A priori ranking and an analysis of factors affecting tire wear

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Abstract. The aim of the paper is to analyze factors affecting tire life and to rank them using experimental data in order to determine how influential each of them is. The issue of tire wear is an important concern for many different companies because tires account for a major part of the operating costs of rubber-tired equipment.

1. Introduction
In the mining industry, the use of large equipment and its maintenance are associated with significant costs at the stages of development, design, and construction and during operation. The development of optimal manufacturing techniques and methods used in the reclamation of worn parts is a topical issue [1].

Equipment failures usually mean significant costs which may eventually exceed the cost of diagnostic equipment that makes it possible to calculate wear rate for parts in contact with each other and find internal defects and stresses in metal frames with sufficient accuracy and efficiency and using methods approved by Gosgortechnadzor [2]. The most important industrial process which influences production efficiency in the mining sector is materials handling, which includes loading and transportation of broken material. The share of motor transport costs in the total costs of surface mining in Russia is substantial and reaches 70% as the depth of the open pit (quarry) increases. At the same time, the effective performance of dump trucks is much lower than the nominal one, the latter one being 2.5 or more times higher for various vehicles, including imported ones. More than half of dump truck performance losses are caused by ineffective maintenance and repair. In view of this, the issue of designing and implementing effective maintenance and repair practices for operating dump trucks in open-pit mines becomes essential.

OTR tires play an important role in ensuring efficient, continuous, and safe operation of mining equipment. It is not by chance that costs for purchasing and maintaining OTR tires are among the major cost items for companies operating open-pit mines. Taking into account the impact of OTR tires on the cost structure of the company and the production process itself, leading producers and consumers of OTR tires are interested in finding ways to manage tire maintenance more effectively [3]. Among the techniques currently used are nitrogen tire inflation, continuous pressure monitoring, and on-board diagnostics (OBD); these techniques seem to be promising, especially for vehicles used in mining [4, 5]. High-quality maintenance of OTR tires will save tire costs and increase production efficiency by minimizing equipment downtime caused by tire failures and replacement.

A weak point of any open-pit vehicle is its impact on the environment. Diesel engines produce a lot of harmful emissions (all the BelAZ dump trucks in operation in open-pit mines located in the Commonwealth of Independent States (17,250 units in total) burn approximately 2.1 million tons of diesel fuel every year), causing environmental degradation in areas where mining operations take place [6]. It is also important to note that tire wear contributes to pollution. Moreover, in the process of tire
tread wear, fine particles are released which have an adverse effect on human health. A decrease in tire wear will mean a reduction in negative impact on the environment as a result of a decrease in the number of harmful particles emitted in the air.

OTR tire life depends on many factors. In order to identify those that influence tire life most prominently, we ranked them using experimental data. In the process of ranking, we used already established methods of weeding out factors that are unimportant. These methods involve conducting a series of experiments and selecting the most influential factors using the results of these experiments [7].

2. Results
In order to do ranking using the method described above, experts from three different groups of nine people each were chosen. Each expert was given a questionnaire with the following list of factors:

1. tire pressure,
2. tire operating temperature,
3. wheel alignment,
4. driving style,
5. vehicle overload,
6. road surface condition,
7. faulty shock absorbers,
8. wheel balancing,
9. speed limits,
10. bent wheel rims,
11. faulty steering gear,
12. spring failure,
13. physical and mechanical properties.

The first group of experts consisted of researchers who identified three factors that they considered to be the most significant contributors to tire wear (Table 1, Figure 1). These factors are tire pressure, tire operating temperature, and wheel alignment.

| Experts (researchers) | Factor rankings |
|-----------------------|----------------|
|                       | x1 | x2 | x3 | x4 | x5 | x6 | x7 | x8 | x9 | x10 | x11 | x12 | x13 |
| 1                     | 2  | 3  | 1  | 9  | 8  | 5  | 11 | 4  | 12 | 6   | 7   | 13  | 10 |
| 2                     | 1  | 3  | 4  | 6  | 2  | 5  | 8  | 7  | 9  | 10  | 12  | 13  | 11 |
| 3                     | 3  | 10 | 1  | 6  | 7  | 8  | 2  | 11 | 4  | 5   | 13  | 9   |    |
| 4                     | 2  | 3  | 1  | 4  | 5  | 12 | 7  | 6  | 8  | 9   | 13  | 11  | 10 |
| 5                     | 1  | 3  | 10 | 4  | 11 | 6  | 7  | 12 | 13 | 9   | 5   | 8   | 2  |
| 6                     | 13 | 2  | 10 | 8  | 6  | 9  | 1  | 7  | 5  | 4   | 3   | 11  | 12 |
| Σ                      | 22 | 24 | 27 | 37 | 39 | 45 | 46 | 38 | 58 | 42  | 45  | 69  | 54 |
| ±Δ                     | 20 | 18 | 15 | 5  | 3  | -3 | -4 | 4  | -16| 0   | -3  | -27 | -12|
| ±Δ2                    | 400| 324| 225| 25 | 9  | 9  | 16 | 16 | 256| 0   | 9   | 729 | 144|

Figure 1. The bar chart showing factor rankings in the first group.
The second group of experts consisted of drivers with more than ten years of driving experience. This group of experts identified the three most significant factors which turned out to be the same as those chosen by the experts in the first group (Table 2, Figure 2).

| Experts (drivers) | Factor rankings |
|-------------------|-----------------|
| Σ                 | 21 31 22 53 62 67 96 82 88 82 72 106 39 |

**Figure 2.** The bar chart showing factor rankings in the second group.

The third group of experts consisted of senior executives in transport companies. They had the same opinion as did the experts in the first two groups (Table 3, Figure 3).

| Experts (executives) | Factor rankings |
|----------------------|-----------------|
| Σ                    | 25 27 24 61 50 82 62 59 87 72 91 95 86 |

**Figure 3.** The bar chart showing factor rankings in the third group.
Next, opinion consistency was analyzed. It was done using Kendall’s coefficient of concordance (W):

\[ W = \frac{12S}{m^2(k^3 - k)} \]  

(1)

where \( S \) is the sum of squared deviations, \( m \) is the number of experts, and \( k \) is the number of factors. The significance of the coefficient of concordance (W) was assessed using Pearson’s chi-squared test. To do this, \( X^2_p \) was found.

\[ X^2_p = m(k - 1)W \]  

(2)

The calculated value was compared to a table value for the given level of significance and the number of degrees of freedom \( F = k - 1 \). The hypothesis that the expert’s opinions are consistent can be accepted if \( X^2_p \geq X^2_i \).

The results of the calculations are presented in Table 4.

| Group | Group 2 | Group 3 |
|-------|---------|---------|
| W     | 0.5     | 0.6     | 0.5     |
| \( X^2_p \) | 58      | 69.7    | 57.1    |
| \( X^2_i \) | 21      | 21      | 21      |

Since \( X^2_p \geq X^2_i \), the experts’ opinions can be considered to be consistent.

3. Conclusion

The results of the calculations confirm the views shared among the different groups of professionals on the importance and ranking of factors affecting tire life.

The dependence of tire life on the group of factors discussed in the paper has yet not been studied in detail. This issue seems to be important given there are costs of tire operation and maintenance, including those for OTR tires.

References

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