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### PERFORMANCE SUMMARY OF CONTINUOUS MINING MACHINE PROXIMITY DETECTION SYSTEMS

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#### ABSTRACT

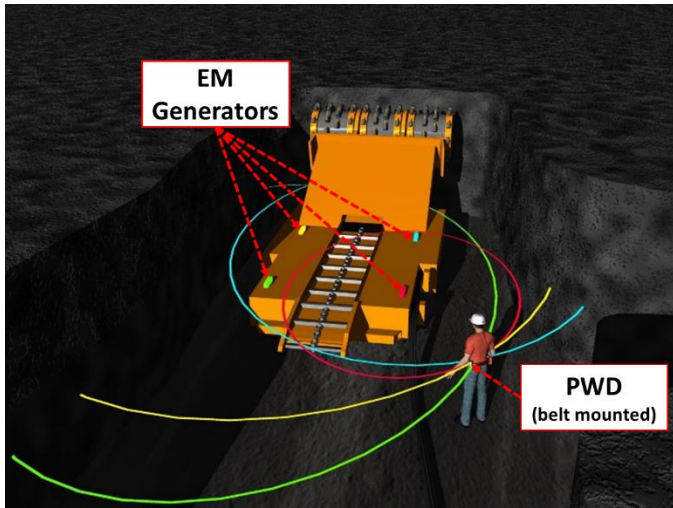
Since 1984, remote controlled continuous mining machines (CMM) have caused 40 crushing and pinning fatalities in the United States. Due to limited space in the underground environment and visibility needs, CMM operators typically work close to the machine which exposes them to the danger of being struck or pinned by it. Because of these fatalities, the Mine Safety and Health Administration (MSHA) has published a rule requiring proximity detection systems (PDSs) on all CMMs except for full-face machines. To test PDS performance, researchers at the National Institute for Occupational Safety and Health (NIOSH) conducted a series of field tests in underground coal mines throughout the United States on CMMs equipped with PDSs. The field tests collected data under a variety of conditions to evaluate the warning and shutdown zone performance of these systems. A baseline test condition was measured when the machine was operating in non-mining mode. Three additional conditions discussed in this paper include testing of the PDS while the machine was operating in mining mode, examining the possibility of parasitic coupling to the trailing cable, and examining the effects of the presence of a shuttle car. The results of this study indicate that the average warning and stop zones vary minimally between non-mining mode and trailing cable influence measurements, as well as between the mining mode and shuttle car presence tests. A majority of the measurements for warning and stop zones showed repeatability within +/- 5 inches (12.7 cm). Additionally, parasitic coupling to the trailing cable was not experienced during this field testing. However, these results show that the range of stop zone measurements varied by 4.7 ft on average and

as much as 11.7 ft in different field sites. This is most likely due to individual preferences by operators during installation when the warning and stop zone distances are set. While a PDS should effectively stop a CMM when an operator gets too close to the machine, the large variations between field test measurements indicate that there is a wide variation of performance established during system installation.

#### INTRODUCTION

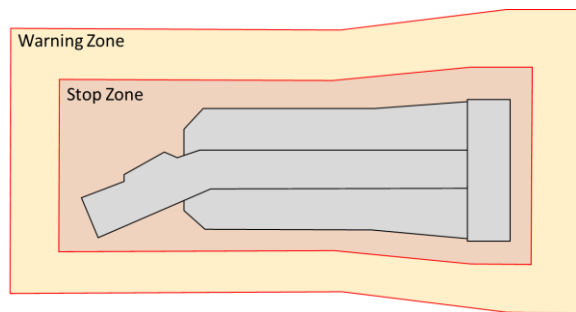
There have been 40 crushing and pinning fatalities in underground coal mines in the United States since 1984 involving a remote controlled CMM. Previous NIOSH research [1] concludes that 32 of 39 of these fatalities could have been prevented by a PDS. An earlier MSHA study examined 39 fatal accidents and concluded that 32 of them would have been prevented by a PDS [2]. In 2015, MSHA published a regulation requiring PDSs to be installed on all CMMs in underground coal mines with the exception of full-face CMMs [3]. PDSs are designed to stop machine motion in order to protect miners from striking, pinning, and crushing hazards. A PDS typically includes four electromagnetic (EM) field generators on the CMM and personnel wearable devices (PWDs), which are worn by the miners to detect the magnetic flux density. An illustration of a PDS installed on a CMM is shown in Figure 1. Four EM generators are shown at their approximate installation points on the machine, along with representations of their corresponding

EM fields, as measured by the PWD which is worn by the operator.



**Figure 1: Illustration of CMM equipped with PDS.**

Most PDSs on CMMs are based on the principle of magnetic flux density (B-field). When a PWD gets closer to the machine, the flux density increases, and vice versa. Different zones can be created around the machine based on the B-fields and can be used to trigger an alarm event (warning zone) or a shutdown event (stop zone), as illustrated in Figure 2. Several commercially available PDSs are MSHA-approved for installation on CMMs [4].



**Figure 2: Representation of commercially available warning and stop zones around a CMM.**

NIOSH researchers conducted field tests from 2013 to 2015 on magnetic field based PDSs installed on CMMs in active underground coal mines with seam heights ranging from 54 inches to 84 inches (137.2 cm to 213.4 cm). Nine field tests were conducted throughout the United States to evaluate the performance of PDSs. Performance was evaluated primarily by determining the distance from the PWD to the CMM when the warning and stop zones were detected. The results indicate that while system performance is generally good, there is still room for improvement due to the large variations between field test sites.

These field tests were designed to quantify the performance of PDSs for four different conditions: baseline CMM operating (not in mining mode), CMM operating in mining mode, influence of a trailing cable on the PWD, and influence of a shuttle car in the loading position. Each of these conditions is detailed below.

The baseline testing was performed in order to establish a performance baseline for which to compare the other test conditions. These tests were conducted with the following conditions: the conveyor boom centered and in its low position, the cutter head inactive and dropped to the floor along with the gathering pan, the trailing cable in the normal position, and no shuttle car. These tests establish a performance baseline to compare against the other three tests (mining mode, influence of trailing cable, influence of shuttle car).

Mining mode is a feature on commercially available PDSs that reduces the zones towards the rear of the machine along the conveyor boom and at the rear bumper, allowing operators to position themselves near the CMM while cutting coal. Mining mode is activated whenever the cutter head motors are energized. This keeps the operators in a position where they have sufficient visibility to perform their work while out of harm's way of the shuttle car while the CMM is cutting coal. It should be noted that this feature is not used in some mines. Whenever the cutter head on the CMM is not active, such as when the machine is tramming between locations, mining mode is not active; thus the zones are not reduced.

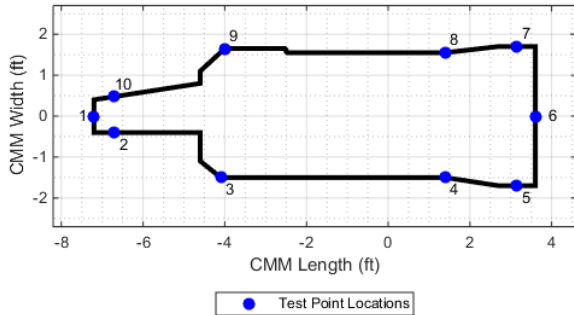
A principle known as parasitic coupling has been reported [5] by a number of mine operators, where it has been suggested that PWDs located near a trailing cable are causing spurious machine shutdowns even though the operator is not near the machine. It is suggested that parasitic coupling may occur when the magnetic field generated on the CMM couples to the trailing cable, effectively extending the warning and stop zones farther than intended. Because of this possibility, the influence of a trailing cable on the zone measurements is examined in these field tests.

When a shuttle car maneuvers into the loading position while the CMM is mining coal, a large mass of metal (the shuttle car) is introduced nearby the CMM. This could possibly reshape the field towards the rear of the machine. Therefore, these field tests were designed to quantify the effect that the presence of a shuttle car has on the PDS system.

## FIELD TESTING

While a variety of test parameters were studied and examined based on field testing [6, 7], the focus of this paper is on the four scenarios previously mentioned. Ten test points were defined around a CMM, as shown in Figure 3. At each test point, a NIOSH researcher would start at a perpendicular distance from the machine that could not be detected by the PDS, and walk towards the machine with a PWD on a reference pole until a

warning zone incursion alarm occurred. The distance from the machine to the PWD along with the PWD height were measured. Then the researcher would again walk towards the machine until a shutdown zone incursion occurred, at which point the distance from the machine to the PWD and PWD height were recorded. At least two measurements were recorded for each test point; if the two measurements varied by more than +/- 5 inches (12.7 cm), then a third measurement was taken. This process was completed for all ten test points, for all of the conditions being tested.



**Figure 3: Ten test point locations around a continuous mining machine.**

While multiple measurements were taken at all of the test points, some measurements were not practical for some of the test conditions. For the baseline test condition (CMM not in mining mode), all test points were used. For the test condition where the CMM operates in mining mode, all test points with the exception of test points 5, 6, and 7 were used in order to prevent a researcher from walking towards a rotating cutter head.

For the trailing cable influence test condition, only test points 3 or 9 was used, depending on which side the trailing cable was on the CMM. This test involved looping the trailing cable along the side of the machine and then routing it perpendicular from the machine at the test point location, and performing the measuring sequence with the PWD positioned directly above the trailing cable.

For the shuttle car presence test condition, only test points 3, 4, 8, and 9 were used. When the shuttle car is pulled up to bumper of the CMM, test points 1, 2, are 10 are inaccessible. Additionally, when a shuttle car is being loaded, the CMM is cutting coal. As such, test points 5, 6, and 7 were excluded to prevent a researcher from walking towards a rotating cutter head. A summary of the test conditions and test points measured is shown in Table 1.

**Table 1: Summary of test points measured for each of the test conditions. MM = mining mode.**

| Test Point | Test Conditions   |    |                          |                      |
|------------|-------------------|----|--------------------------|----------------------|
|            | Baseline (Non-MM) | MM | Trailing Cable Influence | Shuttle Car Presence |
| 1          | X                 | X  | --                       | --                   |
| 2          | X                 | X  | --                       | --                   |
| 3          | X                 | X  | X                        | X                    |
| 4          | X                 | X  | --                       | X                    |
| 5          | X                 | -- | --                       | --                   |
| 6          | X                 | -- | --                       | --                   |
| 7          | X                 | -- | --                       | --                   |
| 8          | X                 | X  | --                       | X                    |
| 9          | X                 | X  | X                        | X                    |
| 10         | X                 | X  | --                       | --                   |

|                          |
|--------------------------|
| X: measurement included  |
| --: Measurement excluded |

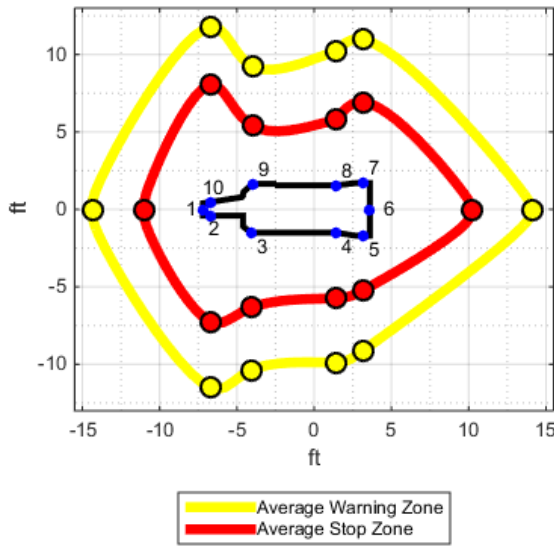
**RESULTS**

Data from all nine field tests were compiled to examine PDS variations at each of the ten test points under varying conditions. Table 2 presents the minimum, maximum, and average distance measurements from the CMM to the PWD for warning and stop zone incursions for the baseline (where the CMM is operating without mining mode) test condition. Additionally, the average warning and stop zones are displayed in Figure 4.

The data shows that for some test point locations, the minimum stop zone distance from the CMM to the PWD was found to be less than 3.0 ft. This distance was determined by previous research [8] to be the distance from the CMM at which the probability of a worker escaping from a pinning or striking scenario greatly diminishes. It should be noted that this distance is not an absolute minimum at which stop zones must occur around the machine, because the MSHA rule is performance based—i.e., the rule requires that the CMM halt before contact occurs. All of these tests are conducted with the machine stationary, with the goal being to survey PDS performance at various field sites. Therefore, this data should not be misconstrued as a finding on proper warning and stop zone distances. Site and machine conditions that affect available tractive effort will cause variable stopping distances. Since these zone sizes are adjustable, installers and maintenance personnel need to consider site-specific conditions to allow the operators to stand near the CMM while still providing protection from striking and pinning.

**Table 2: Field test data showing distances to zones in the baseline test condition.**

| Test Point | Distance from CMM (ft) |           |              |           |              |           |
|------------|------------------------|-----------|--------------|-----------|--------------|-----------|
|            | Minimum                |           | Average      |           | Maximum      |           |
|            | Warning Zone           | Stop Zone | Warning Zone | Stop Zone | Warning Zone | Stop Zone |
| 1          | 4.5                    | 1.5       | 7.2          | 3.8       | 12.9         | 7.2       |
| 2          | 6.1                    | 3.0       | 11.1         | 6.9       | 14.6         | 11.9      |
| 3          | 5.3                    | 2.5       | 8.9          | 4.9       | 13.9         | 10.5      |
| 4          | 6.0                    | 2.3       | 8.4          | 4.2       | 16.0         | 6.5       |
| 5          | 3.9                    | 1.4       | 7.4          | 3.5       | 14.7         | 5.3       |
| 6          | 5.5                    | 3.6       | 10.5         | 6.6       | 19.5         | 10.2      |
| 7          | 6.2                    | 2.4       | 9.3          | 5.2       | 15.0         | 10.5      |
| 8          | 6.3                    | 1.4       | 8.6          | 4.3       | 15.8         | 6.0       |
| 9          | 4.9                    | 2.0       | 7.6          | 3.7       | 15.5         | 5.3       |
| 10         | 7.9                    | 3.8       | 11.3         | 7.6       | 12.5         | 9.0       |



**Figure 4: Plot of average warning and stop zones for testing of CMM without mining mode activated.**

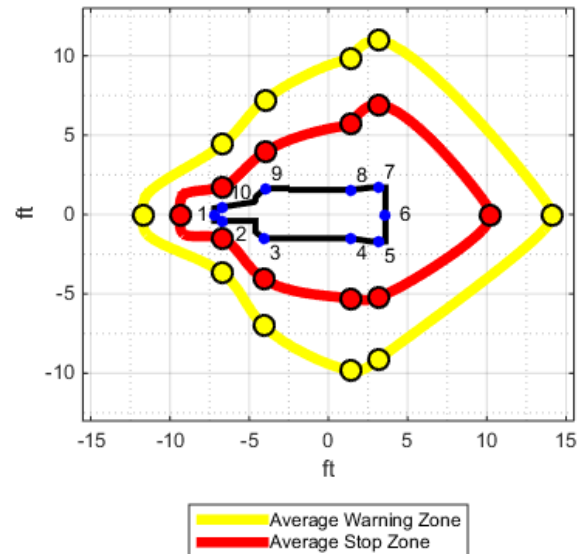
For the test condition where the CMM was operating in mining mode, the minimum, maximum, and average distances from the CMM to the PWD for warning and stop zone incursions are presented in Table 3. Similarly, the average zones for this test condition are shown in Figure 5.

As previously mentioned, measurements were not taken at test points 5, 6, and 7 since the use of mining mode requires a rotating cutter head. The data confirms that mining mode effectively allows an operator to get closer to the rear of the machine at the conveyor boom and rear bumper area of a CMM. This can be seen by examining the minimum warning and stop zone incursion distances for test points 1, 2, 3, 9, and 10. There were field sites where the zone reduction in mining mode was sufficient to allow PWD contact with the CMM. MSHA accident statistics show there has not been a fatal striking/pinning

accident that has occurred while cutting coal. However, with the zones configured in this manner, the PDS has no possibility of preventing such an accident. The remaining two test points for mining mode are at positions 4 and 8, which are located at the pan hinge on either side of the machine. These test points appeared to show minimal change compared with the results from the baseline testing.

**Table 3: Field test data showing distances to zones where the CMM was operating with mining mode activated.**

| Test Point | Distance from CMM (ft) |           |              |           |              |           |
|------------|------------------------|-----------|--------------|-----------|--------------|-----------|
|            | Minimum                |           | Average      |           | Maximum      |           |
|            | Warning Zone           | Stop Zone | Warning Zone | Stop Zone | Warning Zone | Stop Zone |
| 1          | 0.0                    | 0.0       | 4.5          | 2.2       | 11.2         | 5.8       |
| 2          | 0.0                    | 0.0       | 3.3          | 1.1       | 8.5          | 2.8       |
| 3          | 1.3                    | 0.0       | 5.5          | 2.6       | 11.6         | 4.7       |
| 4          | 6.0                    | 2.3       | 8.3          | 3.8       | 14.0         | 4.9       |
| 5          | --                     | --        | --           | --        | --           | --        |
| 6          | --                     | --        | --           | --        | --           | --        |
| 7          | --                     | --        | --           | --        | --           | --        |
| 8          | 6.0                    | 3.6       | 8.3          | 4.2       | 13.3         | 5.4       |
| 9          | 0.0                    | 0.0       | 5.6          | 2.3       | 12.2         | 4.2       |
| 10         | 0.0                    | 0.0       | 3.9          | 1.3       | 8.5          | 3.0       |



**Figure 5: Plot of average warning and stop zones for mining mode tests.**

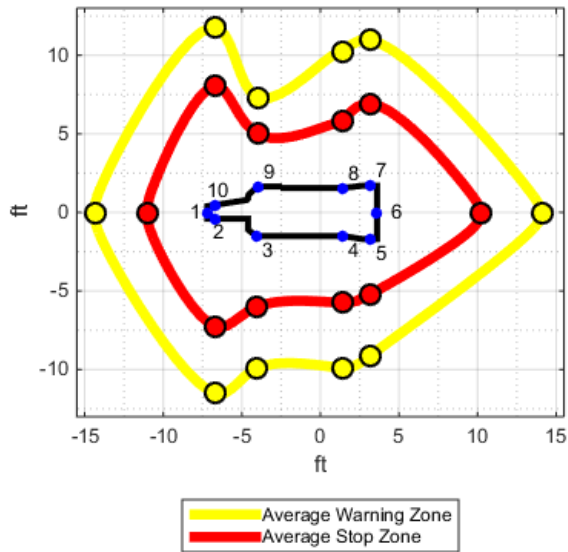
With respect to the test condition examining the influence of a trailing cable, the minimum, maximum, and average distances from the CMM to the PWD for warning and stop zone incursions are presented in Table 4. The average zones are shown in Figure 6.

As previously mentioned, measurements were only taken at test points where the trailing cable existed, which could be either

test points 3 or 9 for a given machine. Compared with the baseline results, the measurements taken to examine the influence of a trailing cable showed minimal effect on the distances from the machine at which warning and stop zones occurred for test point 3. Test point 9 shows little variation across the minimum, maximum, and average distances, though it should be noted that a majority of test measurements occurred at test point 3. As such, significant variation at test point 9 was not expected.

**Table 4: Field test data showing distances to zones for trailing cable influence testing.**

| Test Point | Distance from CMM (ft) |           |              |           |              |           |
|------------|------------------------|-----------|--------------|-----------|--------------|-----------|
|            | Minimum                |           | Average      |           | Maximum      |           |
|            | Warning Zone           | Stop Zone | Warning Zone | Stop Zone | Warning Zone | Stop Zone |
| 1          | --                     | --        | --           | --        | --           | --        |
| 2          | --                     | --        | --           | --        | --           | --        |
| 3          | 5.4                    | 2.3       | 8.4          | 4.5       | 14.0         | 7.4       |
| 4          | --                     | --        | --           | --        | --           | --        |
| 5          | --                     | --        | --           | --        | --           | --        |
| 6          | --                     | --        | --           | --        | --           | --        |
| 7          | --                     | --        | --           | --        | --           | --        |
| 8          | --                     | --        | --           | --        | --           | --        |
| 9          | 5.4                    | 3.2       | 5.7          | 3.3       | 6.0          | 3.4       |
| 10         | --                     | --        | --           | --        | --           | --        |



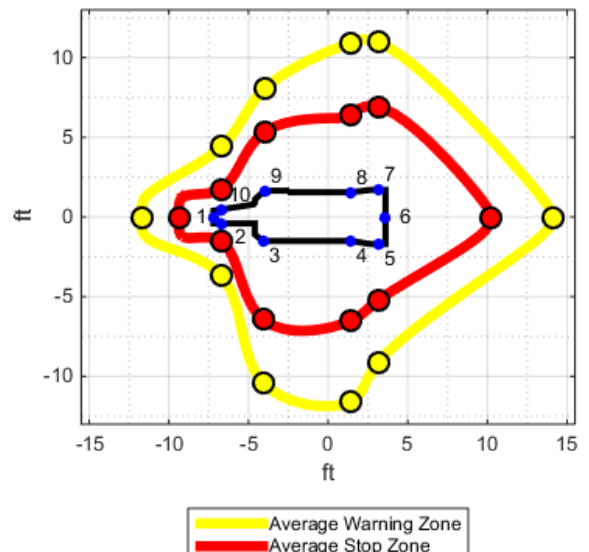
**Figure 6: Plot of average warning and stop zones for baseline tests with the trailing cable influence tests.**

For testing of the influence on the PDS due to the presence of a shuttle car, the minimum, maximum, and average distances from the CMM to PWD for warning and stop zone incursions are presented in Table 5, with the average zones depicted in Figure 7.

Since this test required the presence of a shuttle car in the loading position and a rotating cutter head, only test points 3, 4, 8, and 9 were used. There is less data in this set because a shuttle car was not available to perform this test for every field test. Compared with the results with mining mode active, the shuttle car presence test results indicate that the warning zone and stop zone fields increased for all of the four test points examined. This indicates that the large mass of the metal shuttle car served to extend the warning and stop zones slightly.

**Table 5: Field test data showing distances to zones shuttle car presence testing.**

| Test Point | Distance from CMM (ft) |           |              |           |              |           |
|------------|------------------------|-----------|--------------|-----------|--------------|-----------|
|            | Minimum                |           | Average      |           | Maximum      |           |
|            | Warning Zone           | Stop Zone | Warning Zone | Stop Zone | Warning Zone | Stop Zone |
| 1          | --                     | --        | --           | --        | --           | --        |
| 2          | --                     | --        | --           | --        | --           | --        |
| 3          | 2.7                    | 0.0       | 8.9          | 4.9       | 15.5         | 11.7      |
| 4          | 6.3                    | 3.4       | 10.1         | 5.0       | 15.1         | 6.6       |
| 5          | --                     | --        | --           | --        | --           | --        |
| 6          | --                     | --        | --           | --        | --           | --        |
| 7          | --                     | --        | --           | --        | --           | --        |
| 8          | 6.6                    | 3.7       | 9.3          | 4.9       | 14.3         | 5.8       |
| 9          | 4.3                    | 2.4       | 6.4          | 3.7       | 8.0          | 4.2       |
| 10         | --                     | --        | --           | --        | --           | --        |



**Figure 7: Plot of average warning and stop zones for shuttle car presence tests.**

While every PDS can be configured differently for each CMM installation in a mine, variation between measurements is an indicator of preferences established during installation or subsequent maintenance. Table 6 shows the range of distance measurements for each test point of the four conditions tested.

For the purposes of this paper, distance ranges indicate the difference between the maximum and minimum measurements for a given test condition. As an example, the minimum warning zone distance for test point 8 of the shuttle car presence test condition is 6.6 ft, while the maximum warning zone distance is 14.3 ft. Thus, the distance range for this test point and test condition is 7.7 ft.

**Table 6: Range of distance measurements at each test point for different test conditions.**

| Test Point | Range of Distance Measurements from CMM (ft) |      |     |      |           |     |     |      |
|------------|--|------|-----|------|-----------|-----|-----|------|
|            | Warning Zone                                 |      |     |      | Stop zone |     |     |      |
|            | Base   | MM   | TCI | SCP  | Base      | MM  | TCI | SCP  |
| 1          | 8.4  | 11.2 | --  | --   | 5.7       | 5.8 | --  | --   |
| 2          | 8.5  | 8.5  | --  | --   | 8.9       | 2.8 | --  | --   |
| 3          | 8.6  | 10.3 | 8.6 | 12.8 | 8.0       | 4.7 | 5.1 | 11.7 |
| 4          | 10.0   | 8.0  | --  | 8.8  | 4.2       | 2.6 | --  | 3.2  |
| 5          | 10.8   | --   | --  | --   | 3.9       | --  | --  | --   |
| 6          | 14.0   | --   | --  | --   | 6.6       | --  | --  | --   |
| 7          | 8.8  | --   | --  | --   | 8.1       | --  | --  | --   |
| 8          | 9.5  | 7.3  | --  | 7.7  | 4.6       | 1.8 | --  | 2.1  |
| 9          | 10.6   | 12.2 | 0.6 | 3.7  | 3.3       | 4.2 | 0.2 | 1.8  |
| 10         | 4.6  | 8.5  | --  | --   | 5.2       | 3.0 | --  | --   |

|      |  |
|------|--|
| Base | Baseline test (without mining mode active) |
| MM   | Mining mode active                         |
| TCI  | Trailing cable influence                   |
| SCP  | Shuttle car presence                       |

The warning and stop zones for each test condition can be compared to the baseline measurements to evaluate the performance of PDSs under different scenarios. For each field test and test condition, the average warning and stop zones were determined, and then the absolute difference was calculated to show variation. This information is shown in Table 7.

**Table 7: Average distance variations from baseline at each test point for different test conditions.**

| Test Point | Average Variations from Baseline (ft) |           |              |           |              |           |
|------------|---------------------------------------|-----------|--------------|-----------|--------------|-----------|
|            | MM                                    |           | TCI          |           | SCP          |           |
|            | Warning Zone                          | Stop Zone | Warning Zone | Stop Zone | Warning Zone | Stop Zone |
| 1          | 5.6                                   | 3.3       | --           | --        | --           | --        |
| 2          | 9.2                                   | 6.0       | --           | --        | --           | --        |
| 3          | 2.5                                   | 1.4       | 0.8          | 0.7       | 2.4          | 1.7       |
| 4          | 0.5                                   | 0.3       | --           | --        | 0.4          | 0.5       |
| 5          | --                                    | --        | --           | --        | --           | --        |
| 6          | --                                    | --        | --           | --        | --           | --        |
| 7          | --                                    | --        | --           | --        | --           | --        |
| 8          | 0.7                                   | 0.5       | --           | --        | 0.6          | 1.0       |
| 9          | 2.1                                   | 1.2       | 0.3          | 0.2       | 1.7          | 1.1       |
| 10         | 9.8                                   | 7.1       | --           | --        | --           | --        |

|      |  |
|------|--|
| Base | Baseline test (without mining mode active) |
| MM   | Mining mode active                         |
| TCI  | Trailing cable influence                   |
| SCP  | Shuttle car presence                       |

## DISCUSSION

For the field test data examining the PDS performance for the four test conditions studied, the total zone distances are all normalized as they are taken on different CMMs across the industry that vary by manufacturer and size. The results show that there are significant variations between field sites and that a number of stop zone incursions did not occur until the PWD was very close to the CMM. However, with narrow mine entry widths, it may be necessary in some instances for the warning and stop zones to be minimal.

The first test condition examined the baseline performance of the PDS. This measurement is used to compare different test conditions, and is also applicable to general tramming functions of the machine when mining mode is not expected to be active. Table 2 shows that the minimum stop zone distance for 8 of the 10 test points is less than 3 ft. Table 6 shows that there was considerable variation across measurements, by as much as 8.9 ft for stop zone incursions and as much as 14.0 ft for warning zone incursions.

The next test condition examines the performance of the PDS on CMMs operating with mining mode active. This mode is applicable specifically to cutting coal, and allows the operator the freedom to move closer to the machine near the conveyor boom and rear bumper. From Table 3, it can be seen that at least one field site, the PWD was able to come in contact with the machine at five test points without triggering a stop-zone-induced machine shutdown. Of the other two test points that were tested, only one minimum stop zone distance was greater

than 3 ft. Additionally, Table 6 shows that distance measurements varied by as much as 5.8 ft for stop zone incursions and as much as 12.2 ft for warning zone incursions. Finally, Table 7 shows the average variations from baseline data for each test point. It can be seen that there is a larger variation in the warning zone measurements, which is due to the fact that the B-field strength decreases more rapidly the further away from the source. Test points 1, 2, and 10 showed the largest variations, which was to be expected as mining mode allowed contact with the machine during a number of field tests.

For trailing cable influence testing, only two test points were considered. Based on the nine field tests, only one test had a trailing cable at test point 9, which is the left side of the machine. Table 4 shows that at least one field site had the minimum stop zone incursion distance at test point 3 set to less than 3 ft. Additionally, Table 6 shows the variation between measurements as being 5.1 ft for test point 3's stop zone results. The results for test point 9 are for a single field test, so these results should not be construed as having little variability. The data from the influence of the trailing cable test condition did not show parasitic coupling to be taking place during any field tests. There is little difference between the minimum distance measurements for stop zone incursions between baseline measurements versus testing for trailing cable influence. Additionally, the variations for warning zone incursions are identical, and there is actually less variation for the trailing cable test, where one might presume larger variations for stop zone incursions due to parasitic coupling. This is supported by the data shown in Table 7.

The final condition examined in this study is the effect of the presence of a shuttle car on the PDS. This mode is applicable to the CMM cutting coal when a shuttle car is in the loading position. As the machine is in mining mode during this test, operators should be able to position themselves close to the CMM at test points 1, 2, 3, 9 and 10. Test points 1, 2, and 10 could not be examined as they are physically inaccessible due to the presence of a shuttle car. At least at one field site, test point 3 allowed the PWD to come in contact with the machine. Test point 9 was less than 3 ft, but did not permit machine contact. From Table 6, it can be seen that for this condition, the distance measurements varied by as much as 12.8 ft for warning zone incursions and as much as 11.7 ft for stop zone incursions. As can be seen from the data in Table 7, the variations from baseline measurements indicate that the presence of a shuttle car has some effect on test points 3 and 9, and little effect on test points 4 and 8. This is expected because the shuttle car in the loading position introduces a large mass of metal, which causes the field to increase.

## CONCLUSIONS

While proximity detection systems can greatly improve safety [1], this research has found that there are large variations of distance measurements for both warning zones and stop zones at different field sites. Since all approved PDSs have adjustable

zone distances, this variability is due to preferences set at installation. Site-specific conditions will need to be considered when defining the warning and stop zone distances. A number of measurements showed stop zones to be less than 3 ft. This distance may be inadequate for a CMM operating under adverse traction conditions, such as a wet floor on a slope. These zone distance settings should be tailored to mine conditions, keeping safety in mind. Field test measurements for both warning and stop zones were repeatable, and the majority of the readings only required two measurements.

The mining mode significantly reduces the warning and stop zones at the rear of the CMM, in some cases to zero. Although there are no recorded fatal striking/pinning accidents that have occurred while cutting coal, this could allow contact with the CMM by an operator and could be a safety hazard.

This research also devised tests that were designed to measure the effects of parasitic coupling. The data collected from these tests provide no indication that parasitic coupling has any effect on warning and stop zone distance measurements. Additional testing would be required to further investigate reports of false alarms caused from parasitic coupling.

Also, this research devised tests to measure the effect of a large mass of metal such as a shuttle car or other haulage close to the tail of the CMM. The data shows that the effect of the shuttle car being present was to enlarge the zones slightly.

Future development and installations of PDSs should take this information into consideration, and work to improve the precision of the systems. Additionally, mine operators and PDS installers may want to consider minimum distances when setting zones for production.

## DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Reference to specific brand names does not imply endorsement by the National Institute for Occupational Safety and Health.

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