Noise control has become an important health issue for underground coal mines in the Midwest. Over the last few years, manufacturers of mining machinery have improved their designs and developed new equipment that is less noisy. For example, Joy Mining Machinery and other mining equipment manufacturers have developed dual-strand conveyor chains for use on continuous mining machines (CMs). Evaluating these chains and associated components was the primary focus of this study.

Initial data obtained by MSHA and NIOSH laboratory investigations prior to this study show that these chains are mechanically stronger and produce lower levels of noise than conventional single-strand chains in the same application. However, performance data for production, maintenance, and noise generated under actual mining conditions are very limited. Thus, field industrial engineering studies were performed on CMs with dual-strand conveyor chains and associated components and results were compared with previous studies on conventional CMs to determine any production performance differences. Noise generation studies consisted of: 1) measuring short-term noise levels associated with CM sumps in box and slab cuts, the CM dust collection system, and CM conveyor operations using a hand-held sound pressure level meter; and 2) determining noise levels in particular frequency ranges (noise spectrum) and variations of the noise level and spectrum in time (noise dynamics) with digital continuous recordings. Noise data was also collected for roof bolters and haulage equipment as part of this study.

The study found that sound pressure generated by the CM utilizing double-strand chain was approximately twice less in comparison to the CM with a single-strand conveyor chain. This reduction of acoustical sound pressure corresponds to approximately 3.0 dBA less sound pressure level at the operator’s position. The reduction is entirely attributable to the conveyor’s redesigned structure as noise generated by the CM cutting head and dust collector did not change. A urethane-coated tail roller was tested but its functionality was compromised by the harsh mine conditions. However, use of manmade materials with high damping coefficient and high mechanical resistance to normal and shear stresses should perform well in this application and will be tested in the future.
EXECUTIVE SUMMARY

The focus of this research was priority 3.1D of the Illinois Clean Coal Institute’s (ICCI) RFP08-1, which addresses health and safety issues in Illinois coal mines, including noise in underground mines. In underground coal mines, noise is defined as an “unwanted sound” and is considered to be one of the adverse environmental factors that include unwanted vibrations, air pollution (especially dust), different chemical vapors/gasses, and air drafts. Exposure to elevated noise levels (where time is also a major factor) can cause not only noise-induced hearing loss, but also physical and physiological stress, fatigue, cardiac abnormalities, and other health concerns. Noise standards established by the Mine Safety and Health Administration (MSHA) set the noise exposure level (NEL) for miners at a time-weighted average of 85 dBA (determined using the “A” frequency weighting curve) for an 8-hour exposure. At higher noise levels, the exposure time must be decreased. No employee can be exposed to steady noise levels above 115 dBA regardless of their duration, and impact or impulsive noise above 140 dB peak.

The “A” frequency weighting curve is used most often to evaluate noise levels as it conforms approximately to the response of the human ear especially for low or moderate amplitudes of sound. The “C” frequency weighting curve, which is relatively “flat” over a wide frequency range is also used, particularly when evaluating loud (above 85 dB) or low frequency (below 200 Hz) noise. Since the difference between sound pressure level measurements performed using A- and C-weighted characteristics reaches 20 dB (corresponding to a 100 times change in sound pressure value) at 100 Hz, noise information in the low frequency range measured using the A-weighted curve can be distorted. This property is used to detect the content of low frequency noise in a measured frequency spectrum. For example, it was observed that during normal operation of continuous miner coal excavating drums in interaction with the coal seam and surrounding rock, a large amount of low frequency noise (LFN) was generated. It was desirable to measure/record noise in amplitude form versus frequency (as a frequency spectrum) using C-weighted curves and determine MSHA compliance by extracting SPL values in dBA format from that signal.

All data were collected from the equipment operator’s position. Equipment observed in this study, in descending order from a noise generation perspective, were the continuous miner (CM), the roof bolter, and the battery-powered haulage unit called a ram-car. The noise generated by each depends on their design and operating mode as well as field operating conditions such as mine opening/cavity volume and configuration, CM position within the opening, coal hardness, and in-seam and out-of-seam rock being mined. Operator exposure is also affected by the level of noise control activity performed by the operator during the machine working time. The CM itself has three individual sources of noise: the cutting drum (head), the dust collector (scrubber), and the conveyor (tail). Each generates its own spectrum of noise, which interferes with the others and with the geometrical configuration of the mine opening, presenting a complex equivalent noise characteristic. The mine opening acts as a semi reverberant cavity.
The CM being investigated in this study was manufactured by Joy Mining Machinery (JOY) and was operating at Peabody’s Willow Lake Mine. It was modified in 2008 mainly by replacing the conveyor’s single-strand chain and associated sprocket with a double-strand chain and modified sprocket. The deflecting plates and chain tensioning system were also modified. Field measurements collected at the mine during this study suggest that the design modifications being demonstrated resulted in an acoustical energy in the air that is approximately two times lower in comparison with that generated by an equivalent CM with a single-strand conveyor chain design. Investigations conducted by the National Institute of Occupational Safety and Health (NIOSH) at their Pittsburgh Research Laboratory on the same design had previously shown almost identical results. In addition, reports from JOY and Peabody showed that the double-strand chain is approximately two times stronger and able to deliver twice the amount of coal versus a single-strand chain (approximately 670,000 tons versus 350,000 tons). An attempt to achieve further noise reduction by applying a plastic urethane coating to the CM conveyor tail roller was not successful given the harsh mine environment and the softness of the coating.

In this research, a hand-held sound pressure level (SPL) meter was used to collect short time duration noise data in dBA. Since noise levels generated by both single- and double-strand conveyor chains were variable in time, depending on loading cycle phases and conveyor position, data were collected at the beginning, middle, and end of each loading cycle. It was established by measurements that the beginning phase lasts for approximately 8% of the total loading time and has the highest SPL in dBA weighting mode. The middle and end phases of the loading process lasted for approximately 78% and 14% of the total loading time, respectively. The data also shows that noise levels were elevated with a large component of frequent impact noise when the conveyor was positioned to the left or to the right of its central axis. Collected data were averaged logarithmically in addition to the time-weighted averaging process based on the duration of each loading phase.

Comparing the average SPL in dBA generated by a conventional CM with single-strand chain and a modified CM with the double-strand chain system during a typical ram-car loading sequence clearly shows reduced noise levels for the double-strand chain. The range is from 1.8 to 6.0 dBA with an average of 4.1 dBA. Time studies of the mining sequence show no significant difference in loading times. Both CMs were working in similar mining conditions with typical cut dimensions. These results show that the conveyor with the dual-strand chain design is effective from both a noise reduction and a productivity perspective. Noise data collected as digital files has allowed for an investigation of the dynamics of noise variations during the loading process. This information is reported in terms of frequency and time spectra of noise.
OBJECTIVES

The primary goals of this research are three-fold: 1) Develop field performance production and maintenance data on a continuous miner (CM) equipped with double-strand conveyor chain using industrial engineering (IE) studies and synthesis of available performance data, 2) Develop noise characteristics data for the double-strand CM conveyor chain under a variety of field operating conditions, and 3) Develop noise characteristics data for other CM components such as the dust collection system, and for other production equipment such as haulage units and roof bolters. These studies will form the foundation for further improvement of production and associated support equipment to improve noise generation characteristics while minimizing loss of productivity and production cost. The study was divided into the following tasks:

Task 1: Synthesize pertinent data from the National Institute for Occupational Safety and Health (NIOSH), the Mine Safety and Health Administration (MSHA), and Joy Mining Machinery (JOY) on efforts to reduce noise generated by CMs and other mining equipment. These three organizations above have been working cooperatively in this topical area for some time.

Task 2: Perform IE and noise characteristic studies on existing equipment. Available production performance and maintenance data for existing CMs will be reviewed and time studies will be performed to develop baseline data. Data on noise characteristics under different field operating conditions will be collected as required by MSHA and to satisfy research objectives. Frequency spectrum analysis of collected noise data will be performed in Southern Illinois University Carbondale (SIUC) laboratories. Protocols developed by NIOSH and MSHA will be followed.

Task 3: Perform IE and noise characteristics studies on one or more CMs equipped with double-strand conveyor chain. Arclar Coal’s (Peabody) Willow Lake mine operators such equipment. JOY, the equipment manufacturer, will be a cooperating partner.

Task 4: Develop noise characteristics data for haulage units and roof bolters under typical field operating conditions.

INTRODUCTION AND BACKGROUND

This cooperative study, funded by the Illinois Clean Coal Institute (ICCI), hosted by JOY and Peabody Energy, and conducted by SIUC personnel, was designed to compare noise generated by a CM equipped with a “Quiet Tail” (QT) system with noise generated by a very similar machine using a conventional chain conveyor system. Sound pressure levels (SPLs) generated by conventional and modified CMs were correlated to field operational parameters such as cut location, haulage unit loading time, and physical dimensions of mine entries. SPLs generated by various CMs operations in the field were analyzed in controlled non-production and production environments. Wherever possible, such data
was collected digitally. Similar data for other section equipment (roof bolters, haulage units) were analyzed separately to develop additional knowledge of the underground work environment. IE studies evaluated loading and maintenance characteristics of the QT-CM and compared them to those of the conventional CM. The objective is to gain a better understanding of the dynamics of sound in mining environments that can be used to develop practical methods for noise reduction that will result in an associated reduction in incidences of potential hearing loss.

Noise induced hearing loss (NIHL) is recognized as an occupational illness caused by long-term exposure to excessive sound levels. Currently, the Code of Federal Regulations (30 CFR PART 62 – Occupational Noise Exposure) defines permissible noise levels and provides for the use of “engineering and administrative controls to reduce the miner’s exposure to as low a level as is feasible”. To reduce noise in mining environments, JOY is developing the QT-CM with a conveyor system equipped with sound dampening treatments, including a dual-strand conveyor chain and an improved chain tensioning system. Earlier versions of the QT-CM were tested by NIOSH at the Pittsburgh Research Laboratory (PRL) and in underground mine production environments. Results were promising with an 8-hour average noise exposure reduction of 3 dBA (Smith et al., 2008).

Other coated roller and flight treatments are currently under development but were not available for production testing during this research study. JOY is incorporating other sound treatments in the QT-CM design. Sound treatments on the QT-CM evaluated in this study included: an improved tail cam system and hydraulic chain tensioning device, improved chain return path, modified chain deflector, and a dual, 8-tooth sprocket driven chain.

**EXPERIMENTAL PROCEDURES**

Sound pressure level (SPL in dB) measurements for different equipment were identified by equipment location, mine opening geometry, and mining activity. They were performed at the location defined as the operator position. These measurements combined with IE studies of CM and haulage unit load times were used to create a description of noise generation related to the loading operation. Noise variability during haulage unit loading as well as other operations like drilling/bolting or coal transporting by haulage equipment were also measured and recorded in the form of digital files. The complex CM noise spectrum is comprised mostly from noise generated by three individual sources: front cutting head, dust collector system and chain conveyor. The CM’s hydraulic system also added a distinct noise spectrum, but in comparison with the above three sources, its generated noise level was relatively low. Noise levels associated with CM operations, including those generated by each individual source, were documented in controlled non-production and production situations in mine acoustical environments. SPL data were analyzed for frequency, amplitude and variability with time using a spectrum analyzer, and were correlated to mining operations and the mine environment. SPL measurements were also made on roof-bolters, haulage units, and feeder-breakers.
The QT-CM mechanical configuration was unchanged throughout this study. The QT is equipped with advanced chain tensioning devices and sound treatment. This machine was compared to a control machine with a single-strand chain, driven by a 4-tooth sprocket, and also to the same machine with a dual-strand chain driven by an 8-tooth sprocket. The conventional conveyor tail unit was operated with two different chain designs, single-strand and double-strand. The change of chain design was decided by mine management. Prior engineering studies (Chugh et al., 2006) on JOY CMs (Model 14CM15) at this mine were used in conjunction with measurements in this study to provide valid IE data for single-strand conveyor chain comparison. Interviews with miners combined with records supplied by mine management and JOY were used to compare maintenance characteristics of the conventional and modified CMs.

Mine Description

This study was conducted at a southern Illinois mine extracting Illinois No. 5 seam coal averaging 52 to 58 inches thick at an average mining depth of 290 feet. As shown in Figure 1, the coal seam is overlain by black shale, and by one or more bands of limestone 6 to 12 inches thick. Sandy shale and coal balls (dense hard concretions) are also present in the immediate roof strata. The immediate floor strata consist of claystone underlain by competent shale. Coal hardness, expressed as Hargrove Grindability Index (HGI), ranges from 54 to 62. A limited number of samples were collected for compressive strength testing from the study area and results are summarized in Table 1.

The mine uses a room-and-pillar mining system with an average mining height of 6.5 feet and average entry width of about 20 feet. The mining section studied was an eight-entry super-section with rooms driven on each side as shown in Figure 2. One JOY 14CM15 miner was used to mine each side of the section. Each CM is equipped with a wet-head cutting drum and a wet flooded-bed scrubber. Scrubbers are located on the left side of the CM. Cross-over ductwork is used on the conventional CM scrubber to discharge air away from the operator. The conventional CM is used on the right side of the mining section and is normally operated remotely from the left side of the machine. The modified CM (QT-CM) operates on the left side of the section and is normally operated remotely from the right.

In this study, a cut was defined as the void created by the CM with consecutive haulage unit loads of material from a single mine entry. Seven (7) types of cuts were defined in the wet head study (Chugh et al, 2006) and are listed below.

- Initial straight (starting 0 to 10 feet from the last open crosscut)
- Deep straight (starting 11 to 40 feet from the last open crosscut)
- Deeper straight (starting more than 40 feet from the last open crosscut)
- Right turn
- Right blow-through
- Left turn
- Left turn blow-through
Blow-through is a term used to define a cut that intercepts a previously mined area. Crosscuts may be started with a full cutter head width (FH) when attacked at 90 degrees from an adjoining crosscut or may be turned on a curve starting with an edge of the cutter head contacting a rib and progressing until the FH is engaged with the working face. Each cut is divided into sub-areas defined as box cuts and slab cuts as shown in Figure 3. Box cuts are extracted by the full width of the cutter head. Slab cuts are cut parallel to the box cut to increase entry width to 20 feet. In collecting data, box cuts and slab cuts are numbered consecutively by type within a given cut.

Two twin-boom Fletcher RRII roof bolters were operated on each side of the section to provide primary roof support. Battery powered Oldenburg-Stamler BH-10 ram-cars with a capacity of about 13 tons were used as haulage units (HU) to transport coal from the CM to the feeder-breaker, which loads the coal onto a conveyor belt. HU operators are located on the right side of the CMs.

IE studies investigated loading performance and durability of the QT system (without coating on rollers or flights) with a conventional CM conveyor in two configurations: single- and double-strand chains. Production data collected during this study and similar data collected on single-strand chain during an earlier study, displayed no significant difference in time required to load individual cars in similar conditions.

![Stratigraphic column](image)

Figure 1: Stratigraphic column associated with No. 5 coal seam at host mine.
Table 1: Geotechnical characteristics of coal at the study mine.

<table>
<thead>
<tr>
<th>Location</th>
<th>Unconfined Compressive Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of seam</td>
<td>2,690</td>
</tr>
<tr>
<td>Middle of seam</td>
<td>2,233</td>
</tr>
<tr>
<td>Bottom of seam</td>
<td>2,384</td>
</tr>
</tbody>
</table>

Figure 2: Layout of a super-section with rooms.

Figure 3: Location of box and slab cuts within a CM cut.
RESULTS AND DISCUSSION

Continuous Miner Noise Studies

The QT-CM and a conventional CM with single-strand chain were compared as each CM made four cuts of similar dimensions in similar conditions. In addition to examining noise generation characteristics, this study included time studies to evaluate production characteristics of the two CMs. IE data for the single-strand chain was collected in a previous study. All time study data used in the analysis of production characteristics are provided in the Appendix.

Standard or normal car loads were defined as those where the CM filled the HU without extensive repositioning. Car load times that included clean-up, positioning movement between slab and box cuts, or other non-productive delays (including cars loaded by a trainee CM operator) were filtered out during data analysis. As shown in Tables 2 and 3, average normal load times were 40.71 seconds for the conventional CM versus 40.79 seconds for the QT-CM. It should be noted that cuts extracted by the conventional CM were about six inches higher than those extracted with the QT-CM. Therefore, the conventional CM advanced a shorter distance to produce the same tonnage. Total conveyor run time, linear feet mined and volume extracted are compared for both CMs in Table 4. This data show little difference between the two CMs in loading time per cubic yard. Modifying a CM by adding a quiet tail appears to have no negative impact on CM productivity.

Table 2: Ram-car loading times for conventional CM with single-strand chain.

<table>
<thead>
<tr>
<th>Cut type</th>
<th>Height (ft)</th>
<th>Width (ft)</th>
<th>Length (ft)</th>
<th>Total Loads</th>
<th>Average Load Time (sec)</th>
<th>Normal Loads</th>
<th>Average Load Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep</td>
<td>6.29</td>
<td>18.54</td>
<td>27.0</td>
<td>18</td>
<td>46.50</td>
<td>15</td>
<td>40.73</td>
</tr>
<tr>
<td>Blow Thru</td>
<td>6.50</td>
<td>18.33</td>
<td>26.0</td>
<td>12</td>
<td>54.58</td>
<td>7</td>
<td>41.14</td>
</tr>
<tr>
<td>Deep</td>
<td>6.25</td>
<td>19.17</td>
<td>28.0</td>
<td>18</td>
<td>44.50</td>
<td>14</td>
<td>39.07</td>
</tr>
<tr>
<td>Deeper</td>
<td>6.42</td>
<td>19.17</td>
<td>26.0</td>
<td>17</td>
<td>50.59</td>
<td>12</td>
<td>42.33</td>
</tr>
<tr>
<td>Summary Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48.51</td>
<td></td>
<td>40.71</td>
</tr>
</tbody>
</table>

Table 3: Ram-car loading times for QT-CM equipped with double-strand chain.

<table>
<thead>
<tr>
<th>Cut type</th>
<th>Height (ft)</th>
<th>Width (ft)</th>
<th>Length (ft)</th>
<th>Total Loads</th>
<th>Average Load Time (sec)</th>
<th>Normal Loads</th>
<th>Average Load Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep</td>
<td>5.67</td>
<td>18.50</td>
<td>23.0</td>
<td>14</td>
<td>46.29</td>
<td>11</td>
<td>39.27</td>
</tr>
<tr>
<td>Blow Thru</td>
<td>5.92</td>
<td>18.75</td>
<td>32.5</td>
<td>18</td>
<td>53.83</td>
<td>14</td>
<td>40.50</td>
</tr>
<tr>
<td>Deeper</td>
<td>5.83</td>
<td>19.50</td>
<td>28.0</td>
<td>13</td>
<td>46.62</td>
<td>10</td>
<td>38.40</td>
</tr>
<tr>
<td>Deep</td>
<td>6.00</td>
<td>18.25</td>
<td>35.0</td>
<td>18</td>
<td>60.39</td>
<td>8</td>
<td>46.38</td>
</tr>
<tr>
<td>Summary Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>52.54</td>
<td></td>
<td>40.79</td>
</tr>
</tbody>
</table>
Table 4: Summary of production data collected during this study.

<table>
<thead>
<tr>
<th>Continuous Miner</th>
<th>Number of Car Loads</th>
<th>Loading Rate (sec/cu yd)</th>
<th>Total Conveyor Run Time (seconds)</th>
<th>Distance Advanced (linear feet)</th>
<th>Total Volume Mined (cubic yard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QT-CM</td>
<td>63</td>
<td>6.83</td>
<td>3310</td>
<td>118</td>
<td>484.7</td>
</tr>
<tr>
<td>Conventional-CM</td>
<td>65</td>
<td>6.61</td>
<td>3153</td>
<td>107</td>
<td>476.5</td>
</tr>
</tbody>
</table>

The normal cutting sequence within a straight cut on the QT-CM (left) side of the section was depicted in Figure 3. On the control CM (right) side of the section, the box cut is normally on the left side of the entry with the slab cut on the right. Box cuts are defined as areas extracted from the working face with the full width (11.5 feet) of the cutting drum. Slab cuts are normally less than full drum width (8.5 feet in a 20-ft entry). Slab cut load times tend to be longer than box cut load times as shown in Table 5 because more linear footage is required to fill a car due to the smaller percentage (74% for a 20-ft entry) of the cutting drum engaged at the face. Cutting drum engagement with the face and volume conveyed over time affect sound generation.

Table 5: Haulage unit load times in box and slab cuts (seconds).

<table>
<thead>
<tr>
<th>No. of Cars</th>
<th>Box Cut 1</th>
<th>Box Cut 2</th>
<th>Slab Cut 1</th>
<th>Slab Cut 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>46</td>
<td>39</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>43</td>
<td>39</td>
<td>41</td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>45</td>
<td>35</td>
<td>52</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>33</td>
<td>44</td>
<td>53</td>
</tr>
<tr>
<td>5</td>
<td>39</td>
<td>35</td>
<td>53</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>37</td>
<td>42</td>
<td>39</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>26</td>
<td>35</td>
<td>36</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>47</td>
<td>50</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>43</td>
<td>39</td>
<td>39</td>
<td>58</td>
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<tr>
<td>10</td>
<td>45</td>
<td>51</td>
<td>40</td>
<td>55</td>
</tr>
<tr>
<td>11</td>
<td>41</td>
<td>42</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>35</td>
<td>42</td>
<td>33</td>
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<td>13</td>
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<td>16</td>
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<tr>
<td>17</td>
<td>33</td>
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<tr>
<td>18</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>38.6</strong></td>
<td><strong>43.36</strong></td>
<td><strong>42.0</strong></td>
<td><strong>50.2</strong></td>
</tr>
</tbody>
</table>

A hand-held sound pressure level meter was used to measure SPL (in dBA-slow), at the beginning, in the middle, and at the end of each individual HU loading cycle. Average
measurements are shown in Table 6, with “B”, “M”, and “E” referring to the beginning, middle, and end of the loading process and “Right” or “Left” referring to which side of the CM center axis the CM tail is positioned. Logarithmically averaged and time-weighted SPL measurements are provided in the Appendix. The A-weighted instrument characteristic was applied for all measurements in agreement with NIOSH and MSHA standard procedures.

At the beginning of the loading process, the conveyor is typically empty. Thus, noise damping and lubrication providing by wet coal is absent leading to elevated noise levels. It was found that this elevated noise phase at the beginning of the loading process comprises 8% of the total time it takes to load one ram-car. The lowest SPL readings occurred at the end of the loading process which comprises 14% of total loading time for one ram-car. The remaining 78% of total loading time is referred to as the middle period which was characterized by relatively steady SPL noise readings.

The discharge end of the CM conveyor (tail) can be swung a maximum of 30 degrees to either side of the CM center axis. When the conveyor is so positioned to the left or right, as conveyor flights go around the bend that is created in the tail boom they contact flexible steel deflector plates that are positioned in the bend to keep coal on the conveyor. This leads to increased noise levels due to elevated amplitudes over a wide band of the frequency range generated by metal-on-metal impact.

The highest noise level was observed when both of these conditions (beginning of the loading process and conveyor swung to the side) were applied. As shown on the “Difference” line of Table 6, the CM with the double-strand chain design was significantly less noisy than the CM with the single sprocket and single-strand chain in similar working conditions. Although difficult to quantify, it was observed that elevated SPL readings occurred when the CM cutting head encountered rock, either above, below or within the coal seam.

Table 6: Comparison of average SPL for CMs during typical loading process.

<table>
<thead>
<tr>
<th>Conveyor Position</th>
<th>Straight</th>
<th>To the Right</th>
<th>To the Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading Stage</td>
<td>B M E</td>
<td>B M E</td>
<td>B M E</td>
</tr>
<tr>
<td>Average SPL of Single-strand Chain (dBA)</td>
<td>97.7 96.7 94.3</td>
<td>103.2 97.7 96.1</td>
<td>102.7 97.4 96.3</td>
</tr>
<tr>
<td>Average SPL of Double-strand Chain (dBA)</td>
<td>95.9 92.1 90.6</td>
<td>97.2 94.5 91.6</td>
<td>96.9 94.7 91.8</td>
</tr>
<tr>
<td>Difference (dBA)</td>
<td>1.8 4.6 3.7</td>
<td>6.0 3.2 4.5</td>
<td>5.8 2.7 4.5</td>
</tr>
</tbody>
</table>
A digital recorder was used to collect noise data from over 100 feet away on the CM with double-strand conveyor chain working in typical mining conditions as shown in Figure 4. This data was processed with a B&K Pulse spectrum analyzer to produce visual images of the CM noise spectrum shown in Figures 5, 6, and 7. These charts show distinctions between beginning, middle, and end of the loading cycle as well as when the CM tail is swung to the left or right generating more impact noise. The C-weighted frequency curve used in this analysis allowed for measuring low frequency noise (LFN) characteristic of the mining environment. In every conveyor position and loading phase, the maximum noise level generated by the CM was in the range between 500 Hz and 1600 Hz with the most significant level of noise generated between 400 Hz and 4000 Hz.

A digital recording was also made with the CM backed away from the face into an intersection with an open crosscut. The miner operator turned on each component of the CM and let it run without producing any coal while the recording was made. Recorded noise levels for each noise source are listed in Table 7. With no coal on the conveyor, its noise level was significantly elevated. The frequency spectra generated by the CM hydraulic system, the CM cutting drum rotating freely, and the CM dust collector (scrubber) are shown in Figure 8. The noise spectrum generated by the dust collector is independent of other noise sources and/or working conditions and is not variable in time. The noise generated by the hydraulic system varies with horizontal position of the conveyor and vertical position of the cutting drum. Also, the QT conveyor model utilizes a hydraulically controlled chain tensioning mechanism which influenced the amplitude of noise generated by the hydraulic system.
Figure 5: Noise spectrum generated by CM in average working conditions with double-strand conveyor in the straight position.

Figure 6: Noise spectrum generated by CM in average working conditions with double-strand conveyor swung to the right.

Figure 7: Noise spectrum generated by CM in average working conditions with double-strand conveyor swung to the left.
Table 7: Recorded 1/3 octave SPL of each CM noise source without cutting or transporting coal.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Hydraulics (dBC)</th>
<th>Cutting drum (dBC)</th>
<th>Dust Collector (dBC)</th>
<th>Conveyor (dBC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right</td>
</tr>
<tr>
<td>100</td>
<td>61.1</td>
<td>76.1</td>
<td>86.3</td>
<td>94.1</td>
</tr>
<tr>
<td>125</td>
<td>63.0</td>
<td>78.3</td>
<td>87.8</td>
<td>94.0</td>
</tr>
<tr>
<td>160</td>
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<td>81.4</td>
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<td>92.9</td>
</tr>
<tr>
<td>200</td>
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<td>250</td>
<td>72.6</td>
<td>85.0</td>
<td>85.6</td>
<td>96.1</td>
</tr>
<tr>
<td>315</td>
<td>83.0</td>
<td>86.9</td>
<td>88.7</td>
<td>94.7</td>
</tr>
<tr>
<td>400</td>
<td>60.9</td>
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<td>98.2</td>
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<tr>
<td>500</td>
<td>61.3</td>
<td>89.9</td>
<td>91.4</td>
<td>98.6</td>
</tr>
<tr>
<td>630</td>
<td>67.0</td>
<td>91.3</td>
<td>89.9</td>
<td>99.9</td>
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<td>87.4</td>
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<tr>
<td>1600</td>
<td>58.3</td>
<td>85.7</td>
<td>86.3</td>
<td>100.2</td>
</tr>
<tr>
<td>2000</td>
<td>56.4</td>
<td>80.6</td>
<td>86.0</td>
<td>99.7</td>
</tr>
<tr>
<td>2500</td>
<td>52.7</td>
<td>76.3</td>
<td>84.2</td>
<td>98.6</td>
</tr>
<tr>
<td>3150</td>
<td>54.5</td>
<td>71.1</td>
<td>78.1</td>
<td>97.3</td>
</tr>
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<td>4000</td>
<td>53.4</td>
<td>63.9</td>
<td>75.4</td>
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<td>86.8</td>
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<tr>
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<td>69.6</td>
<td>79.5</td>
</tr>
<tr>
<td>10000</td>
<td>49.3</td>
<td>51.2</td>
<td>68.9</td>
<td>76.3</td>
</tr>
</tbody>
</table>

Figure 8: Noise spectra generated by hydraulic system, cutting drum and dust collector with CM not mining coal.
Maintenance reports of production delays attributed to conveyor system malfunction during a 5-month period from January through May of 2009 are listed in Table 8. Production data and conveyor delay data for the same time period are summarized in Table 9. The QT-CM and a control CM operated side-by-side in the same section advancing similar distances (74,302 feet for the QT-CM versus 73,550 feet for the control CM). There were six conveyor issues for QT-CM compared to 11 for the control CM. Each machine reported two delays involving conveyor frame. It should be noted that the control CM single-strand chain was changed to a new double-strand chain on April 20, 2009, in response to excessive noise from the single-strand chain.

Table 8: Conveyor maintenance issues and related delays (01/06/09 to 05/30/09).

<table>
<thead>
<tr>
<th>Continuous Miner</th>
<th>Date</th>
<th>Maintenance Issue</th>
<th>Loading Delay (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QT-CM</td>
<td>02/02/09</td>
<td>Chain broken</td>
<td>1.08</td>
</tr>
<tr>
<td>QT-CM</td>
<td>02/10/09</td>
<td>Flex board (frame)</td>
<td>0.17</td>
</tr>
<tr>
<td>QT-CM</td>
<td>03/06/09</td>
<td>Flex board (frame)</td>
<td>0.37</td>
</tr>
<tr>
<td>QT-CM</td>
<td>04/20/09</td>
<td>Chain broken</td>
<td>1.33</td>
</tr>
<tr>
<td>QT-CM</td>
<td>05/04/09</td>
<td>Chain and shaft broken</td>
<td>0.42</td>
</tr>
<tr>
<td>QT-CM</td>
<td>05/05/09</td>
<td>Chain broken</td>
<td>0.75</td>
</tr>
<tr>
<td>QT-CM</td>
<td>05/11/09</td>
<td>Chain (3 links replaced)</td>
<td>0.87</td>
</tr>
<tr>
<td>QT-CM</td>
<td>05/21/09</td>
<td>Chain broken</td>
<td>1.08</td>
</tr>
<tr>
<td>Control-CM</td>
<td>01/06/09</td>
<td>Chain broken</td>
<td>1.0</td>
</tr>
<tr>
<td>Control-CM</td>
<td>03/01/09</td>
<td>Take-up</td>
<td>0.5</td>
</tr>
<tr>
<td>Control-CM</td>
<td>03/04/09</td>
<td>Tail jack bracket (frame)</td>
<td>0.65</td>
</tr>
<tr>
<td>Control-CM</td>
<td>03/05/09</td>
<td>Wear strip cut (frame)</td>
<td>0.25</td>
</tr>
<tr>
<td>Control-CM</td>
<td>03/10/09</td>
<td>Chain and shafts broken</td>
<td>1.58</td>
</tr>
<tr>
<td>Control-CM</td>
<td>03/15/09</td>
<td>Tensioner broken</td>
<td>1.0</td>
</tr>
<tr>
<td>Control-CM</td>
<td>03/28/09</td>
<td>Chain broken</td>
<td>1.37</td>
</tr>
<tr>
<td>Control-CM</td>
<td>04/06/09</td>
<td>Tensioner broken</td>
<td>0.42</td>
</tr>
<tr>
<td>Control-CM</td>
<td>04/07/09</td>
<td>Tensioner, tail rounder</td>
<td>0.2</td>
</tr>
<tr>
<td>Control-CM</td>
<td>04/07/09</td>
<td>Tension rod</td>
<td>1.17</td>
</tr>
<tr>
<td>Control-CM</td>
<td>04/19/09</td>
<td>Bent flight cut out</td>
<td>0.25</td>
</tr>
<tr>
<td>Control-CM</td>
<td>04/28/09</td>
<td>Chain broken*</td>
<td>0.2</td>
</tr>
<tr>
<td>Control-CM</td>
<td>05/30/09</td>
<td>Chain and shafts broken</td>
<td>0.37</td>
</tr>
</tbody>
</table>

* Double-strand chain installed on control CM on 4/20/09

Table 9: Summary of production data and conveyor delays (01/01/09 to 05/31/09).

<table>
<thead>
<tr>
<th>Continuous Miner</th>
<th>Feet Advanced</th>
<th>Tons Mined</th>
<th>Number of Chain and Flight Delays</th>
<th>Number of Conveyor Frame Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional #233</td>
<td>73,550</td>
<td>353,040</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>QT #236</td>
<td>74,302</td>
<td>356,649</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>
Prior to this study, JOY and Peabody reported longer life for the double-strand conveyor chain. During the course of this study, the last double-strand chain retired from service at the host mine produced 670,000 tons as opposed to less than 350,000 tons for the average single-strand chain. This result does not take into account QT-CM enhancements such as hydraulic tensioning or improved chain path, which were still under development. According to JOY, consistent, correct tension is one of the most important factors affecting chain performance. For that reason, they continue to develop the new hydraulic tensioning system, which they believe will significantly influence QT-CM chain life.

Maintenance personnel at the host mine reported some difficulties with dual-strand chains. Connecting straps on the double-strand chain were more likely to spread causing chain damage than with the single-strand design. This issue was addressed by JOY with the addition of a cross-connecting bolt between straps, which was reported to have improved performance but not completely resolved the problem. Maintenance crews also reported that threading the dual-strand chain around an 8-tooth drive sprocket required more time and effort than the earlier design. These issues were not quantified but may affect any overall expected performance gain.

**Roof Bolter Noise Studies**

Roof bolting in the study area used fully-grouted 5/8-inch headed rebar bolts with square steel plates. Five bolts were installed per row. Intersections were bolted with 6-ft long bolts. In areas other than intersections, 4-ft long bolts were normally used unless roof conditions required added support. Bolts were installed with a Fletcher RR II twin-boom bolting machine. Drilling was accomplished with 2-edge, 1-inch bits and a 6-sided drill rod. Bolts installed with the left boom were not timed but were mapped. Bolting was done sequentially by row with each boom starting at the respective rib-line and bolt installation proceeding toward the center of the opening. In the bolting process, a hole is drilled into which tubes of resin are inserted. Then, a bolt with a plate is pushed into the hole through the resin and rotated in place with the plate against the roof. In the tightening process, bolts are rotated with upward thrust which mixes resin for proper curing. The average drilling and tightening times for the right-side boom were 12.9 and 3.0 seconds, respectively.

Figure 9 illustrates a 35-ft room crosscut. Bolts used for installation of a wooden curtain board are shown along with roof support bolts. Support bolt rows are labeled “A” through “H”. Bolts installed by the right boom are shown in red. The curtain board bolt row is labeled as “CB”. Location is noted by row and number in row. Drilling and tightening times for each bolt installed with the right boom are shown in Table 10. Bolt number indicates order of installation by right boom. Table 10 also provides SPL measurements (in dBA) for some drilling and bolt tightening.
Figure 9: Bolting pattern in rooms including curtain board.

Table 10: Roof bolter time study and sound measurement data (right boom only).

<table>
<thead>
<tr>
<th>Bolt Number</th>
<th>Bolt Location</th>
<th>Drill Time* (seconds)</th>
<th>SPL (dBA)</th>
<th>Tighten Time (seconds)</th>
<th>SPL (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1</td>
<td>11</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A2</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A3</td>
<td>13</td>
<td>94.7</td>
<td>2</td>
<td>89.2</td>
</tr>
<tr>
<td>4</td>
<td>B1</td>
<td>11</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>B2</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>C1</td>
<td>11</td>
<td></td>
<td>3</td>
<td></td>
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<tr>
<td>7</td>
<td>C2</td>
<td>11</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>C3</td>
<td>13</td>
<td>95.6</td>
<td>3</td>
<td>90.8</td>
</tr>
<tr>
<td>9</td>
<td>D1</td>
<td>12</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>D2</td>
<td>19</td>
<td></td>
<td>3</td>
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<tr>
<td>11</td>
<td>CB1</td>
<td></td>
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<td>3</td>
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<td>3</td>
<td>90.2</td>
</tr>
<tr>
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<td>F1</td>
<td>12</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>F2</td>
<td>10</td>
<td>96.5</td>
<td>2</td>
<td>87.7</td>
</tr>
<tr>
<td>17</td>
<td>G1</td>
<td>10</td>
<td></td>
<td>3</td>
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<tr>
<td>18</td>
<td>G2</td>
<td>11</td>
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<td>3</td>
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<td>G3</td>
<td>11</td>
<td>94.4</td>
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<td>89.3</td>
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<tr>
<td>20</td>
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<td>10</td>
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<td>3</td>
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<td>H4</td>
<td>12</td>
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<td>3</td>
<td></td>
</tr>
</tbody>
</table>

*In room crosscut using 48-inch by 5/8-inch resin bolts.
Noise generated by pass-by ram-cars and the roof bolter drilling holes and tightening bolts was digitally recorded and the recorder signal/spectrum was analyzed using a B&K Pulse spectrum analyzer. Measured results are shown in Table 11. This data was collected over a long time period with a large number of ram-car pass-by cycles and later averaged. The maximum amplitude of noise generated by battery-powered pass-by ram-cars was observed to be around 630 Hz. The amplitude depended mostly on operating conditions like coal payload and style of driving. The maximum amplitude of noise generated by the roof bolter in the drilling phase was around 800 Hz.

The measured noise level generated by the roof bolter in drilling mode using A-weighted frequency curve from the operator’s position (as shown in Table 10) is on the level of noise generated by a working CM, reaching 96.5 dBA. Bolt tightening is almost as noisy with SPL readings reaching 90.8 dBA. These data were obtained using a hand-held SPL meter in dBA-slow mode and are identical to data extracted from simultaneously recorded digital files.

<table>
<thead>
<tr>
<th>1/3 octave frequency band in Hz</th>
<th>Average SPL in dBC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Haulage Unit</td>
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<tr>
<td>100</td>
<td>71.3</td>
</tr>
<tr>
<td>125</td>
<td>74.1</td>
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<tr>
<td>160</td>
<td>77.8</td>
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</tr>
<tr>
<td>10000</td>
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</tr>
</tbody>
</table>
CONCLUSIONS AND RECOMMENDATIONS

Noise exposure is reduced by alterations in engineering design and equipment operation, limiting time of exposure, and by wearing hearing protectors. The most desirable of these is the first one, which is to apply engineering principles to reduce noise level. To evaluate the level of noise reduction achieved, the following noise-related components are evaluated: 1) sources of noise, 2) paths along which the noise travels, and 3) receivers (people) exposed to that noise.

The enhanced engineering design evaluated in this project is a restructured chain conveyor system for a JOY CM where a double-strand chain and modernized mechanical and hydraulic tensioning components replace the conventional single-strand chain and its associated components. Previous to this work, laboratory research had shown that the double-strand chain system had a life span approximately twice that of the single-strand system. The double-strand chain is mechanically stronger in comparison with the single-strand and considering the same rate of coal transportation for both, the double-strand lasted almost two times longer between services and delivered approximately twice the amount of coal by weight. In this study, it was shown that the sound pressure generated by a CM utilizing double-strand chain in a redesigned conveyor structure was approximately twice less in comparison with a single-strand CM conveyor operating in the same conditions. This reduction of acoustical sound pressure corresponds to approximately 3 dBA less sound pressure level (SPL) at the operator’s position. That reduction is entirely attributable to the redesigned conveyor system because noise generated by coal extracting heads and dust collectors did not change.

During the ram-car loading process, the variability in time (noise dynamics) of noise generated by the CM conveyor was observed. In most cases, noise is elevated to at or near its highest levels at the beginning of the loading process. This is caused by uneven distribution of stress on the chain itself and not enough deposition of coal on the conveyor to properly lubricate and dampen moving parts. The proper operators approach can be having efficient deposition of coal on the conveyor before restarting its operation. This can lower those elevated noise levels at the beginning of the loading process. Another noise reduction technique serves a dual purpose. Adding water at the point of extraction (near the cutter head and bits) and to the path of transported coal not only reduces generated noise, but also the amount of dust in the air. This study showed that the CM cutter head interacting with the coal seam, using considerable force to extract and move coal (and sometimes the rock above and below it), generates a large amount of low frequency noise (LFN). LFN can be measured by applying the “C” instead of the “A” frequency weighting curve. Future research should investigate specific means for controlling the generation of and personnel exposure to LFN. Of course, high frequency noise (HFN) is also of concern and should be investigated. To facilitate this, the frequency range being measured should be expanded to full audible range.

Often, due to excavating conditions, the ram-car was positioned to the left or to the right of the CM’s center axis forcing the CM operator to adjust the position of the conveyor
tail in a horizontal plane. In these conditions, it was shown that swinging the conveyor tail to either side generates continuously elevated noise levels with significant amounts of acoustical energy in a wide frequency range caused by frequent impact noise (beating) from conveyor flights striking one of the flex plates that keep coal on the conveyor and channel it to the tail of the machine. Future research should consider redesign of these mechanical deflecting components of the conveyor’s structure in an effort to lower this kind of noise.

Additional efforts to redesign components of mining systems and apply noise reduction treatment to parts which are mechanically vibrating in the audible frequency range, should achieve further noise reduction. The use of manmade materials with high damping coefficients and high mechanical resistance to normal and shear stresses should work well in this application. This project included a failed attempt at such efforts when a urethane-coated tail roller did not last very long in the harsh underground coal mine environment. Efforts to develop more wear-resistant and sound dampening materials should continue.

The same noise treatment can be applied to roof bolters and haulage units. Noise generated by both types of equipment was evaluated as part of this study. Roof bolters generated their highest level of noise during the drilling phase. The hardness of the rock being drilled significantly influences the level of noise generated during drilling. There was no opportunity to measure roof bolter SPL in conditions other than those of the host mine, which has a moderately soft shale roof. Reports from other mines with harder roof rock such as limestone indicate that noise levels generated in drilling are directly proportional to hardness of the material being drilled. Haulage units evaluated were battery-powered ram-cars which generate noise by way of their electromechanically powered drive train. The amount of noise generated depends on the payload being hauled and the operator’s style of driving.

REFERENCES


DISCLAIMER STATEMENT

This report was prepared by Dr. Marek Szary of Southern Illinois University, with support, in part, by grants made possible by the Illinois Department of Commerce and Economic Opportunity through the Office of Coal Development and the Illinois Clean Coal Institute. Neither Dr. Marek Szary, Southern Illinois University, nor any of its subcontractors, nor the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development, the Illinois Clean Coal Institute, nor any person acting on behalf of either:

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# APPENDIX

Table A1: Ram-car loading times for conventional CM with single-strand chain recorded during a previous study on August 8, 2006.

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All cut number 9 readings taken left side in stub entry as machine passed—
instruments at mid-machine beginning of cut.