13th DQM INTERNATIONAL CONFERENCE

# LIFE CYCLE ENGINEERING AND MANAGEMENT
# DQM-POLYTECH-2022

Prijevor, SERBIA, 23-24 June 2022

# Proceedings

POLYTECH

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Plenary Lectures

Quality Engineering

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Industrial Engineering

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Energy Efficiency

Lean Production

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Education

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Ljubisa Papic

13th DQM INTERNATIONAL CONFERENCE

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## LIFE CYCLE ENGINEERING AND MANAGEMENT

## PROCEEDINGS

**June 23-24, 2022, Prijevor, Serbia**

**Conference Topics:**

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**Editor:**
**Ljubisa Papic**

**The Research Center of Dependability and Quality Management**
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## 03 Reliability Engineering

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# IDENTIFICATION AND ANALYSIS OF THE RISK OF DOWN TIME IN THE OPERATIONAL WORK OF BULLDOZERS

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***Summary:*** *The subject research is aimed at pointing out the methodology of identification, classification and risk analysis of mining machines. Bulldozers as heavy mobile machines are very useful in mining processes as auxilary machines which generate up to 20% of the total mining costs and cause numerous injections and fatalities. Till now, there have been numerous attempts to understand underlying causes of injury incidents on mining equipment, but available studies very rarely analyze and do not systematically identify, quantify and evaluate risks related to bulldozers. The risk calculation was realized by applying the semi-quantitative method in risk assessment. The experimental part of the research was conducted on a mining machine, bulldozer Komatus K155AX, for which risk mapping was performed and conclusions on the most significant stoppages from the risk aspect were made. The results of the research indicated that there were no high and moderate risk stoppages in the observed machine. The most significant stoppages were identified for danger level 6 mechanical types of stoppages. It is also significant that in the observed time period in which the work of the mining machine was recorded and monitored, no organizational stoppages or stoppages due to human factors were recorded, which indicates the efficiency of the maintenance function.*

***Key words:*** *Bulldozer, work efficiency, stoppages, risk.*

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## 1. INTRODUCTION

The open-cast coal mining is complex and demanding industry which needs high operational efficiency [9]. Historically, mining has also been one of the most dangerous work environments [7,4]. Bulldozers as heavy mobile machines are very useful in mining processes as auxilary machines which generate up to 20% of the total mining expenses [3]. They are equipped with a front pusher blade, which can be raised or lowered by hydraulic control and is used for digging and pushing [6,10] by which contribute to the efficient performance of work on mining sites. They are designed to satisfy the highest standards even when working in a three-shift mode and under unfavorable weather conditions [3]. The bulldozers, usage costs consist not only of investing in new equipment, but laso of its later failures, inability to complete assignments and standstills. Even more, the health and safety of the employees in open pit mines or thier injuries are also very important [11], [12]. But, the proportion of total mine fatalities attributable to the equipment such as bulldozer is rising over time [7]. Till now, there were numerous attempts to understand underlying causes of injury incidents on mining equipment [3,8,13,11,1,5,2]. However, these studies very rarely analyze and do not systematically identify, quantify and evaluate risks related to bulldozers. Therefore, there is a need to collect data and develop a risk assessment process and in that manner characterize risks associated with bulldozers as this survey aims to. The structure of this survey is as follows. After introduction, this paper introduces methodology applied, later on gives experimental research and at last conclusions are given.

## 2. RESEARCH METHODOLOGY

The methodology of research work refers to the analysis of the operational work of the observed machine through the ratio output/input, i.e. the amount of fuel/number of operating hours of the machine, and then to identify stoppages that occurred on the observed machine. The preparation of the research refers to the identification of parameters that need to be recorded in a period of one year. Therefore, in addition to monitoring the amount of fuel refueled and the number of operating hours, it is necessary to record the time of occurrence of stoppage, Down Time, the type of stoppage that occurred and a brief description of stoppage.

The research plan proposed that all stoppages should be classified according to type into: technological, electrical, mechanical, human factor, organizational and external stoppages.

The aim of the research is to determine the stoppages with the highest risk based on the frequency of stoppage by type and Down Time, which would indicate the direction of the maintenance strategy in the direction of risk reduction (worker safety, machine efficiency, maintenance costs, etc.).

## 3. EXPERIMENTAL PART OF THE RESEARCH

The study monitored the operation of the bulldozer Komatsu 155AX (year of manufacture 2011) over a period of 18 months. Table 1 shows the data on the operational work of the observed machine and the average fuel consumption.

*Table 1. Operational work of Komatsu 155AX bulldozer*

| Motor hour | Month | Number of machine operating hours | Fuel consumption |
|---|---|---|---|
| 18593-18833 | jan | 240 | 27,58 |
| 18833-19005 | feb | 172 | 29,83 |
| 19005-19268 | march | 263 | 28,9 |
| 19268-19508 | april | 240 | 29 |
| 19508-19745 | may | 237 | 26,54 |
| 19745-19979 | jun | 234 | 28,72 |
| 19979-20220 | july | 241 | 28,3 |
| 20220-20402 | avg | 182 | 28,57 |
| 20402-20627 | sept | 225 | 27,33 |
| 20627-20880 | okt | 253 | 30,04 |
| 20880-21135 | nov | 255 | 28,75 |
| 21135-21278 | dec | 143 | 31,89 |
| 21278-21370 | jan | 92 | 28,15 |
| 21370-21390 | feb | 20 | 27 |
| 21390-21648 | march | 258 | 30,43 |
| 21648-21891 | april | 243 | 29,84 |
| 21891-22180 | may | 289 | 27,47 |
| 22180-22492 | jun | 312 | 29,97 |
| 22492-22761 | july | 269 | 28,29 |
| 22761-23019 | avg | 258 | 28,1 |

Figure 1 graphically shows the data given in Table 1. Uniform average fuel consumption can be observed during the recorded time period, but also significant deviations in the operational work of the machine during February and deviations in the amount of refueled fuel also during February.

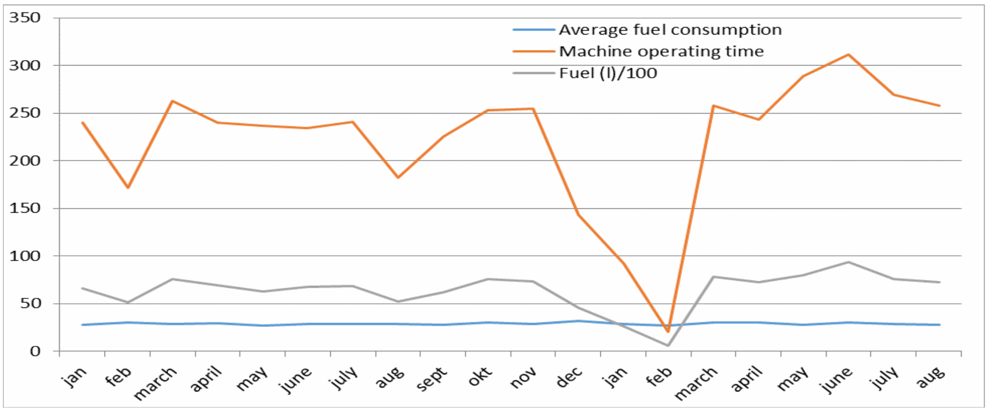


*Figure 1. Operational work of the bulldozer and the amount of fuel poured by months*

In addition to the operational work of the observed mining machine, stoppages were monitored in terms of duration and frequency. All identified stoppages were classified into danger categories on a scale of 1 to 10 (where a score of 10 represents the highest level of danger). During the monitored period, no stoppages with a score of 10 were identified. In the further research, only stoppages with a level of danger greater than or equal to 6 were observed as relevant stoppages for further research. A total of 102 such stoppages have been identified. In Table 2, the summary duration of stoppages of danger levels 6 and more per month is presented.

*Table 2. Down Time by months*

| Date | Danger level 6 | Danger level 7 | Danger level 8 | Danger level 9 | Total |
|---|---|---|---|---|---|
| june2014 | | | 60 | 30 | 90 |
| july2014 | 135 | 170 | | | 305 |
| sept2014 | 455 | 180 | 55 | | 690 |
| avg2014 | 150 | 55 | 60 | | 265 |
| okt2014 | | 30 | | | 30 |
| nov2014 | 355 | 175 | 30 | | 560 |
| dec2014 | 725 | 90 | 205 | | 1020 |
| jan2015 | 165 | | 30 | | 195 |
| feb2015 | 275 | | | | 275 |
| apr2015 | 55 | | 60 | | 115 |
| march2015 | 30 | | 60 | 210 | 300 |
| may2015 | 60 | | | | 60 |
| june2015 | 40 | | | | 40 |
| july2015 | 190 | 20 | 120 | | 330 |
| avg2015 | 55 | | | | 55 |
| sept2015 | 60 | | | | 60 |
| Grand Total: | 2750 | 720 | 680 | 240 | 4390 |

In order to compare the data, in Table 3 only shows the months in which the operational work of the fuel consumption machine (in liters, divided by 100 due to the size of the unit), average fuel consumption and monitored stoppages (period from July to August next year), Down Time and frequency of occurrence were recorded.

Figure 2 graphically shows the data from Table 3. A comparison of the data indicates that the number of stoppages and Down Time does not correlate with the number of operating hours of the machine, nor the amount of fuel filled. That is, the maximum number of operating hours of the observed machine was recorded in

June (312) and in that month the maximum amount of fuel (935 liters) was filled, while the Down Time was only 0.67 hours and there were only 8 stoppages of danger level  6 and more. On the other hand, the highest frequency of stoppages was recorded in December, when the Down Time was the highest (17 hours), while the number of operating hours of the machine was only 143 and 456 liters of fuel were poured. The amount of refueling and the number of operating hours of the machine are highly correlated (0.99 correlation coefficient), also the frequency of stoppages and Down Time are highly correlated (0.85 correlation coefficient), while the correlation coefficient between the number of operating hours and Down Time was only 0.35.

*Table 3. Operational work of the machine and frequency and Down Time*

| Month | Number of machine operating hours | Fuel (l)/100 | Avg Fuel consumption | Down Time [hours] | Stoppage frequency |
|---|---|---|---|---|---|
| july | 241 | **68,2** | 28,3 | 5,08 | 5 |
| avg | 182 | **52** | 28,57 | 11,50 | 10 |
| sept | 225 | **61,5** | 27,33 | 4,42 | 12 |
| okt | 253 | **76** | 30,04 | 0,50 | 1 |
| nov | 255 | **73,3** | 28,75 | 9,33 | 13 |
| dec | 143 | **45,6** | 31,89 | 17,00 | 19 |
| jan | 92 | **25,9** | 28,15 | 3,25 | 6 |
| feb | 20 | **5,4** | 27 | 4,58 | 6 |
| march | 258 | **78,5** | 30,43 | 1,92 | 4 |
| april | 243 | **72,5** | 29,84 | 5,00 | 4 |
| may | 289 | **79,4** | 27,47 | 1,00 | 2 |
| jun | 312 | **93,5** | 29,97 | 0,67 | 8 |
| july | 269 | **76,1** | 28,29 | 5,50 | 8 |
| avg | 258 | **72,5** | 28,1 | 0,92 | 3 |

In the further research, only the causes of stoppages were considered, regardless of the operational work of the machine and their distribution by months during the recorded time period. The aim of the research is to determine the causes that most often lead to machine stoppage, according to the degree of danger, in order to identify the causes of stoppages that pose the greatest risk to the operation of the machine. In this sense, all recorded stoppages are classified by type of stoppage into: technological, electrical, mechanical, organizational, human factor (abuse) and external (caused by external factors). During the short period of time, no stoppages of organizational, abuse and external nature were recorded. Table 4 shows the frequencies of stoppages by level of danger and type of stoppage.

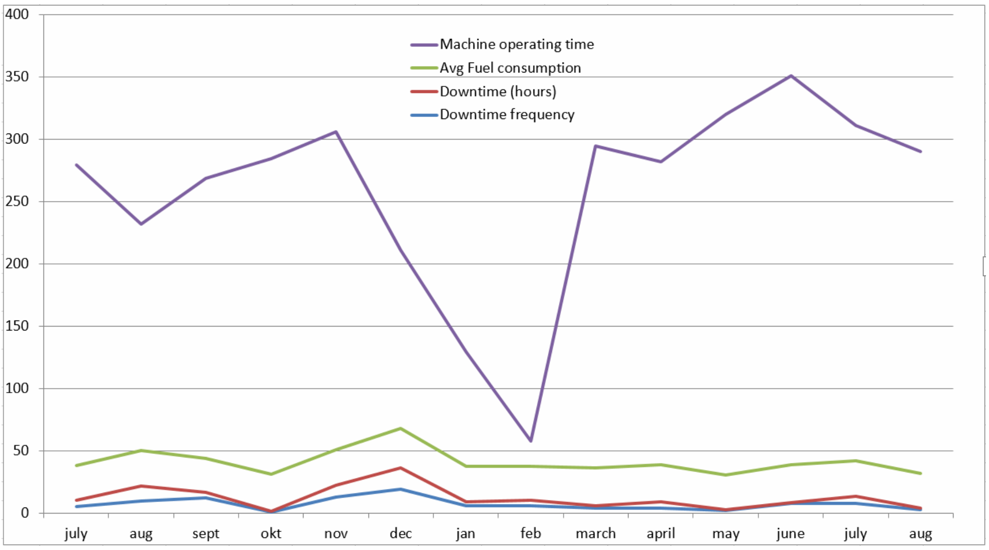


*Figure 2. Comparison of machine operation time and Down Time*

The largest number of stoppages was of a mechanical nature (failure of a component, malfunction, etc.), i.e. the percentage of mechanical stoppages was 73%. Figure 3 shows the percentage share by types of stoppage, while Figure 4 shows the percentage share of stoppages by danger levels. From the aspect of the level of danger, the largest share in the frequency of occurrence are stoppages of the level of danger 6, i.e. 70%.

*Table 4. Frequency of occurrence of stoppage by level of danger and type of stoppage*

| Danger level | Technological | Electrical | Mechanical | Total |
|---|---|---|---|---|
| Danger level 6 | 25 | 1 | 46 | 72 |
| Danger level 7 | 1 | 1 | 13 | 15 |
| Danger level 8 | | | 12 | 12 |
| Danger level 9 | | | 3 | 3 |
| Total: | 26 | 2 | 74 | 102 |

Figure 5. shows the percentage share of stoppages by danger level and type, while Figure 6. shows the percentage share of stoppages by type and danger level.

The calculation of stoppage risk [14] is performed according to the formula:

$$R = P\ (\text{probability}) \cdot Co\ (\text{Consequnces}) \quad (1)$$

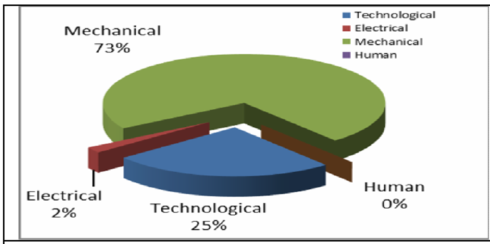


*Figure 3. Percentage share of stoppages by type*

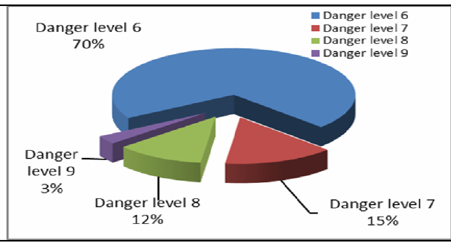


*Figure 4. Percentage share of stoppages by danger levels*

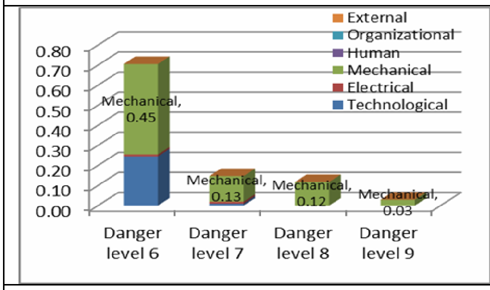


*Figure 5. Percentage share of stoppages by danger level and type*

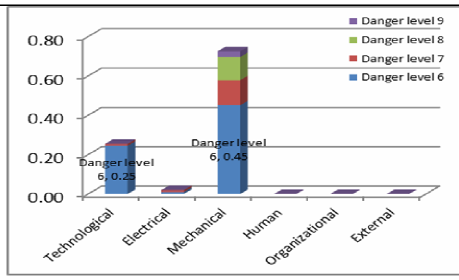


*Figure 6. Percentage share of stoppages by type and danger level*

Since the frequency of occurrence can be used as a value of the assumed probability of an adverse event and the level of danger as a value expressing the magnitude of the consequences, it follows that it is possible to calculate the risk of identified stoppages, as shown in Table 5.

*Table 5. Calculation of risk for identified stoppages (percentage share of stoppage frequencies (level of danger)*

| Danger level | Technological | Electrical | Mechanical | Total |
|---|---|---|---|---|
| Danger level 6 | 14,71 | 0,59 | 27,06 | 42,35 |
| Danger level 7 | 0,69 | 0,69 | 8,92 | 10,29 |
| Danger level 8 | 0,00 | 0,00 | 9,41 | 9,41 |
| Danger level 9 | 0,00 | 0,00 | 2,65 | 2,65 |
| Total: | 15,39 | 1,27 | 48,04 | 64,71 |

Figures 7 and 8 show the calculated risk by types of stoppage and danger levels. The risks of mechanical danger levels 6 stand out in terms of importance, however, the risk calculation has increased the importance of mechanical risks of danger levels 7 and 8.

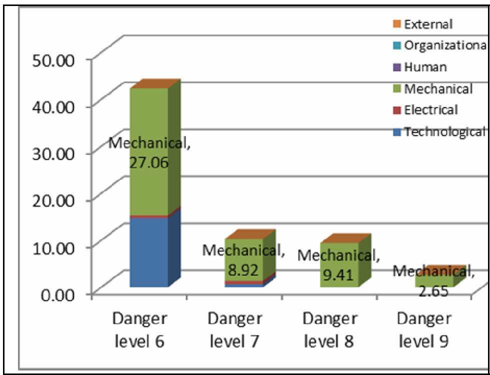


*Figure 7. Risk calculation by danger levels and types of stoppages*

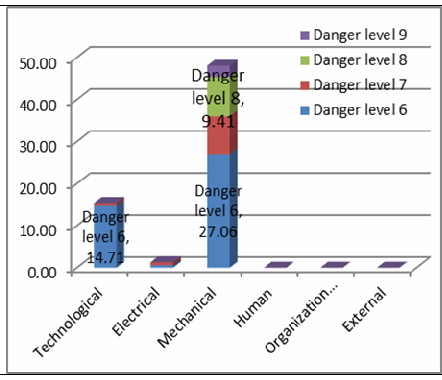


*Figure 8. Risk calculation by types of stoppages and danger levels*

In Table 6, the ranking of risks by importance was performed, and only the most significant identified stoppages from the aspect of risk are shown.

*Table 6. Ranking of stoppage risk by priority*

| Type of stoppage | Danger level | Danger level | Risk | X-axis |
|---|---|---|---|---|
| Mechanical | Danger level 6 | 6 | 27.059 | 45.10% |
| Technological | Danger level 6 | 6 | 14.706 | 24.51% |
| Mechanical | Danger level 7 | 7 | 8.922 | 12.75% |
| Mechanical | Danger level 8 | 8 | 9.412 | 11.76% |
| Mechanical | Danger level 9 | 9 | 2.647 | 2.94% |
| Electrical | Danger level 7 | 7 | 0.686 | 0.98% |

Figure 9 shows the risk mapping. The x-axis shows the percentage frequency of occurrence of adverse events, while the y-axis shows the level of danger. The analysis indicates that the most significant in terms of risk are mechanical stoppages of danger level 6, followed by mechanical stoppages of danger levels 8 and 9. The key causes of stoppages in the category of danger levels 8 and 9 are: bolt, caterpillars and guide wheel.

## 4. CONCLUSION

The paper presents the methodology of research on risk identification in bulldozers, classification and risk assessment based on stoppages that occurred in the previous period. The research methodology was based on the semi-quantitative approach of risk assessment in the observed machine. Quantitative data referred to the numerically calculated probability of unwanted stoppages in the observed machine, while qualitative data referred to the expert qualitative assessment of the level of danger of each of the identified stoppages. The results of the research indicated that there were no high and moderate risk stoppages in the observed machine. The most significant stoppages were identified for danger level 6 mechanical types of stoppages. It is also significant that in the observed time period in which the work of the mining machine was recorded and monitored, no organizational stoppages or stoppages due to human factors were recorded, which indicates that the efficiency of the maintenance function.

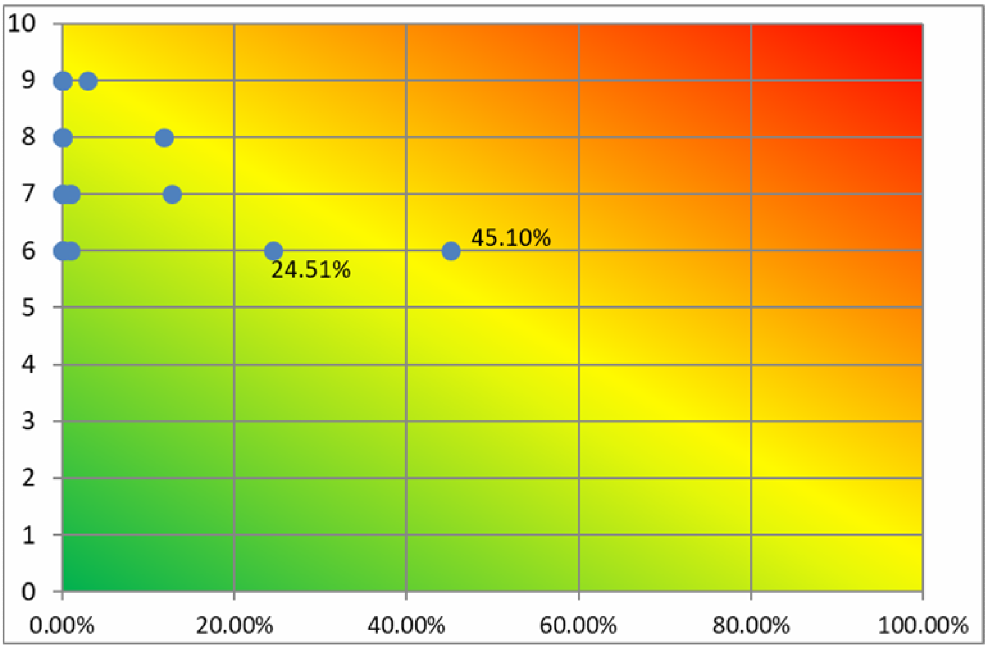


*Figure 9. Risk mapping*

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