Economic considerations in the use of rubber tyres in mechanized deep-level mining

by R.H.C. Andrew*

Synopsis

With the advent in recent years of mechanization in deep-level gold and platinum mines, large quantities of rubber tyres are being used on both production and support vehicles. Conditions in these types of mines are extremely harsh and, as a result, tyre performance is significantly lower than in other types of mining such as open-cast base-metal mining, where more favourable conditions prevail. Various options are available to the user to reduce tyre costs, including the use of retreads, the filling of tyres, and the repair of damaged tyres. While these methods may be generally successful in open-cast conditions, their use in deep-level mining needs to be carefully evaluated for each particular set of conditions. A basic requirement for any evaluation of tyre costs is the availability of reliable data on tyre performance and, for this

Introduction

Although pneumatic rubber tyres have been widely used in other types of mining operations such as open-cast base-metal and coal mining, as well as in a variety of earthmoving activities, it is only relatively recently that tyres are finding application in deep-level mining. Unlike conditions in other types of mining, those in deep-level mining are not conducive to good tyre performance, and tyre costs are consequently far more significant in deep-level mining than in other types of mining.

The tyres used in deep-level mining are similar to those used elsewhere, but have important differences to cater for extremely high wear rates, short tramming distances, slow travelling speeds, and heavy loading requirements, all of which are special features of the production vehicles used in mechanized deep-level mines. For maximum traction and to minimize cutting and tearing, no tread pattern is used with this type of tyre, which is commonly referred to as a **slick**.

Tyre costs can be reduced by improved roadway conditions and enhanced driving skills, and by the promotion of good tyre monitoring and management practices, all of which are generally under the control of the user. Other methods, which fall more into the domain of the tyre supplier, are the use of retreads, the filling of tyres, and the repair of damaged tyres. All these options have significant economic implications and should be evaluated constantly. Of particular importance to the user is an ability to evaluate the cost of retreads and filling, and to assess whether the repair of a damaged tyre is more cost-effective than the purchase of a new tyre.

The different conditions encountered in deep-level mining and the different circumstances, e.g. difficult accessibility, must be considered when cost evaluations are undertaken, and comparisons with tyres used in other, more favourable mining conditions should be carried out with due caution.

Design and Construction of Tyres

A section of a typical earthmover tyre commonly used in deep-level mining is given in Figure 1. The smooth or slick tread is used, instead of a block or lugged tread pattern, on tyres fitted to production vehicles such as load–haul–dumpers (LHDs) and front-end loaders, to offer a maximum surface contact area and to minimize cutting and tearing. Many dump trucks also use this type of tyre under harsh roadway conditions. The maximum available depth of tread is used (commonly referred to as the **L5** tread pattern), and rubber compounds with the highest degree of cut and abrasion resistance are employed.

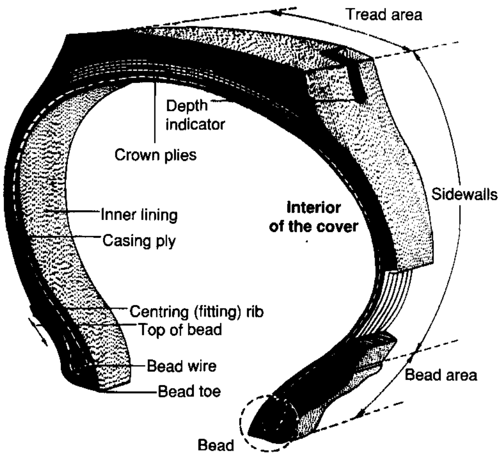

Figure 1—Cross-section through a tyre (slick)

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reason, it is essential that proper tyre records are maintained.

This paper reviews the performance of tyres in deep-level gold and platinum mines in Johannesburg Consolidated Investment Company, Limited (JCI) over a period of about 8 years, and shows how the costs of retreading and tyre filling can be evaluated in practice. It also discusses the cost implications of repairing damaged tyres.

The smooth tyre tread includes a cut-out at equally spaced positions around the circumference of the tyre to provide the user with the means of monitoring tread wear during service. This can also be used to indicate the point at which the tyre should be removed from service for retreading. Since the retreading process requires a certain amount of the original tread to be present, the tyre must be removed before the full depth of tread has been consumed. In deep-level mining this point is normally reached when 80 per cent of the tread has been consumed (or with 20 per cent of the tread depth remaining (TDR)). If the roadway conditions are such that they produce a smooth profile of tread wear, which is normally the case in open-cast mining but not in deep-level mining, retreading a tyre with a 10 per cent TDR is possible. If the tyre is not removed at this critical point, retreading will not be possible and the tyre will have to be scrapped.

Since the side-walls of tyres are particularly vulnerable to damage, many manufacturers now include an extra **buffer** section of rubber for additional protection. The cross-ply type of tyre is most commonly used, although radial tyres are also available. The larger contact surface area (**footprint**) of a radial tyre is an advantage in that it provides better traction, but the susceptibility of the radial side-wall to damage is a disadvantage. With few exceptions, most tyres used in deep-level mining are of the tubeless type.

Performance of Tyres in Deep-level Mining

Since the inception of mechanized mining in its gold and platinum mines, Johannesburg Consolidated Investment Company, Limited (JCI) has adopted a rigorous computerized system to monitor and record tyre performance. In this system, the date on which a tyre is fitted to a particular vehicle is recorded, together with all other relevant data such as project number, tyre position on vehicle, tyre brand and serial number, new or retreaded tyre, and the hour-meter reading of the vehicle. When the tyre has been removed from service, the hour-meter reading is again recorded and the reason for removal is stated. A tyre may be removed because it is to be retreaded, if it has failed prematurely, for later matching purposes on another vehicle if there has been uneven wear on the tyres or because the full tread of the tyre has been consumed. When analysed, these data provide a wide range of information on tyre performance, including the average tyre life for each project, for each different brand and type of tyre used, for different types of vehicles, and for retreads.

From a considerable amount of data collected over a period of 8 years at JCI's gold and platinum mines, the following conclusions on tyre performance can be stated.

- There is a wide variation in tyre life and, for a typical mining project, a distribution histogram similar to that given in Figure 2

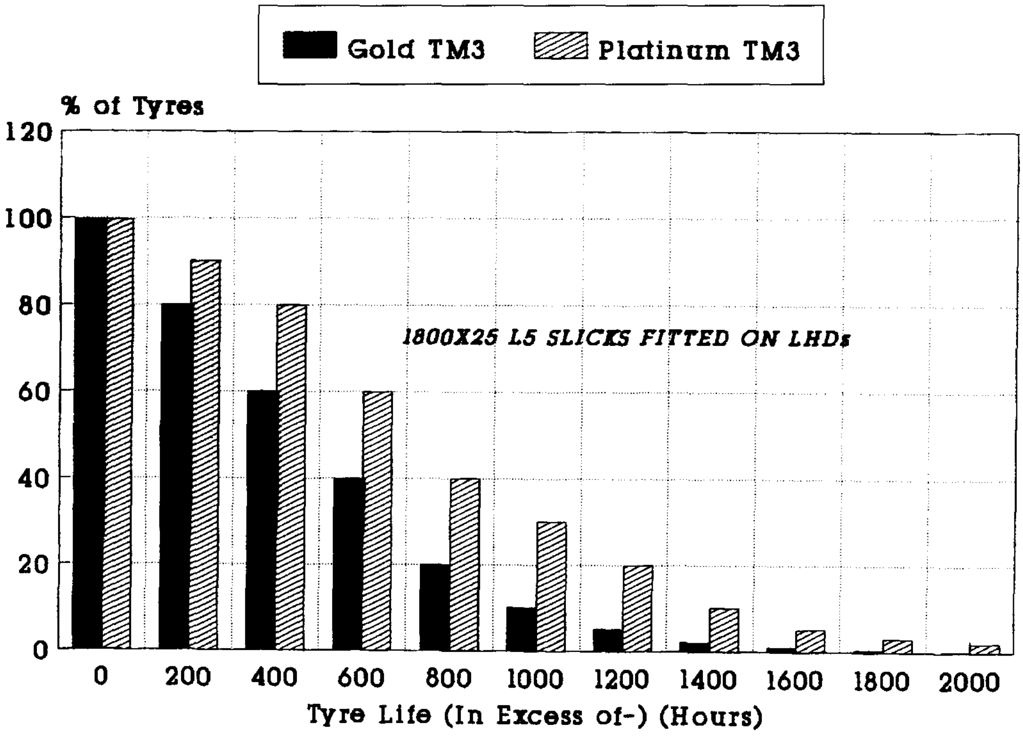

Figure 2—Typical distribution of tyre life

is common.

- The figure shows that a substantial number of tyres in a single project (20 to 30 per cent) fail prematurely. Since these tyres are usually severely damaged, they cannot be retreaded and have no scrap value. Prematurely failed tyres represent a source of high losses, and in February 1994 cost about R100 per hour in the case of the commonly used 1800X25 L5 slick used in gold-mining conditions[1].
- For LHDs, the average tyre life, where the full tread depth has been consumed (run-out), is approximately 800 hours in gold mines and 1000 hours in platinum mines. Dump trucks, which are not normally used in loading operations, showed a 20 to 30 per cent improvement in tyre life[1].
- When a deliberate retreading policy was implemented, it was found that tyres were removed at an average TDR of 22 per cent and, for the LHDs used in gold mining, this corresponded to a new tyre life of approximately 500 hours[2].
- On average, in gold-mining conditions, a retreadability rate of 30 per cent was achieved, although 60 per cent of the tyres had been deliberately removed for retreading. This indicated that half the tyres removed for retreading could not be retreaded on account of excessive damage detected during the retreading process. Since these tyres had sacrificed an average 22 per cent of their first life capability, their failure to return to service as retreads was a source of major losses[2].
- The life achieved with retreaded tyres was equally as variable as that with new tyres but, on average, was between 70 and 90 per cent of the average new tyre life[2].
- Less than 5 per cent of tyres were capable of being retreaded twice, and virtually no tyres were retreaded more than twice. This is a major difference compared with open-cast mining, where multiple retreading is common[3], and is indicative of the harsh conditions in deep-level mining.
- The typical average cost per hour for a new 1800X25 L5 slick on an LHD was R15 to R25 per hour for gold mining and R10 to R15 per hour for platinum mining (February 1994)[4]. This implies that the cost of tyres for an operating LHD was between R40 and R100 per hour, which represents a substantial portion of an LHD's total operating costs.

Table I

Typical modes of tyre failure in deep-level mining

Failure mode	Number of tyres	Percentage
Bead damage	11	2
Casing fatigue	1	0,2
Casing separation/disintegration	5	1
Crown cut failure	56	12
Tread cracking, lifting, disintegrating	23	5
Cut separation	2	0,4
Deflation damage	24	5
Delamination	3	0,6
Inner-liner failure	3	0,6
Injuries over retreading limits	11	2
Crown impact damage	22	4
Loose bead wires	2	0,2
Mechanical damage	2	0,4
Oil saturation	34	7
Crown penetration	5	1
Repair failure	9	2
Sidewall cuts	49	18
Shoulder separation	2	0,4
Sidewall impacts	1	0,2
Sidewall separation	5	1
Tyres used to run-out	114	24
Total tyres damaged	386	82
Tyres suitable for retreading	85	18
Total tyres	471	100

Analysis of Scrap Tyres

Apart from records of tyre life, tyre performance can be gauged from an examination of used tyres to assess their mode of failure. Table I gives a typical analysis of tyre failures. This analysis was carried out for 471 used tyres of different types and sizes collected over a period of 3 months from JCI's gold and platinum mines[5]. This analysis shows that only 85 tyres (18 per cent) were suitable for retreading, while 272 tyres (58 per cent) were damaged and had to be scrapped. Various modes of failure were noted, with cuts, deflation damage (under-inflated tyres), and oil saturation the major areas of concern. Oil saturation is particularly harmful since, not only does it initiate other forms of damage, but it also precludes retreading.

The high losses that can arise from premature failure are shown in Table II, which analyses the losses from 347 prematurely failed tyres based on wasted residual tread[5]. Since these failures occurred over a period of 3 months, the loss of approximately R473 000 represents an annual loss of approximately R2 million, which at the time was equal to about 10 per cent of the total annual tyre account for JCI's mechanized gold and platinum mines[6].

The examination of scrap tyres can also form the basis for possible claims against manufacturers and retreaders, since many of the failures were shown to have been initiated by inherent processing defects. It is of concern that, based on JCI experience, approximately 10 per cent of all new tyres and 5 per cent of retreads are subject to claims[6]. This is believed to be considerably higher than is experienced in other areas, e.g. open-cast mining.

Table II

Estimated losses from premature failure of tyres

Size	Number	TDR[*], %	Loss (Rands)[†]
1400X24 (new)	84	33	116 101
1400X24 (retread)	52	22	26 555
1600X25 (new)	4	43	10 247
17,5X25 (new)	19	31	23 988
17,5X25 (retread)	6	38	5 347
1800X25 (new)	84	21	187 110
1800X25 (retread)	79	16	54 000
20,5X25 (new)	15	43	40 322
20,5X25 (retread)	4	18	3 867
23,5X25 (retread)	2	31	5 454
Total	347		472 911

[*] Tread depth remaining at time of failure

[†] Losses are calculated on proportional costs of TDR using new and retread prices as at February 1994

Retreading

The main reason for the use retreads is to reduce costs. However, retreading can also have important ancillary benefits for conserving tyres and for promoting good tyre-management practices.

The Mechanics of Retreading

Unlike in other areas where retreaded tyres are freely available, e.g. in the passenger-car and heavy-duty vehicle industries, retreads in deep-level mining have to be generated by the user. New tyres must first be used and carefully monitored so that they can be removed at the correct point before the tread has been fully consumed. This sacrifice of first life, as well as the additional cost of retreading, must be shown to be economically justified compared with the alternative of using the tyre to destruction. As mentioned earlier, indicators of tread wear can be used to show the correct time at which the tyre must be removed. In deep-level mining, this is normally at 20 per cent TDR, although the 10 per cent TDR criterion can be used if conditions have produced a uniform pattern of wear.

Figure 3 shows the mechanics of retreading, together with simple mathematical expressions that can be developed for the cost evaluation of retreads in particular situations. The following symbols are used:

m = the cost of a new tyre, in Rands
n = the cost of retreading, in Rands
Lro = the average life of a new tyre if used to destruction (**run-out life**), in hours
Lrt = the average life of the new tyre to the point at which it is removed for retreading, in hours
Y = the average life of the first retread, in hours
Y' = the average life of the second retread, in hours.

Then, from Figure 3,

Cost per hour of the new tyre to run-out = m/Lro

Cost per hour of the new tyre plus retread = $m + n/Lrt + Y$

Cost per hour of the new tyre plus two retreads = $m + 2n/Lrt + Y + Y'$.

If it can be assumed that the retread price is equal to half the price of a new tyre, which is often the case, and if the first retread life is equal to 80 per cent of the run-out life and the second retread life is equal to 80 per cent of the first retread life, which are often used as the criteria for the acceptability of retreads, then

where Lrt = 80 per cent of Lro (20 per cent TDR):

Cost per hour for one retread = 0,93 m/Lro
Cost per hour for two retreads = 0,88 m/Lro;

where Lrt = 90 per cent of Lro (10 per cent TDR):

Cost per hour for one retread = 0,80 m/Lro
Cost per hour for two retreads = 0,76 m/Lro.

Since the cost of using a new tyre to destruction is given by m/Lro, the analysis shows that, in the idealized case where *all* tyres are removed and retreaded, retreading once can produce savings of 7 to 20 per cent, depending on the point at which the tyre is removed, and retreading twice can produce savings of 12 to 24 per cent.

Figure 3 also shows the conservation aspect of retreading in that a new tyre that has been retreaded once is equivalent to 1,5 new tyres and, if retreaded twice, to 2,1 new tyres.

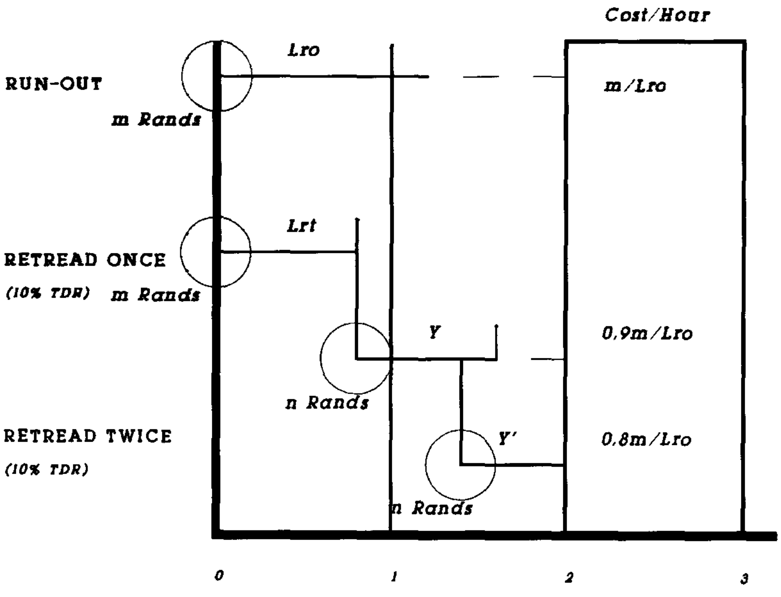

Figure 3—The mechanics and cost structure of retreads

Practical Constraints in Retreading

The previous section considered an idealized situation in which *all* tyres were assumed to be retreaded. In the more realistic situation, mainly on account of the severity of deep-level mining conditions, the number of retreads that can actually be used is restricted by the following.

- Some tyres are used to destruction (run-out) because they were not removed timeously or because they were judged to be unsuitable for retreading.
- Others, which were removed at the correct point for retreading, are subsequently found to be unsuitable for retreading during the retreading process and are scrapped.
- Still others fail prematurely and are scrapped.

In the practical situation, these various categories of tyres will co-exist with retreaded tyres, and the overall cost per hour will depend on the number of tyres in each category and on the average tyre life achieved by each category.

In the analysis of actual tyre costs in the practical situation,

a = the proportion of tyres that are used to destruction and achieve their run-out life value (Lro)
b = the proportion of tyres that are removed at the correct point for retreading (Lrt) and that return to service as retreads
c = the proportion of tyres that are removed at the correct point for retreading (Lrt) but that *do not* return to service
d = the proportion of tyres that fail prematurely at an average life of p hours and are scrapped.

Then, using the same symbols as before, noting that by definition $a + b + c + d = 1$, and assuming only first retreads, one obtains the following:

$$\text{Overall cost per hour} = \frac{am + b(m + n) + cm + dm}{aLro + (b + c)Lrt + bY + dp},$$

which simplifies to

$$\text{Overall cost per hour} = \frac{m + bn}{aLro + (b + c)Lrt + bY + dp}. \quad [1]$$

Expression [1] can be used for the calculation of the overall tyre costs in any practical situation. This is shown here for the data given in Table III.

New tyre price = R10 500 (1800X25 L5 slick)
Retread price = R5000 (February 1994)
Retread life = 640 h.
Then from [1],
Cost per hour using retreads = R15,86
Cost per hour with no retreads = R14,19.

Table III

Data used in the calculation of costs

Category	Proportion, %	Average life, h
Run-out *(a)*	10	800
Retreaded *(b)*	40	640
Not retreaded *(c)*	40	640
Premature failure *(d)*	10	200

In this case, the use of retreads has no cost benefits even though a retread rate of 40 per cent was used.

It should be noted that premature failures occur^5 both when retreads are used and when no retreads are used and, for practical purposes, premature failure can be ignored in comparisons of retreading versus run-out costs. However, the cost of premature failure in a particular situation can be calculated from expression [1].

Sensitivity Analysis

The effects of different factors when retreads are used, e.g. the proportions of various categories of tyres, the life of new tyres to the point for retreading, the run-out life of new tyres, and the life of retreads can be estimated from expression [2] by way of a sensitivity analysis. In the following example, the effect of the retread rate is studied.

From [1], and assuming there is no premature failure (i.e. $d = 0$),

$$\text{Cost per hour} = \frac{m + bn}{aLro + (b + c)Lrt + bY}.$$

If it can be assumed that the retread price is equal to half the new tyre price (i.e. $n = 0{,}5\,m$), the life of the new tyre to the retreading point is equal to 80 per cent of the run-out life (i.e. $Lrt = 0{,}8\,Lro$), and the life of the retread is equal to 80 per cent of the run-out life (i.e. $Y = 0{,}8\,Lro$). When only first retreads are considered, then from [1],

Cost per hour = $X \cdot m/Lro$,

$$\text{where } X = \frac{1 + 0{,}5b}{a + 1{,}6b + 0{,}8c}. \quad [2]$$

Since the cost per hour of the run-out condition (no retreads) is given by m/Lro, the value of X, for a given set of values for a, b, and c, will indicate whether or not retreading is cost-effective. If X is greater than 1, the use of retreads will not be cost-effective, while a value of X less than 1 will show that retreads are cost-effective.

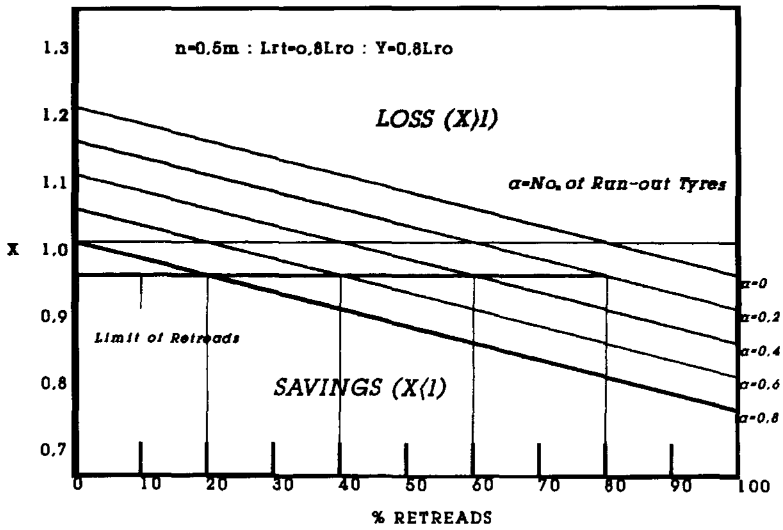

Figure 4—Sensitivity analysis : retread rate

Figure 4 shows expression [2] plotted for various values of *a*, *b*, and *c*. It can be seen that, in this case, the potential for producing a loss by the use of retreads is greater than the potential for savings, since the maximum possible saving is only 7 per cent while the maximum loss with retreads is about 20 per cent. Figure 4 also indicates practical limits if retreads are used, e.g. if 40 per cent of the tyres are used to their run-out value, a *minimum* retread rate of 40 per cent is required and, since there is a fixed number of tyres being used, a *maximum* of 20 per cent of the tyres can be scrapped.

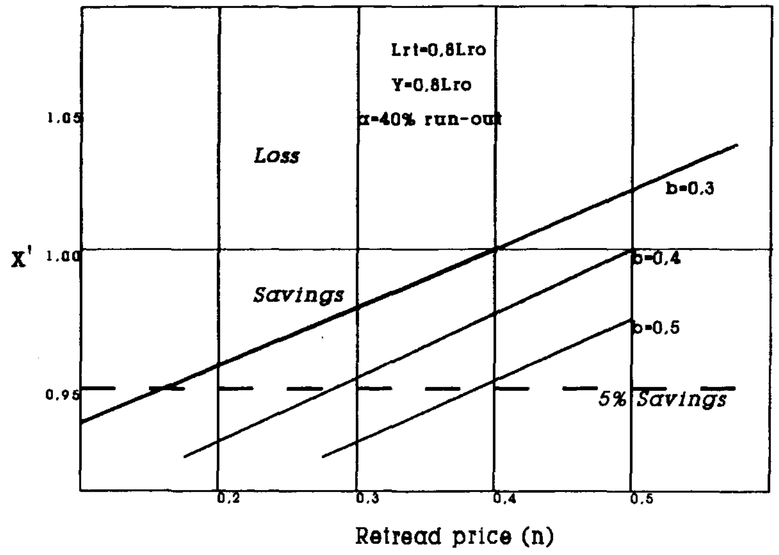

Figure 5—Sensitivity analysis : retread price

Expression [1] can also be used to determine the way in which the retread price (n) influences tyre costs at different retread rates (b). If the life of a new tyre to the retreading point is again assumed to be equal to 80 per cent of the run-out life (i.e. $Lrt = 0{,}8\,Lro$), and if 40 per cent of the tyres attain their run-out life (i.e. $a = 0{,}4$), then from [1]

Cost per hour = $X' \cdot m/Lro$,

$$\text{where } X' = \frac{1 + bn}{a + 1{,}6b + 0{,}8c}. \qquad [3]$$

Expression [3] is plotted in Figure 5 for various values of the retread rate (b) and for different values of the retreading price (n), where the retreading price is expressed as a fraction of the new tyre price (m). In this case, to achieve a 5 per cent saving by the use of retreads, the retread price must be 35 to 43 per cent of the new tyre price. If the retread price is close to half the new tyre price (as is often the case), there are no cost benefits with a retread rate of 40 per cent, and only marginal savings (about 2 per cent) with a retread rate of 50 per cent.

Summary

A retreading policy that deliberately removes tyres from service before the full tread has been consumed is at best only marginally cost-effective in practice and has to be implemented within very strict limits:

- 30 to 40 per cent of the tyres must be used to destruction.
- 20 to 30 per cent of the tyres must be retreaded.
- The life of a new tyre to the point at which it is removed for retreading must be 90 per cent of the life of a new tyre.
- The life of a retread must be at least 80 per cent of the run-out life of a new tyre.
- The price of the retread must not be greater than 46 per cent of the price of a new tyre.

In practical deep-level mining situations, many of the limits given here are difficult to satisfy on account of the harsh mining conditions, which promote severe tyre damage and premature failure. It is also important to note that retreading has other *hidden* costs, such as the need for a vehicle to be taken out of service more frequently.

When tyres are removed for reasons other than for deliberate retreading, e.g. if removed for *matching* purposes on other vehicles, the cost implications of retreading are considerably less onerous on the user, since there is no sacrifice of tyre life. The use of retreading in this type of situation will result in the conversion of good used tyres (which must satisfy retreading requirements for minimum residual tread depth) to tyres that should be able to achieve at least 80 per cent of the life of an equivalent new tyre at a substantially lower cost. In deep-level mining, this strategy, i.e. the use of new tyres and retreading only when good used tyres are available, will produce the most favourable results.

Tyre Filling

Filling can be used to eliminate or reduce the premature failure of tyres and thereby increase the overall average life, as well as avoiding production losses. Filling can also increase the run-out life of a tyre since a filled tyre can often be used past the normal point at which a pneumatic tyre is considered to be unsafe.

Tyre-filling material is normally a two-component iso-cyanate polyurethane, which is pumped into a tyre and which, after curing, achieves a resilience approaching that of a conventional pneumatic tyre. The substitution of air by elastomeric polyurethane implies that the tyre cannot deflate when the casing or tread is damaged.

For the purpose of the following cost analysis, it was assumed that filling eliminates premature failure and serves to increase the run-out life by 10 per cent. With the same symbols as used previously and if

k = the percentage decrease in the average overall run-out life (Lro) as a consequence of premature failure, and

x = the cost of filling expressed as a fraction of the new tyre price,

Cost per hour with no filling = $m/kLro$ [4]

Cost per hour with filling = $m(1 + x)/1{,}1\ Lro$. [5]

For filling to be cost-effective, the cost per hour with filling must be less than the cost per hour without filling, or

$m(1 + x)/1{,}1\ Lro$ must be less than $m/kLro$,

or $1 + x/1{,}1$ must be less than $1/k$. [6]

Figure 6 shows the inequality in [6] plotted for different values of x and k, and from this the data of Table IV can be deduced.

Table IV

Data from Figure 6

Cost of filling (vs new tyre) %	Minimum decrease in average run-out life to justify filling, %
50	26, point (a) in Figure 6
40	20, (b)
30	15, (c)
20	9, (d)

In February 1994, the price of filling ranged from 40 to 50 per cent of the new tyre price. At these prices, it is cost-effective to fill tyres only if it can be shown that any premature failure serves to lower the average run-out life by no less than 20 to 26 per cent.

The example of Table V shows how this analysis can be used in practice to determine whether the filling of 1800X25 L5 slick tyres is justified in a given set of conditions. In this case, the cost of filling tyres is not justified since it would *increase* the tyre cost by 10 per cent.

Table V

Costs of filling tyres

New tyre price	R10 500
Filling price	R4 635 (45% vs new tyre)
From tyre monitoring records:	
Average run-out life (excluding premature failed tyres)	800h
Average run-out life (including premature failure	660h
Decrease in run-out life caused by premature failure	17,5%
From Figure 6:	
Cost of decrease in run-out life	23%
Cost of filling	33%

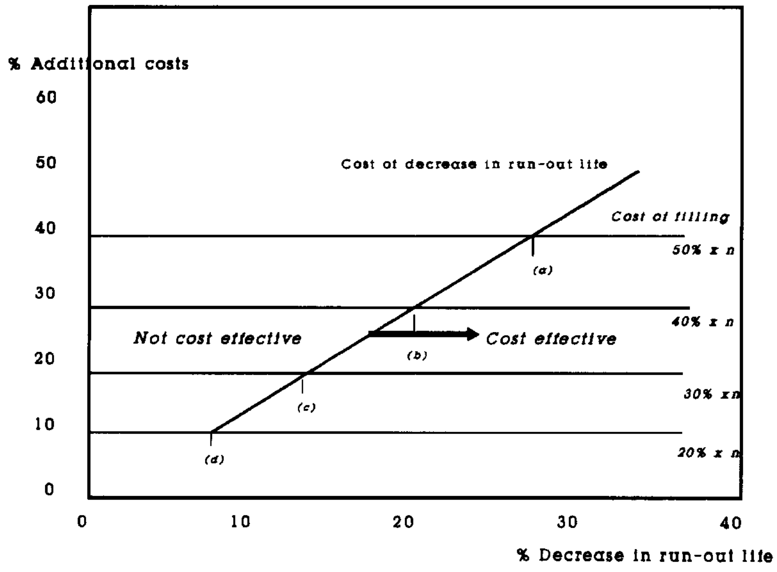

Figure 6—Cost evaluation of tyre filling

Cave mining—the state of the art

by D.H. Laubscher*

Synopsis

Caving is the lowest-cost underground mining method provided that the drawpoint spacing, drawpoint size, and ore-handling facilities are designed to suit the caved material, and that the drawpoint horizon can be maintained for the life of the draw. In the near future, several open-pit mines that produce more than 50 kt per day will have to examine the feasibility of converting to low-cost, large-scale underground operations. Several other large-scale, low-grade underground operations will experience major changes in their mining environments as large dropdowns are implemented.

These changes demand a more realistic approach to mine planning than in the past, where existing operations have been projected to increased depths with little consideration of the change in mining environment that will occur. As economics force the consideration of underground mining of large, competent

Introduction

Cave mining refers to all mining operations in which the orebody caves naturally after undercutting and the caved material is recovered through drawpoints. This includes block caving, panel caving, inclined-drawpoint caving, and front caving. Caving is the lowest-cost underground mining method provided that the drawpoint size and handling facilities are tailored to suit the caved material and that the extraction horizon can be maintained for the life of the draw.

The daily production from cave-mining operations throughout the world is approximately 370 kt per day, with the following breakdown from different layouts:

	kt
Grizzly	90
Slusher	35
LHD*	245
Total	370

* Load–haul–dump units

By comparison, South African gold mines produce 350 kt per day.

In the near future, several mines that currently produce in excess of 50 kt per day from open-pit mines will have to examine the feasibility of implementing low-cost, large-scale underground mining methods. Several cave mines that produce high tonnages from underground are planning to implement dropdowns of 200 m or more. This will result in a considerable change in their mining environments. These changes will necessitate detailed mine planning, rather than the simple projection of current mining methods to greater depths.

As more attention is directed to the mining of large, competent orebodies by low-cost underground methods, it is necessary to define the role of cave mining. In the past, caving has been considered for rockmasses that cave and fragment readily. The ability to better assess the cavability and fragmentation of orebodies, and the availability of robust LHDs, an understanding of the draw-control process, suitable equipment for secondary drilling and blasting, and reliable cost data have shown that competent orebodies with coarse fragmentation can be cave-mined at a much lower cost than with drill-and-blast methods. However, once a cave layout has been developed, there is little scope for change.

Aspects that have to be addressed are cavability, fragmentation, draw patterns for different types of ore, drawpoint or drawzone spacing, layout design, undercutting sequence, and support design.

Table I shows that there are significant anomalies in the quoted performance of different cave operations.

Table I

Quote	Explanation
96% of ore recovered for 100% mineral extraction	Under-evaluation of the orebody and dilution zone
The correct drawpoint spacing, but there has been 200% overdraw with 30% waste dilution entry	A case of highly irregular draw and under-evaluation of the dilution
15% dilution entry in spite of correct drawpoint spacing and uniform fragmentation	Drawpoints being drawn in isolation
Ore from the lower 100 m of the draw column still reporting in the drawpoint, even though 260 m of ore has been drawn	A large range in fragmentation, and irregular, high values in the dilution zone

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