1. FOREWORD

Vulcan mine plant is one of the oldest underground hardcoal mines in the Jiu Valley coalfield. Jiu Valley hardcoal is mined out since 1850, actually in 4 plants, other 3 being in downsizing and closure process. Vulcan is one of active mines, belonging to the Hunedoara Energetic Complex, with an output of about 300000 tons/year, with a foreseen lifespan until the year 2022.

The location of Vulcan mining field in the layout of Jiu Valley coalfield can be seen in figure 1.

The mine plant, due to its age and the tectonics of the coal seams, has been developed on horizontal and vertical directions in a way which led to a very large extension. In plus, the used technology specific to thick inclined seams in horizontal slices, with top coal caving, in the past 20 years, has as result a very complex and irregular structure of the conveying system.

The main conveying system consist in belt conveyors TMB 800 and TMB 1000 (the figure indicating the width of the belt) on main gates at the levels 250, 315 and 360 (elevation related to the sea level) until the intermediary silos and finally to the main hoisting shaft.

From faces to intermediate silos, the coal is conveyed using scraper conveyors.

As resulted from the mine management reports, the transportation system is responsible for many downtimes and is a real bottleneck in the constant and
adequate production, and the suspicion is the weak state of belt conveyers, which are the spinal column of the extraction process. For this reason, a comprehensive reliability analysis has been decided, in order to deliver a maintenance-upgrading plan.

2. RELIABILITY ANALYSIS OF MAIN BELT CONVEYORS

The reliability study of the main belt conveyors at Vulcan mine plant, has been performed using the data from the conveyor system monitoring books taking into accounts the records in the period June 2012 – March 2013.

The structure and occurrence frequency of faults of the conveyors in the period are presented in table 1 and in figures 2 and 3.

Table 1. Structure of faults occurred at belt conveyors

<table>
<thead>
<tr>
<th>No.</th>
<th>Subassembly failed</th>
<th>Absolute frequency of faults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No. of faults</td>
</tr>
<tr>
<td>1</td>
<td>Belt - staples</td>
<td>119</td>
</tr>
<tr>
<td>2</td>
<td>Upper and lower idlers</td>
<td>76</td>
</tr>
<tr>
<td>3</td>
<td>Belt tensioning system</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>Belt – requiring replacement</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Mechanical drive system</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>Line supports</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>256</td>
</tr>
</tbody>
</table>

The table above shows that the most frequent is the belt sections coupling staples, about 47%. This kind of fault is more relevant because they are 9 conveyers, each with one, two or three joints, remediation of a failure paralyzing for about two-three hours all the haulage system, which dramatically influence the operation cycle in all working faces.

The idlers fault and replacement has a less impact on overall mining plant availability, despite their large amount, and its large share in total of faults - about 30% because of reduced time consumption for their replacement. The large share of staple joint faults in one year of operation was the main concern leading to the necessity of the present reliability analysis.
Analyzing the occurrence of stapled joints failures, we selected from the overall 9 conveyors 3 which are similar length, working conditions and width of belt. A factor which is more difficult to be quantified is the degree of ageing of belt’s material, the three conveyors having, at the beginning of the study different operating hours.

From the available data, we inferred the running hours until the failure, obtaining the time series as follows: 50; 50; 50; 50; 50; 50; 50; 58; 58; 58; 58; 58; 58; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 60; 88; 88; 88; 88; 88; 88; 100; 100; 100; 100; 100; 100; 100; 110; 110; 110; 110; 135; 135; 147; 147; 147; 147; 147; 150; 150; 150; 150; 150; 150; 150; 154; 154; 154; 154; 170; 170; 200; 200; 200; 200; 200; 200; 200; 200; 200; 200; 200; 210; 210; 210; 210; 210; 220; 220; 220; 220; 220; 220; 230; 250; 340; 400; 420; 460; 620; 760; 760; 1100

This statistical series have 92 values and it is a statistical series of type S2 with redundant values.

For this series of running hours between two faults, the calculated empirical repartition function, \( \hat{F}(t_i) \) are presented in table 2.

<table>
<thead>
<tr>
<th>( i )</th>
<th>( t_i, ) hours</th>
<th>( n_i )</th>
<th>( f_i )</th>
<th>( \hat{F}(t_i) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>9</td>
<td>0,097826</td>
<td>0,097826</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
<td>8</td>
<td>0,086957</td>
<td>0,184783</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>21</td>
<td>0,228261</td>
<td>0,413043</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>4</td>
<td>0,043478</td>
<td>0,456522</td>
</tr>
<tr>
<td>5</td>
<td>110</td>
<td>3</td>
<td>0,032609</td>
<td>0,489130</td>
</tr>
<tr>
<td>6</td>
<td>135</td>
<td>2</td>
<td>0,021739</td>
<td>0,510870</td>
</tr>
<tr>
<td>7</td>
<td>147</td>
<td>6</td>
<td>0,065217</td>
<td>0,576087</td>
</tr>
<tr>
<td>8</td>
<td>150</td>
<td>4</td>
<td>0,043478</td>
<td>0,619565</td>
</tr>
<tr>
<td>9</td>
<td>154</td>
<td>3</td>
<td>0,032609</td>
<td>0,652174</td>
</tr>
<tr>
<td>10</td>
<td>170</td>
<td>2</td>
<td>0,021739</td>
<td>0,673913</td>
</tr>
<tr>
<td>11</td>
<td>200</td>
<td>8</td>
<td>0,086957</td>
<td>0,760870</td>
</tr>
<tr>
<td>12</td>
<td>210</td>
<td>5</td>
<td>0,054348</td>
<td>0,815217</td>
</tr>
</tbody>
</table>
The values of the Empirical repartition function are calculated with the formula:

\[ \hat{F}(t_i) = \sum_{j=1}^{i-1} f_j, \text{ for } i = 1, 2, \ldots, 22 \]  
(1)

Considering the nature of the subassembly in the study, it is assumed that the times of failure, considered between two consecutive failures are distributed following a Weibull distribution law, as this will be confirmed or infirmed using concordance tests.

The probability density of failures for tri-parametric Weibull distribution is expressed by the relation:

\[ f(t; \eta, \beta, \gamma) = \frac{\beta}{\eta} \left( \frac{t-\gamma}{\eta} \right)^{\beta-1} \exp \left( -\left( \frac{t-\gamma}{\eta} \right)^\beta \right) \]  
(2)

where \( \beta \) is the shape parameter, \( \eta \) is real scale parameter and \( \gamma \) is the initializing parameter.

The parameters of a tri-parametric Weibull distribution can be calculated using the method of moments. The shape parameter \( \beta \) is obtained by solving the equation

\[
CV = \sqrt{\frac{\Gamma \left( \frac{2}{\beta} + 1 \right) - \left[ \frac{1}{\beta} + 1 \right]^2}{\Gamma \left( \frac{1}{\beta} + 1 \right)}}
\]  
(3)

where \( CV \) is the coefficient of variation, which is obtained using the relation

\[ CV = \frac{s}{m} \]  
(4)

where \( s \) is the standard deviation and \( m \) is the mean value of the string.

The scale parameter \( \eta \) is calculated with
\[ \eta = s / C_\beta \]  

(5)

and initializing parameter \( \gamma \) with the relation

\[ \gamma = m - \eta K_\beta \]  

(6)

In these relations \( K_\beta \) and \( C_\beta \) are coefficients dependent on the shape parameter \( \beta \), which are calculated from the relations:

\[ K_\beta = \Gamma \left( \frac{1}{\beta} + 1 \right) \]  

(7)

\[ C_\beta = \sqrt{\Gamma \left( \frac{2}{\beta} + 1 \right) - \left[ \Gamma \left( \frac{1}{\beta} + 1 \right) \right]^2} \]  

(8)

For the data above, with the mean value \( m = 288.363636 \), standard deviation \( s = 258.257447 \) and \( CV = 0.895596 \), the parameters of the Weibull distribution are obtained are: \( \beta = 1.118460; \eta = 300.455874 \) ore; \( \gamma = -9.0421 \times 10^{-5} \); \( K_\beta = 0.959754; \) \( C_\beta = 0.859552 \).

By calculating the elements needed to define the distribution and verification of the Weibullian character of the analyzed product behavior using the Kolmogorov-Smirnov concordance test, we obtain the maximum distance, \( D_{\text{max}} = 0.367631 \approx D_{\alpha, n} = D_{99.5, 22} = 0.357818, D_{99.5, 22} = 0.085254 < D_{\alpha, n} = D_{80, 71} = 0.124985, D_{80, 71} \) being the Kolmogorov-Smirnov test feature for a confidence level of 99.5% and \( n = 22 \) values, so that the Weibullian character of failure times distribution is validated.

The tri-parametric Weibull distribution parameters characteristics are calculated with the equations:

- Reliability function:

\[ R(t; \eta, \beta, \gamma) = \exp \left[ -\left( \frac{t - \gamma}{\eta} \right)^\beta \right], \% \]  

(9)

- The non-reliability function:

\[ F(t; \eta, \beta, \gamma) = 1 - \exp \left[ -\left( \frac{t - \gamma}{\eta} \right)^\beta \right] \]  

(10)

- Intensity or rate of failure:

\[ z(t; \eta, \beta, \gamma) = \frac{\beta}{\eta} \left( \frac{t - \gamma}{\eta} \right)^{\beta-1} \]  

(11)

- average uptime:

\[ m = \gamma + \eta \Gamma \left( 1 + \frac{1}{\beta} \right) \]  

(12)

- median of uptimes:

\[ t_{\text{med}} = \gamma + \eta (-\ln 0.5)^{1/\beta} \]  

(13)

In figures 3, 4, 5, 6 these reliability parameters variation are presented.
Fig. 3. Variation of the reliability function

Fig. 4. Variation of the non-reliability function
Fig. 5. Probability density of failure occurrence

Fig. 6. Failure rate
The mean time to failure of belt joint is 288 hours, and the median is 216 hours.

Considering that the running time is about 20 hours per day, it is expected to have a fault of joint each 14 days.

This low reliability is shown by the diagrams above; the probability to not fail after 100 hours, i.e. one week is about 75%.

So, in order to reduce the downtimes it is necessary to improve the quality of belt joining, e.g. by replacing stapled joints with vulcanized joints.

REFERENCES

