Automation in Underground Coal Mining

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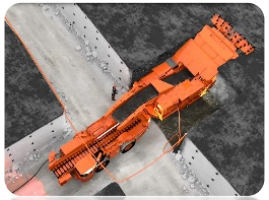
Technology Drivers for Joy Mining Systems

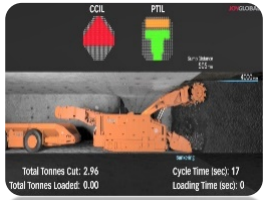
- Sustainability and Safety
- Efficiency and Selective Extraction
- Productivity – Rate and consistency
- Digitization – Empowering performance
- Total Cost of Ownership

Levels of R&P Automation

Full Operator Responsibility → Full Equipment Responsibility



Level 0 **Manual Operation**



Level 1 **Operator Assist**

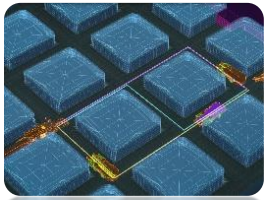
- The system has some function-specific automated features.
- The operator completes most tasks and maintains control.

Level 2 **Semi-Automated**

- The system performs a portion of its tasks autonomously within a set of defined operations.
- The operator performs other tasks and is generally responsible for situation awareness.

Level 3 **Conditionally Autonomous**

- The system can complete continuous operations autonomously, including situation awareness in the designated autonomous area.
- The system can identify when intervention is needed and will enter a halted state.
- An autonomous operator/supervisor can disengage the system and must be available to operate it manually as a fallback.



Level 4 **Highly Autonomous**

- The system can complete continuous operations autonomously (including situation awareness) in the designated autonomous area.
- The system can identify when intervention is needed and functions as a fallback, adapting the operations to accommodate minimal risks. It will enter a halted state in higher risk situations.
- Changes possible

Level 5 **Fully Autonomous**

- The system can complete continuous operations autonomously with and without a designated autonomous area.
- The system can identify when intervention is needed and functions as a fallback, adapting operations to accommodate minimal risks.
- It will enter a halted state in higher risk situations. The system can be re-engaged

Automation Challenges in Soft Rock Mining

- Environmental
  - Hazardous due to Gas, and Dust – requires specialized technology,
  - High Heat and Humidity – specialized hardware
  - Vibration and Shock – Robustness of application, narrows technology pool
  - Dust and airborne moisture affecting image capture
- Continually changing location, conditions and spatial positioning
- Position/Spatial Tracking systems must be self-maintaining, predictive and stable – No GPS
- Roof Support and Cable/Services Management
- Exception management – Geological and operational variances
- Technology – skills gap
- Interoperability between manufacturers, users, networks…..
- Economy of scale - highly advanced and complex systems…relatively low Longwall population
- Automation changes the risk profile faced in the operation…..management of change is as important as the technology

Autonomous Section Transformation

High precision cutting

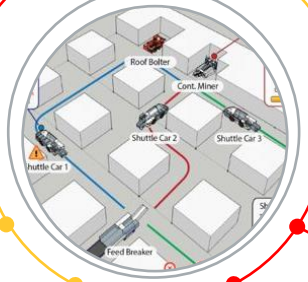
CM maintains desired heading and stays in seam
"Cutting to a plan"
Service products to support application

Remote Oversight and Operations

All data and visuals available outbye or on surface
Remote operators can take control
Section Planner
Fleet management

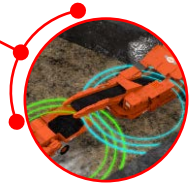
Automated Haulage

Follows optimal routes - guidance
Avoids obstacles
Automated loading and dumping
Package for third-party shuttle cars
Battery-operated shuttle car



Data Analytics

Artificial intelligence to optimize mining cycles
Predict and manage conditions
Calculate real-time metrics for performance
Machine health



Proximity Detection, Collision Avoidance, M2M Communication

Machines know where other machines are
Awareness of surrounding and location
Reliable, high-speed data

Auto-Bolting

Fully automated roof bolting
Consumables management system

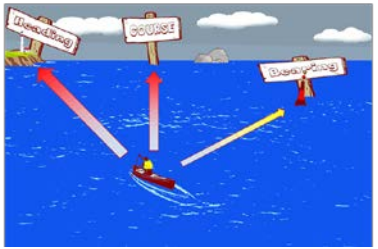
Reduced operators, limited cables

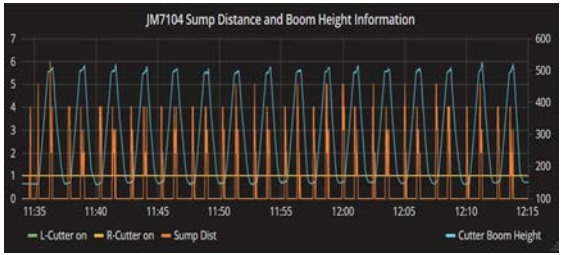
Existing Feature: Autocut “CMA” for CM’s

- Sequence-based cutting automation (“Continuous Miner Assist”)
- Initial developments implemented at the Compass Minerals Goderich Mine in Goderich, Ontario, Canada and Winsford Mine in Winsford, England
  - Further deployment at coal mines in South Africa and Australia, potash mine in USA
- Cut-cycle defined by sequence table
- Operator aligns machine manually, activates automation to cut in a straight line
- Benefits:
  - Cycle time consistency, with cycle time improvement when properly calibrated
  - Smoother ribs, floor, and roof
  - Minimal operator input, reduce operator fatigue
  - Allows operator to monitor the environment better
- Multiple coal sites recently activated

Key Development for Continuous Miner Automation:

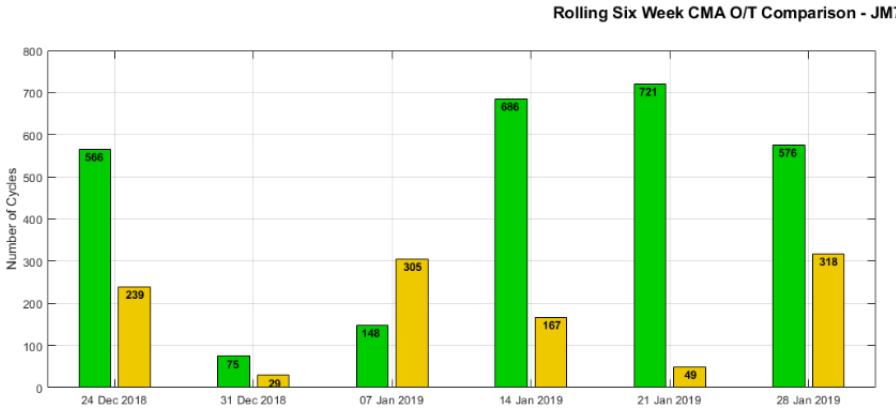
Automated Continuous Miner Cut Cycle Sequence w/ Heading Co

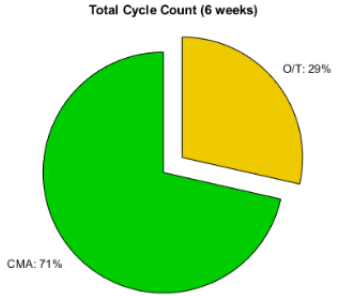




CMA – Time Study from Industrial Minerals

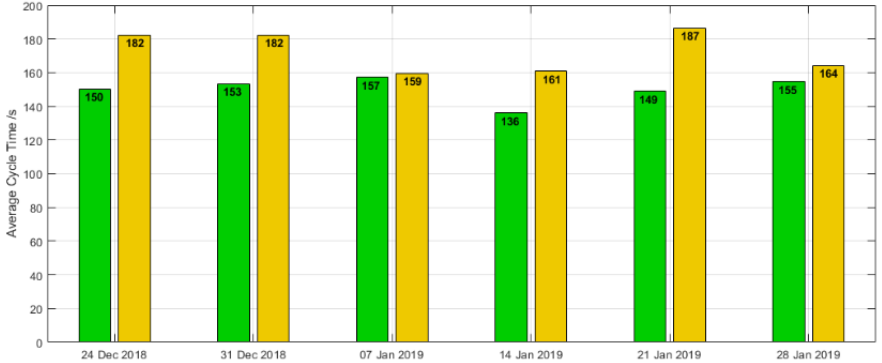
Operators use CMA regularly

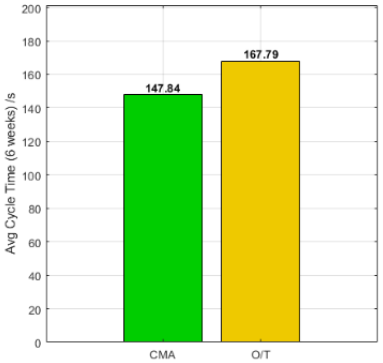




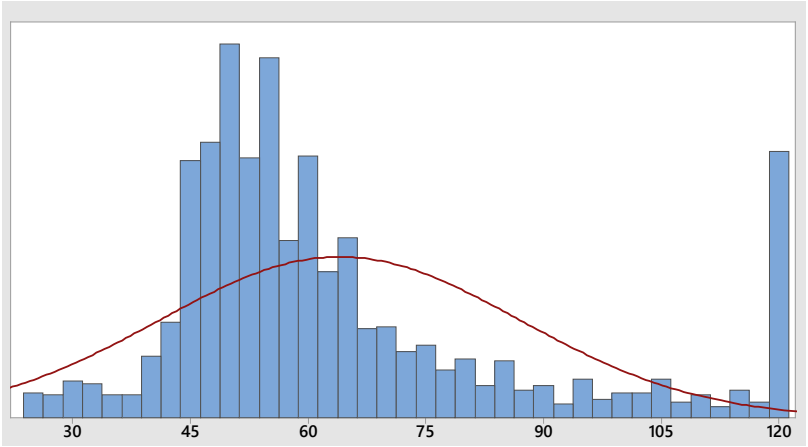
Cycle times are improved and are more consistent

- 12% cycle time improvement





CMA – Time Study in Coal Application

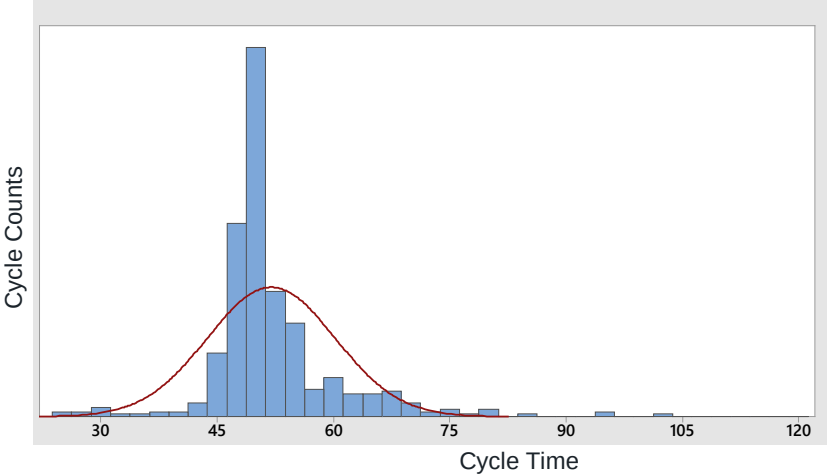


Manual Operation

- Wider spread of cycle times (flatter curve)
- Higher average cycle time (center of curve) ~62s/cycle

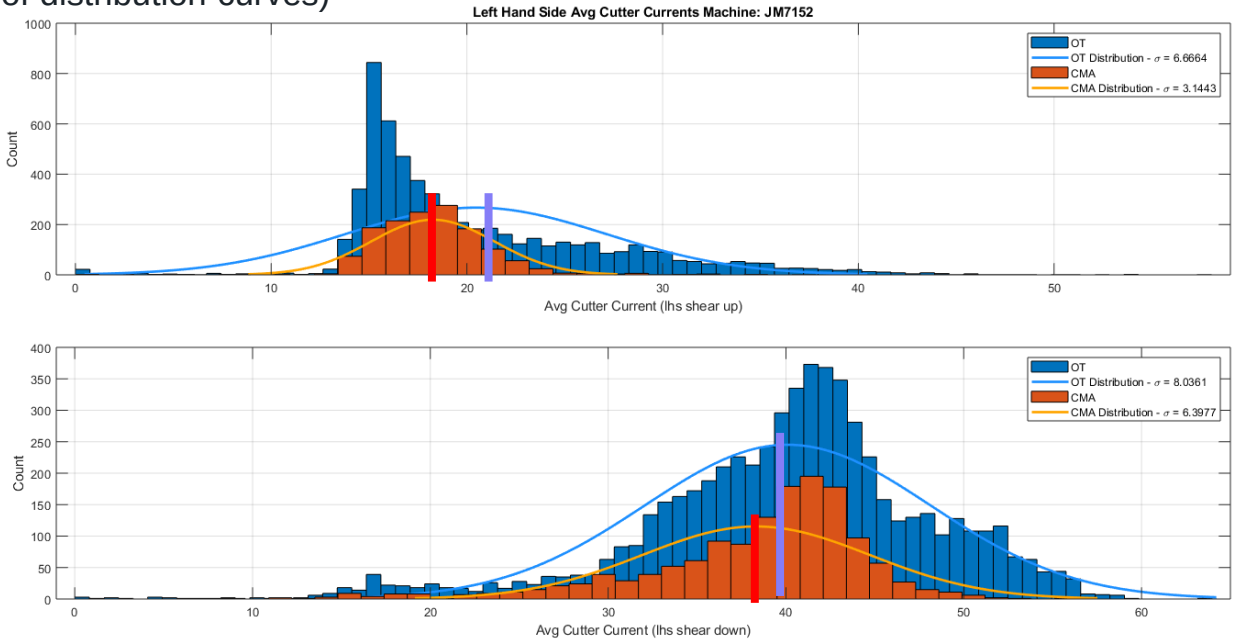
Automation (CMA)

- Narrow spread of cycle times (peaked curve)
- Lower average cycle time (center of curve) ~52s/cycle
- Represents a productivity improvement of 16%



Case Study: CM Cutter Currents

- Reduced cutter currents and improved cutter-current consistency with CMA (observe peaks of distribution curves)



- Takeaways:
  - Operators are likely pushing the machines much harder in OT, to the point of causing jam-trips, increasing wear
  - Consistent currents with CMA result from consistent sumps – when operators sump, they are just “eyeballing” it

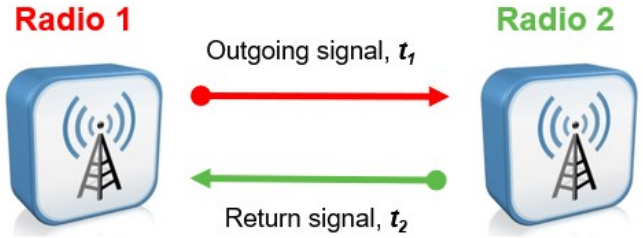
Existing Development: Continuous Haulage Automation

Anti-collision and “follow mode” automation features for the FCT using Ultra-Wideband sensor technology

- Provides reference position of the CM bumper for the FCT
- When running in manual mode, FCT anti-collision is active
- In “follow mode”, the FCT automatically maintains a target distance to the CM
- Automatic speed-matching
- Pre-start alarms and visual indications prior to movement

Successful at Compass Goderich Mine

FCT operator can be freed-up to inspect the FCT and surrounding conditions

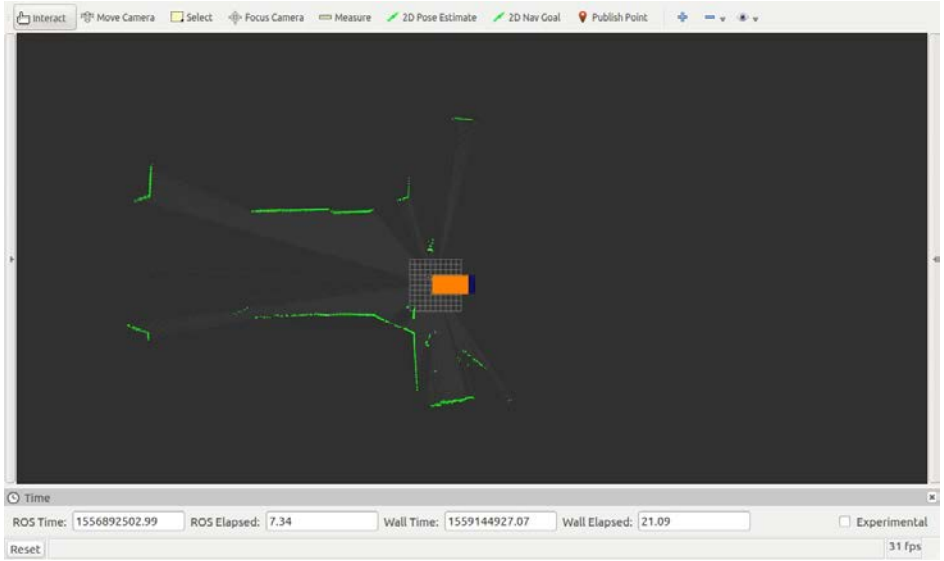


$$\text{distance} = \frac{(t1 + t2) * \text{signal speed}}{2}$$

Heading Control and Navigation

The Use of Lidars to Establish and Maintain the CM Heading

- Machine-mounted lidars continuously capture previously cut areas (walls or ribs) around the machine, which have been surveyed and verified to be cut appropriately
- Prior cut rib locations can be used to precisely predict where the machine should be going.
- Using the real-time data, a lidar based map of the recently mined area is created via SLAM (Simultaneous Localization and Mapping).
- From this map, the machine's position and heading can be determined relative to the previously cut area.
- Initial goal is to cut 150ft on the desired heading in a straight line.
- Ultimately, will lead to navigation, automated place-changing, obstacle avoidance



In Summary

- Automation has the power to increase productivity safely
- Risk Profile will change
- 70-80% of Komatsu R&D spend will improve safety.
- Foundational technologies are being proven
- Automation and Digitization of the value chain will deliver max value
- Funding and collaboration will increase momentum
- The great news is that development is still accelerating
- Automation is becoming an accessible reality to the broader industry