

COMPARATIVE ANALYSIS OF DIFFERENT METHODS OF RELIABILITY ASSESSMENT FOR CONTINUOUS MINING TECHNOLOGICAL SYSTEMS

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Abstract The paper deals with the analysis of reliability parameters of continuous mining systems using different approaches in order to perform a quick assessment of the overall equipment effectiveness of this kind of production systems, such as Monte Carlo simulation and stress-strength interference.

Keywords: mining, reliability, simulation, effectiveness

1. GENERAL REMARKS

The continuous mining production systems consist mainly in a string of equipment starting with winning equipment (shearer loader, in case of underground longwall mining or bucket wheel excavator in case of open pit mining), hauling equipment (armored face conveyor in longwall mining or the on-board belt conveyor in case of excavators), main conveying equipment (belt conveyor in both cases), transfer devices, stock pile or bunker feeding equipment. This system of mainly serially connected elements is characterized by the throughput (overall amount of bulk coal respectively overburden rock), which is dependent on the functioning state of each involved equipment, and is affected also by the process inherent variability due to the randomness of the cutting properties of the rock.

2. RELIABILITY ANALYSIS BY SIMULATION

In fig 1 the diagram of the monthly production of a bucket wheel excavator based production system operating in a Romanian open pit mine is presented, in comparison with another, presented in fig. 2. The first one has a more intensive operating regime (throughput larger with about 50% than the second one, due to the smaller ratio coal/ overburden produced). Also we can see the breakdown total hours are greater for the first one than the second one, working mainly in overburden rock.

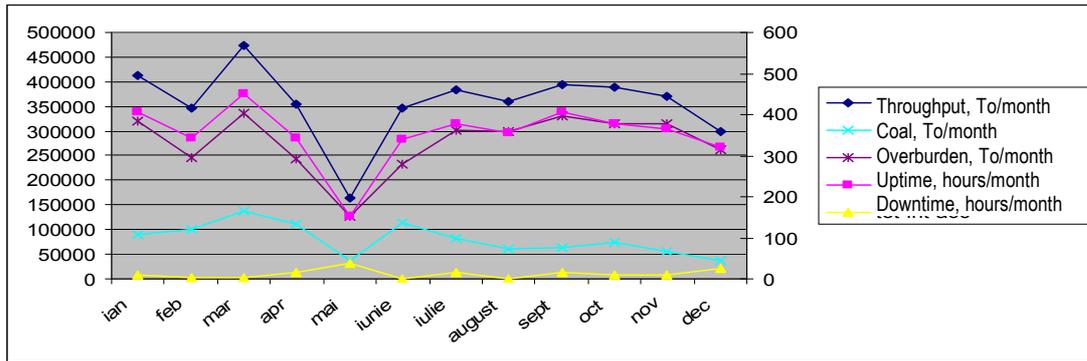


Fig. 1. Operation diagram of the Excavator no. 1

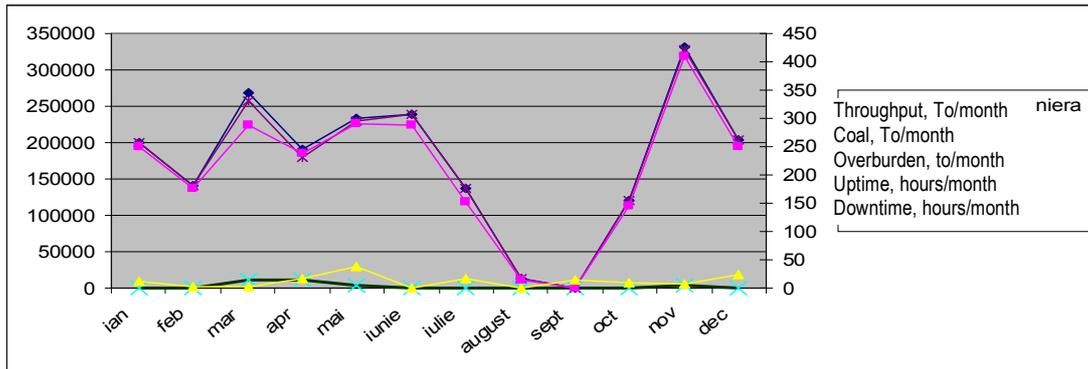


Fig. 2. Operation diagram of the Excavator no. 2

Starting from the main reliability parameters determined on the basis of these recorded data, such as MTBF and MTTR, respectively, λ and μ , the exponential distribution associated parameters, rate of failure and rate of repair, using the Monte Carlo simulation method, we simulated the operating cycles during one month.

This kind of continuous production system is producing a variable material flow until the breakdown of an element at the moment t_{fi} which causes the stop of the system. After a certain period of time t_{ru} , the system is repaired and restarts, until the next breakdown is produce at the moment t_{fi+1} .

The production flow can be seen as weighted with a series of Heaviside functions containing binary values 1 and 0, the cadence of breakdowns, the duration of operating times and the duration of repair times being random variables.

The alternating uptimes and downtimes are cumulated until they reach the simulation period T . The simulation is repeated many times using different values for Q_m and σ , describing the variability of the production (fluctuations) and for λ and μ , characterizing the random behavior of the cadence of uptimes and downtimes.

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- average monthly production $Q_{\text{month med}} = 357\,400 \text{ m}^3/\text{month}$;
- average hourly production $Q_{\text{hour med}} = 1117 \text{ m}^3/\text{hour}$;
- monthly production standard deviation $\sigma_{\text{month}} = 96\,998 \text{ m}^3/\text{month}$;

- hourly production standard deviation $\sigma_{\text{hour}} = 303 \text{ m}^3/\text{hour}$;
- average monthly operating time $T_{\text{fm}} = 320 \text{ hours /month}$
- working time standard deviation $\sigma_{\text{tf}}=91 \text{ hours}$;
- overall available time $T= 744 \text{ hours}$;
- Breakdown rate $\lambda=1/(320/30) = 0,09375$; repair rate $\mu =0.071$
- Average number of breakdowns $n_{\text{def}} = 30$.

The simulated variability of the production system, with above data, considering breakdown-safe operation is given in figure 3. This case of simulation has been realized an average hourly production $Q_{\text{med hour}} = 1094 \text{ m}^3/\text{hour}$ and a standard deviation of $\sigma_{\text{hour}} = 302 \text{ t(m}^3\text{)}/\text{hour}$ Using the exponential distribution law we obtained by simulation the histograms of the distribution of operating and repair times shown in figures 4 and 5.

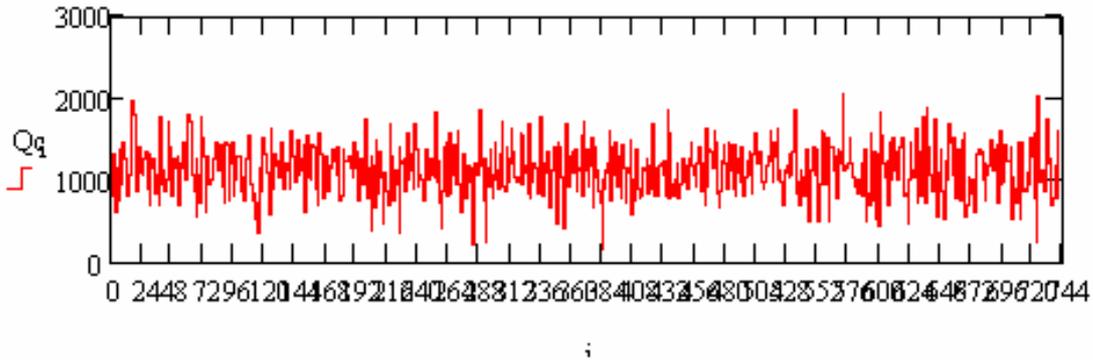


Fig. 3 The inherent production fluctuation over time

The state diagram showing the transition cadence from operating to down times and vice versa is presented in fig. 6.

Superposing the two diagrams (fig 3 and fig 6) we obtain the hourly production diagram which takes into account the up and downtimes, as in fig. 7.

If we realize a number high enough of iterations, by averaging, we obtain the average data near to start input data considered. In this way, we calibrate the model to reflect the actual situation.

Now, we can study different scenarios changing the input parameters, as reduction of the average repair time, or reducing the fluctuation of the production rate.

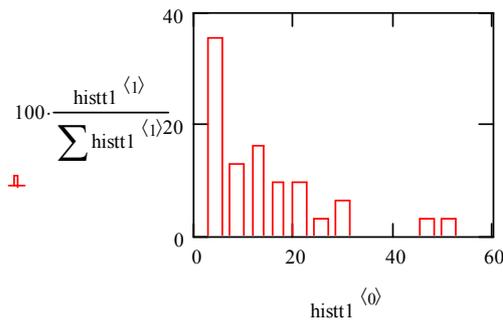


Fig. 4 Histogram of uptimes

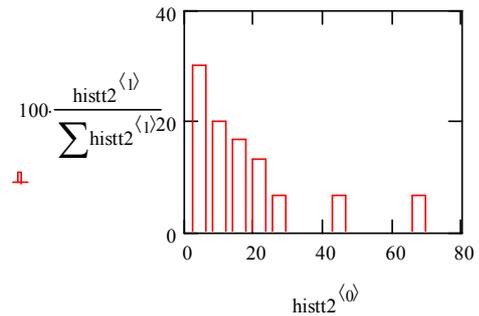


Fig. 5 Histogram of downtimes

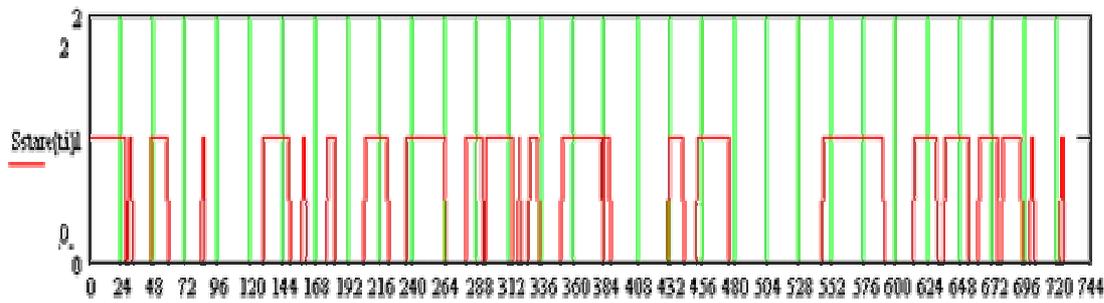


Fig. 6 Simulated state diagram of the system

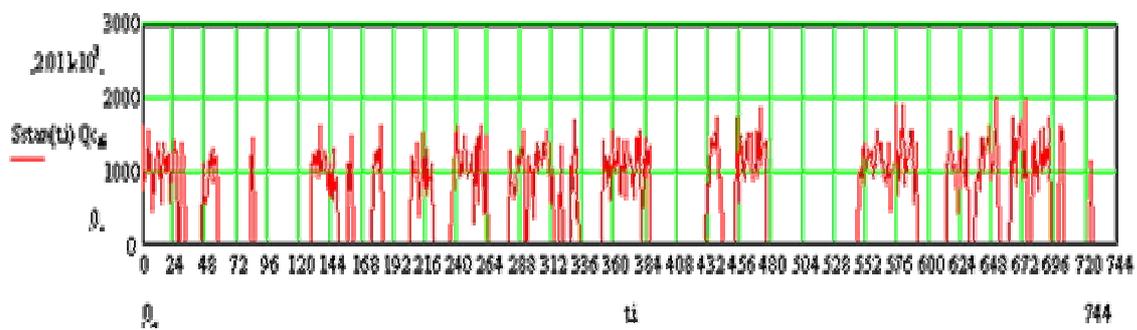


Fig. 7 Diagram of simulated hourly production during 1 month

3. STRESS STRENGTH INTERFERENCE

In the literature, the influence of operating regime, load, stress, requirement, as independent variable, on the safety of work, reliability, probability of failure, and degree of damage of the failure as dependent variable is considered in the conditional reliability theory using the stress-strength interference method. The method is originated in the sizing methods based on probability of the variable loaded systems, as a response to the limits of classical sizing procedures.

In the frame of the classical method, the yield value of strength S and the estimated value of load L are defined. It is presumed that L is always less than S , the difference $S-L$ being called safety range while the ratio S/L is called safety factor.

By designing a system based on this theory, the reliability of a system is considered infinity, and the probability of failure is equal to zero. The failure occurrence after a time period is considered due to the decrease of S over time due to the fatigue, or the occurrence of an accidental load greater than L .

Mining equipment is facing both causes of probability of failure due to the randomness of the sources of load, accidental overloads and fatigue due to wear of components. We propose and demonstrate the application of this method to the analysis of the safety of operation of mining production systems.

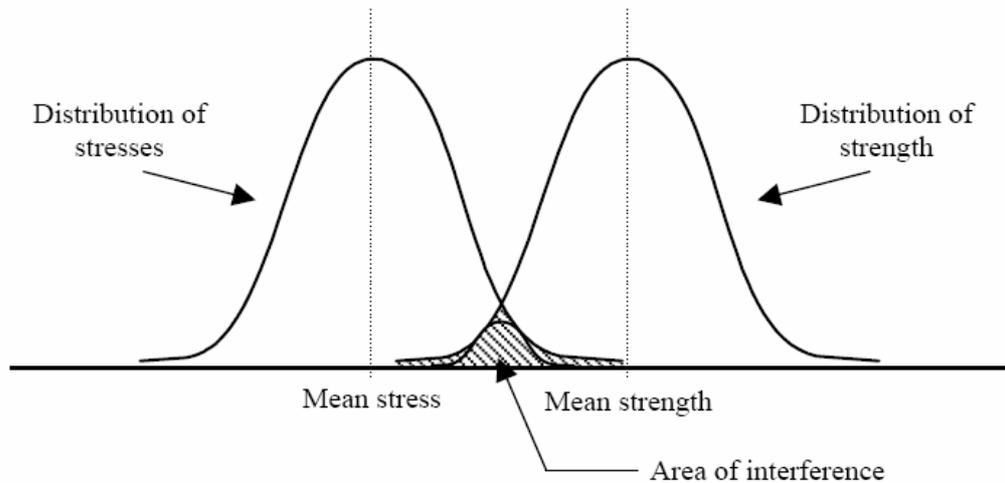


Fig. 8. Principle of the stress-strength interference

In the fig. 8 is presented the principle of the method. The strength S , in general meaning, is a metric of the capacity of a component to resist to loads without damaging, and has not a constant value, being a random variable. On the horizontal axis we have compatible meanings, such as load, requirement, capacity, flow rate, in physical values. On the vertical axis we have probabilities or probability densities, of the occurrence of the given values. Similarly to strength, the load has also a random variation, so we can represent both distributions on the same picture.

As it can be seen, the two probability fields present an area of interference, which signify that it is possible to existing situations in which the load is greater than the strength. From here it results a third distribution, the probability of the event $L \geq S$, which is the conditional failure probability.

As an example, using a MathCAD program, we drawn up the Load Strength interference diagrams for the Bucket Wheel Excavators discussed before.

In our study, we consider as load the specific cutting energy is considered, which is between 0,08 and 0,4 kWh/ m³ for lignite, with a larger spread of values, respectively 0.18 and 0,2 kWh/ m³ for overburden rock, with narrower spread. As strength, the nominal value of the excavator was considered, as 0.35 kWh/m³, with a normally distributed variability, due to variability of working conditions.

With these values, the Load Strength interference diagrams were drawn up for the two cases, presented in figs. 9 for overburden and 10 for lignite.

As it can be noticed, the degree of non-reliability is greater for the excavator operating in lignite, about 15% , then for the excavator working in overburden, hen is practically zero.

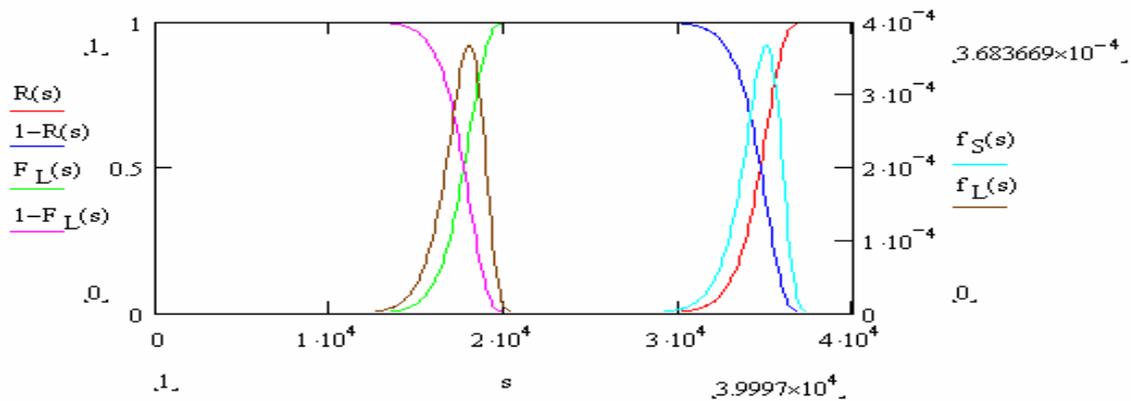


Fig. 9. The L-S interference charts for the excavator working in overburden rock (Specific energy consumption in kWh/ m³ 10⁵ on x axis)

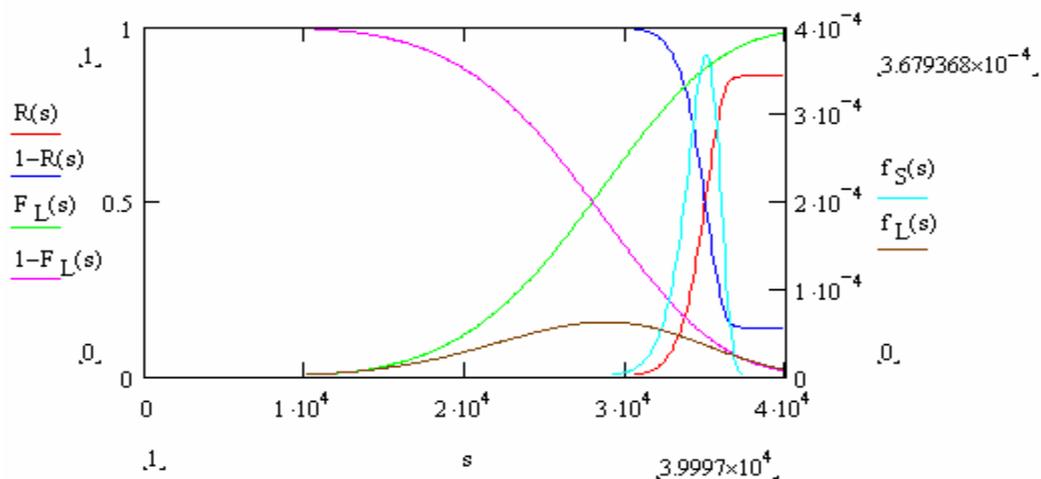


Fig. 10. The L-S interference charts for the excavator working in lignite (Specific energy consumption in kWh/ m³ 10⁵ on x axis)

4. CONCLUSION

In order to find out new methods for the quick assessment of large production systems used in coal mining, we presented and tested by real world examples two alternative – complementary methods of reliability analysis, namely the Monte Carlo simulation and the Load Strength Interference methods. The results obtained are convergent and offer the opportunity for further developments of their application.

5. REFERENCES

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