NSW GOVERNMENT

NSW Resources Regulator

COLLISION BETWEEN SEMI-AUTONOMOUS DOZER AND AN EXCAVATOR

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Causal investigation

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Executive summary

A Caterpillar dozer operating semi-autonomously collided with a manned Hitachi hydraulic excavator at Wilpinjong Coal Mine near Mudgee, NSW, on 27 May 2019. The excavator operator was scaling a section of a highwall in the operating area of the semi-autonomous dozer fleet. The excavator travelled into the path of the dozer (working in semi-autonomous mode) while the dozer was reversing.

When the machines made contact, the excavator was pushed about 1.5 metres sideways. After five seconds, the dozer's semi-autonomous system identified the tracks were slipping and stopped tramming as programmed. The excavator operator did not suffer any injuries however needed assistance to evacuate the excavator, as the ladder system was damaged.

Following preliminary investigations, the NSW Resources Regulator decided to undertake a causal investigation.

A causal investigation team, comprising representatives from the mine operator Peabody Energy – Wilpinjong Coal Mine, worker representatives and the Regulator, was established on 7 June 2019. The team investigated the circumstances that resulted in the collision.

The contributing causal factors included:

- The location of the manually operated excavator was not able to be seen by the control system of the semi-autonomous tractor system (SATS) dozers or the SATS operator.
- The windrow, that separated the manually operated excavator from the SATS dozers, was absent, allowing the excavator to unknowingly encroach into an active SATS dozer slot.
- The height of the excavated material along the back bench restricted the excavator operators' vision of all SATS dozers.
- Communication between the excavator operator and SATS operator failed to identify the operating locations of all SATS dozers.
- Workers were inconsistently trained in the most recent SATS task guidelines and procedures.

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1. Causal investigation

A preliminary investigation and assessment of the incident was carried out by the NSW Resources Regulator, which did not identify any material breaches of work health and safety laws. Following this assessment, the Regulator determined that an investigation under our Causal Investigation Policy would enable a better understanding of the causes of the incident and reduce the likelihood of a reoccurrence through the publication of lessons learnt.

Notably, a causal investigation is an investigation into a safety incident that has been notified to the Regulator under work health and safety laws. It is not to obtain evidence for a prosecution, but to identify the causal factors of safety incidents, the effectiveness of the controls used and the factors which may have contributed to the failure of these controls. Timely communication helps to ensure that duty holders, under the work health and safety laws, can better understand the risks they must manage and the necessary controls needed to prevent reoccurrences of similar incidents.

A causal investigation team, comprising representatives from the mine operator Peabody Energy – Wilpinjong Coal Mine, worker representatives and the Regulator, was established on 7 June 2019.

The investigation considered potential deficiencies in procedures, equipment and training that may have contributed to the exposure of hazards to workers or other people.

The scope of the causal investigation included, but was not limited to:

- collision avoidance systems fitted to plant operating within the SATS avoidance zone
- the suitability of controls to limit interaction between semi-autonomous and manned equipment
- the effectiveness of controls when manned vehicles enter a semi-autonomous work zone
- monitoring workers conducting semi-autonomous and tele-remote operations of dozers and workers within an autonomous control zone.

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The investigation was undertaken using the incident cause analysis method (ICAM) framework, with human factors analysis conducted where appropriate. The causal investigation team considered:

- the causal circumstances of the incident, including an incident timeline
- identification and maintenance of controls
- human and organisational factors
- the regulatory environment in which the incident occurred
- recommendations for the mining industry to prevent a similar incident reoccurring

1.1. Preliminary report

An Investigation Information Release was issued on 24 June 2019 outlining what was known at the time. The preliminary report prompted mine operators to review their safety management systems, focusing on:

- reviewing controls to prevent workers inadvertently entering an area where automated equipment is operating
- confirming that the hierarchy of controls were applied when developing controls to manage interactions between manned equipment that interacts with semi-autonomous and tele-remote equipment
- having a suitable physical barrier in place relevant to the equipment being operated, when segregation is required between manned equipment and semi-autonomous and tele-remote equipment
- scheduling workplace inspections by supervisors of workers operating adjacent to or within semi-autonomous, autonomous and tele-remote operation zones.

1.2. The mine operator

Wilpinjong Coal Mine is owned and operated by Peabody Energy. The mine is about 40 kilometres north east of Mudgee, mining the Ulan seam to produce coal for the domestic and export markets. Wilpinjong employs 530 people and in 2018 produced 12.6 million tonnes of saleable coal. The mine uses bulk dozing methods to remove overburden. Wilpinjong has implemented a semi-autonomous dozer program to improve the efficiency of this process.

2. Background

2.1. Process overview

The bulk dozer push operating technique requires an excavator to clean the back of the bench against a highwall. This is required to remove the rear bench material where the dozers reverse to before commencing a push. Typically, the push area is operated so that an excavator will work one half and the dozers work the opposite half.

When the excavator is removing the excess material behind the dozer slots, the material is used to create a windrow at the back of the slots. This windrow is built across the back of the dozer push area. Once the excavator has completed one half, the dozer and excavator operations are swapped.

There is a procedural control that a manned machine should not be operating in the active slot of any dozer.

Each SATS enabled dozer is fitted with four cameras. When a dozer is selected by the operator, a screen in front of the operator displays four cameras. A small side panel also shows two camera views for each of the other three dozers (refer to figure 1). At any point, the operator can swap between dozers.

Figure 1 Overview of the SATS operator camera display screen immediately before the incident

When in semi-autonomous mode, the dozers can only conduct pushing operations in a designated slot within the avoidance zone.

At the time of the incident, the strip being mined included an established avoidance zone that was approximately 300 metres long, 135 metres wide and consisted of 30 slots.

Figure 2 Overview of the SATS operational area on the morning of the incident

When first implemented in 2015, the SATS was installed in a single Caterpillar D11T dozer. This increased to three dozers in 2017 and a fourth was added in 2018. On the day of the incident, three dozers were operating semi-autonomously while the fourth dozer was undergoing maintenance.

2.2. Controlled area

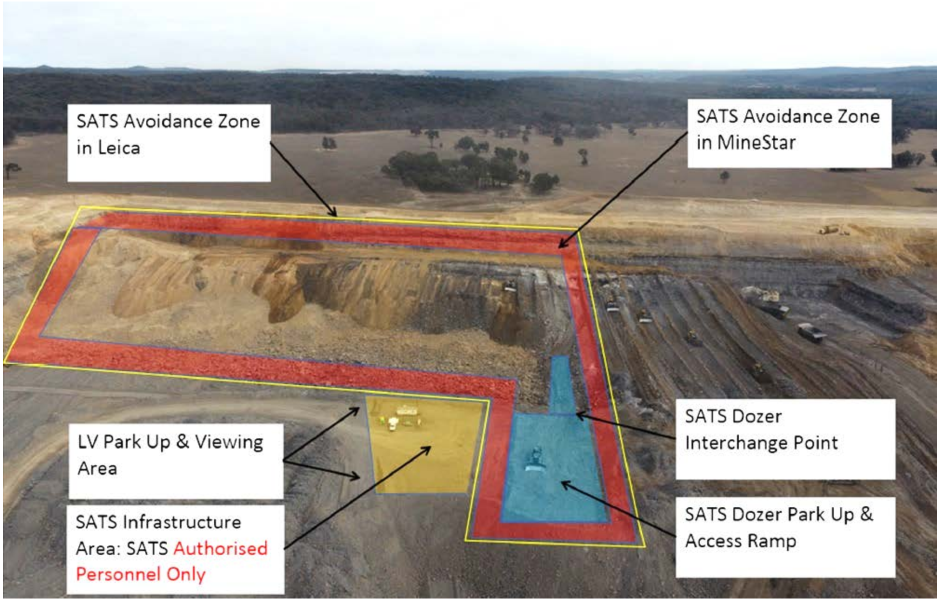
The SATS Operational Area is controlled via several digital avoidance zones as well as physical delineation and bunding.

The mine uses two separate avoidance zone systems - Leica MineOPS and Caterpillar MineStar, each having a geofence designated in the form of a digitised polygon.

The Leica MineOPS system is also used for dispatch and delay recording. The Leica MineOPS system geofence is the outer of the two avoidance zones and will alarm when any Leica-fitted vehicle crosses the avoidance zone. This avoidance zone is intended to function as a ‘barrier out’ system but did not stop the vehicle.

The Caterpillar MineStar system is a proprietary system using high precision GPS and machine monitoring to gauge the current and future positions of the machine. The Caterpillar MineStar geofence is established inside the boundaries of the Leica MineOPS system. This avoidance zone is intended to function as a ‘barrier in’ system and will result in a stop command to any SATS dozer attempting to cross the boundary.

Figure 3 An example of a SATS area set up



2.3. Equipment

2.3.1. Excavator

The incident involved a manually operated Hitachi EX1200 hydraulic excavator. The EX1200 is the smallest excavator model used in the SATS operational area and has an operating weight of 120 tonnes. The mine had previously used alternative excavator sizes and models in the operational area. These machines were larger however were not considered as efficient by the mine. After the incident, it was identified that the operator cabin of the Hitachi EX1200 excavator and the ripper box of the Caterpillar D11T are of similar height.

The excavator was not fitted with the Caterpillar MineStar system. At the time of the incident, a Leica MineOPS system was fitted but was inoperable due to a damaged boom sensor. With both avoidance systems non-operational, the location of the manned excavator was not visible to either the SATS dozers or the SATS operator.

The operator of the excavator was relying on positive communications and a visual line of sight to manage the proximity to the SATS dozers.

Figure 4 The Hitachi hydraulic excavator

2.3.2. Dozers

The SATS uses up to four Caterpillar D11T dozers that have been modified for tele-remote (referred to as remote control by the mine) and semi-autonomous operations. There are multiple control systems fitted to the dozers that monitor the current and future positions. As part of the conversion to be SATS capable, several cameras are fitted to the dozers. Cameras are:

- one roof-mounted, rear-facing camera
- one roof-mounted, forward-facing camera
- two roof-mounted, forward-facing cameras mounted to each side of the machine (looking forward over the left and right sides of the blade).

The SATS-enabled dozers can be operated in several modes:

- manually with an operator in the cabin
- by tele-remote control, with the operator manually controlling the machine from a remote operating station (ROS), or
- in a semi-autonomous control, where the operator monitors the machine from a ROS.

To operate semi-autonomously, the SATS operator allocates a dozer to a planned slot and creates a push profile mission. The SATS operator conducts the first push of the mission in tele-remote mode to stamp the terrain. Following the completion of the first push, the SATS operator can then activate the planned mission.

The dozer continues to operate in the same slot until either the mission is completed or until 12 passes have been conducted without any intervention by the SATS operator. After this, the operator must reconnect to the dozer before the system can restart in a semi-autonomous mode.

If a dozer operating semi-autonomously fails to move as expected, it faults and requires an operator to select the machine and reinitiate the semi-autonomous operation.

Figure 5 A dozer with modifications for semi-autonomous operations

2.3.3. Command for dozer control centre

The SATS dozers are controlled by a SATS operator in a remote command for dozer control centre. The command centre is a transportable trailer which consists of a ROS. The ROS is used for tele-remote operations and setting up each slot in the dozer push area for semi-autonomous operations.

Having additional monitors and keyboards, the ROS replicates the operator controls found within the cabin of a dozer. The ROS monitors and keyboards allow access to the operational screens and machine-mounted cameras from each SATS dozer. The ROS also contains an additional display allowing an aerial overview of the SATS push area. This display is also shared with the Leica MineOPS system.

The SATS operator can manually select each SATS dozer and override the operating mode at any time during the SATS push sequence.

Figure 6 The command for dozer control centre

Figure 7 The remote operator station (ROS) inside the command for dozer control centre

3. The Incident

3.1. Before the incident

On Monday 27 May 2019, the excavator involved in the incident was assigned to the dozer push work team. The excavator was manned by an experienced dozer push operator. A trainee SATS operator was controlling the dozer fleet under the supervision and instruction of an experienced SATS operator.

At the start of the shift, the excavator operator saw a visible windrow on the rear bench, between the highwall and slot 16, in accordance with site procedures. The excavator operator began work, scaling the northern highwall and throwing the material at the rear of the dozer slots, forming a windrow between the dozer push area and the rear bench.

About 10.30am, a production supervisor and an open cut examiner (OCE) performed an inspection of the SATS area. The production supervisor instructed the excavator operator to relocate and build an edge bund along the crest of the highwall above the rear of the SATS/dozer push area.

The excavator relocated to the top of the highwall and dragged material up from the highwall face to build the crest bund across the full width of the bench. Once this was completed, the excavator travelled back towards the entrance to the dozer push area, then to the refuelling area, where it was refuelled. The excavator operator stopped for a meal break about 12.30pm.

After the break, the excavator operator, the SATS trainee and the SATS trainer discussed the activities for the rest of the shift. The excavator operator said he was going to scale down loose material and move to the southern area to excavate the bench behind the dozer push slots.

The specific working locations for each of the three SATS dozers was not discussed. The excavator operator believed that the SATS dozers were not operating in the northern area and thought all of the machines had been relocated during his break.

Throughout the shift, the excavator remained within the SATS operational area and did not cross the avoidance zone boundaries of either of the Leica MineOPS or Caterpillar MineStar systems.

3.2. The Incident

At 1.30pm, the excavator operator resumed work within the SATS avoidance zone from the north, travelling towards the south. As the edge bund was constructed using material from the highwall face, some loose material was hanging up across the face. The operator used the excavator to scale the loose material from the face, as he travelled towards the southern section of the SATS avoidance zone.

As the excavator had previously scaled and cleaned up the northern area, a windrow had been built between the rear bench and the SATS dozer push slots. This resulted in the excavator working between the highwall face and the windrow. As loose material was scaled down, it was added to the windrow. The task progressed towards the south until the excavator travelled to the end of the windrow and was positioned adjacent to the rear of slot 16.

At this point, dozer DZ2003 was operating in slot 16, while dozer DZ2002 and dozer DZ2010 were working in adjacent slots in the southern section of the avoidance zone about 50 metres away. Dozer DZ2003 had been operating semi-autonomously for some time. Immediately before the collision, the SATS operator had selected and was observing dozer DZ2002 until dozer DZ2010 ceased pushing. The SATS operator switched to this machine and started fault finding.

Dozer DZ2003 had completed a push and was reversing towards the rear of slot 16 to start the next push. At this time the excavator proceeded past the windrow, into slot 16. About 1.40pm, dozer DZ2003 hit the rear of the excavator. When initial contact was made, the excavator was pushed about 1.5 metres sideways, into the base of the highwall. The excavator then stopped sliding and dozer DZ2003 continued to tram in reverse, colliding with the excavator multiple times trying to reach its programmed GPS coordinates.

Dozer DZ2003 eventually lost traction and after five seconds, the control system faulted and stopped tramming. From the initial contact to dozer DZ2003 stopping was about 14 seconds. The excavator had some damage however the operator was uninjured.

After the initial collision, the excavator operator tried to contact the control via radio however was unsuccessful because of radio traffic. After changing radio channels, the excavator operator contacted the SATS operator however by this stage, dozer DZ2003 had faulted and stopped tramming.

Figure 8 The incident scene immediately following the collision

3.3. Initial response

All SATS dozer operations were initially paused and then shutdown following the initiation of the emergency response. The collision damaged the platform access ladder on the excavator resulting in the excavator operator being unable to safely exit the machine. A rescue plan was developed and the Regulator was notified of the incident.

Dozer DZ2003's operating mode was changed to manual operation, to allow it to be manually driven away from the excavator. Following the dozer removal, the excavator operator was safely assisted from the machine.

The incident scene was preserved. Photos and witness statements were taken and provided to the Regulator.

3.4. Incident response

The Regulator sent inspectors to attend the mine the morning following the incident. An initial site assessment was completed and a causal investigation was proposed.

4. Investigation

The investigation of the incident and contributory factors followed the incident causation analysis method (ICAM). The ICAM investigation was initiated by Wilpinjong Mine on 4 June 2019, which used an independent facilitator to lead the investigation.

The ICAM investigation was intended to identify the root causes, in order to determine possible actions to strengthen management systems, and minimise the potential for a reoccurrence of this, or similar incidents.

4.1. Causal factors

The ICAM investigation concluded that the cause of the incident was that the excavator encroached in the area where dozer DZ2003 was operating in SATS mode. The dozer reversed to the upper end of slot 16 and collided with the excavator, which was facing away from the slot while scaling the adjacent wall.

4.1.1. Absent or failed defences

The ICAM investigation identified the absent or failed defences which contributed to the incident as:

- A bund used to separate the SATS dozer and manual excavator was absent and therefore failed to stop the excavator encroaching into the avoidance zone, allowing a collision to occur.
- Position awareness was fitted to SATS and terrain-enabled dozers, but absent on other equipment, including manually operated excavators.
- Collision avoidance was fitted to SATS and terrain-enabled dozers, but absent on other equipment, including manually operated excavators.
- Inspection regimes failed to identify the missing or compromised bund.
- Regional cameras were not reset and available to provide oversight of the area.
- Regional camera feed was to a shared screen with LEICA MineOPS system, reducing the availability of the oversight of the area.
- A work plan discussion between the excavator operator and SATS operators failed to highlight that dozer DZ2003 was operating in SATS mode in slot 16 on the northern end of the SATS avoidance zone.
- A training and competency plan failed to ensure all relevant workers were trained in SATS (task guidelines).

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4.1.2. Individual or team actions

The ICAM investigation identified the individual or team actions that contributed to the incident as:

- The excavator operator encroached into an active SATS dozer slot.
- Supervisors did not identify that the separation bund was missing or compromised.
- Operators did not follow procedure – the bund was an unreliable barrier due to the frequency of dozers' movements during the shift.
- The regional cameras were not reset and used as per requirements of SATS procedures and task guidelines.
- The excavator operator decided to work north-to-south – towards the SATS dozer operations.
- The excavator operator assumed that the SATS dozers were all working in the southern end of the SATS area.
- The dozer push supervisor failed to ensure that workers were suitably trained in SATS procedures and task guidelines and that required pre-start forms and inspection forms were completed.

4.1.3. Task and environmental conditions

The ICAM investigation identified the task and environmental conditions that contributed to the incident as:

- The excavated dirt was positioned in a place that impacted on the excavator operator's visibility of the dozer DZ2003 working in slot 16.
- There were an unusually high number of remote control movements and activities on the day (at least five movements between 6.30am and 1.30pm).

4.1.4. Organisational factors

The ICAM investigation identified the organisational factors that contributed to the incident as:

- The risk assessment conducted to operate and maintain multiple SATS dozers did not consider whether additional controls were necessary because of an increased number and frequency of movement by SATS dozers.

- The risk assessment identified potential engineering controls (such as collision avoidance) in addition to a separation bund with regards to manually operated equipment operating in a SATS avoidance zone. However, these engineering controls were not implemented as the mine considered they were not reasonably practicable.

5. Outcomes

5.1. Key lessons

There are potential safety and commercial benefits to using autonomous equipment. Autonomous operation can significantly minimise risks to machine operators by removing them from the location of mining activities. The segregation of workers from autonomous operations is generally the primary risk control measure, however all autonomous equipment requires some form of human interaction. Autonomous control system design and implementation, especially around human interaction, is critical and if it is not adequately managed, can also impact health and safety in the workplace.

Risk assessments must consider all reasonably foreseeable risks. In assessing risk, existing controls are often assumed to be adequate if an incident is not known to have previously occurred. Work, health and safety legislation stipulates that risks are to be managed, so far as is reasonably practicable, and the effectiveness of risk controls are to be reviewed after a high potential incident occurs. These requirements compel a mine operator to challenge the adequacy of control measures. Put simply, instead of asking why an additional control should be implemented, this should be a question of ‘why not?’.

The hierarchy of control measures is typically referred to in most high-level site safety documents like principal hazard control plans and safety management systems. In the practical application of determining risk control measures however, the hierarchy is often overlooked. The implementation of soft procedural controls in lieu of hard barriers or high engineering level controls should always be questioned where alternatives are known to exist.

Changes to equipment, operational staff, work processes and the operating environment is inevitable over time and requires proactive management. When changes occur, the adequacy of existing control measures must be considered. In determining the adequacy of the existing controls, consideration should also be given to advances in technology and the availability of new control measures.

Advances in technology should provide an opportunity to improve existing control measures. Just because a control may not have been readily available at the time of installation, does not mean that people conducting business or undertaking (PCBUs) should not provide consideration to new control measures, once improvements become available.

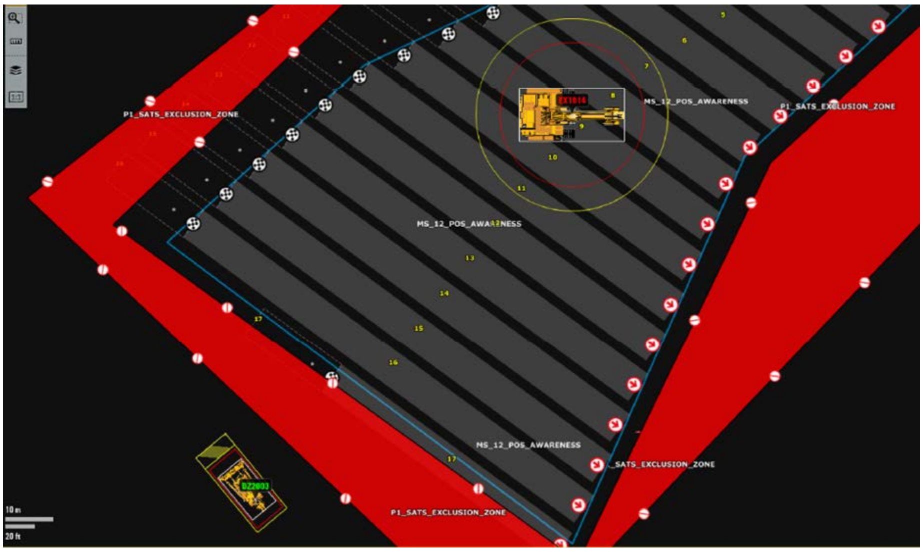
5.2. Mine actions

As a result of the investigation, the mine installed a proximity awareness system and an autonomous stop system to the excavator involved in the incident. This additional system functionality allows the control systems of SATS dozers and the excavator to track the real-time location of each machine and apply virtual proximity boundaries through high precision GPS.

These proximity boundaries automatically alert and initiate a proximity stop of any SATS dozer that encroaches within a set radius of the manned excavator. From the centre of rotation on the excavator, a yellow alert boundary is set at 25 metres and a red proximity stop boundary is set at 20 metres. Alternatively, the manually operated excavator will receive an alert and apply a proximity stop on a SATS dozer when the manually operated excavator encroaches within an active dozer slot.

The proximity awareness system includes an 'RC override' mode that provides a 30 second manual override of an active proximity stop. This mode is available for recovering a SATS dozer that has made contact with a proximity stop boundary. The proximity awareness system provides collision avoidance protection against SATS dozers operating in both remote control and semi-autonomous modes.

Figure 9 Caterpillar MineStar system displaying the alarm and trip proximity boundaries for the excavator and dozer DZ2003



The autonomous stop system provides another layer of protection that allows any worker to remotely stop all SATS dozer operations within a 400 metre radius of the portable system device, for any reason.

In addition to the new engineering controls, the mine has also implemented the following additional procedural controls:

- The requirement for all workers who enter the SATS avoidance zone to carry a portable autonomous stop system device.
- The specification of a minimum two-slot separation distance between manually operated equipment and an active SATS dozer slot.
- The creation of a SATS dozer interchange point on the access ramp between the SATS dozer park-up area and the SATS operational area. This new interchange point triggers communications between the SATS operator and all equipment operators on entry/exit of the SATS operational area.
- A new screen has been fitted in the control room as a dedicated regional aerial camera display.
- Updated control room pre-operation inspection checklist, which includes confirming operation of the regional aerial camera and the activation of the Leica MineOPS geofence, Caterpillar MineStar geofence, Caterpillar proximity awareness system and the autonomous stop system.
- A register has been created for signing in and signing out the portable autonomous stop system devices.
- The development of four new task guidelines for specific interaction activities within the SATS operation area.

With the new engineering controls implemented, the mine no longer needs to use windrows or bunds within the SATS avoidance zone. The proximity awareness system and an autonomous stop system are now the primary control for managing the interactions between the SATS dozers and manned equipment.