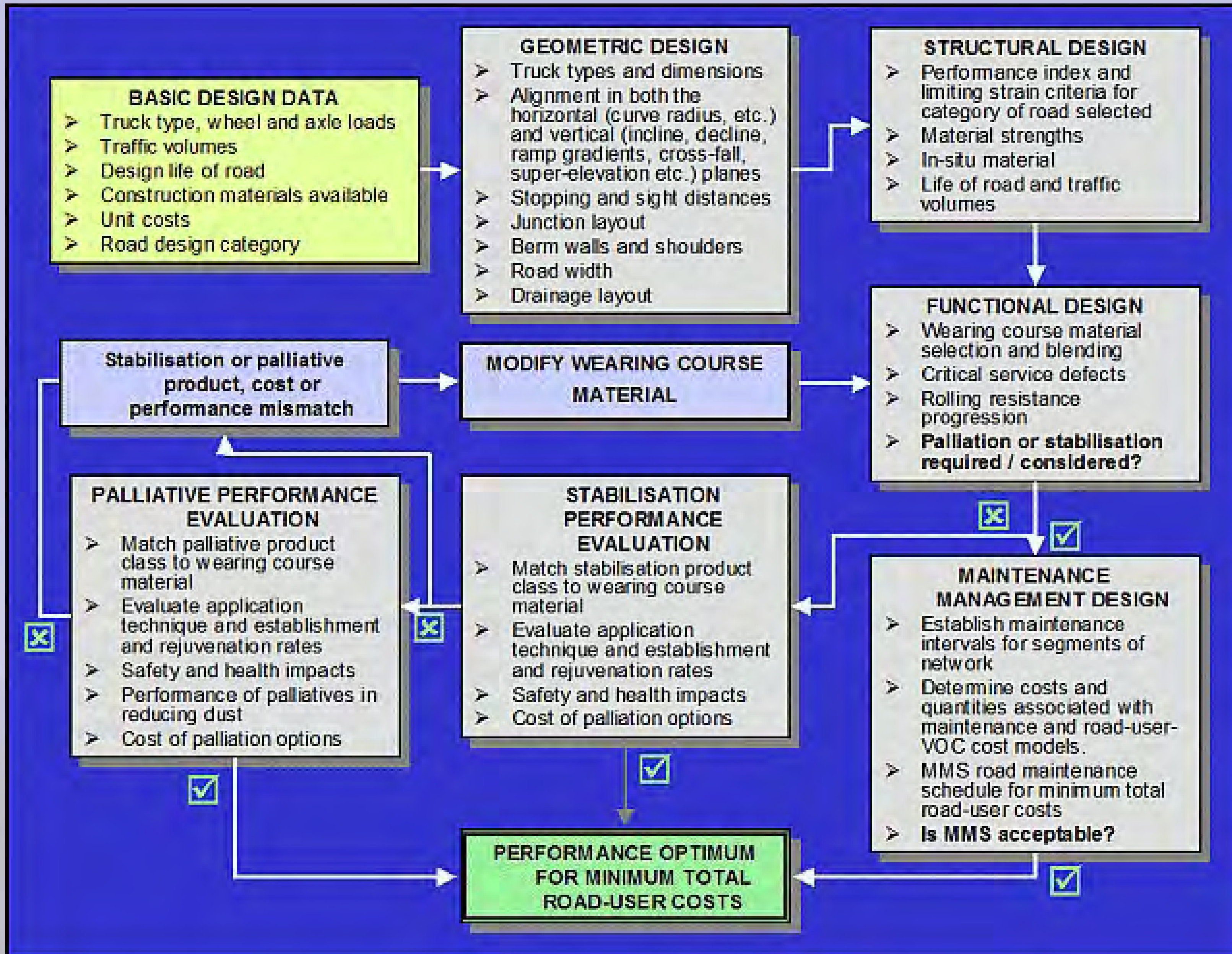
MINE HAUL ROAD ROLLING RESISTANCE VISUAL EVALUATION			
DATE		EVALUATOR	
ROAD		VEHICLE SPEED km/hr (V)	
CHAINAGE		TRAFFIC kt/day	

DEFECT	RDS (Rolling resistance)				
	DEGREE (1-5)		EXTENT (1-5)		DEFECT SCORE
Potholes		x		=	
Corrugations		x		=	
Rutting		x		=	
Loose material		x		=	
Stoniness - fixed		x		=	
TOTAL ROUGHNESS SCORE (RDS)					

ESTIMATED ROLLING RESISTANCE (%) Refer to graph for rolling resistance percentages	



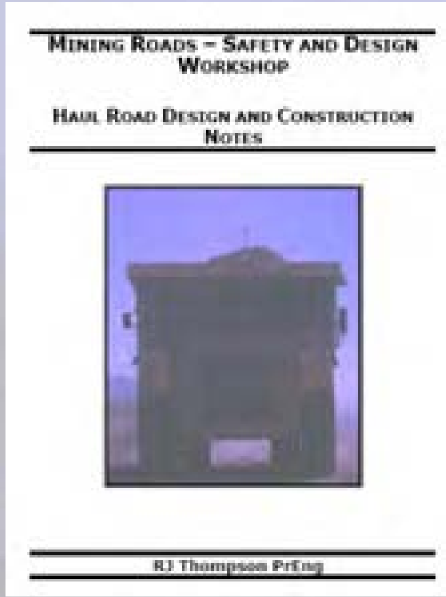



BASIC DESIGN DATA
Truck type, wheel and axle loads
Traffic volumes
Design life of road
Construction materials available
Unit costs
Road design category
GEOMETRIC DESIGN
Truck types and dimensions
Alignment in both the horizontal (curve radius, etc.) and vertical (incline, decline, ramp gradients, cross-fall, super-elevation etc.) planes
Stopping and sight distances
Junction layout
Berm walls and shoulders
Road width
Drainage layout
STRUCTURAL DESIGN
Performance index and limiting strain criteria for category of road selected
Material strengths
In-situ material
Life of road and traffic volumes
FUNCTIONAL DESIGN
Wearing course material selection and blending
Critical service defects
Rolling resistance progression
Palliation or stabilisation required / considered?
Stabilisation or palliative product, cost or performance mismatch
MODIFY WEARING COURSE MATERIAL
PALLIATIVE PERFORMANCE EVALUATION
Match palliative product class to wearing course material
Evaluate application technique and establishment and rejuvenation rates
Safety and health impacts
Performance of palliatives in reducing dust
Cost of palliation options
STABILISATION PERFORMANCE EVALUATION
Match stabilisation product class to wearing course material
Evaluate application technique and establishment and rejuvenation rates
Safety and health impacts
Cost of palliation options
MAINTENANCE MANAGEMENT DESIGN
Establish maintenance intervals for segments of network
Determine costs and quantities associated with maintenance and road-user-VOC cost models.
MMS road maintenance schedule for minimum total road-user costs
Is MMS acceptable?
PERFORMANCE OPTIMUM FOR MINIMUM TOTAL ROAD-USER COSTS

Course Introduction

Haul Road Design and Operational Benchmarking

Introduction



MINING ROADS – SAFETY AND DESIGN WORKSHOP

HAUL ROAD DESIGN AND CONSTRUCTION NOTES

RJ Thompson PrEng

Resources

- For more information on issued raised today;
  - http://mining.curtin.edu.au/people *click on RJT for further links to haul road publications*
  - www.edumine.com *search for haul road design and construction – Uni British Columbia and ABET/ISO/IACET accredited self-study course.*
  - www.smartmines.com/mhroad/guidelines.pdf *haul road design guidelines (2000) for Oil Sands Mines (Alberta Canada).*

Resources

- www.cdc.gov/niosh/mining/pubs *search for ‘IC8758.pdf’ 1977 USBM haul road design guidelines*

- www.mhsa.gov/readroom/handbook *search for ph99-I-4.pdf design and audit guidelines for mine roads*

- www.smenet.org *SME Mining Engineering Handbook, Third Edition, 2011, Ch 10 Mine Haul Roads*

- *Copy of presentation and full supporting notes available through DEEDI Mines Safety and Health web-site….*