ERGONOMIC AND EXISTING SEAT DESIGNS COMPARED ON UNDERGROUND MINE HAULAGE VEHICLES

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ABSTRACT

NIOSH researchers conducted a study to compare seat designs on underground coal mine haulage vehicles. The objective of the study was to support prior findings that NIOSH-designed seats, which incorporated ergonomic design features (e.g., viscoelastic foam padding and low-back support), are improved designs. Based on measured levels of vehicle jarring/jolting and perceived discomfort, researchers evaluated four different designs – two in-use and two NIOSH-developed, ergonomic designs. Researchers collected data using a short questionnaire, a linear, visual analog scale, and accelerometers with a data recorder. Results showed that vehicle operators favored the NIOSH seats with added adjustability, low-back support, and improved seat padding over the existing seats. In addition, the measurements indicated all NIOSH seats performed better than the existing seat, under the no-load (worse of two) conditions, in reducing peak acceleration, crest factor, and RMS acceleration. The authors summarize the data collected and operator preferences for seat designs and different foam padding arrangements.

INTRODUCTION

Industrial equipment exposes individuals to whole-body vibration (WBV) and mechanical shock. This exposure can adversely affect their health, safety, comfort, as well as, working efficiency and performance. For many years, seat design was not a priority in vehicle design. Yet, proper seat design is a basic consideration in reducing the adverse effects of WBV exposure to vehicle operators. Since the human body is sensitive to low frequency WBV, ride quality has become an important need in seat design. This is especially true in the mining industry. When designing a suitable seat, it is prudent to answer two fundamental questions (Amirouche et al., 1997): 1) What is the vibration environment that individuals are exposed to? 2) How well can they tolerate this environment?

Mayton et al. (1999) reported on a low-coal, mine shuttle car seat design with limited, yet successful, underground mine field trials. The current seat design comparison study, an extension of earlier work, was a more systematic evaluation of the low-coal shuttle car seat design and included a mid-coal shuttle car seat design. By gathering information with a larger sample of shuttle car operators, research supported earlier findings that NIOSH seats, with unique viscoelastic foam padding, are improved seat designs in isolating shuttle car operators from jars and jolts. The NIOSH seat designs include viscoelastic foam that has properties similar to those found in a mechanical spring/damper suspension system. The NIOSH seats also include ergonomic features, such as, an adjustable lumbar support and fore-aft seat adjustment. This contrasts with some existing seats, which have limited adjustability, little or no lumbar support, and include inexpensive foam padding commonly used in furniture.

THESIS

The authors assert that NIOSH seat designs offer better alternatives to some existing seat designs for mine shuttle cars in isolating operators from vehicle jarring/jolting and for reducing discomfort. This is demonstrated from both subjective and objective data collected through operator responses and recorded vibrations during production operations. The data indicate NIOSH seat designs are preferred by haulage vehicle operators and incorporate ergonomic features, such as viscoelastic foam padding, low-back support, and greater adjustability.

MINE FIELD TRIALS

Underground mine field trials for the study were performed at the Elk Run Coal Company's Laurel Alma and Black King underground coal mines near the Beckley/Charleston area of West Virginia. The coal seam thickness and mining height for the Laurel Alma mine averaged 183 cm (72 in) with a range of 152 to 244 cm (60 to 96 in) for seam thickness and 206 cm (81 in) with a range of 198 to 244 cm (66 to 96 in) for mining height. Black King mine averaged 124 cm (49 in) with a range of 102 to 127 cm (40 to 50 in) and 142 cm (56 in) with a range of 132 to 152 cm (52 to 60 in), respectively, for seam thickness and mining height. The study focused on two shuttle cars, a mid-coal-seam and a low-coal-seam model. Eight vehicle operators performed their regular duty cycles (comprising no-load and full-load conditions) with the shuttle cars using four distinct seat designs that included seven different foam padding arrangements. Data were collected using three techniques: a short questionnaire; a linear, visual analog scale (VAS); and accelerometers connected to a data recorder.

Seat design trials were conducted on a mid-coal seam, side-saddle-style shuttle car operating at the Laurel Alma mine and a low-coal-seam shuttle car operating at the Black King mine. (The side-saddle-style refers to how the vehicle operator is positioned in the vehicle cab. In this case, the operator is perpendicular to, instead of facing, the direction of travel.) Four basic seat designs were compared on the shuttle cars. Mid-coal-seam vehicle seats were designated as M1 (existing) and M2A and M2B (NIOSH), Figure 1a. Low-coal-seam vehicle seats, shown in Figure 2a, were designated L1 (existing) and L2A, L2B, and L2C (NIOSH). The viscoelastic foam padding arrangements distinguishing the different NIOSH seats are shown in Figures 1b and 2b.

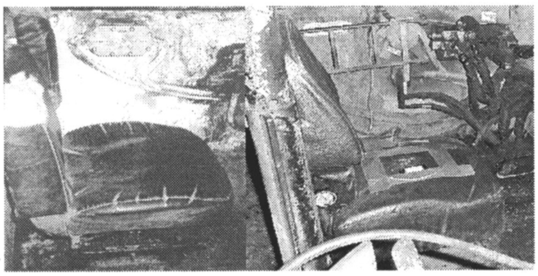

Figure 1a. Mid-coal-seam shuttle car seats – existing (left) and NIOSH/Ergonomic (right).

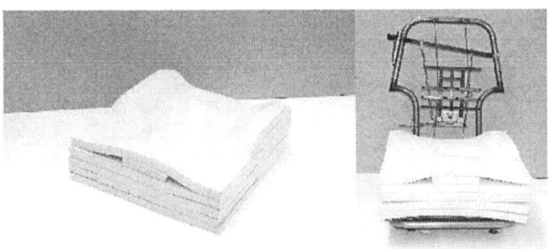

Figure 1b. Viscoelastic foam padding arrangements M2A (left – without pudgee) and M2B (right – with pudgee).

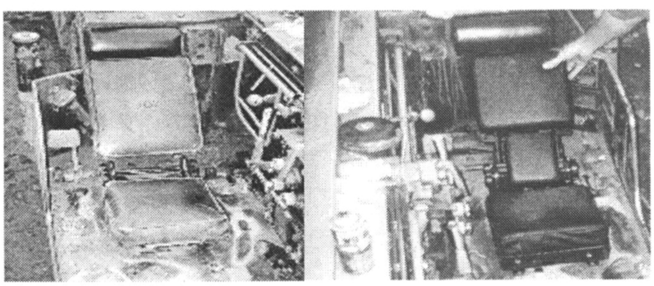

Figure 2a. Low-coal-seam shuttle car seats – existing (left) and NIOSH/Ergonomic (right).

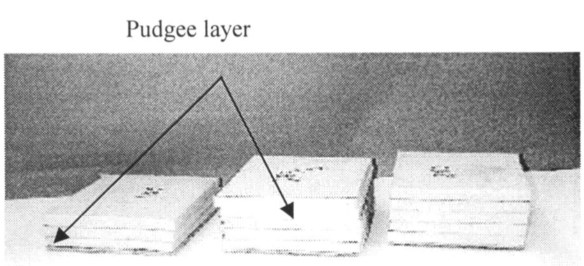

Figure 2b. Viscoelastic foam padding arrangements left to right, L2A, L2C and L2B (without pudgee).

Since they were in service for some time, the existing seats were more worn than the NIOSH seats, which were like new. The seats (after the NIOSH design) for the mid-coal-seam shuttle car, were designated according to viscoelastic foam arrangements as follows:

- Seat M2A – included a total thickness of 13 cm (5 in) Sun-Mate Extra-Soft (XSS) foam padding.
- Seat M2B – included padding with a combination of Pudgee (PU) and XSS and a total thickness of 13 cm (5 in).

For the low-coal-seam shuttle car, the seats (after the NIOSH design) were designated according to the viscoelastic foam arrangements as follows:

- Seat L2A – included padding with a combination of PU and XSS and a total thickness of 8 cm (3 in).
- Seat L2B – included a total thickness of 13 cm (5 in) XSS foam padding.
- Seat L2C – included padding with a combination of PU and XSS and a total thickness of 13 cm (5 in).

METHODS

Researchers interviewed shuttle car operators to obtain a major portion of subjective data. The interview guide was administered at the conclusion of each trial for each seat and took approximately 5 to 10 minutes to complete. The list of seven questions included on the quide is summarized as follows:

- How would you rate the seat in terms of comfort?
- How would you rate the seat relative to reducing shock and vibration?
- What do you like about the seat?
- What don't you like about the seat?
- Rate seat padding, lumbar support, reclining seatback, seat-pan tilt, armrest, and fore-aft adjustment.
- What would you do to improve this seat?
- Compare the seats to each other.

The remaining portion of the subjective data was collected using a linear, visual analog scale (VAS) and a brief questionnaire. The VAS was used to obtain the operators' immediate impressions of shock, vibration and discomfort levels for the vehicle ride on each of the seats and viscoelastic foam configurations. The shuttle car operator marked this scale after traveling with a full load of coal and with no load on the first, third, and sixth round trip of the trials for each seat. A round trip consisted of traveling to the coalface with no load and returning to the load discharge location with a full load of coal.

Objective data gathering was done with a data recorder, accelerometers, signal conditioning amplifiers and in-line, low-pass filters. Researchers collected data to determine the acceleration and impact energy entering the seat through the floor from the vehicle frame. Triaxial accelerometers were placed on the floor of the operator's compartment near the base of the seat (frame measurement) and on the seat at the subject/seat interface (seat measurement). Because of muddy conditions, the frame accelerometers were mounted to the frame of the shuttle car above the control panel. During the field trials, mine roadway conditions were noted as smooth, pothole-riddled, debris-strewn, rutted, dry, wet, and water-filled.

FINDINGS

Questionnaire Data – Mid-Coal-Seam Shuttle Car

Researchers used the numerical scales: 1 = very comfortable, 2 = comfortable, 3 = uncomfortable and 4 = very uncomfortable for operator assessments of comfort; and 1 = very good, 2 = good, 3 = fair and 4 = poor for operator assessments of reducing vibration or vehicle jarring/jolting. Figures 3 and 4 represent average values for the eight shuttle car operators.

Seat M1 ranked the lowest in comfort, vibration reduction (Figure 3), seat padding and lumbar support; however, one-operator liked its comfort and another liked the way the body fit the seat frame. Broken (from weakness in seat mounting) and no comfort were the leading dislikes of Seat M1. Suggested improvements to Seat M1 included adding armrests and removing and replacing the seat.

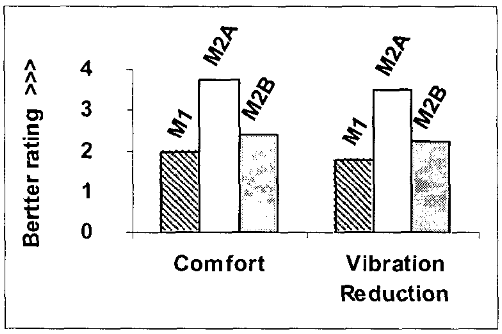

Figure 3. Mid-coal-seam shuttle car seat designs rated for comfort and vibration reduction

Seat M2A was ranked most favorable. Operators liked the seats ability to absorb vibration and jars. The seat provided good support to the back and felt comfortable. The seat was apparently too low for good visibility and seat placement caused the controls to be too close. Adding armrests and improving seat location were the major suggestions to improve Seat M2A.

Seat M2B was ranked second in comparisons relative to comfort and vibration. Operators liked the seat comfort and firmness and disliked the way it absorbed shock and the stated that the back support was too stiff. Operators offered several suggestions to improve Seat M2B such as to make the seat softer, add armrests and improve lumbar supports.

In summary, the ratings reflect how the seats felt to the operator. Seat M2A was the favored. Seat padding rated well for both Seat M2A and SeatM2B. Seat M1 was the least favored in all ratings. Adding armrests was the improvement most often suggested for any of the seats.

Questionnaire Data – Low-Coal-Seam Shuttle Car

Seat L1 ranked the lowest in seat comfort and vibration reduction (Figure 4). Nevertheless, prior to using the NIOSH seats, the operators commented that they liked the way Seat L1 reduced jars and jolts; one operator even thought it was fairly comfortable. However, operators disliked its durability and stated that the lumbar support was too thick. Suggestions to improve the seats were to make the back support better, improve adjustments for better visibility, and improve padding. Seat L1 did not have seat-pan tilt or fore-aft adjustment.

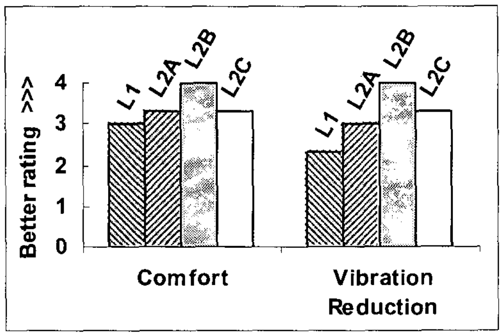

Figure 4. Low-coal-seam shuttle car seat designs rated for comfort and vibration reduction

Seat L2A and Seat L2C ranked well in comfort and vibration reduction. Operators liked how Seat L2A reduced lower back strain when the shuttle car traveled across large holes. Also, operator's liked the thick cushion on Seat L2A and how the seat adjusts to the body. Operators liked Seat L2B for how comfortable it felt, how it reduced shocks, and for its thick cushion. Both seats were situated too close to the controls and did not fit the shuttle car confined area. Regarding Seat L2B, operators rode the shuttle car slower to avoid being bounced into the canopy. Suggested improvements for Seat L2A and Seat L2B were to make the lumbar support wider. An operator suggested improving the operator's control panel envelope to accommodate better seats, such as Seat L2B.

Seat L2C was favored. Operators liked the padding for its comfort and shock reduction properties and the lumbar support for reducing back strain. However, operators did not like the lumbar width. Also, the seat was too big for the confined area of the shuttle car. Operators' suggested several improvements to Seat 2C: make lumbar support and seat wider and add a scaled down seat so as to fit better behind the controls.

In summary, Seat L1 was the least favored in all ratings. Seat padding, lumbar support and seat-pan tilt were rated better in Seat L2B than any other seat. Reclining back is better on Seat L2B and surprisingly favored on Seat L1. Making the seat a better fit for the operator compartment was a suggested improvement. This could improve clearance between operator and controls and allow for better operator adjustability and visibility.

VAS and Measured Data

Tables 1 and 2 present the results of the analysis for VAS and measured data. The VAS ratings showed that vehicle operators rated overall (on average from 3 trial ratings) the NIOSH-designed seats better than the existing seats. The ratings were transformed from the marked linear scale into a decimal value between 0 and 1.0, which is interpreted as no jarring/jolting or discomfort and extreme levels of the same, respectively. For the mid-coal-seam vehicle, under the no-load (worse case of two) conditions, operators rated level of jarring/jolting 31 to 66% lower and level of discomfort 40 to 65% lower with the Seats M2A and M2B. (Data on Seat M2A was obtained with two fewer subjects than for Seat M1 and Seat 2B.) For the low-coal-seam, under no-load conditions, operators rated levels of jarring/jolting as 7 to 23% lower with the Seats L2A, L2B, and L2C. In addition, operators rated level of discomfort 7% lower with Seat L2C, but 2 to 7% higher with Seats L2A and L2B. Researchers determined the higher discomfort ratings with Seats L2A and L2B were largely due to mounting the NIOSH seats in existing bolt holes. This caused location of the NIOSH seats to be closer to the control panel and forced vehicle operators to assume a more awkward and slightly cramped posture when driving the vehicle.

Table 1. Perceived and measured reductions in discomfort and jarring/jolting levels for operators of mid-coal-seam shuttle cars (no-load)

Seat Description	Perceived Reduction in		Measured Reduction in Jarring/Jolting		
	Dis-comfort (%)	Jarring/ Jolting (%)	Peak *a* (%)	RMS *a* (%)	Crest Factor (%)
M1 (Existing)	-	-	-	-	-
M2A (NIOSH 5 in XSS)	65	66	16	13 *	23
M2B NIOSH (5 in XSS/PU)	40	31	4	11 *	11

* Increase instead of reduction; *a*: acceleration

Table 2. Perceived and measured reductions in discomfort and jarring/jolting levels for operators of low-coal-seam shuttle cars (no-load)

Seat Description	Perceived Reduction in		Measured Reduction in Jarring/Jolting		
	Dis-comfort (%)	Jarring/ Jolting (%)	Peak *a* (%)	RMS *a* (%)	Crest Factor (%)
L1 (Existing)	-	-	-	-	-
L2A (NIOSH 3 in XSS/PU)	7 *	7	22	10	14
L2B (NIOSH 5 in XSS)	2 *	23	14	7	8
L2C (NIOSH 5 in XSS/PU)	7	12	8	9	0

* Increase instead of reduction; *a*: acceleration

The quantitative levels of vehicle jarring/jolting for no-load conditions showed that NIOSH Seats M2A and M2B for the model mid-coal-seam performed better than the existing seat, in terms of peak acceleration and crest factor; whereas, L2A, L2B, and L2C performed better than the existing seat in terms of peak acceleration, RMS acceleration, and crest factor. (Data on Seat L2C was obtained with one less subject than Seats L1, L2A, and L2B.) Field trials included shuttle cars operating under full- and no-load conditions.

During full-load conditions, the foam- or air-filled tires provided primary damping or attenuation of jars/jolts as a result of the extra mass from the load of coal. The performance of the seat in providing this attenuation of jars/jolts is thus secondary. However, the extra mass is lacking under no-load conditions and allows for more severe levels of jarring/jolting for the shuttle car operators. Consequently, it is significant that NIOSH-designed seats performed better than the existing seats when comparing average values for peak acceleration, RMS acceleration, and crest factor.

With the mid-coal-seam vehicles, the NIOSH Seat M2A showed a 16% and 23% reduction in peak acceleration and crest factor. Seat M2A, however, showed a 13% increase for RMS acceleration. Similarly, Seat M2B showed a 4% and 11% reduction in peak acceleration and crest factor and a 11% increase in RMS acceleration. Nevertheless, NIOSH researchers considered RMS acceleration the least significant of the three measurement parameters in terms of jarring/jolting levels for the vehicle operator.

Even better results were obtained with NIOSH-designed seats for the low-coal-seam vehicle. NIOSH Seat L2A showed a 22%, and 14% reduction in peak acceleration and crest factor. Moreover, Seat L2A reduced RMS acceleration by 10%. Similarly, Seat L2B showed 14% and 8% reductions in peak acceleration and crest factor and also a 7% reduction for RMS acceleration. Finally, Seat L2C showed 8% and 9% reductions in peak acceleration, and RMS acceleration with no change for crest factor.

DISCUSSION

Research concerning underground coal mining has shown that equipment operators experience adverse levels of exposure to WBV, which includes vehicle jarring/jolting (identified as the higher-amplitude, peak component of WBV). Remington, et al. (1984) showed that shuttle car haulage vehicles are among the major sources of exposure to WBV and vehicle jarring/jolting in underground coal mines. These circumstances have changed some since 1984, yet there is still much room for improvement.

Additional evidence exists to illustrate the serious health effects that can result from prolonged exposure of vehicle operators to jarring and jolting. A study, done in New South Wales, Australia, identified jarring/jolting as a significant concern to mobile equipment operators. Cross and Walters (1994) reviewed WBV and vehicle jarring as a contributing factor to back pain in the Australian mining industry. They examined 28,306 compensation claims for a 4-year period (July 1986 to March 1990) that included surface and underground mining environments. From the 8,961 claims relating to the head, back, and neck that they identified, 11% (986) were due to vehicle jarring. Underground transporters and shuttle cars accounted for 53% of all injuries attributed to vehicle jarring.

In summarizing the results from the questionnaire data, the ratings reflect how the seats felt to the operator. For the mid-coal-seam shuttle car, Seat M2A is the favorite. Seat padding rated well for both Seat M2A and Seat M2B. Seat M1 is the least favorite in all ratings. Adding armrests is the improvement most often suggested for any of the seats.

For the low-coal-seam shuttle car, Seat L1 is the least favorite in all ratings. Seat padding, lumbar support and seat-pan tilt are rated better in Seat L2B than any other seat. The reclining back is better on Seat L2B and surprisingly favored on Seat L1. Making the seat a better fit for the operator compartment is a suggested improvement. This could improve clearance between operator and controls and allow for better operator adjustability and visibility.

Average ratings from VAS responses indicated that the NIOSH-designed seats were superior to the existing seats used in the shuttle cars. For both no-load and full-load conditions, average ratings of mid-coal-seam shuttle cars operators showed levels of jarring/jolting and discomfort as lower with the NIOSH seats using the two different 13-cm (5-in) viscoelastic foam padding arrangements. Seat M2A with 13 cm (5 in) of XSS foam padding was most preferred by operators of the mid-coal-seam shuttle car. Similarly, for shuttle car no-load and full-load conditions, average ratings of low-coal-seam shuttle car operators showed lower jarring/jolting with the NIOSH seat using three different viscoelastic foam pad arrangements. The seats and viscoelastic foam padding arrangements, in order of operator preference, were Seat L2B with 13 cm (5 in) of XSS foam, Seat L2A with 8 cm (3 in) of PU/XSS foam, and Seat L2C with 13 cm (5 in) of PU/XSS foam. Nevertheless, concerning levels of discomfort, the average operator rating favored the existing seat slightly better than the NIOSH seat with the three different viscoelastic foam pad arrangements seat, under full-load and no-load conditions. The explanation for this is the closer proximity of the NIOSH seats to the control panel which made the shuttle car operators feel awkward and slightly cramped. Researchers had to use existing bolt holes when mounting the NIOSH seats in the shuttle car. In addition, the NIOSH seats L2B and L2C with 13-cm (5-in) thick foam padding elevated operators nearer to the canopy.

Results from recorded levels of jarring/jolting showed NIOSH-designed seats performed better than the existing seats when comparing average values for peak acceleration, RMS acceleration, and crest factor under no-load conditions with more severe levels of jarring/jolting for the shuttle car operators. Concerning model mid-coal-seam shuttle car, the NIOSH Seat M2A featuring the 13-cm (5-in) XSS foam pad smoothed out bumps better than the Seats M1 and M2B with a 16% and 23% reduction in peak acceleration and crest factor. Seat M2A, however, showed a 13% increase for RMS acceleration, the least significant of the three measurement parameters in terms of jarring/jolting levels for the vehicle operator. Similarly, Seat M2B with the 13-cm (5-in) PU/XSS foam pad showed a 4 % and 11% reduction in peak acceleration and crest factor and a 11% increase in RMS acceleration. Results for NIOSH-designed seats on the model low-coal-seam vehicle were even better than those obtained on the model mid-coal-seam vehicle. NIOSH Seat L2A with the 8-cm (3-in) viscoelastic XSS/PU foam pad provided significantly larger reduction in values of peak acceleration (22%) and crest factor (14%). Moreover, Seat L2A reduced RMS acceleration by 10%. Similarly, Seat L2B with the 13-cm (5-in) XSS foam pad showed 14% and 8% reductions in peak acceleration and crest factor and also a 7% reduction for RMS acceleration. Finally, Seat L2C, featuring the 13-cm (5-in) PU/XSS foam pad showed 8% and 9% reductions in peak acceleration and RMS acceleration with no change for crest factor.

Finally, the findings of this study provides the mining industry with supportive information that NIOSH ergonomic seat designs are improvements over some existing designs for isolating operators from vehicle jarring/jolting and for providing comfort. In particular, researchers have provided this important information to Dynamic Systems, Inc., a seat foam manufacturer, and JOY Mining Machinery, a mining equipment manufacturer, who is already incorporating seat design recommendations from earlier NIOSH research (Mayton et al., 1999). Furthermore, the additional data collected from shuttle car operators provided the opportunity to refine and improve the NIOSH seat designs.

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