EVALUATION OF LOADER FAILURES USING PARETO ANALYSIS

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Abstract

Mining industry is still the only supplier of mineral resources. Loading and transportation represents an integral part of the logistics system in each mining company. Shovel loaders are often used as part of the technological process in quarries. The trouble-free condition of loaders is one of the basic factors of their long-term performance. The aim of the paper is to evaluate the failure rate of loaders using Pareto analysis. Based on this method, the most common loader failures within a specified time are identified. The results of the analysis will be further examined and the basis for drawing conclusions.

Keywords: Loader, failure, Pareto analyses

1. INTRODUCTION

Mining industry is still the only supplier of mineral resources. Loading and transportation represents an integral part of the logistics system in each mining company. Mining operations include drilling, blasting, loading, and transport. Loading is one of the most essential parts of the mining unit operation. Any failure in the loading system will result in shutdowns of all mining-related systems. Time of the interruption of the loading system due to a failure must be kept to a minimum and the system must return to its original state and operating condition as soon as possible.

Different types of wheel loaders are used as loading machines in quarry operations [1]. Wheel loader maintenance is an important part of being an operator of such a machine. One of the best things you can do for effective maintenance of these equipment is to develop a schedule and routine. The pre- and post-operation inspections are an essential part of regular maintenance for any piece of loaders. Some key items of wheel loader to check for include for example: tire pressures and tire damage, any loose, worn, or damaged parts, oil or coolant leaks, engine oil and other vital fluid levels. Performing routine maintenance on wheel loader and excavators is critical to safety, productivity, and machine uptime [2].

The aim of the paper is to analyze the failures of loaders and excavators in the selected quarry by applying Pareto analysis based on their number during the observed period.

Pareto analysis is used to detect failures. It is a method that helps to prioritize the resolution of the company's main problems. This analysis shows that 80% of the consequences are caused by only 20 % of the causes. If we want to eliminate 80 % of losses, we must focus our activities on predefined problems in the range of 20 %.

The Pareto diagram is a powerful tool for identifying the significant factors influencing objects, processes, services, etc. In the production sphere, it is very suitable for analysis of defects and their impact [3].

The Pareto analysis belongs to the analytical tools that are integrated in the concepts of maintenance management - RCM (Reliability Centred Maintenance) and TPM (Total Productive Maintenance). Pareto histograms are commonly used to determine maintenance priorities by classifying equipment failures according to their number. [4]

Pareto analysis is a method used in various areas of research, too: e.g. for the illustration of categorical possibilities of evaluating the effectiveness of engineering production processes [5,6], to analyse and assess the causes of accidents that involve construction [7], for identified the causes of various categories in Production Process of Hot Rolling Mill [8], for analyse the criticality assessment of the different battery technologies used in photovoltaic applications [9], in the area of economic analysis was used Pareto analysis [10], and other.

2. METODOLOGY

Even with a small amount of data, the characteristics can be identified by applying the methods like the Pareto analysis [4] which belongs to the key decision-making tools used by maintenance manager.

Two variants of Pareto analysis will be used in this paper: Simple Pareto analysis and Weighted Pareto analysis. Pareto analyses procedure use in this paper is in **Table 1**.

Table1 Pareto analyses procedure

Simple Pareto analysis	***Weighted Pareto Analysis***
1. The list of failures and their number, p_i.	1. **The l**ist of failures and their number, p_i.
2. The data sorting in descending order according to the number of failures, the data is written to the table.	2. The assignment of weights to individual failures based on a scale, w_i
3. Calculation of cumulative sums of values of failure numbers and their expression in percent.	3.Parameter calculation $u_i = p_i \cdot w_i$
4. Construction of the Pareto diagram and Lorenz curve.	4. The data sorting in descending order according to the parameter of u_i, the data is written to the table.
	5.Calculation of cumulative sums of parameter u_i, their expression in percent.
	6. Construction of the Pareto diagram and Lorenz curve.

Construction of the Pareto diagram, as follows:

- we mark the failure categories on the x-axis,
- the left vertical axis is a scale from 0 to the total number of failures / a scale from 0 to the total u_i,
- on the right vertical axis is the scale of relative cumulative sums from 0 - 100%,
- we construct a column graph, where each column represents one type of failure and the height of the corresponding column corresponds to the number of failure / to the parameter u_i,
- construction of the curve of accumulated numbers/parameter u_i in percentage expression, the so-called Lorenz curve.

The Pareto diagrams and Lorenz curve will be constructed using Microsoft Office Excel software.

3. RESULTS AND DISCUSION

Pareto analysis was used to identify failures of loading equipment in a selected quarry operation. There are wheel loaders in operation for loading the raw material.

Every day at the beginning of the shift, it is necessary to perform operational maintenance on each machine according to the operation log. The following checks must be performed on wheel loaders: check the functionality of the lights, oil pan air cleaner check, headlight inspection, tire inspection, and check the oil level in the hydraulic system and in the engine, lubrication of all steering bearings, including the upper bearing of the frame joint.

The identified deficiencies are recorded in the appropriate diary and the employees try to solve the fault immediately. If the failure cannot be resolved on a given day, the machine manager decides whether the vehicle is able to operate despite the failure that has occurred. It is necessary to make an entry in the operation log of the given machine. Before starting the machine, a visual inspection of the condition of the engine, hydraulics, and cooling system in terms of fluid leaks is also required.

3.1. Simple Pareto analysis

Data on failures were used to perform the analysis from the operation logs of the equipment. **Table 2** shows the input values (detected failure (damaged parts) on the equipment and their number of failures), calculated cumulative numbers of failure and cumulative numbers of failures as a percentage for the wheel loader 1. Based on **Table 2**, a bar graph of the number of individual failure and the Lorenz curve is created, **Figure 1**.

Table 2 Input and calculated data for wheel loader 1

Failure		Numbers p_i	Cumulative numbers	Cumulative numbers in %
A	Damaged hydraulic hoses	12	12	22,22
B	Loss and damage of a tooth on a shovel	8	20	37,03
C	Service light functionality	7	27	50,00
D	Leaking fluid from the radiator	6	33	61,11
E	Damaged part of the shovel	5	38	70,37
F	Damaged windshield	4	42	77,78
G	Damaged wheel apron	3	45	83,33
H	Control unit failure	3	48	88,89
I	Gearbox failure	2	50	92,59
J	Brake system failure	2	52	96,29
K	Empty battery	1	53	98,15
L	Hydraulic distributor failure	1	54	100,00

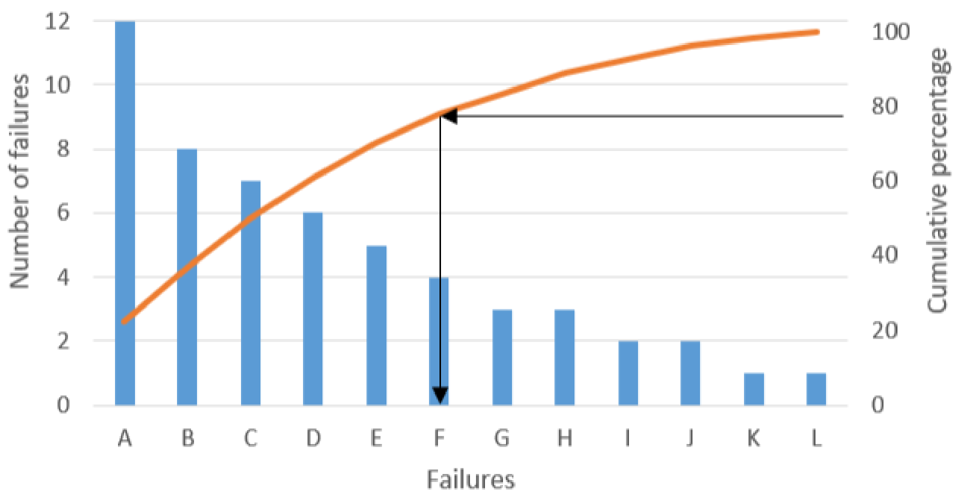

Figure 1 Pareto diagram: Wheel loader 1

The number of detected loader failures is 12 and the total number of failures on the Loader 1 is 54. The most common failures for wheel loader 1 were identified by a simple Pareto analysis: damage by hydraulic hoses and loss and damage to the teeth on the excavator. These damages are common during operation of this machine. In this case, 78% of failures are caused by failures that occurred on 6 parts of the loader.

Table 3 shows the input values (detected failure (damaged parts) on the equipment and their number of failures), calculated cumulative numbers of failure and cumulative numbers of failures as a percentage for the wheel loader 2. Based on **Table 3**, a bar graph of the number of individual failure and the Lorenz curve is created, **Figure 2**.

The number of detected loader failures is 13 and the total number of failures on the wheel loader 2 is 59. The most common failures for wheel loader 2 were identified by a simple Pareto analysis again damage by hydraulic hoses and loss and damage to the teeth on the excavator. In this case, 75 % of failures are caused by failures that occurred on 6 parts of the loader.

Table 3 Input and calculated data for wheel loader 2

Failure		Numbers p_i	Cumulative numbers	Cumulative numbers in %
A	Damaged hydraulic hoses	11	11	18,64
B	Loss and damage of a tooth on a shovel	9	20	33,89
C	Battery damage and discharge	7	27	45,76
D	Gearbox failure	6	33	55,93
E	Leaking fluid from the radiator	6	39	66,10
F	Service light functionality	5	44	74,57
G	Damaged windshield	5	49	83,05
H	Hydraulic distributor failure	3	52	88,13
I	Damaged part of the shovel	2	54	91,52
J	Engine failure	2	56	94,91
K	Engine starter inoperative	1	57	96,61
L	Damaged wheel apron	1	58	98,30
M	Cooling system failure	1	59	100,00

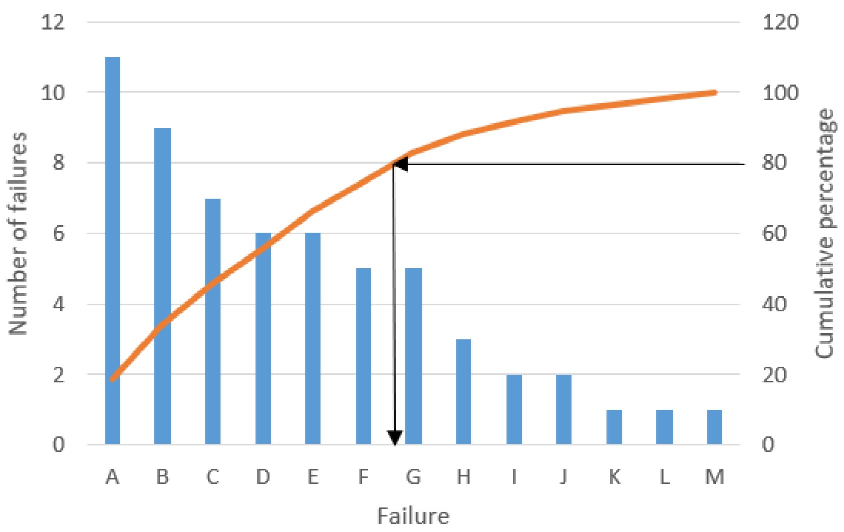

Figure 2 Pareto diagram: Wheel loader 2

3.2. Weighted Pareto Analysis

As can be seen from Tables 2 and 3, several parts of the loader have failed during operation, some of which can be considered serious and some of which are common to the day-to-day operation of the loader.

For this reason, a weighted Pareto analysis was also performed. In this analysis, individual failures are assigned a weight that expresses the importance of the failure. The weight for individual failure can be determined in various ways, like the weighting of the criteria in the multicriteria assessment. For this case, the determination of weights from the point scale is chosen: 1- failure weakly significant, 3 - failure minor, 5 - failure moderate, 7- failure significant and 10- failure highly significant.

Table 4 shows the data for performing the weighted Pareto analysis for wheel loaders 1 and 2. **Figures 3 and 4** show the Pareto diagrams.

Table 4 Input data, weights, and calculated values

Wheel loader 1					***Wheel loader 2***				
Failure	p_i	w_i	$u_i = p_i \cdot w_i$	Cumulative percentage	Failure	p_i	w_i	$u_i = p_i \cdot w_i$	Cumulative percentage
A	12	5	60	22,47	D	11	5	55	18,23
F	8	3	30	33,70	A	9	3	27	34,95
D	7	3	30	44,94	C	7	7	49	49,84
E	6	5	25	54,30	D	6	10	60	58,96
B	5	5	24	63,29	B	6	5	30	67,17
C	4	5	21	71,16	G	5	3	15	74,77
I	3	3	20	78,65	H	5	5	25	81,15
F	3	10	20	86,14	J	3	7	21	87,23
L	2	10	14	91,38	F	2	5	10	91,79
G	2	7	9	94,75	I	2	10	20	94,83
L	1	7	7	97,37	K	1	7	7	96,96
K	1	7	7	100	M	1	3	3	99,08
					L	1	7	7	100

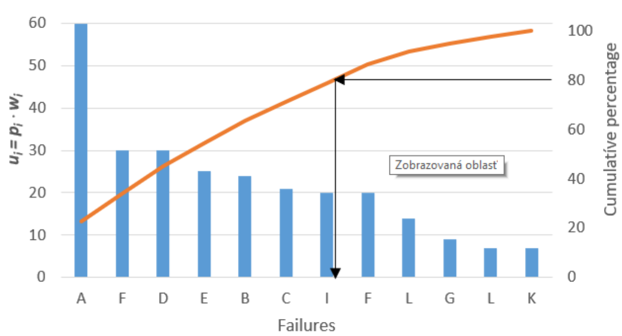

Figure 3 Pareto diagram: Wheel loader 1

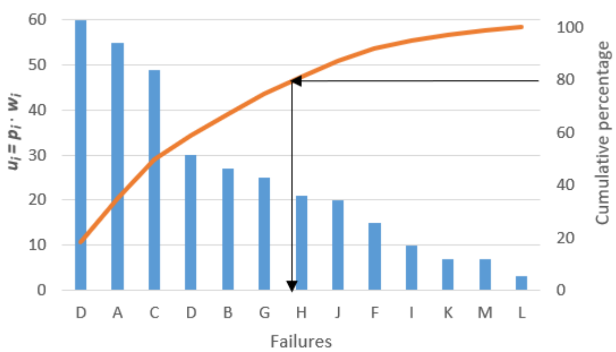

Figure 4 Pareto diagram: Wheel loader 2

4. CONCLUSION

Pareto analysis is a suitable tool for obtaining important characteristics and control parameters of maintenance, as well as for supporting decision-making processes. Pareto analysis was used to assess failure that occurred at selected devices. Loader failures were evaluated based on a simple Pareto analysis and a weighted Pareto analysis. However, as can be seen from **Figures 1-4**, the Pareto 80/20 rule was not confirmed in the assessment of failures. In addition to these two variants of Pareto analysis, it is possible to use the so-called multiple Pareto analysis. Pareto analysis in which another parameter enters the evaluation, e.g., the number of failures is multiplied by the length of downtime that resulted from the failure. For the evaluation of loading equipment, it is appropriate to use other analytical methods such as Failure Mode and Effect and Criticality Analysis (FMECA) and Weibull analysis These methods can highlight the criticality of some failures and the actions needed to improve the reliability loaders and a better mining productivity [11].

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REFERENCES

[1] ŠADEROVÁ, J., ŠOFRANKO, M. *Active and passive elements of logistics chains*. 1. vyd. - Ostrava: Vysoká škola báňská–Technická univerzita Ostrava, 2021.

[2] 7 steps to effective wheel loader maintenance. [online]. 2022. [viewed: 2022-05-24]. Available from: https://www.heavyequipmentguide.ca/article/31148/7-steps-to-effective-wheel-loader-maintenance

[3] GERMANOVA-KRASTEVA, D., DIMCHEVA, I. Analysis of defects and their impact on the production losses using Pareto diagrams. In: *E3S Web Conf.* 2020, vol. 207, 03007 Available from: https://doi.org/10.1051/e3sconf/202020703007.

[4] AMBRIŠKO, Ľ. Analysis of public transport vehicles maintenance costs. In: *CLC 2018 Carpathian Logistics Congress : Logistics, disribution, transport and management*. Ostrava (Česko): Tanger, 2019, pp. 368-373 [CD-ROM]. ISBN 978-80-87294-88-8.

[5] IMAEKHAI L., SINATRA, A.I. Pareto Analysis. A Categorical Imperative in the Evaluation of the Effectiveness of Engineering Production Processes. *Research and reviews on experimental and applied mechanics*. 2021, vol. 4, no. 2, vol. 1–7. Available from: https://doi.org/10.5281/zenodo.5215896

[6] MATISKOVÁ, D. 2015. Evaluation of the Effectiveness of Engineering Production Processes using Pareto Analysis. *TEM Journal*. 2015, vol.4, no. 1, p. 96-101.

[7] HOŁA, A.; SAWICKI, M.; SZÓSTAK, M. Methodology of Classifying the Causes of Occupational Accidents Involving Construction Scaffolding Using Pareto-Lorenz Analysis. *Appl. Sci.* 2018, vol. 8, no. 48. Available from: https://doi.org/10.3390/app8010048

[8] MALINDZAKOVA, M., CAGÁŇOVÁ, D., ROSOVA, A., MALINDZAK, D. (2019). Risk Analysis Causing Downtimes in Production Process of Hot Rolling Mill. In: *Smart Technology Trends in Industrial and Business Management*. EAI/Springer Innovations in Communication and Computing. Springer, Cham. Available from: https://doi.org/10.1007/978-3-319-76998-1_24

[9] IMEN, A., INÈS, H., KAIS B., FAOUZi, B. A., Criticality assessment with Pareto diagram of the different solar batteries technologies. In: *2020 17th International Multi-Conference on Systems, Signals & Devices (SSD)*, 2020, pp. 513-518. Available from: https://doi.org/10.1109/SSD49366.2020.9364179.

[10] AMBRIŠKO, Ľ., TEPLICKÁ, K. Proactive Maintenance as a Tool of Optimization for Vehicle Fleets, in Terms of Economic and Technical Benefits. *Acta Polytechnica Hungarica*. 2021, vol 18, no. 8, pp. 235-249 [print, online]. ISSN 1785-8860. Available from: http://dx.doi.org/10.12700/aph.18.8.2021.8.13...

[11] BALABA, B., IBRAHIM M. Y., GUNAWAN, I Utilisation of data mining in mining industry: Improvement of the shearer loader productivity in underground mines. In: *IEEE 10th International Conference on Industrial Informatics.* 2012, pp. 1041-1046. Available from: https://doi.org/10.1109/INDIN.2012.6301364.