# Maintenance Cost Optimization on Heavy Equipment Tires by Goal Programming Method at Nickel Mine Operation

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## Abstract
Tires are one of the grounds engaging tools that have a large portion of the costs in maintenance mining heavy equipment at nickel mine operations. In line with competition in the mining business, companies are required to spend optimum cost. The study was carried out to research the tire life and its relation to achieve the operating hours target on a mine haul truck, optimizing tire maintenance costs, and minimize the truck downtime. The objectives to be achieved in the study conducted are minimize tire maintenance costs by optimizing tire life and increase physical availability. The goal targets that must be achieved are consist of the maximum limit of downtime due to tire damage, cost reduction target for tire maintenance costs, as well as the total running hours that must be met by the tire, make goal programming modelling is an appropriate method in solving this problem. The results of the optimization research found that by setting the composition of the use of three types of tires, namely new tires, re-tread tires and rental tires, with a lifetime target according to the results of the mathematical model calculated, then the three objectives set can be achieved.

## Keywords
Goal Programming, Preemtive GP, OHT Tires Life and OHT Tires Cost.

## 1. Introduction
Optimizing the reliability of mining equipment in mine production is the most important factor considering the costs incurred in mining operations. These costs are mostly generated by operational activities and maintenance of heavy equipment. As a supporting facility to meet production needs, this nickel mine company uses both heavy equipment with track type and tire wheel drive type. Comparison of the population of track type and tire wheel drive operating in this nickel mine company is 45% of heavy equipment with track type and 55% of heavy equipment with tire wheel drive, and 40% instead of tire wheel drive type is OHT hauling truck. Tire costs in mining operations are a ground engaging tool that takes a significant portion of maintenance costs. At the mine site, with a limited number of trucks, the loss of working hours for one tire can result in the loss of hundreds of thousands of dollars.

Previous studies largely discussed how the technical characteristics of tire reliability and tire failure analysis (Vaghar 2015), methods of how to manage haul truck tires in their effects on tire life (Lindeque, 2016), and the effect of tire pressure on braking and suspension conditions (Toma et al. 2018). Studies on optimizing the cost of heavy equipment tires maintenance with a lifetime approach to tires are still rare. The study in this paper focuses on modeling the optimization of maintenance costs for 100 Ton OHT hauling truck tires size 27.00 R49 with a tire life approach. The optimum tire life calculation is needed in achieving the minimization of tire maintenance costs within the limits of various targets that must be achieved.

### 1.1. Background
From the various tires size used by heavy equipment in mining operations, tires for 100 Ton Off Highway Truck (OHT) are tires with a high maintenance cost, because 70% of the costs are allocated for maintenance of 100 Ton OHT tires. The other 30% of the cost is allocated for various tires size.

The other strategy to reduce the cost of tire maintenance activities is to use three types of tires. There are new tires, retread tires and rental tires with different service tire life. Tire life fluctuation is one of the contributing factors that can affect tire maintenance costs in mining company operations. Data recorded starting from the year

2017 into 2019 shown that the tire life hours of new tire are 50% higher than retread tire life hours. On the other side, the price of retread tire is 60% cheaper than a new tire but, considering the retread rubber material availability in the market becomes another constrain to use retread tire for tire replacement. Another alternatives tire that can be use is rent tire, this type of tire only uses in the year 2018 with life hours the same with retread tire, the problems by using this type of tire is availability of rent tire in the market that predicted cannot fulfill the required maintenance operation.

Operating hours of mining trucks carrying materials are factors of the Physical Availability (PA) and Utilization of Availability (UoA) from each truck. Another thing that becomes a concern in tire maintenance operations and needs to be aligned with mining operational needs is reliability. The strategy adopted by the company for downtime targets allowed due to tire maintenance activities is below 2% of the total annual operating hours. If the contribution of downtime due to tire damage to the truck is more than 2%, it can disrupt the productivity of mining heavy equipment.

### 1.2. Problem Identification

Fluctuations in tire maintenance costs on 100 Ton OHT trucks with a size of 27.00 R49 tend to decrease started from the year 2017 until 2019.The actual tire maintenance cost in the year 2017 was $6.67 million, this value is $570,000 below budget, where the budget is around $7.24 million. Actual tire maintenance cost profile in the year 2018 was $6.69 million and also has an under-spending budget of $540,000, where the budget for the year 2018 is $7.23 million. While the cost budget surplus in the year 2019 is only $100,000, with the budget figure $6.02 million and actual cost spending for tire maintenance was $5.9 million. The optimization target set in the year 2020 for tire maintenance cost is $5.4 million, which is $500,000 below actual tire maintenance cost in the year 2019. This paper will be modelling the target of this tire maintenance cost target and integrated with other parameters that should be achieved.

This research also put annual running hours to become a goal constrain in the optimization model. The running hour history profile of the haul trucks to be achieved tend to increase 2%, with cost per hour target decrease 10% every year from the year 2017 until 2019. Annual running hours target in the year 2020 for haul trucks is 569,813 hours with cost per hour target $1.58 per hour.

There are three objectives to be achieved in this optimization study, that consist of minimizing cost, maximize operating hour, and minimize downtime. An approach through goal programming is carried out to produce minimum tire maintenance costs by considering the target operating hours of the equipment to be achieved, as well as minimizing the downtime hours that occur on 100 Ton haul trucks that using 27.00 R49 tires. Goal programming is an approach that is capable to handle the decision-making problems having multiple conflicting goals and the objective function of a goal programming model composed by non-homogeneous units of measurement and includes only the deviational variables that are complementary to each other (Kumar 2019). Another important thing from Goal Programming are where the objectives are assigned a specific value and a solution is found that minimizes the weighted sum of deviations of these objective functions from their respective goals (Kaur and Tomar 2015).

## 2. Goal Programming

The optimal solution is obtained by building a model. There are two categories: quantitative model and qualitative model, and multi-objective programming categorized as a quantitative model (Wicaksono et al. 2019). The concept of the model is built in getting optimal solutions through three stages, namely the structure of the model, the impact on the model and evaluation of the model (Sawaragai et al. 1985). The first step is to formulate an optimization problem so that the model developed approaches the real situation. The second stage is carried out by identifying the impact on the model. The final stage is to study the results of the model. The expected output is the optimal solution of existing operating problems.

Goal programming aims to minimize the deviation between the goals set and what can be achieved with certain constraints. Goal Programming is one of the mathematical models deemed suitable for multi-purpose problem solving because through its deviation variable, goal programming automatically captures information about the relative achievement of existing goals. The mathematical model of goal programming is illustrated in Table 1.

Table 1. Goal programming mathematic model.

| Type of Constraint | Mathematic Model of Goal Programming | Minimize Deviational Variable |
|---|---|---|
| $F_1(x) \geq b_1$ | $F_1(x) + d_1^- - d_1^+ = b_1$ | $d_1^-$ |
| $F_1(x) \leq b_1$ | $F_1(x) + d_1^- - d_1^+ = b_1$ | $d_1^+$ |
| $F_1(x) = b_1$ | $F_1(x) + d_1^- - d_1^+ = b_1$ | $d_1^+, d_1^-$ |

Where;
$F_1$ = Constraint
$b_i$ = Right Hand Side
$d_1^+$ = Positive Deviational (*overachieved)*
$d_i^-$ = Negative Deviational *(underachieved)*

In the Goal Programming method, weighting is used by management in an organization to determine a goal to get priority to determine goals with a priority level starting from the target level that has a higher importance to a lower target level (Render et al. 2015). The approach through goal programming is the most popular method of solving multi-objective problems with more than one goal or with conflicting goals. Therefore, based on the hierarchy of priority levels in goal programming there are two considerations in solving problems, namely:

- Non-preemptive goal programming

In consideration of this first category, all objectives have the same priority, so that in the process of calculation and problem solving without being limited by the priority of the objectives to be achieved.

- Preemptive goal programming

The second consideration is where the goals of primary interest receive priority, whereas goals with secondary interest are in the second priority and so on, until the goal with the lowest importance level. Preemptive goal programming used when there are differences in the importance level in the objectives to be achieved.

The priority level of the objective function is called preemptive priority factors, where this priority factor has a relationship $P_1 >>> P_2 >>> P_3 >>> ... >>> P_n$. This illustrates that the purpose of $P_1$ is far more important than the objective of $P_2$ (Endurance Ajayi-Daniels 2019). Priority relationships show that multiplication with any number cannot change the priority level below it to a higher priority level ($P_i > P_i + 1$). Problem solving using the preemptive goal programming method through several stages in accordance with how the priority level of the goals to be targeted to be resolved (Kongar and Sobh 2008). The preemptive goal programming is stated in the form of:

$$Minimize\ Z = \sum_{i=1}^{m} \quad P_i d_i^+ + d_i^- \qquad (1)$$

Where;
$P_i$ = *Pre-emptive priority factors* from goal – *i*

## 3. Model Development

The study carried out is to develop mathematical modelling for the operating conditions of tire maintenance activities. The mathematical model that built aims to analyse the cost of heavy equipment tires maintenance, especially the type of 100 Ton OHT haul truck to obtain optimal tire replacement costs. To achieve the optimization of tire maintenance costs, it is necessary to evaluate the strategy of truck tire maintenance activities, especially in terms of tire use and its impact on the cost of replacing tires. Terminology of maintenance defined in this paper covers of tire replacement and accessories. Physical condition of tires has not become a thing that considers on a model in this paper. Decision variables to be defined on this model in this paper are as below:

- $X_i$ = Life hour of tire type *i*
- *i* = Type of tire used. i = 1,2,3.

$X_1$ describe the life hours of new tire, $X_2$ describe the life hours of re-tread tire, and $X_3$ describes the life hours of rent tire. The goal constraint in establishing the goal programming model is set with concerning achieving the target. The goal constraints set in this study are consists of:

- Goal constraint for maximizing annual operating hours

The function of this constraint is to make the decision variable for the tire life produced to meet the target operating hours required in operation, the formulation used is as below:

$$522\, X_1 + 102 X_2 + 36 X_3 + d_{a1}^- \geq 3{,}418{,}878.87 \qquad (2)$$

The coefficient on the equation above defined by multiply the percentage composition of tires type *i* used with the total population of haul trucks and also by the number of tires in one unit haul trucks (6 pcs per unit haul truck). Total population of haul trucks in this model is 108 units, with the percentage composition for new tire

80%, re-tread tire 15%, and rent tire 5% allocated to those fleet. Each decision variable coefficient on equation number (2) describe the quantity of tire annual usage used by fleet for tire replacement activity.

● Goal constraints for minimizing tire maintenance costs

These constraints indicate the availability of budget constraints that can be used to carry out heavy equipment tire replacement and maintenance activities. Within the budgetary constraints, the formulation used is:

$$824\,X_1 + 161X_2 + 57X_3 - d_{b2}^{+} \leq \$\,5{,}400{,}000 \quad (3)$$

The coefficient on the equation above defined by multiply each coefficient in equation number (2) with the cost per hour target that will be achieved in this model, which is \$1.58 per hour. This decision variable coefficient describes total cost per hour of tire in annual usage by fleet.

● Goal constraints for minimizing downtime

This constraint is a function of constraints which shows that the downtime allowed to make repairs and replacements related to tire damage is limited. This is limited so that the performance and productivity of heavy equipment transporting mining materials can be maintained. The limit of downtime to be achieved is below the value of the right-hand side. Mathematical formula will be:

$$2{,}4\,X_1 + 15X_2 + 5{,}4X_3 - d_{b3}^{+} \leq 68{,}377 \quad (4)$$

Downtime occur for tire replacement per stoppage is 6 hours for all types of tire, and the quantity of tire replaces per unit stoppage are two for new tires, five for re-tread tires, and three for rent tire. Each type of tires has various percentage contributes to downtime hours, that is 20% for new tire, 50% for re-tread tire, and 30% for rent tire. The coefficient of equation number (4) define by multiply all factors that consist of the hours downtime occur, the quantity of tire replaces, and percentage the type of tires to downtime. Each decision variable coefficient describes total annual downtime taken by fleet to stopped for tire replacement activity. Result of optimal solution decision variables will describe the interval stoppage of unit that should be achieved to minimize the deviational value from target.

Limiting formulation in the modelling created has economic constraints (hard constraints) and goal constraints (soft constraints). Economic constraints in the compiled modelling are constraints that must be met and must not be violated because they relate to the fulfilment of resources. In the constraint function of writing this study, those included in the category of economic constraints are as follows:

● New tire life hours; $X_1 \geq 5{,}500$
● Re-tread tire life hours; $X_2 \geq 2{,}500$
● Rent tire life hours; $X_3 \geq 2{,}200$

# 4. Result

## 4.1. Model Calculation Result

The mathematical model that was formed then solved using the LINDO software application. The results of calculations using the LINDO program are the values of the decision variables to achieve the goals of the optimization objectives. Refer to the results of mathematical model calculations using the LINDO application, the optimum tire life span of new tires 5,909.15 hours, the optimum service life of re-treaded tires is 2,501.00 hours and the rental tires is 2,200.00 hours as shown in Table 2.

Table 2. Decision variables result.

| No. | Decision Variable | Description | Hours |
|---|---|---|---|
| 1. | $X_1$ | New tire life time | 5,909.15 |
| 2. | $X_2$ | Re-tread tire life time | 2,501.00 |
| 3. | $X_3$ | Rent tire life time | 2,200.00 |

The results have shown that all targets can be achieved, after the value of the decision variable put into the equation of the objective function to be achieved, following the specific target. The results of calculating the value of the right-hand side of the decision variables model are described in Table 3.

Table 3. Goal achievement optimization result.

| Priority Level | Description | Target | Optimization Result | Deviational from Target |
|---|---|---|---|---|
| I | Goal 1: **Achieved** Annual operating running hours target | 3,418,878.87 hours | 3,418,878.30 hours | 0.57 hours |
| II | Goal 2: **Achieved** Minimize budget target | $ 5,400,000 | $ 5,399,999.09 | $ 0.91 |
| III | Goal 3: **Achieved** Minimize down time due to tire failure | 68,377.57 hours | 63,576.96 hours | 4,800.61 hours |

- Priority I

In the first goal priority, target to meet the operational running hours can be achieved. The amount of negative deviation is 0.57 hours or 0.0000168% in percentage, that still can be acceptable operationally.

- Priority II

In the second goal priority, target to minimize tire maintenance cost can be achieved. It's mean that there is a positive variance between the budget target and the calculation results of the optimization model. When compared with the actual cost budget in 2019, it can be illustrated in Figure 1. The waterfall graph in Figure 1 are shown the potential savings in tire maintenance for the size of 27.00 R49 used in mining trucks. The amount of potential saving is $499,907.91 compared to the actual tire maintenance cost in 2019. With a target tire life for new tires, re-tread tires and rent tires according to the model the results of optimization with the method of pre-emptive goal programming, there is a potential savings in the maintenance budget of 27,00 R49 tires used on 100 Ton OHT trucks. This can be solved with the support of technical operations and the operating situation of the tires used according to the service life of each type of tire can be obtained according to the results of optimization in the destination programming model.

- Priority III

The third goal priority target to minimize the downtime can be achieved, where a negative deviation value of the result is 4,800.62 hours or 7% below the allowable downtime hours. The decrease in downtime by optimizing tire life also increasing the value of tire physical availability from 98% to 98.14%. Figure 2 shown graphically an increase in Physical Availability (PA) and a decrease in downtime. If the deviation value converts into trucks running hours by dividing by 6, the downtime hours per unit trucks will be 800.10 hours. Those numbers are described how long the trucks will stop can be eliminated for tire maintenance activities. The loss value is a factor of lost truck productivity because it has to stop operating for tire maintenance. The value of the potential savings obtained by the company from reducing downtime due to tire damage is $760,403 per month as per shown in Table 4.

Table 4. Potential saving by reduce down time hours.

| Description | Value | UoM |
|---|---|---|
| Down time variance (for 6 tires) | 4800.62 | Hours |
| Monthly hours operate per month/ unit truck | 520.2 | Hours |
| Down time hours convert to month period | 1.54 | month |
| Value per ton nickel produce monthly/ unit truck | $ 494,388.33 | |
| Potential saving by reducing down time monthly | $ 760,403.21 | |

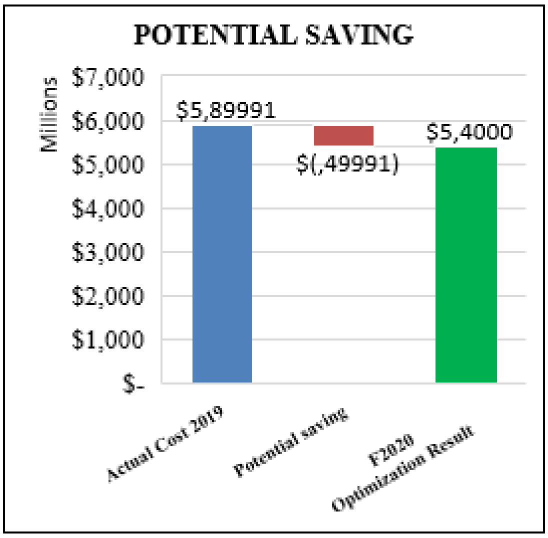


Figure 1. Potential saving result.

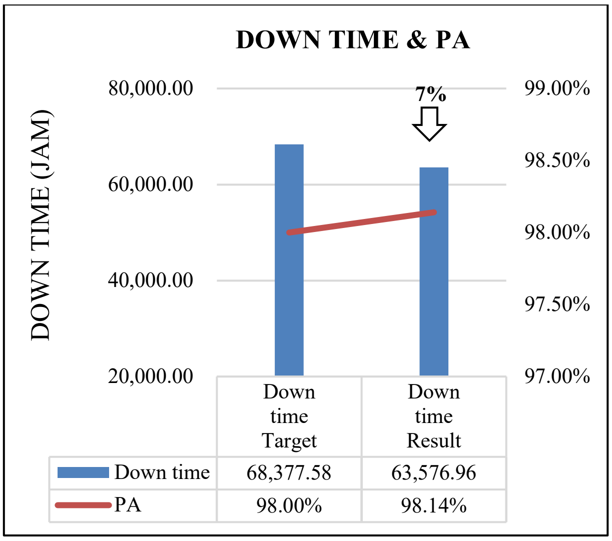


Figure 2. Potential saving by reduce downtime.

## 4.2. Sensitivity Analysis

Sensitivity analysis is carried out on optimizing the goal programming results to find out the permitted changes in the optimization results that have been obtained. Another goal of sensitivity analysis is to learn about changing the parameter values of the model within certain limits without changing the optimal solution (Dhoruri 2017). As of this writing, the discussion of sensitivity analysis carried out only includes consideration of the sensitivity of the optimal solution to the coefficient of the objective function and the sensitivity of the optimal solution to the value constraints of the right-hand side.

The results of the sensitivity analysis performed on the optimal solution to the objective function coefficient are shown in Table 5 and the sensitivity analysis of the optimal solution to the right-hand side value is shown in Table 6. From this table we can find out the limit changes in parameter values that are allowed to continue to get the optimum value. The sensitivity analysis table with the "infinity" increase or decrease limitation can be interpreted that, if the value of the right-hand side or the coefficient is increased or decreased in any way, it will not change the outcome of the objective function so that the optimal solution does not change.

Table 5. Sensitivity analysis for coefficient.

| Description | Coefficient Value | Upper Limit | Lower Limit |
|---|---|---|---|
| New Tire – $X_1$ | 2.4 | 74, 36 | Infinity |
| Re-tread Tire – $X_2$ | 15 | Infinity | 14,53 |
| Rent Tire – $X_3$ | 5.4 | Infinity | 5,23 |

Table 6. Sensitivity analysis for RHS.

| Description | RHS | Upper Limit | Lower Limit |
|---|---|---|---|
| Budget | $5,400,000 | Infinity | 2,798.68 |
| Total annual running hours | 3,418,878.78 | 1,772.95 | 78,75 |
| Total down time hours | 68,377 | Infinity | 4,800.03 |
| New tire life time | 5,909 | 0,15 | Infinity |
| Re-tread tire life time | 2,501 | 0,77 | 2,501 |
| Rent tire life time | 2,200 | 2,18 | 2,200 |

## 4.3. Recommendations for Corrective Action

Based on the optimization results, to get the optimum cost, then with the composition in the use of new tires 80% of the total population of the unit, then the life of a new tire is required to reach a minimum of 5.909 hours or an increase of 6.9% from the target lifetime that has been previously determined by the company. As for the life of re-tread tires, with a composition of 15% of the total population use of the unit, the age of re-tread tires must be achieved a minimum of 2,501 hours. This is 3.8% below the target set by the company beforehand. For the life of the rental tire, with the composition of the use of 5% of the total population of the life unit that must be achieved by the rental tire is a minimum of 2,200 hours.

Table 7. Tire life time comparison.

| No. | Description | Actual Life Hours | Company Target | Optimization Result |
|---|---|---|---|---|
| 1. | New Tire | 5,293 Hours | 5,500 Hours | 5,909.15 Hours |
| 2. | Re-tread Tire | 2,272 Hours | 2,600 Hours | 2,501.00 Hours |
| 3. | Rent Tire | 2,266 Hours | 2,200 Hours | 2,200.00 Hours |

Table 7 also shows that there is still a deviation between the tire service life target set by the company and the results of optimization calculations, especially for the service life of new tire types. Three main factors that are significant in influencing tire life are tire pressure, load and speed of mining material trucking units. Corrective action required to be done to be able to increase the life of the tire so that the life of the tire can reach the optimum value according to the calculation results are:

- Monitoring tire pressure

The recommended corrective action to increase tire life is tire pressure telemetry checking. This can be done with a Tire Pressure Monitoring System (TPMS). The system that is built will give an alarm when the condition of the tire pressure is less and real time monitoring of the tire pressure during the unit is used for operation.

- Monitoring TKPH tires

Ton Kilo Per Hour (TKPH) is a work parameter for a safe range of overheating when a tire is used for operations. TKPH tires are a function of the payload factor and the speed of the mining machine unit. TKPH ban may not exceed TKPH field. The recommended corrective action recommended is to monitor TKPH tire measurements in real time, because currently the payload data and unit speed can already be monitored in real time. This needs to be done to prevent overheating of the tires, tires with overheating conditions can cause defects in the tire separation resulting in decreasing tire life.

- Maintain mine haul road condition index

The level of damage to a mine haul road due to the operation of a heavy equipment is measured by an index called the mine haul road index or also known as the severity index. Monitoring of the level of damage to the mine road needs to be done because it impacts the life of the tire. Currently monitoring is carried out on a weekly basis and does not run consistently and becomes a late report if there is road damage that exceeds the acceptable range value. Recommendations for improvement are suggested by conducting real time monitoring and integrating it with maps and work orders for road repairs. Damaged mining roads can cause undulations that can cause damage to the sidewall portion of the tire.

## 5. Conclusion

This optimization study of maintenance costs for mining heavy equipment was carried out by developing a goal programming model through the tire life time approach. The first conclusion obtained in this study is to achieve the optimum cost, the lifetime of a tire size of 27.00 R49 that must be achieved is 5,909 hours for new tires, 2,501 hours for re-tread tires, and 2,200 hours for rental tires. Optimization result shown that by reaching those tire lifetime targets, the objective to minimize deviational from objective function can be obtained. Annual running hours deviation from target is only 0,57 hours, maintenance cost deviation from target is $0.91, and down time target 7% below the maximum down time hours limit. The second conclusion is the results of optimization modelling related to tire life in this study can make a positive contribution to the company, especially on the potential cost savings. Some of the potential cost savings gained from the hourly cost of tires can be reduced from $1.74 per hour to $1.58 per hour, so that value of money, when compared to the actual costs in 2019, can be reduced by $499,907.91 or 9% of previous year. In terms of a reduction in downtime due to tire damage, modelling can also provide potential savings $760,403.21 for company of and increase the productivity of mining material transport trucks. Labour cost factor for tire maintenance and the tire defects condition can be opportunities for further evaluation in optimization research related to cost optimization on mining heavy equipment tire maintenance.

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