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# Pareto analysis in bulldozer's failures and stoppages risk management[6]

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***Abstract****: Research related to risk management of failures and stoppages in the operation of bulldozer is very limited, so this topic needs more attention. This study aims to identify all possible causes for bulldozer failures and stoppages before highlighting the most significant ones. Descriptive statistics are provided, followed by a scatterplot for the dissipation diagram between hazard rate and bulldozer failure and stoppages, and histograms of hazard rate and failures and stoppages for bulldozers. Then, for three categories, a Pareto analysis was performed on failures and stoppages frequency, time spent in failures and stoppages, and failures and stoppages risk level. The Pareto analysis revealed that the most important failures and stoppages in all three categories were caused by heating repair, oil change, bulldozer cleaning, tonsil adjustment, filter replacement, hose replacement and screw replacement. The step towards "maintenance free factories" should include planning of identified activities in work breaks as preventive rather than corrective activities.*

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***Keywords**:* Pareto analysis, bulldozer, failure type, failure frequence, failure time, failure risk

## Primena Pareto analize u menadžmentu rizikom otkaza i zastoja buldozera

***Apstrakt**: Istraživanja vezana za otkaze i zastoje u radu buldozera veoma su ograničena, te je ova oblast nedovoljno istražena. Cilj ovog rada je da identifikuje sve uzroke otkaza i zastoja buldozera, a potom da izdvoji one najuticajnije. Data je deskriptivna statistika, a zatim i dijagram rasipanja za stepen opasnosti i vremena otkaza i zastoja buldozera i histogrami stepena opasnosti i vremena otkaza i zastoja za buldozere. Potom je data Pareto analiza za tri kategorije: frekvenciju otkaza i zastoja, vreme trajanja otkaza/zastoja i nivoa rizika od otkaza/zastoja. Pareto analiza je pokazala da su sve kod tri kategorije da najčešći otkazi/zastoji nastali zbog popravke grejanja, zamene ulja, čišćenja, podešavanja krajnica, zamene filtera, zamene creva i zamene vijaka, te da je neophodno posebnu pažnju obratiti na ove otkaze/zastoje. Korak ka „fabrikama bez održavanja" trebalo bi da uključi planiranje identifikovanih aktivnosti u pauzama rada kao preventivne, a ne korektivne aktivnosti.*

***Ključne reči**: Pareto analiza, buldozer, tip otkaza, frekvencija otkaza, vreme trajanja otkaza, rizik od otkaza*

## 1. Introduction

When it comes to safety concerns, the mining sector is one of the most complex (Duarte, Baptista, & Torres, 2019). The effect of mining machines and equipment on accidents is still not entirely understood, despite the fact that the majority of dangers have been recognized and extensively investigated (Duarte et al., 2019). As one of the most often used machines in challenging surface mining environments, bulldozers are under constant pressure to deliver optimum performance with minimal stoppages and failures and stoppages and lower operating costs (Tanasijevic, Jovancic, Ivezic, Bugaric, & Djuric, 2019). It is impossible to overstate the significance of maintenance in the mining and construction industries since it has a significant impact on the equipment's productivity, efficiency, and capacity (Akinnuli & Olaleye, 2013). While the fast development of new technologies attempts to improve working conditions and the environment by providing answers to well-known issues in the field of occupational safety, its application may also result in new dangers and risks that need to be considered and controlled (Spasojević Brkić, Klarin, & Brkić, 2015).

That is the reason why is essential to identify firstly all causes of failures and stoppages and later on to focus on primary ones. Fatigue is the main cause of breakdowns on heavy mining equipment such as bulldozers (Fry, 2003). The material qualities are deemed adequate in many failures and stoppages, and the loads, strains, and large number of cycles are to blame for the failures and stoppages (Fry, 2003). Six possible design adjustments are suggested by a study by Deulgaonkar, Karambelkar, Kulkarni, & Kashid (2021) that focused on the bulldozer transmission system in order to lessen the stress on the system. Horberry, Burgess-Limerick, Cooke, & Steiner, (2016) point out that structured, human-centered redesign of mining machines is necessary nowadays. Kazan & Usmen (2018) add that bulldozers have 31.8% as degree of injuries and notice that they together with backhoes still have the highest frequency of accidents and fatalities. Misita et. al., (2022) focused on dumper operation risk analysis model and as criteria for risk analysis are: time spent in downtime, frequency of downtime and level of danger, while Misita et al. (2021) have compared impact of mechanical and technological mining machinery time in fault and mechanical and technological mining machinery downtime frequencies on machine work done. Spasojević-Brkić et al. (2022) focused on leadership style and transport and mining machines' operator's attitudes in the safety climate context and Serbian operators' population.

Previous research indicate that the causes of bulldozer failures and stoppages have not been thoroughly examined, and that special attention is required to avoid or reduce these failures/stoppages.

This research aimed to list all factors that contribute to bulldozer failures and stoppages and then identify the most significant factors in each of the following three categories: failure/stoppage frequency, failure/stoppage time, and failure/stoppage risk level. The introduction is followed by a research methodology, then descriptive statistics of bulldozer failures and stoppages, and a dissipation diagram between the failures and stoppages risk level and the failures and stoppages time are given. There are additionally given histograms for failures/stoppages, failures and stoppages risk level, and the product of failures and stoppages time and failures and stoppages risk level. Later on, a Pareto analysis was performed on failures and stoppages frequency, time spent in failures and stoppages, and failures and stoppages risk level in aim to identify the most important failures and stoppages in all three categories in conclusion.

## 2. Research methodology

Research methodology used is this paper was Pareto analysis, which recognizesthe “vital few” causes which are responsible for 80% of phenomenon, while the “trivial many” account for the remaining 20% (Craft & Leake, 2002). This model has become associated with the "80/20" rule, which states that 20% of the known variables will affect 80% of the results (Craft & Leake, 2002). Pareto analysis is also referred to as ABC analysis in literature (Flores & Clay Whybark, 1986), however more accurately, interpretations identify ABC analysis as a Pareto analysis variant (Conger, 2015). Three distinct zones are identified by the ABC analysis: area A is the zone of greatest increase, area B is the zone of noticeable increase, and zone C represents the zone of low-growth (Annie Rose Nirmala, Kannan, Thanalakshmi, Joe Patrick Gnanaraj, & Appadurai, 2022). The research was conducted on data gathered from several different mining sites which have included bulldozer operation during the 2021. There were 23 different types of bulldozer failures and stoppages that have been found. Failures and stoppages frequency, which measures the total number of separate failures and stoppages types, failures and stoppages time, and failures and stoppages risk level have all been determined. Gathered data depending on the type of failure/stoppage are shown in Table 1 and Figures 1, 2 and 3.

*Table 1. Descriptive statistics*

| Type of Failure / Stoppage | N | Mean | Median | Min | Max | Range | Standard Deviation | Coefficient of Variation (%) |
|---|---|---|---|---|---|---|---|---|
| Technological | 26 | 30.385 | 30.0 | 15 | 80 | 65 | 13.261 | 43.64 |
| Electrical | 2 | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* |
| Mechanical | 74 | 76.622 | 60.0 | 5 | 350 | 345 | 77.26*5 | 100.84 |
| Misuse | 0 | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* |
| Organizational | 0 | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* |
| External | 0 | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* | n.t.* |
| Danger Level | 102 | 1.980 | 2 | 1 | 5 | 4 | 1.169 | 59.02 |
| Total Failure / Stoppage time | 102 | 81.137 | 30 | 5 | 480 | 475 | 94.249 | 116.16 |
| Product of failure / stoppages time and failure / stoppages rate | 102 | 181.706 | 87 | 5 | 1750 | 1745 | 313.366 | 172.46 |
| * Not tested (insufficient sample size) | | | | | | | | |

*Figure 1. Dissipation diagram between the failure/stoppages risk level and the failure/stoppages time*

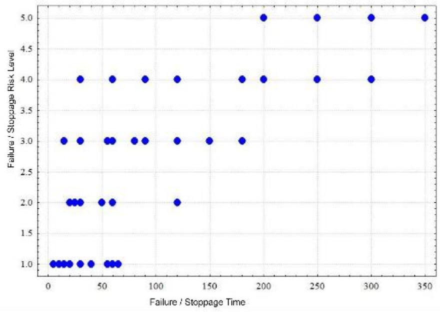



*Figure 2. Failures/stoppages risk level histogram*

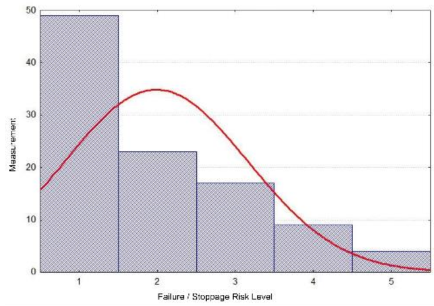



*Figure 3. Failures/stoppages time histogram*

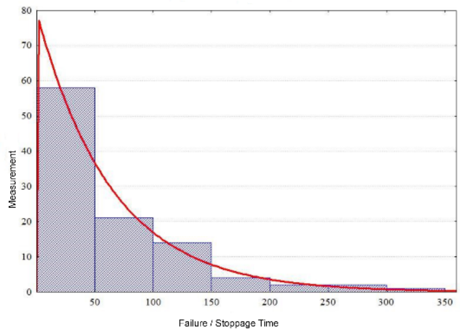
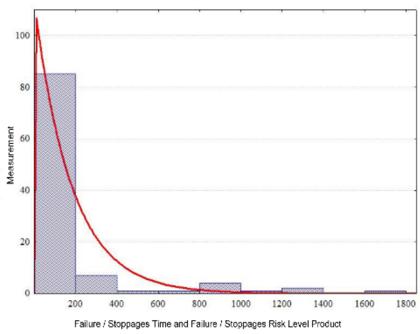



*Figure 4. Failures and stoppages time and failures and stoppages risk level product histogram*




After gathering of all of previos information, a Pareto analysis was carried out.

# 3. Results and Discussion

## 3.1. Pareto analysis of bulldozer failures and stoppages frequencies

The failures and stoppages frequency for 23 distinct types of bulldozer failures and stoppages is shown in Table 2. The calculated failures and stoppages ratio and the failures and stoppages ratio expressed as a percentage are also displayed.

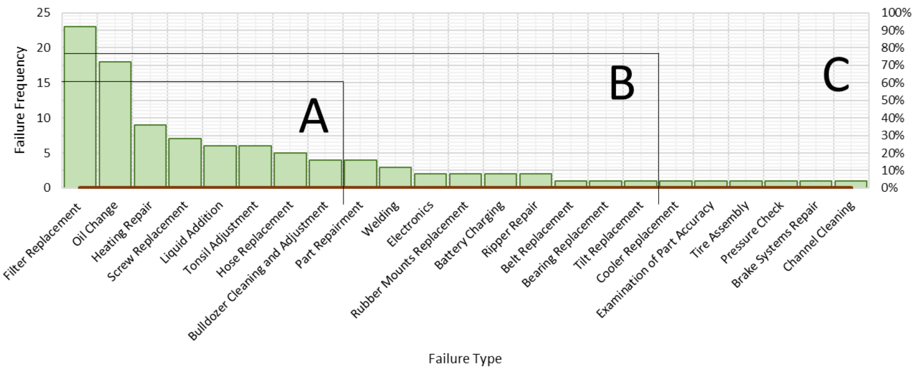
*Table 2. Bulldozer failures and stoppages frequencies*

| **Failure/stoppages Type** | **Failure/stoppages Frequency** | **Failure/stoppages Ratio [%]** |
|---|---|---|
| Filter Replacement | 23 | 22.5% |
| Oil Change | 18 | 17.6% |
| Heating Repair | 9 | 8.8% |
| Screw Replacement | 7 | 6.9% |
| Liquid Addition | 6 | 5.9% |
| Tonsil Adjustment | 6 | 5.9% |
| Hose Replacement | 5 | 4.9% |
| Bulldozer Cleaning | 4 | 3.9% |
| Part Repairment | 4 | 3.9% |
| Welding | 3 | 2.9% |
| Electronics | 2 | 2.0% |
| Rubber Mounts Replacement | 2 | 2.0% |
| Battery Charging | 2 | 2.0% |
| Ripper Repair | 2 | 2.0% |
| Belt Replacement | 1 | 1.0% |
| Bearing Replacement | 1 | 1.0% |
| Tilt Replacement | 1 | 1.0% |
| Cooler Replacement | 1 | 1.0% |
| Examination of Part Accuracy | 1 | 1.0% |
| Tire Assembly | 1 | 1.0% |
| Pressure Check | 1 | 1.0% |
| Brake Systems Repair | 1 | 1.0% |
| Channel Cleaning | 1 | 1.0% |

Pareto diagrams shown on Figure 4, was created by using data from Table 2.

The Pareto diagram may be divided into three proportionate areas, 80:15:5, according to Figure 4. The areas with the greatest increase, or those that are quantitatively characterized by the greatest number of failures and stoppages (A), also include the following causes of failure and stoppages: filter replacement, oil change, heating repair, screw replacement, liquid addition, tonsil adjustment, hose replacement, and bulldozer cleaning.

*Figure 4. Pareto analysis of relationship between type and frequency of the failures and stoppages*




Part repair, welding, electronics, rubber mount replacement, battery charging, ripper repair, belt replacement, bearing replacement, tilt replacement, and cooler replacement are the 10 causes of failures and stoppages that fall under the category of noticeable increase (B).

The following factors contribute to failures and stoppages in the low-growth area (Area C): examination for part accuracy, tire assembly, pressure checks, brake system repairs, and channel cleaning.

### 3.1. Pareto analysis of bulldozer failures and stoppages time

The further step is a Pareto analysis of bulldozer failures and stoppages time.

The time spent in failures and stoppages for 23 distinct types of bulldozer failures and stoppages are shown in Table 3.

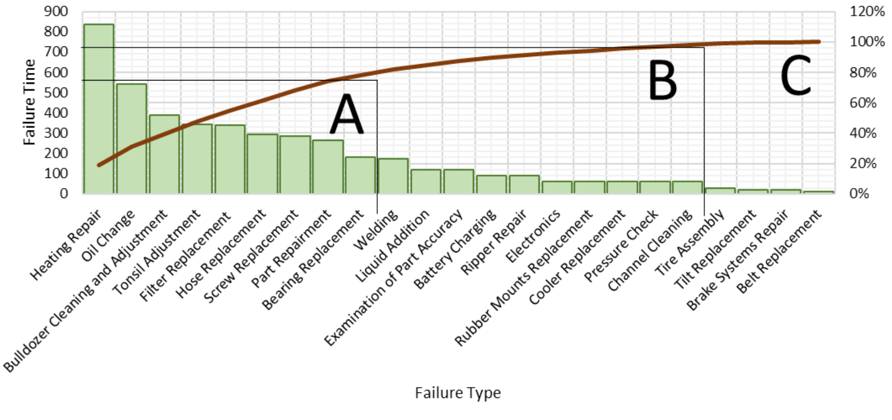
The calculated failures and stoppages ratios and the failures and stoppages ratios expressed as a percentage are also displayed in Table 3.

Pareto diagram shown on figure 5, was created by using data from Table 3.

*Table 3. Bulldozer failures and stoppages time*

| Failure/Stoppages Type | Failure/Stoppages Time [min] | Failure/Stoppages Ratio | Failure/Stoppages Ratio [%] |
|---|---|---|---|
| Heating Repair | 835 | 0.18764 | 18.8% |
| Oil Change | 540 | 0.121348 | 12.1% |
| Bulldozer Cleaning | 390 | 0.08764 | 8.8% |
| Tonsil Adjustment | 345 | 0.077528 | 7.8% |
| Filter Replacement | 340 | 0.076404 | 7.6% |
| Hose Replacement | 295 | 0.066292 | 6.6% |
| Screw Replacement | 285 | 0.064045 | 6.4% |
| Part Repairment | 265 | 0.059551 | 6.0% |
| Bearing Replacement | 180 | 0.040449 | 4.0% |
| Welding | 175 | 0.039326 | 3.9% |
| Liquid Addition | 120 | 0.026966 | 2.7% |
| Examination of Part Accuracy | 120 | 0.026966 | 2.7% |
| Battery Charging | 90 | 0.020225 | 2.0% |
| Ripper Repair | 90 | 0.020225 | 2.0% |
| Electronics | 60 | 0.013483 | 1.3% |
| Rubber Mounts Replacement | 60 | 0.013483 | 1.3% |
| Cooler Replacement | 60 | 0.013483 | 1.3% |
| Pressure Check | 60 | 0.013483 | 1.3% |
| Channel Cleaning | 60 | 0.013483 | 1.3% |
| Tire Assembly | 30 | 0.006742 | 0.7% |
| Tilt Replacement | 20 | 0.004494 | 0.4% |
| Brake Systems Repair | 20 | 0.004494 | 0.4% |
| Belt Replacement | 10 | 0.002247 | 0.2% |

*Figure 5. Pareto analysis of relationship between bulldozer failures and stoppages time and failures and stoppages type*



The Pareto diagram is divided into three proportionate areas, 80:15:5, according to Figure 5. Within the area of the greatest increase, that is, the area that includes most of the failures and stoppages (A), the following causes of failures and stoppages are included: heating repair, oil change, bulldozer cleaning, tonsil adjustment, filter replacement, hose replacement, screw replacement, part repairment, bearing replacement.The following 10 reasons for failures and stoppages fall into the category of noticeable increase (B): welding, examination of part accuracy, liquid addition, ripper repair, battery charging, electronics, cooler replacement, rubber mounts replacement, pressure check, channel cleaning. Area (C) is a low-growth area, and the causes of failures and stoppages in this area are tire assembly, tilt replacement, brake systems repair, belt replacement.

## 3.3. Pareto analysis of bulldozer's failures and stoppages and stoppages risk level

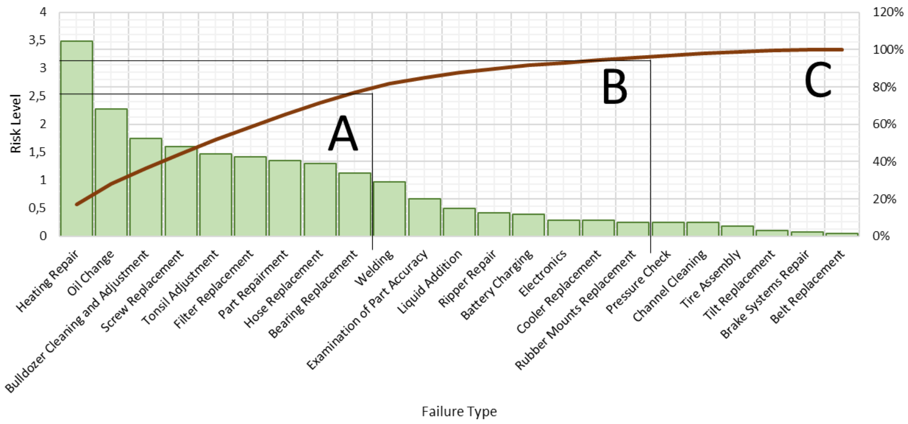
The risk level for 23 distinct types of bulldozer failures and stoppages is shown in Table 4. The calculated failures and stoppages ratio and the failures and stoppages ratio expressed as a percentage are also displayed.

*Table 4. Bulldozer failures and stoppages risk level*

| Failure/Stoppages Type | Risk Level | Failure/Stoppages Ratio [%] |
|---|---|---|
| Heating Repair | 3.479167 | 17.0% |
| Oil Change | 2.270833 | 11.1% |
| Bulldozer Cleaning | 1.75 | 8.5% |
| Screw Replacement | 1.604167 | 7.8% |
| Tonsil Adjustment | 1.475694 | 7.2% |
| Filter Replacement | 1.416667 | 6.9% |
| Part Repairment | 1.357639 | 6.6% |
| Hose Replacement | 1.305556 | 6.4% |
| Bearing Replacement | 1.125 | 5.5% |
| Welding | 0.972222 | 4.7% |
| Examination of Part Accuracy | 0.666667 | 3.3% |
| Liquid Addition | 0.5 | 2.4% |
| Ripper Repair | 0.416667 | 2.0% |
| Battery Charging | 0.395833 | 1.9% |
| Electronics | 0.291667 | 1.4% |
| Cooler Replacement | 0.291667 | 1.4% |
| Rubber Mounts Replacement | 0.25 | 1.2% |
| Pressure Check | 0.25 | 1.2% |
| Channel Cleaning | 0.25 | 1.2% |
| Tire Assembly | 0.1875 | 0.9% |
| Tilt Replacement | 0.097222 | 0.5% |
| Brake Systems Repair | 0.083333 | 0.4% |
| Belt Replacement | 0.048611 | 0.2% |

Pareto diagrams shown on figure 6, was created by using data from Table 4.

*Figure 6. Pareto analysis of the relationship between bulldozer failures and stoppages risk level and failures and stoppages type*




According to Figure 6, the Pareto diagram may be divided into three proportional areas, 80:15:5.

The following causes of failures and stoppages are included in the area of greatest growth, or the area that experiences the majority of failures and stoppages (A): heating repair, oil change, bulldozer cleaning, screw replacement, tonsil adjustment, filter replacement, part repairment, hose replacement, and bearing replacement. The area of noticeable growth (B) designates the region in which the following 8 reasons of failures and stoppages includes: welding, examination of part accuracy, liquid addition, ripper repair, battery charging, electronics, cooler replacement, and rubber mounts replacement. Area (C) is a low-growth area, and the following failures and stoppages -causing factors includes in: pressure check, channel cleaning, tire assembly, tilt replacement, brake systems repair, and belt replacement.

## 4. Conclusion

Bulldozer identifies 23 possible causes for failures and stoppages. Eight causes of failures and stoppages are found in the region with the highest growth, ten causes are found in the area with noticeable growth, and five failures and stoppages are found in the area with low-growth area, according to a Pareto study of the link between the number of failures and stoppages and the failures and stoppages causes. With up to 23 failures and stoppages, Figure 10 identifies filter replacement as the most frequent reason of downtime. Pareto analysis of the relationship between failures and stoppages and stoppages time and failures and stoppages causes, the region with the highest growth in failures and stoppages has 9 failures and stoppages causes, the area of the noticeable growth has 10, and the area of the low-growth in failures and stoppages has 4 failures and stoppages. Heating repair is highlighted in Figure 11 as the most frequent reason for downtime, accounting for 835 minutes of failure and stoppages. According to a Pareto analysis of the link between failures and stoppages risk and the reason for failure and stoppages, the region with the highest growth has 9 failures and stoppages causes, the area with noticeable growth has 8 failures and stoppages causes, and the area with low-growth has 6 failures and stoppages. With a risk score of 3.479, heating repair is highlighted in Table 12 as the most frequent reason for failure and stoppages.

According to the results of the Pareto analysis, the most frequent failures and stoppages from the perspective of their frequency are filter replacement, oil change, heating repair, screw replacement, liquid addition, tonsil adjustment, hose replacement, and bulldozer cleaning. while the most frequent failures and stoppages from the perspective of failure and stoppage time are welding, examination of part accuracy, liquid addition, ripper repair, battery charging, electronics, cooler replacement, rubber mounts replacement, pressure check, channel cleaning. Finally, from the aspect of failure risk, the most frequent failures are heating repair, oil change, bulldozer cleaning, screw replacement, tonsil adjustment, filter replacement, part repairment, hose replacement, and bearing replacement. As a result, it can be said that the heating repair, oil change, bulldozer cleaning, tonsil adjustment, filter replacement, hose replacement, screw replacement requires special attention because they are located in area of the greatest growth in all three categories. Risk management activities regarding bulldozers should more intensively focus on identified maintenance activities. The step towards “maintenance free factories” should include planning of identified activities in work breaks as preventive rather than corrective activities.

Ishikawa analysis of the primary causes found in the Pareto analysis as well as Failure Mode Effects Analysis (FMEA) of those causes may be included in future studies.

## References


Akinnuli, B., & Olaleye, J. (2013). An Expert System for Diagnosing and Proffering Solutions to Causes of Overheating in a Bulldozer Engine (Case Study Model D60s-6 Komatsu Products). *Engineering Management Research*, *2*(2), Article 2. https://doi.org/10.5539/emr.v2n2p56

Annie Rose Nirmala, D., Kannan, V., Thanalakshmi, M., Joe Patrick Gnanaraj, S., & Appadurai, M. (2022). Inventory management and control system using ABC and VED analysis. *Materials Today: Proceedings*, *60*, 922–925. https://doi.org/10.1016/j.matpr.2021.10.315

Conger, S. (2015). Six Sigma and Business Process Management. In J. vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 1: Introduction, Methods, and Information Systems* (pp. 127–146). Springer. https://doi.org/10.1007/978-3-642-45100-3_6

Craft, R. C., & Leake, C. (2002). The Pareto principle in organizational decision making. *Management Decision*, *40*(8), 729–733. https://doi.org/10.1108/00251740210437699

Deulgaonkar, V. R., Karambelkar, A., Kulkarni, A., & Kashid, C. (2021). Failure analysis of Taper-Lock bush used in aggregate batcher plant for construction applications. *Engineering Failure Analysis*, *130*, 105753. https://doi.org/10.1016/j.engfailanal.2021.105753

Duarte, J., Baptista, J. S., & Torres Marques, A. (2019). Occupational Accidents in the Mining Industry—A Short Review. In P. M. Arezes, J. S. Baptista, M. P. Barroso, P. Carneiro, P. Cordeiro, N. Costa, R. B. Melo, A. S. Miguel, & G. Perestrelo (Eds.), *Occupational and Environmental Safety and Health* (pp. 61–69). Springer International Publishing. https://doi.org/10.1007/978-3-030-14730-3_7

Flores, B. E., & Clay Whybark, D. (1986). Multiple Criteria ABC Analysis. *International Journal of Operations & Production Management*, *6*(3), 38–46. https://doi.org/10.1108/eb054765

Fry, P. R. (2003). Loads and stresses—The real cause of failures in surface mining machinery. *Practical Failure Analysis*, *3*(2), 7–14. https://doi.org/10.1007/BF02717417

Horberry, T., Burgess-Limerick, R., Cooke, T., & Steiner, L. (2016). Improving Mining Equipment Safety Through Human-Centered Design. *Ergonomics in Design*, *24*(3), 29–34. https://doi.org/10.1177/1064804616636299

Kazan, E., & Usmen, M. A. (2018). Worker safety and injury severity analysis of earthmoving equipment accidents. *Journal of Safety Research*, *65*, 73–81. https://doi.org/10.1016/j.jsr.2018.02.008

Misita, M., Spasojević Brkić, V., Brkić, A., Kirin, S., Rakonjac, I., & Damjanović, M. (2021). Impact of downtime pattern on mining machinery efficiency. *Structural Integrity and Life*, *21*(1), 29–35.Accepted: 2022-09-19T19:22:54Z

Misita, M. Ž., Spasojević-Brkić, V. K., Rakonjac, I. M., Damjanović, M. Z., Perišić, M. B., Papić, N. L., & Đurić, G. P. (2022). Dumper operation risk analysis model and HAMRISK expert system. *Tehnika*, *77*(5), 617–624. https://doi.org/10.5937/tehnika2205617M

Spasojević Brkić, V. K., Klarin, M. M., & Brkić, A. Dj. (2015). Ergonomic design of crane cabin interior: The path to improved safety. *Safety Science*, *73*, 43–51. https://doi.org/10.1016/j.ssci.2014.11.010

Spasojević-Brkić, V. K., Veljkovic, Z., Brkic, A., Misita, M., Perisic, M., & Papic, N. (2022). Transport and mining machines operators' behavioral attitudes in safety climate context. *Journal of Applied Engineering Science*, *20*(4), Article 4. https://doi.org/10.5937/jaes0-37669

Tanasijevic, M., Jovancic, P., Ivezic, D., Bugaric, U., & Djuric, R. (2019). A fuzzy-based decision support model for effectiveness evaluation – a case study of examination of bulldozers. *International Journal of Industrial Engineering: Theory, Applications and Practice*, *26*(6), Article 6. https://doi.org/10.23055/ijietap.2019.26.6.3304