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OVERALL EQUIPMENT EFFECTIVENESS ASSESSMENT OF THE OPEN PIT COAL MINING PRODUCTION SYSTEM

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Abstract: Using simulation for materializing the metrics of OEE in case of open pit lignite mines production systems considering the reliability, availability and performance in order to assess and predict the overall production capacity of a continuous complex production system is done for the first time in Romania. Defining the instantaneous production rate as a combination of fluctuant random variable and a binary probability state function, the recorded data considering the duration of repairs and the cadence of breakdowns, in the frame of an informatic system, and using Monte Carlo simulation are new approach in the study of such systems, and translation of the concept of OEE in the continuous mining systems behavior are fruitful for the formulation of practical recommendations.
Keywords: mining, lignite, excavator, reliability, availability, uptime, downtime

1. STATEMENT OF THE PROBLEM

In the manufacturing systems analysis, a synthetic metric is used, to describe the effectiveness of assets, known as OEE (abbreviation for the manufacturing metric Overall Equipment Effectiveness). OEE takes into account the various sub components influencing the effectiveness of a manufacturing process – Availability, Performance and Quality. After the various factors are taken into account the result is expressed as a percentage. This percentage can be viewed as a snapshot of the current production efficiency for a machine, a production line or a manufacturing cell.

Generally, OEE is considered to be the product *OEE= Availability x Performance x Quality.*

The mining production systems which produces a quasi uniform flow of bulk product, the availability is the probability of the system to fulfill the task, the performance is the degree of operating relative to the nominal production rate, and the quality is the grade of the ore, or other parameter describing the net value of the product. For this particular type of production systems, the OEE can be redefined as *OEE= Availability x Utilisation x Production Performance.*

By this, not only the performance of the equipment is taken into account, but also the amount of utilization of the time budget.

The Availability (A) is the proportion of time the equipment is able to be used for its intended purpose.

The Utilization (U) is the proportion of the time that the equipment is available and it is used for its intended purpose. It is important to realize the difference between availability and reliability. While availability measures the proportion of the total time that the equipment is available, reliability measures the frequency with which it breaks down.

The Reliability (R) describes how often the equipment does not fulfill its intended purpose - usually measured by Mean Time Between Failures (MTBF).

Clearly Reliability and Availability are related, but not necessarily directly - it is possible to have a piece of equipment that breaks down frequently, but for short periods, which as a result has a reasonable level of availability. Similarly, it is possible to have a piece of equipment that is highly reliable, but has a low level of availability because it is out of service for maintenance for long periods at a time.

The traditional view of Availability and Utilization maintains that achieving high equipment Availability is a Maintenance responsibility, while achieving high utilization is a Production responsibility. By maintaining both high equipment utilization and high equipment availability, maximum output will be achieved from the equipment.

Consider, however, the situation where a conveyor is operating, but, because of some problems it can only haul at 80% of its normal capacity. The conveyer is available, and being utilized, according to our definitions, but clearly maximum output is not being achieved.

Consider also, for example, the situation where an excavator trips to another location, causing a certain delay while it is reset. During this time, the conveyors are available, but they are working empty. They are available, and being utilized, but maximum output is not being realized.

We must include an additional measure - which is called Production Efficiency, or Production Performance.

The Production Performance is the ratio of actual output from a machine (which meets the required quality standards) to its rated output, during the time that it is operating.

Poor reliability, while having some impact on equipment availability, is likely to have a bigger impact on Production Efficiency, due to the inefficiencies associated with starting up and shutting down equipment, and the time and effort that it takes to get the production operation back to a steady state situation.

It is fair to say that the costs of poor reliability generally show up in lower Production Efficiency. This is a measure that is often not given the same emphasis as Availability or Utilization measures, and in any case is generally considered to be a Production responsibility, with the impact of Maintenance on this figure generally being ignored.

Furthermore, analysis of reliability figures at many mining operations indicates that the Mean Time between Failures (i.e. process interruptions), can be as low as a few hours. Not unsurprisingly, Production output in these operations falls well short of the theoretical rated capacity. In these operations, the impact of poor reliability far outweighs the costs associated with equipment availability and utilization (which are generally quite high).

As a relatively new measure being used for Equipment performance is the Overall Equipment Effectiveness. This gives an overall measure of how effectively an asset is being used.

The open pit coal mines production system consist mainly in a string of equipment starting with winning equipment (bucket wheel excavator), on board hauling equipment , conveying equipment, transfer devices, spreaders or stackers , used alternatively for overburden removal conveying disposal and for coal winning conveying stacking. This system of mainly serially connected elements is characterized by the throughput (overall amount of bulk coal respectively overburden rock), which is strongly dependent on the functioning state of each involved equipment.

According to V. Pavlovic [1] the forecast of the throughput of a continuous mining system is base don the reliability metrics. As the wining hauling spreading/stacking systems are. The reliability metrics are derived starting from the analysis of the different possible states of a system taking into account the states of operation and breakdown duet o shutdowns, technological breaks, and all kind of non planned stop. Planned stops are not object of this analysis. The operation of a continuous mining system is considered as a random process with exponential distribution for continuous operating and repair times and normal distribution of the instantaneous throughput.

The instantaneous throughput is defined as the product of an average constant production rate with the random variation (fluctuation) with a given distribution and the uptime probability.

Thus, the technical system of open pit production line can be considered as a system of n elements connected in serial connection representing a Markov type random system with exponential distribution of operating time (uptime) T_f and out of work-repair time (downtime) T_r.

The states of the system, working state with probability P_o and out of work (repair state) with probability P_1, are characterized by the uptime rate □ and the downtime (repair) rate μ and are described by the differential equations:

$$\frac{dP_0}{dt} = -\lambda P_0 + \mu P_1 \ , \tag{1}$$

$$\frac{dP_1}{dt} = \lambda P_0 - \mu P_1 , \tag{2}$$

Where

$$P_0 + P_1 = 1 , \tag{3}$$

From which it results

$$\frac{dP_0}{dt} = -(\lambda + \mu) P_0 + \mu \ . \tag{4}$$

By integrating we obtain the values for the probabilities P_0 and P1:

$$P_0(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}, \tag{5}$$

$$P_1(t) = \frac{\lambda}{\lambda+\mu} - \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t} = 1 - P_0(t), \tag{6}$$

where

$$\lambda = \lambda_1 + \lambda_2 + \ldots + \lambda_n, \tag{7}$$

$$\mu = \frac{\lambda_1 + \lambda_2 + \ldots + \lambda_n}{\sum_{i=1}^{n} \frac{\lambda_i}{\mu_i}}. \tag{8}$$

When $t \to \infty$, the analysis is performed on a long term, the given probabilities are:

$$P_0 = \frac{\mu}{\lambda+\mu}, \tag{9}$$

$$P_1 = \frac{\lambda}{\lambda+\mu}. \tag{10}$$

The availability of the system is dependent on the states A_{ij}, of the components, for i=0 the working (operating) state as for i>0 the non operating states duet o different reasons. For 1<i<n, and j=1, the system is waiting for repair, for j=2, the repair is ongoing, for j=3, the system is waiting to start after repair. The state $A_{n+1,1}$ is corresponding to the situation in which the system is available, but cannot function because of incompatible auxiliary operations, the state $A_{n+2,1}$ describes the situation in which the system is available but doesn't work because of operating environment. We can also consider the state $A_{n+3,1}$ corresponding to the nonfunctioning duet o lack of manpower, and the state $A_{n+4,1}$ when the system is out of work duet o other causes. Other states $A_{n+5,1}$, $A_{n+6,1}$, $A_{n+7,1}$ are states of out of work duet o planned repair or maneuvers.

The production rate or throughput of a continuous production system is the flow of mined out ore or overburden representing a random function with random presence and absence of the material flow. The random throughput Q(t) can be represented as a product of a discrete(binary) value $Q_p(t)$ describing the probability of the presence of the flow and a continuous random process of the throughput flow $Q_m(t)$ representing the random fluctuation around a mean value, duet o the random influences of working environment variability. .

The discrete part of the process can record only two values, respectively $Q_{p1} = 0$ and $Q_{p2} = 1$, the state transfer probability from 0 to 1 being aΔt, and from 1 la 0 being bΔt, where a and b are the inverses of the average times of presence and absence of the flow of produced material.

The instantaneous (actual) production rate is characterized by the material flow rate Qc, as a continuous component of the process output which is also random function with a mean (average) value (expectation) Qe =E(Q). Previous researches has shown that the throughput of a bucket wheel excavator fits a normal distribution with a mean value Qe and a standard deviation S, with fluctuations inside the interval Qc=Qe± kS

The most appropriate method to study such a process is the Monte Carlo simulation which offers the assessment of different scenarios base don data recorded from real systemsn increased efficiency in the working of the excavator shall depend on which type of excavator is being selected, in accordance with the actual mining conditions and in correlation with all the other equipment on the technological flow for mining of lignite and sterile rocks from the roof of the lignite beds. The safety in operation of a machine or engineering system represent the extent to which these machines shall fulfill their tasks and depends on their accessibility, reliability, capability and maintainability.

2. SIMULATION OF THE OPERATION OF WINNING /HAULING/ STACKING TECHNICAL SYSTEM OF THE OPEN PIT LIGNITE MINE

A continuous production system is operating producing a variable material flow until the breakdown of an element at the moment t_{fi} 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 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.

The following example refers to an open pit mine working in overburden removal in which a Bucket Wheel Excavator is excavating the rock and a haulage line with belt conveyors conveys it to a spreader which spread the rock on a waste deposit.

A simulation model was realized using MathCAD. By processing recorded data, we uses the following input figures:

- average monthly production $Q_{lun\ med}$ = 357 400 m^3/month;
- average hourly production $Q_{orar\ med}$ = 1117 m^3/hour;
- monthly production standard deviation σ_{lun} = 96 998 m^3/month;
- hourly production standard deviation σ_{orar} = 303 m^3/hour;
-average monthly operating time T_{fm} = 320 hours /month
- working time standard deviation σ_{tf}=91 hours;
- overal available time T= 744 hours ;
- Breakdown rate λ=1/(320/30) = 0,09375; repair rate μ =0.071
- Average number of breakdowns n_{def} = 30.

The simulated variability of the production system, with above data, considering breakdown-safe operation is given in figures. This case of simulation has realized an average hourly production $Q_{orar\ med}$ = 1094 m^3/hour and a standard deviation of σ_{orar} = 302 t(m^3)/hour

Using the exponential distribution law we obtained by simulation the histograms of the distribution of operating and repair times shown in figures 1 and 2.

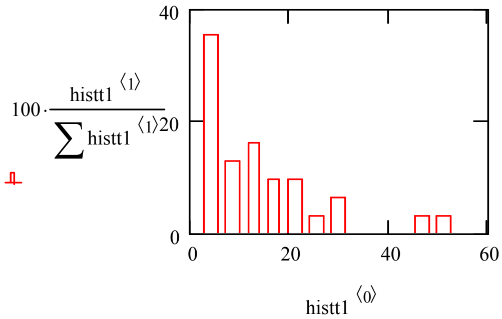

Fig. 1 *Histogram of uptimes*

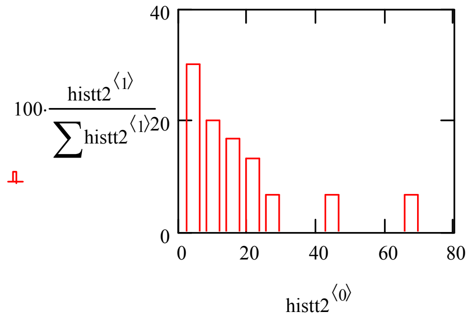

Fig. 2 *Histogram of downtimes*

The state diagram showing the transition cadence from operating to down times and vice versa is presented in fig. 3.

Superposing the two diagrams (fig 3) we obtain the hourly production diagram which takes into account the up and downtimes, as in fig. 4.

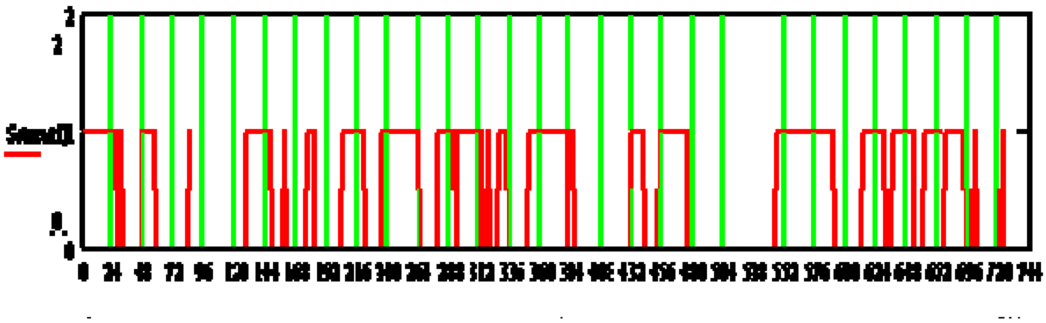

Fig. 3 *Simulated state diagram of the system*

The results of simulation are presented in table 1. 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 fluctation of the production rate. In table 2 we present the data obtained after a large number of iteration, for each month during a year compared with recorded field data. The same data are shown graphically in fig. 5.

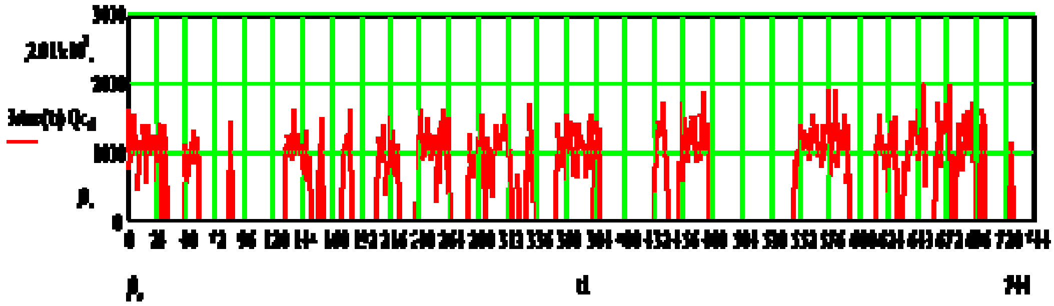

Fig. 4 *Diagram of simulated hourly production during 1 month*

Table 1

No.	Specification	Symbol	U.M.	Value
1	No. of iterațions	i	buc.	104
2	Monthly production	Q_{lun}	t(m^3)/lună	3,749·10^5
3	Hourly production	Q_{orar}	t(m^3)/oră	882,132
4	Overall time	T	ore	948
5	Operating time	T_f	ore	425
6	Downtime	T_s	ore	523
7	Operating rate	λ	1/oră	0,094
8	Repair rate	μ	1/oră	0,071
9	Mean Time Between Failures	MTBF	ore	10,667
10	Mean Time to Repair	MTR	ore	14,085

Table 2. Simulation results comparred with field data

Month	Q_{lun}		Q_{orar}		Time		Operating time		Repair time		λ	μ	MTBF	MTR	K_d
	Sim.	Real	Sim.	Real	Sim.	Real	Sim.	Real	Sim.	Real					
1	432100	409800	935	852	462	481	413	390	49	91	0,045	0,2388	22,22	4,188	0,89
2	234500	322700	664	899	353	359	279	285	74	74	0,045	0,15	22,22	6,667	0,79
3	388400	389800	848	864	458	451	366	341	92	110	0,045	0,1765	22,22	5,667	0,79
4	86460	140000	592	892	146	157	90	123	56	34	0,095	0,1194	10,53	8,375	0,61
5	224200	253000	821	814	273	311	231	221	42	90	0,039	0,1125	25,64	8,889	0,84
6	414200	398000	770	869	538	458	395	355	143	103	0,032	0,1069	31,25	9,357	0,73
7	518900	396200	1014	753	512	526	465	350	47	176	0,039	0,2537	25,64	3,941	0,90
8	432300	445300	834	837	518	532	391	410	127	122	0,025	0,474	40,00	2,11	0,93
9	322200	401800	570	815	565	493	344	340	221	153	0,035	0,09396	28,57	10,64	0,60
10	400100	369600	868	760	461	486	352	335	109	151	0,035	0,1045	28,57	9,571	0,76
11	339900	405200	676	817	503	496	307	360	196	136	0,032	0,06878	31,25	14,54	0,61
12	175600	192100	689	684	255	281	167	160	88	121	0,032	0,07018	31,25	14,25	0,65

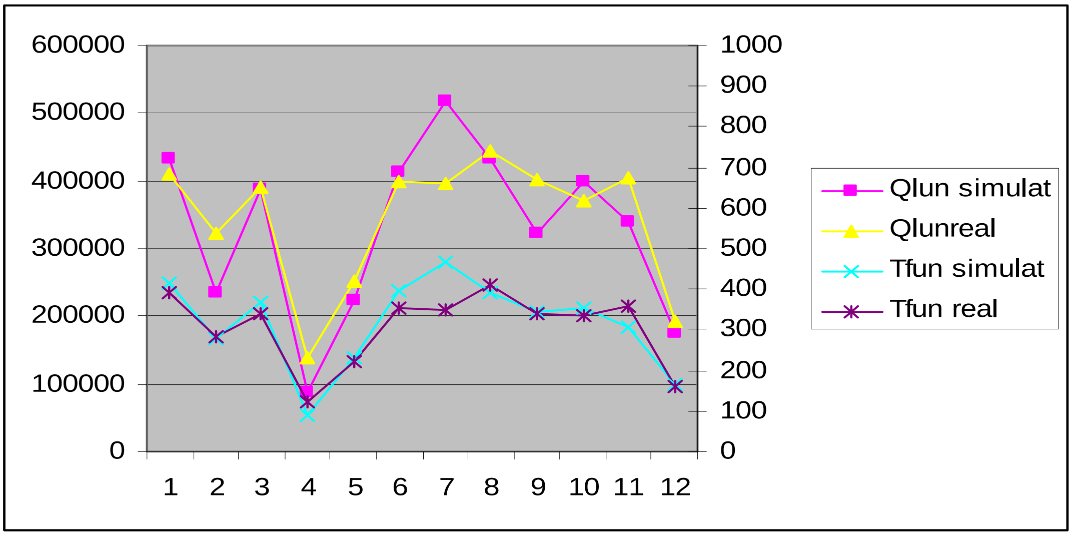

Fig. 5 *Simulated data compared with field data for 1 year*

3. CONCLUSION

Using simulation for materialising the metrics of OEE in case of open pit lignite mines production systems considering the reliability, avaialbility and performance in order to assess and predict the overall production capacity of a continuous complex production system is done for the first time in Romania. Defining the instantaneous production rate as a combination of fluctuant random variable and a binary probability stae function, the recorded datat considering the duration of repairs and the cadence of breakdowns, in the frame of an informatic system, and using Monte Carlo simulation are new approach in the study of such systems, and translation of the concept of OEE in the continuous mining systems behaviour are fruitfull for the formulation of practical recommendations.

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