O T R A C O (International) Pty Ltd

Tyre Selection, Use and Operational Issues to Maximise Tyre Life

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OVERVIEW

Tyres are typically one of the major costs incurred by Mining and Quarrying operations. However, the selection, maintenance and operation of tyres is one operational aspect which is not normally adequately addressed, given its overall impact on performance.

The correct selection of tyres can dramatically impact on the overall cost of any earthmoving operation, as tyres can account for between 25% to 40% of these costs. This paper will examine the selection process for earthmover tyres, along with operational practices to maximise tyre life.

TYRE SELECTION

As with most selection criteria, tyre selection is a compromise. There are many mutually exclusive criteria which need to be balanced against one-another to achieve an optimum tyre life and cost.

Tyres are exposed to a variety of operating conditions including overloading, rock damage and heat build-up within the tyre from flexing. All of these operating conditions create different loads that the tyre must withstand. However, a tyre's ability to withstand one of these conditions lessens it's ability to withstand the other two conditions. Therefore a major part of the tyre selection process will include an assessment of the operating conditions which the tyre will face.

It is essential that the selection task is carried out by professionals who will understand the tasks required of your tyres and recommend only the optimum tyre for the task. This recommendation should be based on sound assessment techniques, to achieve the minimum operational costs, backed up with practical experience.

The design and operation of mines and quarries is a continually evolving process. The nature of the evolution is dependant on the type of mine, type of material being reclaimed and the actual geology of the operation itself, along with the fixed plant infrastructure locations. Therefore, tyre selection should also be re-evaluated as operational changes occur.

Tyres are normally rated in terms of their heat resistance (ability to perform work), cut and abrasion resistance (resistance to damage) and their traction characteristics (usually a function of tyre construction and tread pattern). The method of selection to determine a particular tyre's suitability, for a given operation, is usually based on the operational conditions at the particular mine and the tyre's Tonne Kilometre per Hour rating (TKPH).

As a tyre rotates, the deflection of the tyre causes the tyre's structure to flex. As the tyre rotates through the tyre's contact point, the tyre's structure compresses then releases to its original shape. Due to the in-elastic properties of the tyre's structure, some of the energy introduced through the flexing of the structure is retained as heat. If the cycle of flexing and release is rapid, heat builds up within the tyre.

The critical temperature for a tyre varies between construction methods. Figure 1 shows the statistical probability of a tyre undergoing a heat separation relative to internal temperature. If the internal temperature of a tyre should rise above the critical temperature (normally taken to be 97°C for radial tyres and 109°C for bias tyres), then the probability of heat related failures due to chemical and physical changes within the tyre increases.

The two main operational influences on tyre heat build-up are:

- Speed - as this affects the number of cycles per unit time.
- Load - as this affects the amplitude of tyre deflection, hence energy transferred.

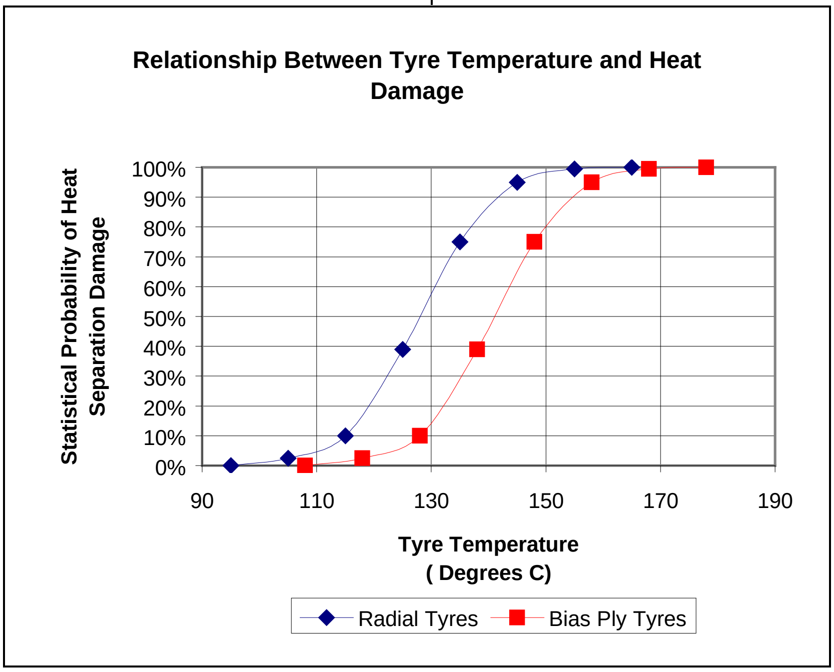


Figure 1 - Tyre Temperature versus Heat Damage

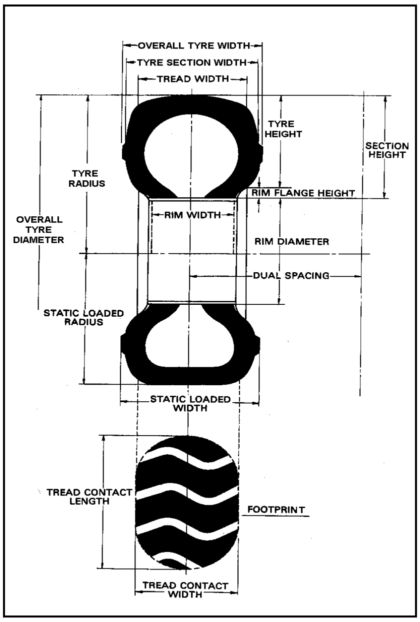


Figure 2 - Tyre Reference Dimensions

Figure 2, above shows the most commonly used reference dimensions for earthmover tyres.

Construction

Types of Tyres

For earthmoving applications, there are two main types of tyres. These are radial and bias-ply tyres. This excludes solid tyres or other special tyres such as steel wheeled or tracked vehicles.

The development of radial tyres has been rapid. In 1960, radial tyres comprised only two percent of all light vehicle and earthmover tyres in operation world wide. One manufacturer, Michelin, accounted for approximately 90% of these tyres.

During the 1960-70's the use of light vehicle radial tyres became widespread, firstly on passenger vehicles, then on light trucks and finally on heavy road trucks. By 1980 radials comprised the majority of light vehicle tyres in service, but only 5 percent of earthmover tyres.

Since then radial tyre acceptance by the mining industry has increased dramatically. The proportion of radial earthmover tyres rose to 65 percent by 1990 and is continuing to grow.

A parallel development over the same period was the reduction in the number of major earthmover tyre manufacturers from eight to three. Bridgestone, Goodyear and Michelin account for most of the radial earthmover tyres being produced today.

Bias-Ply Construction

Figure 3 below shows a typical bias-ply tyre construction.

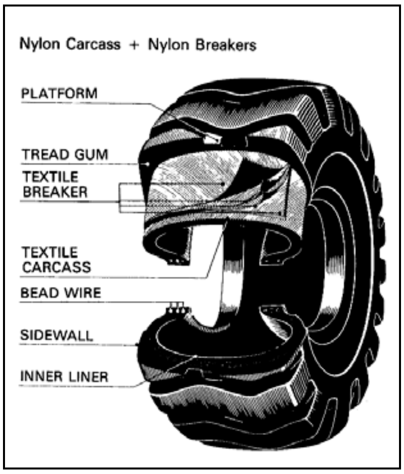


Figure 3 - Bias-Ply Tyre Construction

A bias-ply tyre has a bulky casing composed of many criss-crossed nylon layers as shown in Figures 3 and 4. Tyre flexing causes deformation of the casing and "hour-glassing" of the section of tread in contact with the ground, as shown in Figure 4. This results in tread squirm and uneven contact pressure across the footprint area. Tyre flexing also causes "scissoring" of adjoining ply layers, increasing casing stress and heat build-up.

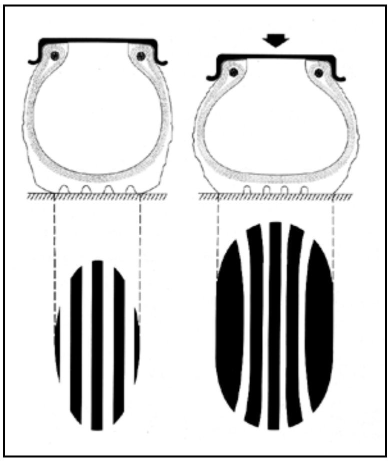


Figure 4 - Bias-Ply tyre tread patterns (loaded and unloaded)

Radial Ply Construction

Figure 5 below shows a typical radial tyre construction.

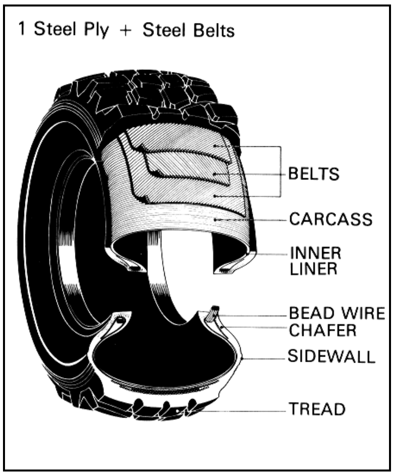


Figure 5 - Radial Tyre Construction

A radial tyre has a thin casing composed of a single radially orientated steel ply layer which is contained by several circumferentially aligned steel tread belts. Tyre flexing is absorbed by the radial casing ply with little deformation of the tread; the steel belts act like a tank track providing uniform ground contact pressure. The radial's thin casing also generates less heat and stress making it better suited to high speed applications and more amenable to repairs, especially in the side wall area.

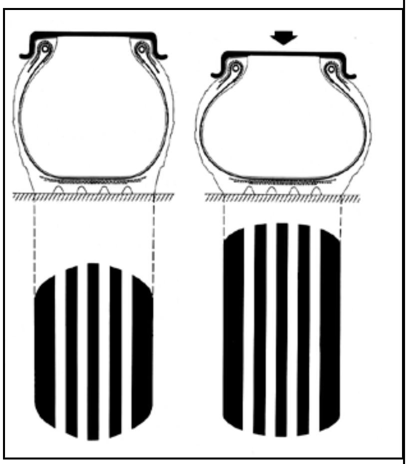


Figure 6 - Radial tyre tread patterns (loaded and unloaded)

Radial tyres have several advantages over bias-ply tyres. These are:

- Radials commonly have a higher TKPH rating than the same size bias tyre.
- Heat generation in radial tyres is lower due to construction and the thinner casing required.

- The tread of a radial tyre is not affected by the side wall flexing, creating less deformation of the tread, leading to reduced tread wear.
  (Figures 4 and 6 highlight this.)
- Higher grip levels.
- Lower fuel consumption through reduced rolling resistance and friction.
- Smoother ride because of the reduced side wall stiffness.
- Better flotation characteristics.
- Steel belts that provide additional resistance to tread damage.
- Higher repair success rate.

Once the choice between a radial and bias-ply tyre has been finalised, the detailed analysis begins. Areas that have to be examined include, type of road surface, condition of road, road profile, weather conditions, traction requirements, previous failure history if available and type of material being transported.

Pattern

The pattern of the tyre is normally related to the type of operation that the tyre will be utilised in. Typically tyre manufacturers provide varying patterns varying from traction to rock patterns.

As the name suggests, a traction pattern tyre is designed to maximise available traction. This type of tyre is usually characterised by a large open tread style, with many individual tread lugs.

A rock pattern normally has fewer individual lugs. The reduced open area prevents rocks being captured in the tread voids and cutting into the tyre.

As a general rule, the higher the rock protection the higher the actual level of reinforcement and protection of the tyre. Conversely the higher the rock protection the lower the tyres traction, adhesion and operating speed limits.

Therefore it is essential that the optimum compromise be obtained between traction and rock resistance. Traction tyres operating on rocky surfaces will wear quicker than rock type tyres. Operator safety can be jeopardised if rock tyres are used in areas requiring traction. If any tyre is subjected to excessive wheel slip or spin, wear rates will be dramatically increased.

Ply Rating (where applicable)

For bias-ply tyres, the load carrying capability of the tyre is normally proportional to the ply rating. The ply rating is the strength of the tyre expressed against the equivalent number of cotton plys.

Bias-ply tyres were originally manufactured utilising cotton for the ply weave. To assist in comparisons and understanding, when newer materials such as nylon etc were introduced, tyre ratings were measured against a “standard cotton“ construction tyre, rather than the actual number of plys present.

The higher the number of plys, the higher the load carrying capability of the tyre.

For radial tyres, a star rating (H) is utilised. Radial tyres are given a star rating from one to three (most earthmover applications are normally one or two star). Manufacturers may publish conversion tables for star to ply ratings, but it is better to use the load inflation tables to determine the maximum loads for each tyre.

By knowing the maximum tyre load (preferably from weighbridge analysis), the tyre with the correct load carrying capability can be determined.

Tread Depth and Tyre Compound

The tyre compound refers to the actual type of rubber compound and tyre construction used. Manufacturers can vary the stiffness and hardness of the structure and the rubber to achieve optimal tyre characteristics.

Tyres are normally available in three types of compound, cut resistant, heat resistant and ultra heat resistant. The choice of which is preferable is based on failure history, operating conditions and Tonne Kilometre Rating (TKPH).

Service	BS Code No.	Structure
Earthmover	1A 2A 3A	Standard Cut-resistant Heat-resistant
Grader	1A 2A	Standard Cut Resistant
Loader & Dozer	2A 2V[=] 2Z[=]	Cut-resistant Special (Type V)[1] Special (Type Z)[2]

Table 1 - Bridgestone constructions

[1] Steel breaker construction
[2] Side steel breaker construction
= Bias-ply tyres only

Tables one through to three give the varying construction and compound tyre types available from Bridgestone, Goodyear and Michelin

Table 4 gives the Tyre and Rim Association (TRA) Off-the-road tyre nomenclature and type of service applicable.

Compound Description	Compound Code	Construction Description	Construction Code
Heat Resistant (HR)	2	Standard	S
Standard Abrasion Resistant (AR)	4	Steel Breakers	J
Ultra Abrasion Resistant (UAR)	6	Heavy Undertread	U

Table 2 - Compound and Construction Types for Goodyear Tyres

Tread Depth Code	Relative Tread Depth	Construction Code	Construction Type
N	100%	type A	Rock and abrasion resistant
D1	150%	type B	Heat resistant
D2	250%	type C	High speed, long haul

Table 3 - Michelin Tread Depth and Construction Codes

Vehicle Type	TRA Code Number	Tread Type	Maximum Speed (kph)	Maximum Distance (one way)
Earthmover  **Dump trucks, scrapers, articulated dump trucks.**	E-1	Rib	65	4.0 km
	E-2	Traction	65	4.0 km
	E-3	Rock	65	4.0 km
	E-4	Rock Deep Tread	65	4.0 km
	E-7	Flotation	65	4.0 km
Graders 	G-1	Rib	40	Unlimited
	G-2	Traction	40	Unlimited
	G-3	Rock	40	Unlimited
	G4	Rock Deep Tread	40	Unlimited
Shovels, Loaders, Bulldozers, Load-Haul Dump Trucks 	L-2	Traction	10	75 m
	L-3	Rock	10	75 m
	L-4	Rock Deep Tread	10	75 m
	L-4S	Smooth Deep Tread	10	75 m
	L-5	Rock Extra-Deep Tread	10	75 m
	L-5S	Smooth Extra Deep Tread	10	75 m

Table 4 - TRA Classification of Tyres for Earthmoving

Where the TRA table calls for deep tread tyre, the tread depth is 150% of a standard tread depth tyre and an extra deep tread tyre tread depth is 250% of a standard depth tyre.

From Table 4, there are choices that have to be made as to the type of tyre performance required. The choices involve a trade-off between heat resistance and rock / cut resistance. The trade-off between heat resistance and cut resistance occurs as carcass strength and rubber hardness vary between the two types of tyres. This variance in hardness changes the amount of energy generated per revolution of the tyre.

Approximately 80% of the cost of manufacturing an earthmover tyre is expended in the casing. The remaining 20% is expended in the tread. Therefore, to extend a tyres life, one method is to increase the tread depth. Based on the 20% cost of the tread, a 50% increase in tread depth could be achieved for only an approximate 10% increase in the tyre purchase price. If this extra 50% of tread can be utilised in service, this would dramatically decrease the tyre's cost per kilometre or cost per hour.

The disadvantage of thicker tread is (due to the greater amount of material utilised) heat is not dissipated as quickly. A thicker tread tyre usually carries a lower TKPH rating than a standard tread depth tyre for this reason. The actual depth of tread chosen will normally depend on the past performance of tyres on site, or practical experience from similar operations elsewhere.

For example, if standard tread tyres are failing from rock damage at 50% worn, an option would be to extend the life of the standard tread tyres by preventing rock damage as opposed to purchasing deep tread tyres. This is due to the fact that the tread depth will only protect the tyre so much. If major rock damage is occurring, even having 50% more tread depth will not protect the tyre, therefore this extra tread is wasted.

This is a simplistic example however and there may be other factors which have to be accounted for at varying sites. The option of utilising a deep tread tyre should be examined due to the potential savings available.

Tonne Kilometre per Hour Rating (TKPH)

As a basis of determining the suitability of a tyre for a given operation, the final check is the Tonne Kilometre per Hour (TKPH) rating. At its most simplest form, the TKPH rating of a site is a measure of the earthmover's average speed multiplied by the average tyre load. This gives the average working energy that the tyre must withstand during operations.

The "basic" TKPH calculation involves the following formula:

$$M_A = \frac{M_L + M_E}{2}$$

Equation 1 - Average Load on Tyre

Where:

M_A = Average load on tyre.

M_L = Tyre load on a loaded vehicle.

M_E = Tyre load on an empty vehicle.

The average tyre load should be calculated for at least each axle on the vehicle. If there is significant variance across axles, this calculation should be performed for each tyre position. The maximum value obtained from the calculations will be used to determine the TKPH value.

The weight of equipment is best determined from actual weighscale data. If manufacturers data is used, allowances for extra equipment, partial water fill in tyres, mud on chassis, etc must be included. Weightscale data will also highlight if overloading, under loading or uneven loading occurs and if so to what extent.

The haul average speed is calculated by Equation 2, given below:

$$V_A = \frac{L \times N}{T}$$

Equation 2 - Average Speed

Where:

V_A = Average haul speed (kph).

L = Haul length (kilometres).

N = Number of cycles per shift.

T = Duration of shift (hours).

It should be noted that when performing the haul average speed calculation, where there is more than one haul route, the calculation must be performed so that the maximum average speed for the site is determined. The fastest haul route is normally the longest.

Also, for the shift duration time, periods such as dwell time at shovels, unloading points, refuelling, meal breaks etc, are to be included in the shift. Abnormal downtime is not to be included in the shift time calculation, for example breakdowns, stoppages etc.

As evident from the calculation method for the TKPH value, the actual TKPH value calculated is very generic. This causes several problems which have to be overcome. These include:

- No allowance is made for "overloading" of equipment.
- As only the average speed of the equipment is used, there is the potential to exceed this for limited periods and hence exceed the tyres actual TKPH rating.
- Actual TKPH of tyres in service may vary when compared to rated TKPH through improved road design, maintenance and pressure maintenance.
- The TKPH values quoted by manufacturers assume certain standards of pressure maintenance, road condition, speeds and loads. If these conditions are well controlled compared to the assumed levels, actual tyre TKPH may actually increase.
- No allowance is made for load variations between the front and rear of the tray.
- TKPH values supplied by tyre manufacturers are only valid for certain haul lengths, ambient temperatures and speeds.

Even after a TKPH figure has been determined, it may have to be modified to suit pit conditions further. Most TKPH values are quoted at a standard ambient of 38°C. Therefore if the ambient temperature at your site is above or below this temperature, the tyre's TKPH rating needs to be adjusted.

It should be noted, that as most earthmover tyres last approximately a year, (depending on site conditions), the maximum temperature needs to be used to determine the required TKPH. Both Bridgestone and Michelin have individual formula for calculating temperature corrected TKPH. Goodyear do not require their TKPH values to be modified for ambient temperatures.

An example of an actual TKPH calculation is given in Appendix 1 and 2.

Choosing The Actual Tyre Based On TKPH

Normally, the size of the tyre is already determined by what was fitted as original equipment. Depending on rim size, there are still some possibilities for tyre size adjustment, however this normally requires changes in rim widths or rim diameters.

Therefore the starting point is normally the tyre size that has been originally fitted. Reference to the Tyre and Rim Association Standards Manual will give load carrying capacities for most tyre sizes and carcass constructions.

Using the TKPH value calculated, a choice between the short listed bias-ply and radial tyres will have to be made where this choice has not been made prior to this point. Normally the selection of bias-ply or radial tyres has been made prior to this point for other reasons, such as wear life, cost etc.

Once the TKPH requirements have been determined for the site, actual matching of tyres from vendors can be undertaken. It is not within the scope of this article to specify how this is performed, as the choice of tyres is dependant on many variables such as:

- Tyre purchase cost
- Warranty provisions
- Service life
- Brand performance
- Availability / delivery
- Consignment agreements
- Rebates

Tyre Maintenance

To maximise the performance of tyres utilised, correct operation and maintenance is required. The main factors affecting tyre life are listed below.

- Maintenance
  - Pressure Maintenance
    - Pressure Setting
    - Under Inflation
    - Over Inflation
  - Road Maintenance
    - Rocks in Road Surface
    - Over Watering
    - Uneven Surfaces
    - Rocks in Windrows
  - Tyre Maintenance
    - Matching
    - Dual Matching
    - Asymmetrical Wear
    - Rock Removal
    - Run Out Parameters
  - Vehicle Maintenance
    - Tyre Camber
    - Alignment
    - Toe In / Toe Out
    - Brake Adjustments
- Haul Road Design
  - Curve Radius
  - Road Width
  - Road Surface
  - Gradients
  - Drainage
  - Super Elevation
- Operations
  - Driving
    - Vehicle Speed
    - Vehicle Positioning
    - Cornering Speed
    - Gear Changes
    - Wheel Slip / Slide
    - Avoidance of Obstacles
  - Loading
    - Load Position
    - Load Weight
    - Load Type
    - Loading Accuracy
    - Face Condition
    - Backing Trucks onto Face / Rocks
  - Scheduling
    - Balancing of TKPH
    - Waiting Periods
    - Break Periods
    - Release for Maintenance
- Tyre Selection
  - Construction Type
  - TKPH
  - Tread Wear
  - Load Capacity
  - Traction

Maintenance

Maintenance activities include, pressure maintenance, road maintenance, tyre maintenance and vehicle maintenance.

Pressure Maintenance

Pressure Maintenance is the single most important contributor to tyre life. The effects of incorrect pressure maintenance can cause accelerated wear along with other problems. Some of the typical problems associated with pressure maintenance are:

Under Inflation

- Heat separation.
- Uneven wear - excessive heal and toe wear.
- Internal ply separation.
- Bead damage.
- Increased fuel consumption.

Over Inflation

- Uneven wear (excessive centre line wear).
- Cuts.
- Impact damage.

Figure 7 below, highlights the effect that poor pressure maintenance standards can have on the relative tyre life achieved in operation. It should be noted that the type of operation plays a major part in the actual wear rates, in conjunction with pressure maintenance.

There are many methods of checking earthmover tyre pressures. These range from simple visual inspection to continuous monitoring systems. A paper detailing three commercially available systems is included as an Appendix to this article.

It should be noted from Figure 7 that under inflation not only affects tyre life but also safety greater than over inflation.

The pressure setting for tyre is also important. An incorrect setting can dramatically decrease tyre life, even if pressure maintenance is good. Pressure settings can be initially calculated from the tyre load / inflation tables provided by tyre manufacturers. Allowances may have to be made based on operational practices, such as partial water fill, speeds or loading criteria.

Road Maintenance

Road maintenance is usually not factored into tyre life analysis. However road maintenance is vitally important if extended tyre life is to be achieved.

Correct road maintenance requires a coordinated approach which involves all personnel. All personnel should have the ability to request road maintenance crews attend an area of concern.

Road maintenance involves all aspects of maintaining the haul roads to a standard where tyre wear or damage is not accelerated. This includes the removal of rocks laying on the road, rocks imbeded in the road, grading of road surfaces to re-level them, drainage channels and the grooming of windrows and emergency stopping buffers.

Overwatering causes scouring and erosion of the roadbase, which can lead to overloading of individual tyres. Excessive watering can also cause wheel spin and subsequent removal of material leading to grooving of the roadbase with channels which can increase tyre load.

It is important therefore that when watering haul roads, care should be taken to ensure that the road surface is not overwatered. This may necessitate the use of "pulse" sprays. Pulse sprays are typically where the water spray is alternatively on or off for approximately 5 second periods. Other methods to reduce overwatering include using the right hand sprays to wet the uphill side of the road whilst travelling downhill, not watering already wet roads, not watering during rain periods and reduced water delivery rates.

Tyre Maintenance

Tyre maintenance involves the rectification of problems which if left unchecked could lower tyre life. The timely rectification of these problems will ensure that tyre life is maximised.

There are many problems that tyres can have during service. These problems include asymmetrical wear and rocks imbeded in the tread. To correct for asymmetrical wear, the tyres are reverse mounted, whilst any embedded rocks should be removed, as these tend to be drawn into the casing by the flexing of the tyre and can cause the inner liner to be ruptured.

Incorrect matching of rear dual tyres can increase loads in individual tyres dramatically. Matching of tyres is also critical in loader and dozer applications.

Most organisations have limits that a tyre can be worn to and still be fitted to the steering positions of a truck. If these criteria are too stringent, extra tyres will have to be fitted to the front position and if the criteria are too loose, this could lead to increased rates of front tyre failures which may have safety consequences. Front tyre failures also result in increased downtime due to tyre changes occuring outside the workshop environment or having to transport the vehicle back to the workshop.

Vehicle Maintenance

From a tyre perspective, correct vehicle maintenance includes camber adjustments, wheel alignment, toe in and toe out and brake adjustment.

The correct alignment and adjustment of the wheel is critical to achieving long tyre life. If the tyre is misaligned, the tyre will rotate at an angle to the desired direction of travel. This causes slip and increase wear. Some mis-alignment is required for steering and stability purposes, but this should be rigidly controlled.

Incorrect brake adjustment, especially dragging brakes can cause excessive heat loads on the tyre and premature failure. If the

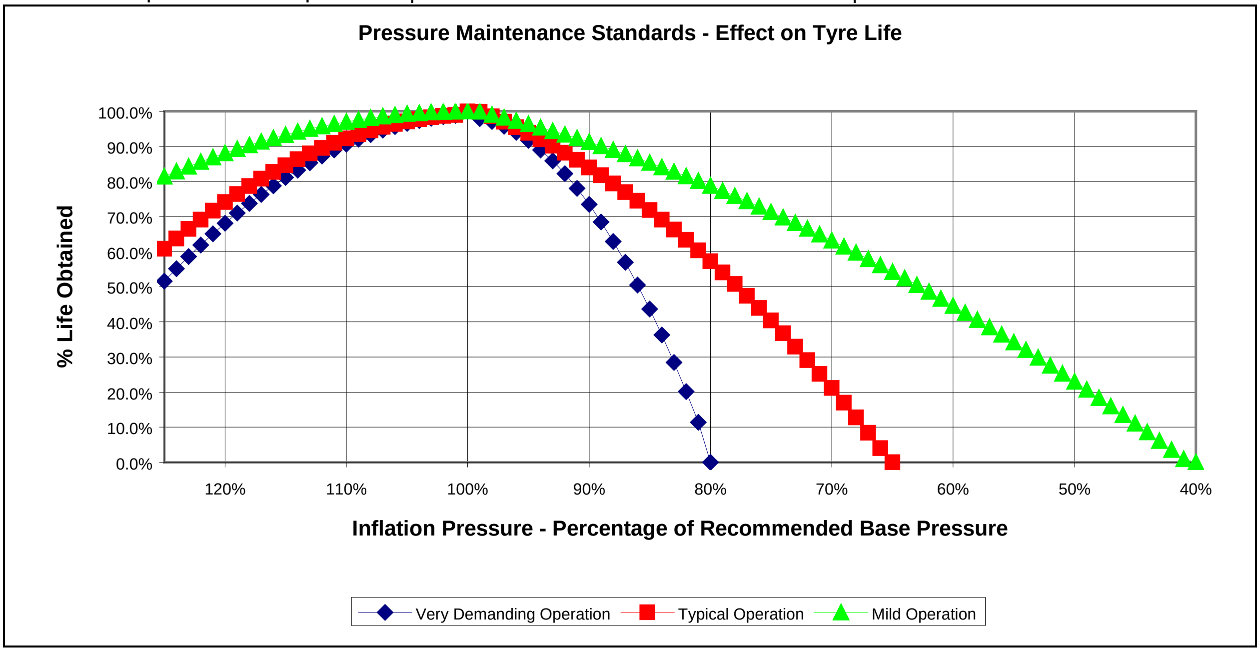


Figure 7 - Pressure Maintenance Relative to Tyre Life

heat levels are extreme there is the possibility of a tyre fire of even a tyre explosion. Both of these events have the potential for serious injury.

Haulroad Design

The impact of haul road design is often overlooked when comparing tyre performance, but this is one of the most critical aspects of achieving high tyre life. The United States Department of the Interior - Bureau of Mines prepared a book titled, “Design of Surface Mine Haulage Roads - A Manual”, authored by Walter Kaufman and James Ault in 1977, which highlights the design requirements for mine roadways.

This publication highlights safety issues associated with mine road design, along with methods of integrating vehicle dynamics and performance into road design.

We will examine the following:

- Horizontal and Vertical Alignment
- Cross Fall
- Drainage
- Superelevation
- Curve Radii
- Road Construction
- Road Width

Horizontal and Vertical Alignment

In the interests of safety, where economically feasible, all roadways should be constructed to provide safe, efficient travel at normal operating speeds. Provision for adequate sight of vehicles and obstacles should be paramount from a safety perspective. Adequate sight will allow operators to avoid obstacles and also enable smoother braking, thereby reducing wear and increasing tyre life. Figure 8 gives a graphical representation of vertical and horizontal alignments to maximise safe working.

The vertical alignment, grades, curve radii etc, is a function of the equipment being utilised. Consideration should be given to the braking and haulage capabilities of the equipment (both current and future), to allow adequate stopping distances. Where equipment is hauling material up hill, then the equipment’s capacity and power requirements, along with brake capacity must be considered.

Where gradients start, adequate blending of the transition between the horizontal and grade areas needs to be performed. Too often, steep grades begin with no transition, which causes the equipment to pitch and, if overloaded, deposit rocks and material on the road surface.

These rocks cut the tyre’s surface and if large enough, cause impact damage to the tyre.

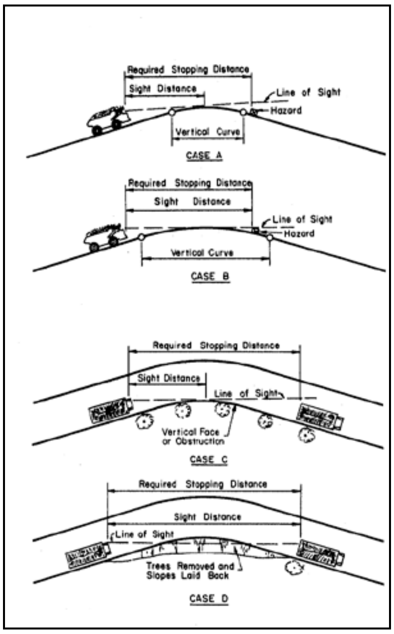


Figure 7 - Road Alignment Criteria

At the lower end of grades, curves if necessary, should be of sufficient width relative to radius, to allow the equipment to easily traverse them. Here speed is the issue, as with correct super elevation, corners should not be a problem.

Horizontal alignment predominantly deals with the safe operation of equipment around curves at speed. Curves are regularly created with little regard to the operating speed of the equipment utilising them, the width of the equipment and stopping distances relative to vision distances.

Cross Fall

Cross fall on vertical sections is not necessary, especially where “pulse” watering can occur. If cross fall is used and is from the outside of the road to the inside, water will tend to drain into the edge of any corner at the bottom of the grade and cause scouring and cutting of the surface.

Cross fall if excessive can cause steering difficulties and slip between the tyres increasing wear. Where cross fall is excessive the inner rear duals can be overloaded also.

Drainage

Drainage is a major consideration, as during heavy rain large amounts of water can collect and run down the grade, causing severe scouring. This scouring can cause overloading of tyres or even impact damage.

Additional problems such as reduced traction and loss of control can also occur if drainage is not adequate. The combination of wet tyres and wheel slip through loss of traction dramatically increases the tyres wear rate.

Superelevation

If curves are made which have very small radii and if there is no super elevation included, the tyres will tend to deflect and skid outwards, increasing loads and wear. Super elevation is a function of both the curves radius and the equipment's speed. Table 5 gives super elevation rates (metres per metre) for a given curve radius (metres) and equipment speed (kilometres per hour).

There needs to be some practical limits as to the amount of super elevation required. If a curve is designed for 45 kph, but in practice equipment only achieves 20 kph, then the net effect is that the driver will require extra effort to manoeuvre the vehicle around the curve.

If the vehicle is moving slowly or has to stop on a super elevated curve, the inner wheels will carry a higher percentage of the load.

Table 5 can also be used to determine the correct entry speeds for a given corner radius. These speeds can then be posted to remind drivers of the correct speed prior to entering the curve.

As important, but often overlooked, is the relationship between super elevation and required run-out. The super elevation runout is the length of transitional road where the amount of super elevation changes from zero to the required, or from positive super elevation to negative.

As the speed of vehicles at most minesites is relatively slow, the positioning of runout is not as critical as other applications such as highways or access roads. However, where cross fall is used on the road surface and it opposes super elevation, the necessary changes in road surface slope should be achieved prior to the corner.

Curve Radii

Sharp bends should be minimised where possible. Figure 8 gives a method of determining the road width during a curve. From a tyre life perspective curves should be as large as possible. If this is not possible speeds should be reduced to minimise the possibility of accidents.

Road Construction

Fundamental to the safe operation of equipment is a stable road base. Vehicle dynamics are severely affected by a roadbase which cannot adequately support the equipment's weight. Productivity is also affected by incorrect roadbase materials, through tyre wear, rework (such as grading and compacting), downtime due to the disruptions that this creates and reduced operating speeds of equipment required to negotiate irregularities.

Too frequently, the economics of road construction is confined to the immediate. Therefore, roads tend to be built such that operations can begin, rather than for the duration of operations. This usually means that operations will over time be subject to delays through restrictions, rework, clearing, leveling and cleaning.

Some common problems occurring with road bases include:

- Incorrect particle sizes
- Low bearing strength
- Flow under load
- Scouring
- Dust
- Sinking

The geology and soil mechanics associated with road construction will not be discussed here.

Care must also be taken to select the most appropriate road surface. Figures for road adhesion coefficients are given in various publications, for example the Caterpillar performance handbook. The correct choice of road surface material will provide not only higher levels of adhesion, but also lower rolling resistance and improved fuel economy.

Radius of Curve (metres)	**Speed of Vehicle (kph)**								
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
50	0.02	0.04	0.06	0.10	0.14	0.19	0.25	0.32	0.39
100	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20
150	0.01	0.01	0.02	0.03	0.05	0.06	0.08	0.11	0.13
200	0.00	0.01	0.02	0.02	0.04	0.05	0.06	0.08	0.10
250	0.00	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.08
300	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.07
350	0.00	0.01	0.01	0.01	0.02	0.03	0.04	0.05	0.06
400	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.05
450	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.04
500	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.04

Table 5 - Recommended Super Elevation Rates (metres per metre)

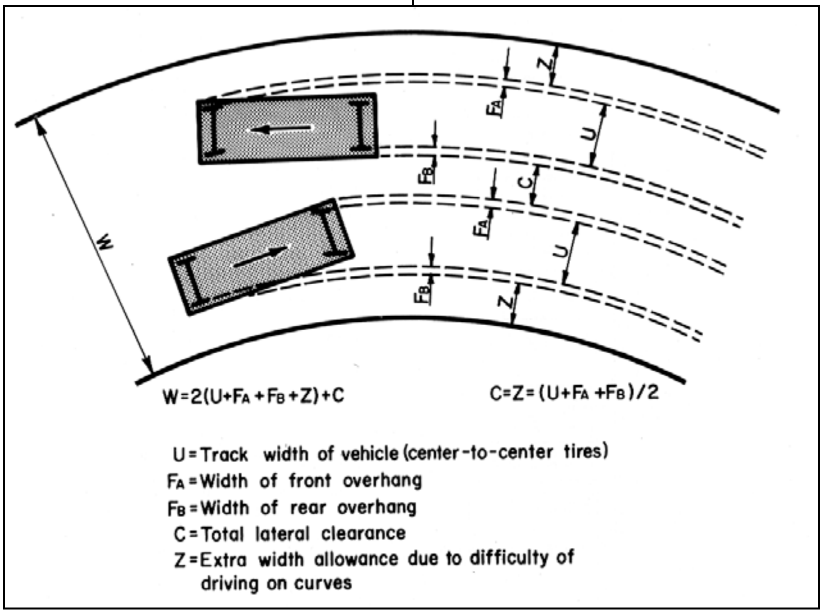


Figure 8 - Roadway Width during Curves

Road Width

Road width is essential to the safe operation of equipment. Earthmoving equipment varies in size dramatically between machines of varying capacity. Therefore road width needs to be set for the largest vehicle that would normally operate over a given route.

If there exists a large discrepancy in the width between normal machinery and some plant, it may be more appropriate to ensure that there is sufficient width for the relocation of the equipment, which would have to be moved under escort.

Table 6 and Figure 9 show relative road widths for varying numbers of lanes and equipment sizes.

Vehicle Width (metres)	1 lane	2 lanes	3 lanes	4 lanes
2.0	4	7.0	10	13.0
2.5	5	8.8	12.5	16.3
3.0	6	10.5	15	19.5
3.5	7	12.3	17.5	22.8
4.0	8	14.0	20	26.0
4.5	9	15.8	22.5	29.3
5.0	10	17.5	25	32.5
5.5	11	19.3	27.5	35.8
6.0	12	21.0	30	39.0
6.5	13	22.8	32.5	42.3
7.0	14	24.5	35	45.5
7.5	15	26.3	37.5	48.8
8.0	16	28.0	40	52.0
8.5	17	29.8	42.5	55.3
9.0	18	31.5	45	58.5
9.5	19	33.3	47.5	61.8
10.0	20	35.0	50	65.0
10.5	21	36.8	52.5	68.3
11.0	22	38.5	55	71.5
11.5	23	40.3	57.5	74.8
12.0	24	42.0	60	78.0
12.5	25	43.8	62.5	81.3
13.0	26	45.5	65	84.5
13.5	27	47.3	67.5	87.8
14.0	28	49.0	70	91.0
14.5	29	50.8	72.5	94.3
15.0	30	52.5	75	97.5
15.5	31	54.3	77.5	100.8
16.0	32	56.0	80	104.0

Table 6 - Recommended Lane Widths (Straight Sections)

Only through proper road design can the long term efficiency of operations, not only tyre wear, be guaranteed.

Operations have a high impact on the overall tyre life. Normal tyre failure modes, such as rock damage, cuts, heat separations, etc, can to some degree be avoided by correct operational practices. These practices will be discussed in the following section of this article.

Operational Issues

Vehicle Speed

Vehicle speed is also a critical factor in tyre life. Previously, only the actual operator could control vehicle speed. However, with the advent of modern computerised mine dispatch systems, vehicle speed, and associated tyre heating, can now be monitored remotely. This monitoring is only a check system, it is not perfect, or 100% accurate.

Drivers should be made aware of the limitations of the tyres that are fitted to the vehicles that they are operating. Common tyre maximum speed restrictions are given below in Table 7. This table is only a guide and each different tyre should be checked for its maximum speed rating.

The average speed for a vehicle should be less than the TKPH value of the tyre divided by the average load, ie: the workday or workshift average speed.

Type of Vehicle	Maximum Speed
Earthmover	65 kph
Scraper	48 kph
Grader	40 kph
Loader & Dozer	10 kph

Table 7 - Typical Vehicle Speed Limitations

Excessive speed can result in many problems which can damage a tyre. These include:

- ♦ Higher heat generation inside tyre
  - Heat damage
  - Heat separations
- ♦ Rapid Braking
  - Chipping
  - Bead damage
  - Reduced tyre life
- ♦ Sharp Cornering
  - Irregular wear
  - Excessive abrasion
  - Bead damage
  - Chipping through slip
- ♦ Road Debris Collisions on Road
  - Cutting
  - Punctures
  - Cut / Burst

Vehicle speed can also cause other problems. When vehicles climb a grade when loaded, the drive tyres can slip. Often this slip cannot be seen with the eye. The grade by which the vehicle has to ascend directly affects tyre wear. Figure 10 shows the relationship between grade, vehicle speed and tyre life. The grade also affects the vehicle's mechanical systems such as brakes, drivelines and engines.

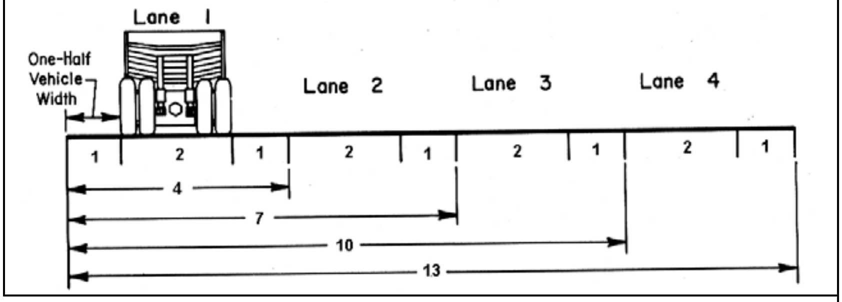


Figure 9 - Road Width Relative to Equipment Width (Horizontal Surfaces)

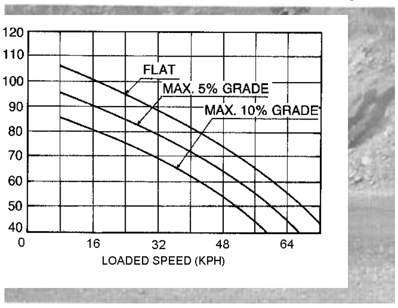
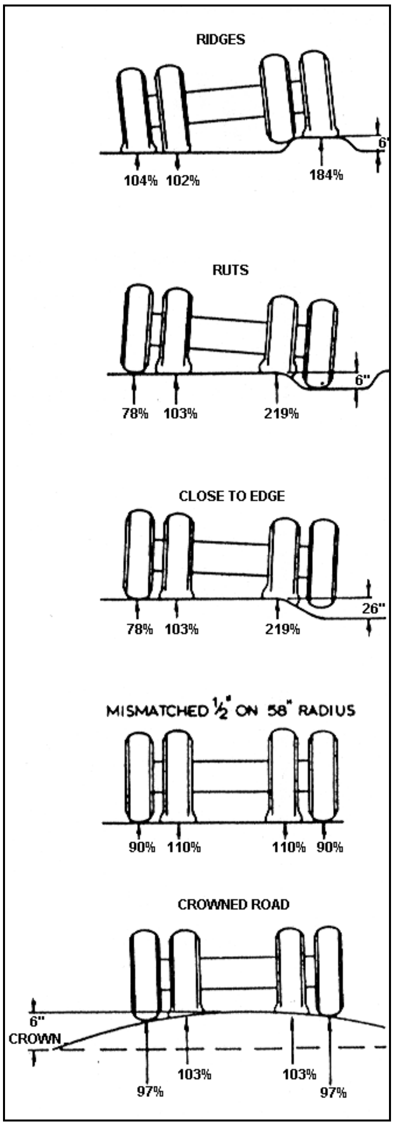


Figure 10 - Reduction in Tyre Life



with Road Grade and Speed

Figure 11 - Effects of Road Profile on Tyre Load Vehicle Positioning

Figure 11 shows the impact that poor positioning of the vehicle can have on the tyre load. This Figure also highlights the need for good road maintenance along with adequate road width, to ensure that there is enough room to manoeuvre around obstacles, or negotiate curves etc at speed.

As can be seen from Figure 11, tyres can be severely overloaded simply from falling into drainage channels, mounting windrows, or from simply being mis-matched. It is in these situations that side wall cuts, rock penetrations and impact bursts, along with internal damage can readily occur.

Damage incurred through operational issues can be overcome, but requires regular informational and training sessions with those concerned, operators and drivers. Without their commitment, consequential damage will not be dramatically reduced.

Care must also be taken to ensure that the design and maintenance of roads are performed so that tyre damage is minimised.

As Figure 11 shows, tyre overloading can occur even when the vehicle is correctly loaded, through road geometry or driver errors. If however, the vehicle is already overloaded, the problems are increased dramatically.

Loading Techniques

It is important that the loading operation be carried out in a manner to reduce tyre wear and damage. Figure 12 highlights the impact that overloading can have on tyre life, without any other factors included.

Care should be taken to ensure that the load is positioned properly, allowances are made for overburden and ore densities, along with allowances for varying truck types and capacities.

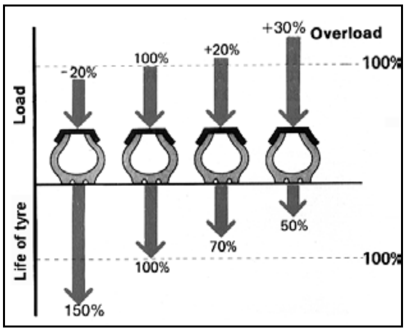


Figure 12 - Effects of Load on Tyre Life

Other issues related to tyre wear and damage that occur when loading, include backing onto the face, lack of face clean-up and overfilling or missing the truck's tray which results in stones falling under the rear tyres.

Backing onto the face can cause severe over-loading on the rear tyres and increase the risk of rock cuts and penetrations (Figures 13 & 14). This is exaggerated where large rocks are present. To remove this problem, regular face clean-up operations should occur, along with accurate loading and removing spilling, as this is the most common cause of face debris. If accurate loading is carried out, eliminating spillage, not only will face clean-ups be less frequent, but there will be less likelihood of rocks falling under the rear wheels.

Figure 13 - Overloading and Spillage

Figures 13 and 14 show actual loading operations. These practices are treated as everyday practices however they dramatically reduce tyre life. Pit surveys and condition reports can help to identify and correct practices such as these.

Figure 14 - Backing onto Loading Area

Figure 15 - Rocks around Face Area

Figure 15, shows the accumulation of rocks, both at the face and in the area around the face, that can occur from overloading. Not only do rocks fall from the tray during loading from overfilling, but they also fall from the tray when the vehicle begins to move. This multiplies the work that the face clean-up crews have to undertake and dramatically increases rock damage to tyres.

Figure 16 - Vehicle Parked on Rocks

Figure 16 shows a vehicle parked on rocks during a shift break. Care should be taken to keep clean any area utilised by the equipment. Parking on rocks is very damaging to the tyres, as the point loads that occur are present for a much greater period of time, dramatically increasing the probability of damage to the tyre.

Figure 17 - Uneven Loading of Vehicles

Figure 17 highlights uneven loading in practice. This is a major concern, especially where road conditions are not favourable. Care should be taken to always ensure that the load is positioned correctly within the tray.

With the advent of new Mine Scheduling Systems, there is the potential to increase truck utilisation, through more efficient dispatch / routing. This however has several

problems in relation to tyre life.

Unless an allowance is made for the increased distance travelled and corresponding increase in average speed, there exists a very high probability that tyres will be operated over their TKPH limits. Some computer systems attempt to address this issue through in-built tyre TKPH algorithm's, but even these are too simplistic to accurately predict tyre TKPH. In severe cases the error could be enough to either have trucks stood down or tyres damaged, depending on the trigger levels set.

The new computerised Mine Scheduling Systems also increase average speeds through a reduction in waiting times at both loaders and crushers. This also may reduce tyre life if not accounted for.

CONCLUSION

Tyres usually account for 25% to 40% of a mining or quarrying operations earthmoving costs. As such, there is a large scope for cost reduction through improvements in tyre utilisation.

Effective utilisation of tyres is not a simple task. The maximisation of tyre life requires a coordinated effort from proper selection through to maintenance and operational practices.

The fundamental areas required to ensure tyre life is maximised include;

- Correct selection
- Correct pressure settings
- Correct pressure maintenance
- Correct tyre maintenance
- Haul road design
- Haul road maintenance
- Correct loading methods
- Correct load area housekeeping
- Correct vehicle operations
- Proper vehicle scheduling

Only if ALL of these areas are properly addressed, will tyre life achieve the maximum possible.

Correct selection ensures that the tyre being utilised is the most cost effective solution for the combination of vehicle, load and operating conditions. The selection process involves many trade-offs and if an incorrect assessment is made, tyre life can dramatically decrease.

Regular trials of tyres which may be suitable can also be carried out to gain a quantitative assessment of their performance. This process can however take several years to complete, during which tyre construction or compound changes may make the results obsolete.

Pressure maintenance is the major building block upon which effective tyre utilisation is founded. Without correct pressure settings and pressure maintenance, tyre life will be significantly reduced.

With an "average" earthmover tyre costing in the vicinity of $10,000 or even greater, the cost of a regular inspection program relative to the potential losses is minimal.

Care should be taken to ensure that employees undertaking this process are properly trained to do so. Otraco has Australia's only accredited tyre serviceman training program.

To maximise tyre life it is essential that haulroad design be adequately addressed. Although the economics of haulroad design are normally confined to the immediate, the longer term ramifications can dramatically exceed the short term benefits.

The benefits of undertaking adequate haulroad design and construction include:

- Reduced downtime
- Reduced maintenance
- Reduced consequential damage
- Reduced tyre failures
- Reduced tyre wear
- Reduced machine maintenance
- Improved operator comfort
- Improved safety
- Improved tyre life

Haul road design covers issues such as curve radii, cross fall, horizontal and vertical alignment, super elevation rates, drainage, camber, road widths, gradients, construction medium, base materials and surfacing material. All of these areas can be optimised to ensure that the most suitable combination is achieved.

Haulroad maintenance is also essential to ensure effective tyre utilisation. Haul road maintenance is dependent on climatic variables, road construction techniques and operational practices.

Tyre life will normally reflect the level of haul road maintenance, if all other criteria are equal. If the level of haul road maintenance is high the tyre life will be relatively high, if haul road maintenance is low, tyre life will be correspondingly low.

Operational issues can also have a dramatic effect on tyre life. Some of the main operational issues which impact on tyre life include loading methods, housekeeping of the loading area, vehicle operations and vehicle scheduling.

Loading methods predominantly revolve around the actual load placement on the truck and truck positioning when loading. Care should be taken to ensure that spillage is reduced as spillage can fall under the tray making the tyre roll over it when leaving the load area. This causes the overloading of the tyre and increases the risk of a rock impact damage or rock cut.

If spillage occurs, or if rocks begin to foul the load area, either the shovel operator or a clean-up crew should clear the loading area prior to continuing. This reduces the likelihood of tyres being parked on rocks, which can cause significant tyre damage. Good housekeeping in the load area should not be seen as lost production time, if it is seen as poor operational practice to cause this spillage in the first place, operator skills will improve.

Vehicle operations includes travel speeds, cornering speeds, gear changes, obstacle avoidance, braking methods, acceleration methods and vehicle positioning. All of these areas can impact on tyre life and have the scope to cause premature failures in the extreme.

Operators should be educated to ensure that they are aware of the consequences of poor operational practices. This education process has proved to be very effective when combined with accurate reporting in reducing the incidence of premature tyre failures through operator error.

Proper vehicle scheduling is now much more readily achieved through modern computerised mine dispatch systems. However, the models utilised have some inconsistencies in relation to TKPH calculations. The algorithms utilised however can still provide a useful first line of defence against tyre damage.

It can be seen that effective tyre utilisation requires a coordinated approach. To achieve the maximum life for a tyre, ALL of the issues raised must be addressed. Tyre life decreases with each criteria that is not adequately controlled or addressed.

The areas listed are not static variable and as such must be continuously monitored to ensure adequate responses are made to new developments. It is essential that periodic reviews of operations are carried out to validate assumptions or confirm values utilised and therefore confirm the processes and tyres in use as being still optimal.

This process is ongoing. But with the correct type of tyre and effective operational practices, effective tyre life should be possible.

ACKNOWLEDGMENTS

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APPENDIX 1 - EARTHMOVER TKPH CALCULATIONS

The follow calculations show the TKPH determination for a typical haul truck, with the following operating parameters, along with a brief overview of a hypothetical tyre selection process.

Based on the data above, the Average Load per Tyre can be calculated as follows,

Unloaded - Front

Operating Weight	61,793 kg
Max. Gross Weight	146,966 kg
Weight Distribution (Empty) Front Rear	 47% 53%
Weight Distribution (Loaded) Front Rear	 33% 67%
Standard Tyres	27.00R49
Standard Rim	49 x 19.50
Haul Route 1 Length (Return)	4.2 km
Haul Route 2 Length (Return)	6.8 km
Number of Cycles per Shift (Route 1)	30
Number of Cycles per Shift (Route 2)	22
Shift Duration	8 Hours
Site Maximum Temperature	50°C
Site Minimum Temperature	12°C
Road Condition	Rocky
Dominant Failure Mode	Rock cut / Impact
Current Tread Utilisation	53%

2 tyres, 47% of 61,793 kg equates to:

$$\text{Load} = \frac{47\% \times 61{,}793 \text{ kg}}{2 \text{ Tyres}}$$

$$\text{Load} = 14{,}521 \text{ kg / Tyre}$$

Unloaded - Rear

4 Tyres, 53% of 61,793 kg equates to:

$$\text{Load} = \frac{53\% \times 61{,}793 \text{ kg}}{4 \text{ Tyres}}$$

$$\text{Load} = 8{,}188 \text{ kg / Tyre}$$

Loaded - Front

2 Tyres, 33% of 146,966 kg equates to:

$$\text{Load} = \frac{33\% \times 146{,}966 \text{ kg}}{2 \text{ Tyres}}$$

$$\text{Load} = 24{,}249 \text{ kg / Tyre}$$

Loaded - Rear

4 Tyres, 67% of 146,966 kg equates to:

$$\text{Load} = \frac{67\% \times 146{,}966 \text{ kg}}{4 \text{ Tyres}}$$

$$\text{Load} = 24{,}617 \text{ kg / Tyre}$$

The average load per tyre can now be calculated.

Average Load Front Tyres:

$$M_A = \frac{14{,}521 + 24{,}249}{2}$$

$$M_A = 19{,}385 \text{ kg / tyre}$$

Average Load Rear Tyres:

$$M_A = \frac{8{,}188 + 24{,}617}{2}$$

$$M_A = 16{,}403 \text{ kg / tyre}$$

Therefore, the maximum average load per tyre occurs on the front tyres and corresponds to an average load of 19,385 kg/tyre.

The site average speed must be determined from the two haul routes and cycle frequency information given.

Therefore, for Haul Route 1;

$$V_{A1} = \frac{4.2 \text{ km} \times 30 \text{ cycles}}{8 \text{ Hours}}$$

$$V_{A1} = 15.75 \text{ kph}$$

and, For Haul Route 2;

$$V_{A2} = \frac{6.8 \text{ km} \times 22 \text{ cycles}}{8 \text{ Hours}}$$

$$V_{A2} = 18.7 \text{ kph}$$

Therefore, the highest average speed is achieved on haul route 2. Using the two maximum figures, the site TKPH can be calculated as follows:

$$\text{TKPH} = 19.385 \text{ Tonnes} \times 18.7 \text{ kph}$$

$$\text{TKPH} = 363$$

This TKPH figure must be “corrected” for the site’s high ambient temperatures.

Using Bridgestone’s correction factor:

$$F(t^{o}C) = \frac{52}{52 + [(50 - 38) \times 0.4]}$$

$$F(t^{o}C) = 0.92$$

This correction factor is multiplied with the tyre’s rated TKPH to give the tyre’s TKPH at 50°C.

To utilised the Michelin tyre data, the TKPH has to be corrected for two factors. The first correction is performed for ambient temperature and the second correction is performed for cycle length. As haul route 2 is over 5 kilometres, the tyre TKPH factor has to be corrected.

Michelin quote correction factor coefficients for varying route lengths. Using the data given for a route length of 7 kilometres, the correction factor, K1 equals 1.06.

To correct for temperature, the following formula must be used for Michelin data.

$$K2 = \frac{V_m + [0.25 \times (TA - 38)]}{V_m}$$

Where:

K2 = The correction factor.

V_m = The site average speed.

TA = Ambient site temperature.

Using this formula and the data given, we obtain:

$$K2 = \frac{12.5 + [0.25 \times (50 - 38)]}{12.5}$$

K2 = 1.24

Therefore the "corrected" TKPH for the given site conditions is:

TKPH = 363 x 1.06 x 1.24

TKPH = 477

Tyre Selection

Tyre selection is normally performed independently from the TKPH calculation. The calculated TKPH values are used as a check to determine if a particular construction,

Table 2 lists all available Bridgestone tyres in the 27.00x49 size and their respective TKPH values, both rated and corrected.

Bridgestone

Tyre	Type	TKPH	Corrected TKPH
RLS 2A	*Bias*	*336*	*309.1*
RLS 1A	*Bias*	*406*	*373.5*
RLS 3A	*Bias*	*431*	*396.5*
RLS 3AUH	Bias	547	503.2
ELS 2A	Bias	350	322.0
ELS 1A	*Bias*	*409*	*376.3*
ELS 3A	Bias	453	416.8
ELS 3AUH	Bias	569	523.5
EL 2A	*Bias*	*423*	*389.2*
EL 1A	Bias	496	456.3
EL 3A	Bias	555	510.6
EL 3AUH	Bias	701	644.9

Table 2 - Bridgestone 27.00x49 Bias Tyre TKPH Values

Tyre	Type	TKPH	Corrected TKPH
VKT/VFT 3A	Radial	736	677.1
VKT/VFT 1A	Radial	654	601.7
VKT/VFT 2A	Radial	490	450.8
VEL / VRL 3A	Radial	693	637.6
VEL / VRL 1A	Radial	612	563.0
VEL / VRL 2A	Radial	449	413.1
VMTS 3A	Radial	652	599.8
VMTS 1A	Radial	571	525.3
VMTS 2A	Radial	448	412.2
VWTS / VRLS 3A	Radial	611	562.1
VWTS / VRLS 1A	Radial	530	487.6
VWTS / VRLS 2A	*Radial*	*407*	*374.4*

Table 3 - Bridgestone 27.00R49 Tyre TKPH Values

Tyres that are close to or under the calculated TKPH rating are shown in italics.

Michelin

The TKPH values for the Michelin 27.00x49 tyre size are given below.

Tyre	TKPH
X VC	1090
X RB	763
X KB	698
X HD1A4	*392*
X HD1A	*480*
X HD1B4	567
X HD1B	654
X KD1A	*392*
X KD1B4	*480*
X KD1B	567

Table 4 - Michelin 27.00R49 Tyre TKPH Values

Goodyear

The TKPH values for the Goodyear 27.00x49 bias tyres are given below.

Tyre	Type	TKPH
HRL-3B-4S	*Bias*	*380*
HRL-4B-2S	Bias	460
HRL-4B-4S	*Bias*	*328*
HRL-4B-6S	*Bias*	*277*
MRL-4D-4S	*Bias*	*277*
SHY-7A-2S	Bias	474

Table 5 - Goodyear 27.00x49 Bias Tyre TKPH Values

Goodyear radial tyre TKPH figures are given below:

Tyre	Type	TKPH
RL3+ 2S	Radial	628
RL3+ 4S	Radial	474
RL-4-2S	Radial	584
RL-4-4S	Radial	445
RL-4J/4J-II-2S	Radial	547
Rl-4J/4J-II-4S	Radial	423
RL-4J/4J-II-6S	*Radial*	*328*

Table 6 - Goodyear 27.00x49 Tyre TKPH Values

Discussion

It is not possible to accurately recommend a tyre from those listed, as the tyre prices and stock availability are unknown. This would play a major part in any decision process. However, based on the site data, a list of preferred option can be formulated.

It should be noted that the actual selection of tyres requires detailed knowledge of past and current tyre performance, in both similar and varied operations to determine tyre suitability prior to actually purchasing tyres and performing tests. This knowledge can save both time and resources by extrapolating known data to other sites, helping form short lists of suitable tyres. This process is especially important when purchasing new equipment which has not been previously operated on site.

Based on the data given, the following tyres would be short-listed for trial:

Bridgestone

Bias-ply Tyres

ELS 1A - Standard construction, deep tread tyre with reasonable rock protection.

EL 2A - High rock protection through cut resistant construction and materials, resistant to cutting, normal tread depth.

The corrected TKPH for these tyres closely match the TKPH figures calculated for the site conditions. The EL 2A should have a higher probability of wearing out, through the combination of stronger construction and standard tread depth.

Radial Tyres

VRLS 2A - The tyres corrected TKPH is closely matched to the TKPH figures calculated for the site conditions and the tyre has a cut resistant construction, with extra deep tread. With TKPH figures being so closely matched, pressure maintenance would have to be regularly carried out to prevent damage from improper inflation.

Michelin

XHD1A - Good operating speed, traction and reinforcement protection.

XKD1B4 - Less traction and lower speed than XHD1A, but better reinforcement and protection.

Both of these tyres have TKPH ratings approximately equal to the site corrected TKPH calculated. Through operational planning (varying haul trucks between the two routes and rigorous pressure maintenance), these tyres should perform well in operation. Also, the TKPH ratings have a correction factor of 1.24 included for the maximum site temperature. As the site minimum is lower, during the cooler months of the year, the tyres should have a small margin of safety incorporated. All of the tyres recommended are “deep tread” tyres, giving 50% extra tread.

If operational and maintenance practices are not able to be organised to suit, then the following tyres should be trialed:

XHD1B4 - Higher TKPH than XHD1A, but lower cut and abrasion resistance.

XKD1B - High heat resistance for long hauls, with the ability to withstand minor fluctuations in pressure maintenance.

Goodyear

RL-(4J/4J II)-4S-E4 - This tyre combines a deep tread, standard construction tyre with a cut resistant composition. The choice between the Rl-4J and the RL-4 tyres would be a choice between the wear and traction / ride characteristics of each tyre.

RL-4-4S - Also a deep tread, standard construction tyre with a cut resistant composition.

There are only 2 Goodyear bias tyres that would meet the TKPH requirements and as both are heat resistant tyres, rather than cut resistant tyres, the optimum choice is for radial tyres only.

APPENDIX 2 - LOADER CALACULATIONS

The following calculations give an overview of the tyre selection calculation process for a front end loader, with the following operating parameters; along with a brief overview of a hypothetical tyre selection process.

Configuration	ROPS canopy, standard lift, teeth and segments, 5.3m^3 rated capacity.
Operating Weight	29,019 kg
Static Tipping Load	18,887 kg
Standard Tyres	29.5-25 22 Ply (L5)
Standard Rim	25x25.00
Haul Route 1 Length (Return)	200 metres (one way)
Haul Route 2 Length (Return)	125 metres (one way)
Number of Cycles per Hour (Route 1)	21
Number of Cycles per Hour (Route 2)	30
Shift Duration	8 Hours
Site Maximum Temperature	50°C
Site Minimum Temperature	12°C
Road Condition	Rocky
Dominant Failure Mode	Rock cut / Impact

Front end loaders and tyred dozers present a different set of selection criteria to those of haul truck tyres. Loader and dozer tyres cannot cope with high speed operation or long travel distances, even at moderate speeds. Care must be exercised in the selection and operation of loader and dozer tyres.

Table 4 gave the TRA classifications for loader and dozer tyre construction. This information is reproduced in Table 7. It should be noted that the maximum operating speed for these tyres is normally 10 kph and the maximum one way distance is 75 metres.

TRA Code	Tread Type
L-2	Traction
L-3	Rock
L-4	Rock deep tread
L-4S	Smooth deep tread
L-5	Rock extra deep tread
L-5S	Smooth extra deep tread

Table 7 - TRA Classifications for Loader & Dozer Tyres

There are several factors to be taken into account when determining the tyre size and construction type to be utilised. These are:

- Tyre load.
- Machine speed.
- Load and carry distances.
- Tyre ballasting.
- The use of chains on tyres.

Special consideration should be given when re-locating machinery over long distances on highways, along with transport services within an operation, such as from face to face movements, travel to workshops, etc, as these can damage the tyre through excessive speed and heat generation.

Unlike haul truck applications, radial tyres have been slow to be accepted into loader and dozer applications. The choice to move to radials should only be taken based on sound experience of results obtained in the field. Current tyre fitments to loader and dozer fleets would still be predominantly bias-ply tyres.

There are several methods of determining the correct tyre for loader and dozer applications. These methods vary between tyre companies and include calculating the tyre load and then determining the corresponding pressure, determining the static tipping load and vehicle weight and using this figure to determine the tyre load or calculating a work capability factor.

Michelin

Using the example data given, the most severe loading occurs when the loader is at the face, loading the bucket. At this point, the loader may have the entire weight of the vehicle on the front wheels. The load exerted on the tyres is a combination of the machines unladen weight and the static tipping load.

Therefore, using the data the loader, this equates to:

$$\text{Max Load} = 29{,}019 \text{ kg} + 18{,}887 \text{ kg}$$

$$\text{Max Load} = 47{,}906 \text{ kg}$$

The equivalent load per tyre is therefore:

$$\text{Load per Tyre} = \frac{47{,}906 \text{ kg}}{2 \text{ Tyres}}$$

$$\text{Load per Tyre} = 23{,}953 \text{ kg / tyre}$$

Using this load per tyre, Michelin recommends the following tyre inflation pressures for the front tyres:

3.5 Bar (51 psi).

Based on the tyre size used, the available tread patterns are:

XHA H - L3

XLDD2A H - L5

XKA HH - L3

XMINED2 - L5

Michelin recommend tyres based on a function of the surface type and condition combined with the service conditions (distances and speeds) that the tyre will encounter.

Table 9 below lists the values given by Michelin for tyre selection.

Using Michelin's guidelines, the highest average speed equates to 8.4 kilometres per hour. This distance precludes the use of the X Mine D2 tyre.

As both cycle lengths are under the minimums specified by Michelin, there are no restrictions placed on tyre selection by this criteria.

Based on the calculations performed and the data given, the Michelin tyre recommended is the XLD D2A H - L5. This tyre has the advantage of an extra deep tread (D2 / L5), combined with a construction highly resistant to cutting, hacking and abrasion. The theoretical pressures for the front and rear tyres would be:

Front	:	350 kPa	(51 psi)
Rear	:	200 kPa	(29 psi)

Goodyear

Goodyear utilise a Work Capability Function (WCB) to determine tyre selection for loader and dozer applications. The WCF formula is given below:

$$M_{Avg} = \frac{M_{Empty} + M_{Loaded}}{2}$$

$$V_{Max} = \frac{L_{Trip} \times N_{Cycles}}{T_{Cycles}}$$

$$WCF = M_{Avg} \times V_{Max}$$

Where:

M_{Avg} = Average tyre load.

M_{Empty} = Empty tyre load.

M_{Loaded} = Loaded tyre load.

V_{Max} = Maximum average speed per hour.

L_{Trip} = round trip distance.

N_{Cycles} = Number of cycles per period.

T_{Cycles} = Length of period (hours).

Using the data given for the operation of the loader, we can compute the WCF:

Take maximum load to be the combination of the operating weight and the static tipping load (straight) distributed over the front tyres only, with the empty load being the vehicle's operating weight distributed over all four tyres.

Therefore:

$$M_{Avg} = \frac{\frac{47{,}906 \text{ kg}}{2 \text{ tyres}} + \frac{29{,}019 \text{ kg}}{4 \text{ tyres}}}{2}$$

$$M_{Avg} = 15{,}604 \text{ kg / tyre}$$

and

V_{Max} = 8.4 kph

Therefore:

WCF = 15,604 kg/tyre x 8.4 kph

WCF = 131 (metric WCF)

Using the Goodyear tyre information for the 29.5x25 tyre size, the following tyres are available which have a WCF equal to or greater than 131:

Tyre	Type	WCF
GP-2B-4S	Radial	226
GP-2B-6S	Radial	190
RL-2F-4S	Radial	168
RL-2F-6S	Radial	161

Table 10 - Goodyear 29.5R25 WCF

Of the tyres available, the following would be the recommended choice:

GP-2B-6S-L3 Radial.

This choice is made as this tyre can be ordered in a L3 (Rock) construction, with a 6S material specification, ultra abrasion resistant material and the WCF factor is high enough to allow a moderate margin of safety.

The theoretical pressures for the front and rear tyres would be:

Front	:	550 kPa	(80 psi)
Rear	:	400 kPa	(58 psi)

Bridgestone

Bridgestone utilise a TKPH calculation to determine the correct tyre to be utilised.

For the loader, the loaded weight corresponds to a full bucket (assume 75% rock and 25% earth with a density of 2000 kg/m^3). This gives a loaded weight of 39,419 kg.

Using this figure:

$$M_A = \frac{39{,}419 \text{ kg} + 29{,}019 \text{ kg}}{2}$$

$$M_A = 34{,}219 \text{ kg}$$

The average speed of the loader is 8.4 kph. Therefore, assuming that the average load acts over the two front tyres only:

$$TKPH = \frac{34{,}219 \text{ kg}}{2} \times 8.4 \text{ kph}$$

TKPH = 144

Using the Bridgestone product catalogue, there are two tyres that have a TKPH rating over 144, these are:

FG-2A

VALS H

The FG-2A tyre would need to be a 28 ply or higher tyre to cope with the loads placed upon it. Using the 28 ply tyre, the theoretical tyre pressures would be:

Front	:	400 kPa	(58 psi)
Rear	:	225 kPa	(33 psi)

The VALS H tyre would have the following theoretical tyre pressures:

Front	:	500 kPa	(73 psi)
Rear	:	400 kPa	(58 psi)

Type of Tyre	Maximum Length of Cycle Permissible (Round Trip)	Average Number of Kilometres Allowed in One Hour
XHA, XRA, XRDNA	1,800 m	16 km
XR D1A, XLD D1A	1,800 m	14 km
XR D2A, XLD D2A, X Mine D1	1,500 m	10 km
X Mine D2, XSM D2	1,200 m	6 km

Table 9 - Michelin Tyre Selection Guidelines