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GUIDELINE FOR IMPLEMENTING SHORT INTERVAL CONTROL IN UNDERGROUND MINING OPERATIONS

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Short Interval Control Sub-Committee of the Underground Mining Working Group

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TABLE OF CONTENTS

DISCLAIMER ii

COPYRIGHT NOTICE iii

TABLE OF CONTENTS iv

1. FOREWORD 1

2. DEFINITIONS OF TERMS, SYMBOLS, AND ABBREVIATIONS 1

- 2.1 Abbreviations 1
- 2.2 Terminology and Definitions 1

3. KEYWORDS 2

4. INTRODUCTION AND BACKGROUND 2

5. SCOPE 2

6. VALUE PROPOSITION 3

- 6.1 Overall Equipment Effectiveness 3
- 6.2 Operational Processes 3
- 6.3 Benefits to Supervisors 4
- 6.4 Safety and Emergency Procedures 4

7. OPERATIONAL MODEL 4

- 7.1 Conceptual Operations 4
  - 7.1.1 Developing the Operational Framework 5
  - 7.1.2 Current State (“As-Is”) 6
  - 7.1.3 Future State (“To-Be”) 7
  - 7.1.4 Short Interval Control Activities 8
- 7.2 Short Interval Control Processes 9
  - 7.2.1 Long-Term Planning 9
  - 7.2.2 Short-Term Planning 9
  - 7.2.3 Weekly Planning 9
  - 7.2.4 Shift Scheduling 12
  - 7.2.5 In-Shift Review 14
  - 7.2.6 Post-Shift Review 17
- 7.3 Data Enablement 19
  - 7.3.1 Level 1: Basic 20
  - 7.3.2 Level 2: Foundational 20
  - 7.3.3 Level 3: Integrated 21
  - 7.3.4 Level 4: Decision-Supported 21
  - 7.3.5 Level 5: Semi-Automated 21
  - 7.3.6 Level 6: Highly Automated 21
  - 7.3.7 Recommended Contextual Reading 21

8. IMPLEMENTATION 21

- 8.1 Introduction 21
- 8.2 Culture 22
- 8.3 Planning 22
  - 8.3.1 Change Management Plan 22
  - 8.3.2 Scope of Work 23
  - 8.3.3 Project Roadmap 24
- 8.4 Deployment 24
- 8.5 Ongoing Review and Updating 25

9. RESOURCES, REFERENCES, AND RECOMMENDED READING 25

APPENDIX A: LEAN MANUFACTURING CONCEPTS APPLIED TO THE IMPLEMENTATION OF SHORT INTERVAL CONTROL IN UNDERGROUND MINING 27

APPENDIX B: CASE STUDIES 28

B.1 Business Case for Short Interval Control at Boliden 28

B.2 Change Management Lessons Learned at PACE – Partners in Achieving Change Excellence 29

B.3 Operations Management System Lessons Learned at Glencore 30

B.4 Continuous Improvement Case Study: Greater Visibility, Control, and Efficiency at AGCO 31

APPENDIX C: SHORT INTERVAL CONTROL ROLES AND RESPONSIBILITIES 33

C.1 Example 1 33

C.1.1 Superintendent (Production, Development, Maintenance) 33

C.1.2 Shift Supervisor (Production, Development, Maintenance) 33

C.1.3 SIC Supervisor/Operator 33

C.1.4 Short-Term/Daily Task Scheduler 34

C.2 Example 2 34

C.2.1 Control Room Supervisor 34

C.2.2 Shift Supervisor 34

C.2.3 Operators 34

C.2.4 Superintendent 34

1. FOREWORD

The Global Mining Guidelines Group (GMG) is a network of representatives from mining companies, original equipment manufacturers (OEMs), original technology manufacturers (OTMs), research organizations, and consultants around the world, creating multi-stakeholder working groups to systematically remove the impediments to building the safe, sustainable, and innovative mines of the future. To achieve this goal, GMG working groups establish focused projects to develop guidelines, such as this one, for the international mining industry. Draft documents are checked and approved by working group members, prior to approval by the GMG Governing Council.

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2. DEFINITIONS OF TERMS, SYMBOLS, AND ABBREVIATIONS

2.1 Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
BLE	Bluetooth® Low Energy
ERP	Enterprise Resource Planning
FMS	Fleet Management System
GPS	Global Positioning System
IPS	Indoor Positioning System
IT	Information Technology
KPI	Key Performance Indicator
LiDAR	Light Detection and Ranging
LTE®	Long-Term Evolution
MES	Manufacturing Execution System
MOM	Manufacturing Operations Management
NVA	Non-Value-Added
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OT	Operational Technology
OTM	Original Technology Manufacturer
PDCA	Plan, Do, Check, Act
PLC	Programmable Logic Control
RFID	Radio Frequency Identification
SCADA	Supervisory Control and Data Acquisition
SIC	Short Interval Control
SMS	Short Message Service
TIMWOOD	Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, Defects

2.2 Terminology and Definitions

This list clarifies key terms and language used in this guideline. Because this guideline deals with concepts and operational processes where the specific terms often vary depending on the mine and region, this list identifies the terms the guideline applies to describe these concepts and disambiguates terms often used interchangeably.

Continuous improvement loop: A system to assess a process and determine how to improve it, test the plan, evaluate the test, and fully implement the improvement with the intention of increasing productivity and minimizing waste.

Control: In mining, the ability to know where assets are and what they are doing, the progress of a shift with respect to a baseline and a target, and to react and mitigate any issues that might arise.

Control room: A central room or area in the mine from which dispersed operations, systems, and equipment can be monitored and controlled. It is often also called an operations centre.

Deviation: An unplanned activity or delay that affects the schedule and/or related plans.

Execution: Completing scheduled tasks and activities to achieve a plan.

Key performance indicators: Measurable values used to assess or demonstrate how effectively a company is achieving key business objectives.

Lean manufacturing: A methodology for making a process more streamlined by eliminating waste and inefficiency.

Mechanisms: Who and what is required for the process to be successfully executed or activity to be undertaken; not changed by the process or activity itself (e.g., people, technology, equipment facilities).

Near-real-time: A system response that lags on the order of minutes but still provides the user a sufficiently quick response (slightly slower than real time).

Non-value-added tasks: Tasks that must be completed in order for value-added tasks to occur.

Plan: A process for meeting an objective in either the long-term or short-term future that identifies the steps and timing needed to complete it.

Real time: System response that, from the user's perspective, is immediate following user input (on the order of seconds).

Schedule: A timetable for tasks, actions, and events that need to be accomplished to align with or fulfill a plan. It also identifies the resources, such as operators and equipment, assigned to each task. There are schedules for individual shifts and schedules that cover several days (e.g., a weekly schedule).

Shift actuals: The real products/results of a shift as opposed to the products/results that were planned or projected.

Short interval: A small amount of time, for example, one hour or one shift.

Short interval control: A structured process in which data are reviewed in short intervals throughout a shift to make improvements and address deviations in real time.

Telemetry: An automated technological process for communicating measurements and other data between remote locations and receiving equipment.

Value-added tasks: Tasks that physically change the product and tasks for which the customer is willing to pay.

Variation: A general term referring variability between tasks and processes. Variation might be caused by deviations (as defined above), but it might also be the result of smaller and more difficult to measure differences.

Waste activities: Activities that neither add value nor must be completed in order for value-added tasks to occur.

3. KEYWORDS

Efficiency, Key Performance Indicators, Lean Management, Risk Management, Shift Planning, Short Interval Control

4. INTRODUCTION AND BACKGROUND

Short interval control (SIC) is a form of control and response. It is a structured process for identifying and acting on opportunities to improve effectiveness and efficiency of mining processes (production, development, and services). The intended outcome is a continuous improvement loop of increased productivity and minimized waste. In a factory setting, SIC is a shop floor process in which data are reviewed approximately three to four times per shift and used to make improvements in real time to minimize deviation from plans. Because shifts in underground mining are often long (e.g., 12 hours), review intervals range from once every six hours to once an hour or less (with the appropriate support). More broadly, SIC enables an effective "plan, do, check, act" (PDCA) loop for mining processes. The PDCA concept is well accepted in manufacturing as a continuous improvement loop that involves assessing a process and determining how to improve it (plan), testing the plan (do), evaluating the test (check), and then fully implementing the improvement (act).

Successful SIC must include the following:

- **Planning (strategic and tactical):** Providing mine operators with up-to-date, trustworthy information enables plan adjustment from a known set-point. It also allows the leadership team to set realistic strategic and tactical goals and hold operators accountable.
- **Situation awareness:** The control room must know team member and asset locations throughout each shift so that they can monitor tasks or actual progress.
- **Resource management:** The control room must be aware of what resources are available, including equipment, assets, and qualified personnel.
- **Operational decision making:** Knowledge of strategic and tactical priorities allows the operational team to adjust and reprioritize in the face of unplanned challenges.

Though the manufacturing industry has used SIC for years, it is relatively new to underground mining because the working conditions and environment are generally more unpredictable. Recently, technological advances and improved communication infrastructure in underground environments have increased opportunities to adopt shift management processes. There is now a strong drive for increased control and automation in underground mining. Many of the industry leaders who have implemented the concept have seen significant productivity and cost improvements, at limited expense. SIC implementation, however, can seem daunting to some because there are no ready-made solutions; each mine needs multiple components, then must integrate them into the specifics of their operation, culture, and business strategy.

This guideline provides much-needed independent direction on the available options for SIC, allowing for greater and faster adoption of control technologies and processes. Enabling SIC adoption will give the mining industry the required processes to optimize shift time and asset use (personnel, equipment, and headings/stopes) in underground mines. This will facilitate better planning, quicker decisions, increased production, lower costs, and safer working.

5. SCOPE

This document is primarily designed for the business leader who is interested in coordinating SIC implementation. This leader has familiarity with mining processes and workflows and will use this guideline to understand the technical, functional, and interpersonal success factors associated with SIC. Systems architects, change management professionals, and technology developers can also use this document to gain a general sense of the subject matter, though it is not specifically designed for their roles.

Stakeholders who could benefit from this guideline include, but are not limited to:

- Mine operators (mine, plant, planning, exploration)
- Consultants (change management, task mapping)
- OTMs (communication suppliers, data visualization, simulation)

This guideline is applicable to the use of SIC in underground mine extraction processes; many aspects could also be applied to open-pit operations. Exploration, mine development, mineral processing, logistics, and remediation can all benefit from SIC, and the management principles are similar; however, the specific SIC functions and technologies required will be different in each situation.

Rather than replace the need for consultants or suppliers, this guideline provides a roadmap to increase the speed and likelihood of success during SIC implementation while avoiding common pitfalls. The aim of the guideline is also to present options and best practices for introducing SIC processes and technologies. The guideline offers a descriptive guiding framework of what SIC could look like in a mine and introduces the concept of "levels of maturity" (see Section 7.3), a scale by which the degree of autonomy of an SIC system is categorized on a scale from manual ("basic") to highly automated.

The guideline is divided into three main sections: A value proposition that makes the case for why SIC is important and useful (Section 6), an operational model that describes what SIC is in its various forms and stages (Section 7), and a high-level roadmap of how to implement SIC (Section 8).

6. VALUE PROPOSITION

SIC is a beneficial process that aims to adjust operations in real time based on actual conditions to meet shift goals and short-term planning targets. This section describes how SIC can increase productivity and reduce costs for mining companies. The value of SIC is discussed broadly, with a focus on improving overall equipment effectiveness (OEE), optimizing processes, reducing burdens on supervisors, and enhancing mine safety and environmental performance. Identifying what benefits are desired from SIC and understanding the value to be derived from those benefits will allow a mine to determine at what level of technological complexity (level of maturity) the SIC system should be implemented. The possible levels of maturity of an SIC system and the benefits that can be realized at each level are described in Section 7.3. As a mine develops its technological maturity over time, the value of SIC increases.

This guideline uses concepts and terminology from the lean manufacturing methodology for minimizing waste. SIC is a tool that can enable the realization of value from this method. See Appendix A for more information about lean manufacturing.

6.1 Overall Equipment Effectiveness

If implemented effectively, SIC can improve OEE in the three areas—availability, utilization, and production rate—without significant capital expenditure (not including wireless infrastructure and associated software).

SIC can improve availability, or equipment "uptime", by maximizing technological advances, such as equipment telemetry, which uses real-time data to alert the control room to equipment alarms. SIC allows for the best possible revision of the plan to adjust to new realities that are communicated. It can also make diagnosing equipment failures easier and expedite repair by providing the location of a stranded asset, parts inventories, required tools, online manuals, procedures, and drawings. Real-time location data can also ensure that required resources are dispatched from optimal locations (e.g., the closest mechanic is sent to a breakdown).

SIC improves utilization (not only of equipment, but also of personnel and headings/stopes) by reducing non-value-added (NVA) activities and waste in all seven categories laid out in the lean manufacturing method, known by the acronym TIMWOOD (Appendix A):

- Transportation (excessive, e.g., moving muck piles several times)
- Inventory (too much, too little, not enough of what is required; too much of what is not required; difficulty locating supplies)
- Motion (excessive, e.g., multiple moves for drill set-up)
- Waiting (e.g., for information and resources; for other tasks to be completed; in fueling lines; in congested traffic)
- Overproduction (e.g., overmucking or overusing equipment for one purpose, potentially putting another sector behind and not following the mine plan)
- Overprocessing (e.g., making processes more complicated than necessary)
- Defects (e.g., having to complete re-drills or placing re-drill in the wrong location)

SIC can improve production by bringing the actual production rate closer to the target rate. This can be accomplished by modifying plans during the shift to mitigate risk and adjust to real-time conditions, thereby increasing the probability that production goals will be met by the end of the shift. For example, supervisors can ensure muck tonnage or drill metres meet the target by adding or reassigning resources.

6.2 Operational Processes

In the short term, near-real-time data from SIC make it possible to adjust process operations that deviate from the schedule soon after a deviation occurs. In the long term, it provides a wealth of data and information to identify and analyze recurring problems so that effective countermeasures can be implemented to reduce the frequency with which the issue repeats. It can also help to effectively deter-

mine maintenance requirements and production per asset and coordinate maintenance and production schedules for all equipment assets.

The ability to predict future performance reduces waste from task variation. For example, monitoring task requirements (e.g., muck tonnes required from a stope) mid-way through the shift and taking corrective action as needed to achieve the goal (e.g., assigning more trucks) makes the task more repeatable and predictable during future shifts.

6.3 Benefits to Supervisors

The ability to support production from a control room with an improved planning and problem-solving system reduces burdens for supervisors and other management. Supervisors have many responsibilities and must accomplish numerous daily tasks to meet production goals. They are often required to solve immediate problems and complete many NVA tasks. SIC can support the supervisor's decision-making processes.

The control room structure allows the supervisor to oversee all operations and understand connections between them. With this visibility, they can make decisions based on a reliable understanding of the situation rather than assumptions based on limited data. Supervisors will also save time looking for relevant resources and information about people and equipment. They will be able to readily access information and resources, such as drill and blast plans or letters, to solve problems in a timeframe that enables value capture and/or prevents value loss. They will also be able to manage administrative tasks more efficiently because they can gather information more easily about issues that need to be addressed in preparation for workplace inspections, and they can prepopulate the shift log while data (tonnes, hours, parking locations, drill metres) are gathered.

With less time focused on administrative and NVA tasks, supervisors can spend more time on value-driven tasks, including:

- Recognizing and addressing hazards, performing inspections, and considering other safety concerns
- Conducting job observations and coaching operators on how to work more productively and improve their quality of work
- Stope preparation planning (drill or muck), development heading, and construction planning
- Problem-solving and resolution efforts

6.4 Safety and Emergency Procedures

Using SIC and the associated digital infrastructure enhances mine safety and environmental performance. It can help prevent emergencies before they occur by providing data and information that facilitates safety performance analysis to drive improvements to safety procedures. At higher levels of maturity, digitally enabled and connected equipment safety devices can deliver automatic notifications and alerts based on data from the device and other integrated systems. Data typically collected manually (e.g., visual inspections) can be added to the system in real time using tablets or similar devices so that the information is immediately available to supervisors and other control room personnel. Tablets can also be used during inspections to update the condition and quantity of related safety equipment and devices; this information can be sent directly to the control room, removing the need for manual data input at a later date and making the inventory immediately available.

To prevent incidents resulting from unauthorized access to restricted areas, technologies such as geofencing can be used to designate restricted areas and automatically detect and inform personnel entering these zones. The control room can be concurrently notified so that protocols are initiated, if necessary, to ensure safety and prevent an emergency situation.

SIC infrastructure can also help mitigate the consequences of emergency situations. In the event of an emergency, real-time knowledge and information about personnel and equipment reduces the incident response time and makes it possible to positively confirm personnel status, location, and condition.

In the future, highly automated SIC in the areas of safety and emergency response might become available. However, this has not been documented in detail here because further advances in artificial intelligence (AI), machine learning, and neural networks are required before industrialized solutions become available.

7. OPERATIONAL MODEL

This section presents an operational model for SIC in three parts:

- Conceptual operations, a framework for developing SIC
- SIC processes, explored through a series of descriptions and workflow visualizations
- Data enablement, a discussion of how technology can enhance SIC processes in underground mining through the lens of the SIC maturity model

7.1 Conceptual Operations

This section outlines a suggested approach to defining and developing SIC and describes a conceptual framework for SIC operations. Potential steps to developing tangible deliverables through a staged process to create, test, and

scale up implementable in-shift SIC activities are illustrated (Figure 1).

The conceptual SIC framework is intended to leverage legacy technology, both software and hardware, and available data at any point in the process while implementing innovative digital technologies and equipment with sufficient built-in flexibility to allow stakeholders to regularly review the value impact and incorporate future developments in the workforce, processes, tools, and technology. The current maturity of the operation set out in the Section 7.3 will determine how SIC can initially be implemented, including the degree of integration between activities, associated data, and performance measures, as well as the level of automation for data visualization, data analytics, decision-making processes, value-adding actions, and underlying plans and dataset updates.

The key considerations during SIC development include:

- What data are available (information technology/ operational technology [IT/OT] dependent)
- When and how often data are collected
- The sequence of data receipt
- The events that typically occur during a shift
- Options for corrective/alternative actions
- The capacity for each corrective/alternative action to result in value loss prevention and/or value gain
- Information management and data flow constraints
- Data governance
- Data security

7.1.1 Developing the Operational Framework

In an ordinary shift plan, the weekly plan received by the short-term planners is based on the medium-term production plan. The short-term planners divide this into days, shifts, and hours for detailed planning and scheduling. Resources are assigned and performance expectations are set using key performance indicators (KPIs). KPIs are measurable values used to assess or demonstrate how effectively a company is achieving key business objectives.

The schedule and performance are monitored and reviewed based on targets, metrics, and KPIs. SIC takes effect when there is a deviation from the plan (e.g., as a result of an unforeseen delay or downtime) that prompts action to

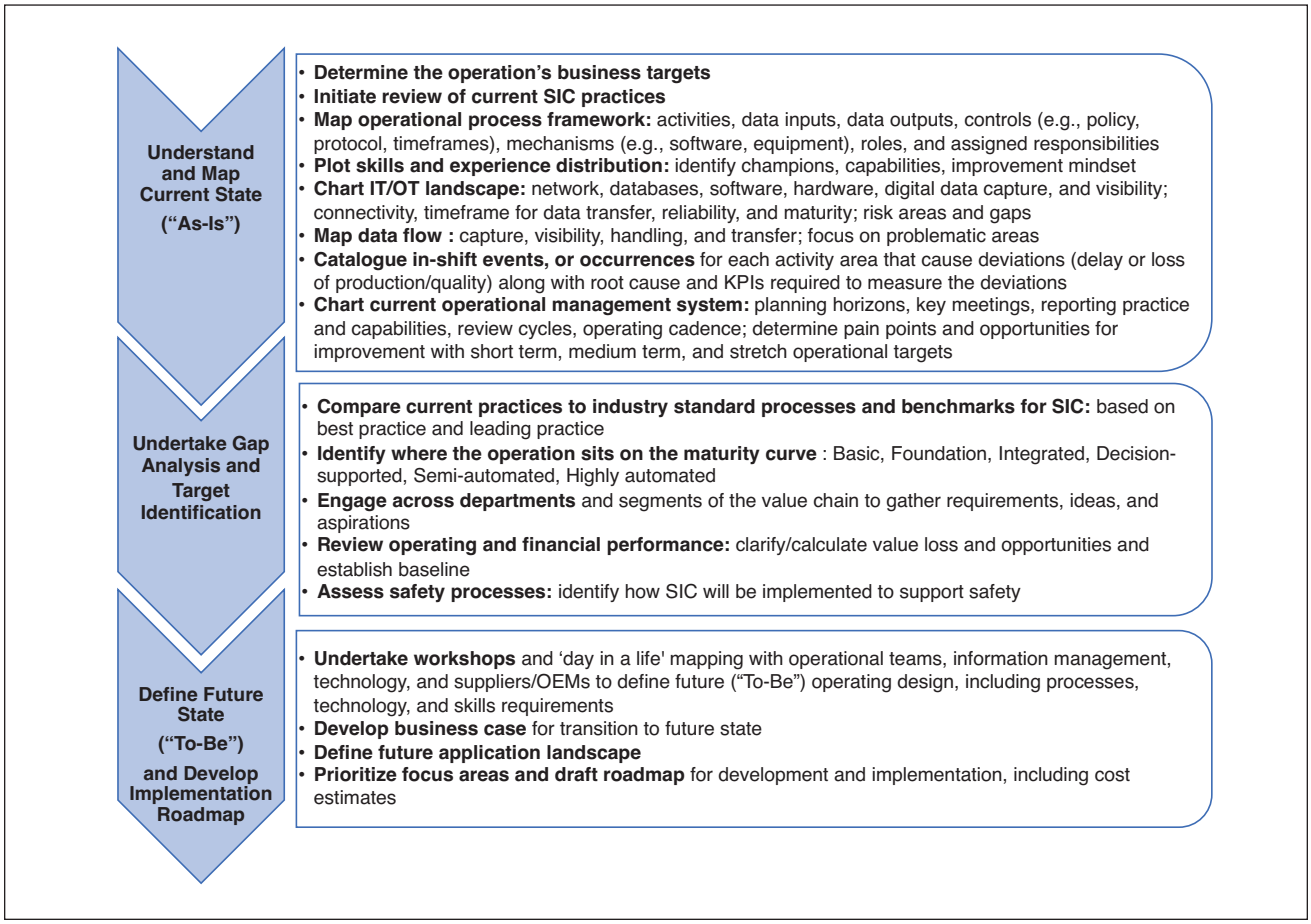

Figure 1. Conceptual Process to Develop a Short Interval Control (SIC) Framework

get back on plan or to achieve the next best outcome that ensures optimal safety and value. Recent developments in data capture, storage, processing, and technology support the implementation of operation-specific and efficient SIC to achieve maximum safety and productivity, which will depend on the maturity level of the system (see Section 7.3).

Regardless of the maturity of the system, developing and implementing SIC involves four stages:

- Determining the current state ("As-Is")
- Defining the future state ("To-Be")
- Implementation, testing, and scale up
- Ongoing review and updates

Determining the current state and defining the future state are explored in the following sections to illustrate suggested actions to develop the conceptual operating framework. Implementation and ongoing review are addressed in the context of the operational framework development and are covered in detail in Section 8.

7.1.2 Current State ("As-Is")

Before considering what SIC will look like in a mining operation, it is critical to understand the mine's current characteristics, health, and lifespan, day-to-day conditions, and strategic management goals. The target of SIC is to adapt to changing conditions to get as close as possible to the plan and to drive continuous improvement based on recorded data and events to ensure operational plans are based on the fullest and most accurate understanding of the situation.

To ensure an efficient response to a deviation, it is essential to prioritize data. Rather than map all data captured, received, handled, and transferred, it is recommended that the system prioritizes in-shift data necessary to complete the required activities to fulfill the shift deliverables—the processes and activities expected as part of the schedule plus data related to typical events that would cause a deviation from the schedule and a resultant loss of value.

Where data are considered relevant and critical to SIC, it is important to know:

- The data origin and whose responsibility it was to input the data
- The data input format
- How often data are collected
- How the data are captured and delivered
- Controls (e.g., standards, protocols) or governance (e.g., meetings, event triggers) influencing how, when, and in what format data are generated
- The output data format and destination

Figure 2 presents a model of data flow during a process or activity. The data are generated using the inputs (data, materials, funding); these data come from the originator and have a distinct data input format. Data generation—how, what, and when data are generated throughout the process/activity—is subject to controls and governance as well

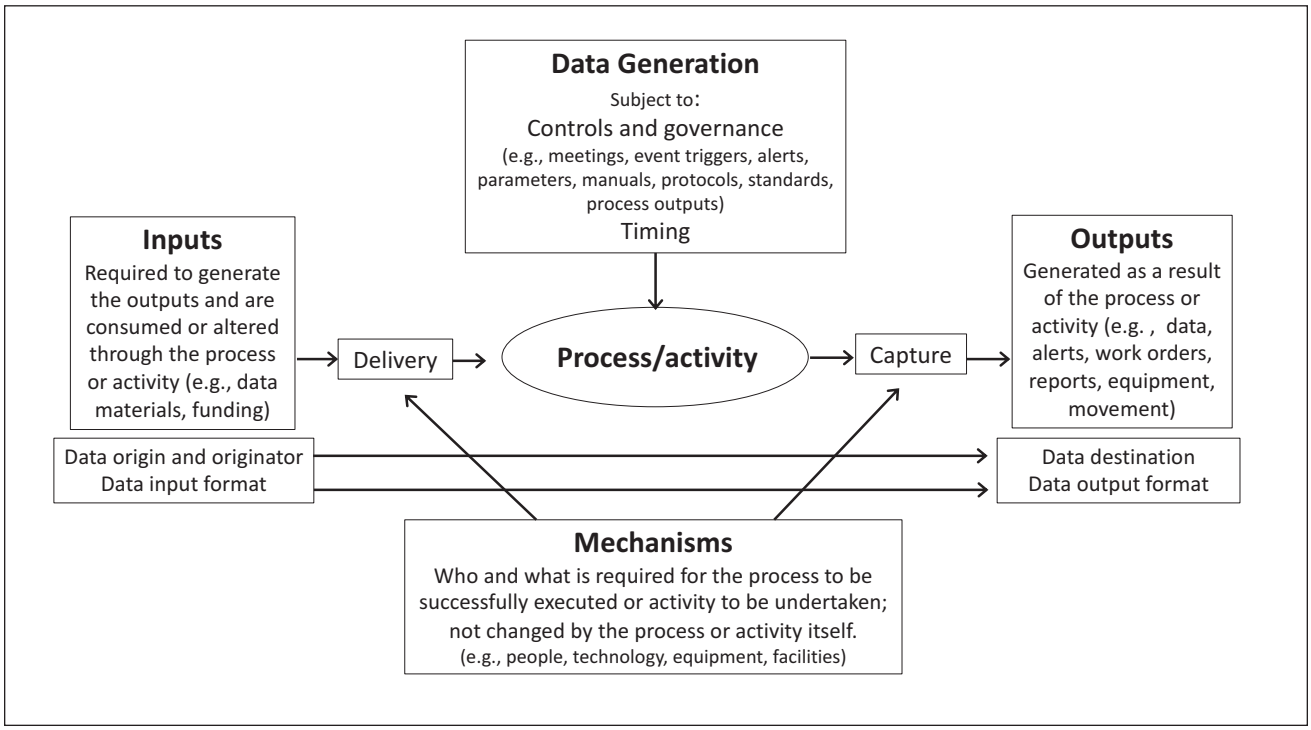

Figure 2. Model of Data Flow

as timing. The delivery mechanisms (people, technology, equipment, and facilities required for the process to be successfully executed or activity to be undertaken) deliver the inputs through the process/activity in question to the capture mechanisms. The results of the process/activity are the outputs (data, alerts, work orders, reports, equipment movement), which arrive at the data destination in a predetermined data output format.

Using the model in Figure 2, those implementing SIC at all maturity levels can build a map of data capture and handling that illustrates the relationships and dependencies between activities, disciplines, and segments of the value chain. They can use this framework as the basis for mapping events that trigger SIC and identifying which KPIs are relevant. It is important to understand KPIs in the context of the current state to determine the future state. It is also possible to determine maturity, identify gaps, and rationalize which types of data and what KPIs are applicable to SIC and associated future analytics to develop a roadmap to advance the maturity of SIC toward increased automation.

Once identified, relevant baseline data capture and handling processes should be compared to industry standard processes and benchmarks for SIC, based on best practice and leading practice. By its very nature, leading practice is continually evolving and the opportunities to partner with new companies, technology developers, innovators, and change management specialists to develop SIC will also evolve. As clients, mining companies have the power to seek out the best possible partners to accelerate their performance and evolution and maintain their competitive edge.

To define and develop the future state, the following steps are recommended:

- Map out the future framework and flow for data that are relevant and essential to SIC
- Define the future KPIs; they can be compared to existing KPIs and entered into SIC digital enablers such as:
  - Technology bridges, wraps, add-ons
  - Shared/integrated platforms/applications
  - Function specific digital tools (e.g., blast reconciliation)
  - One interface to source information by role/responsibilities
- Define events that trigger SIC:
  - Catalogue events and priorities by risk to health and safety, value, impact, and frequency
  - Define diagnostic steps and data requirements for root cause analysis
  - Determine timeframe for root cause analysis (dependent on maturity)
  - Detail options for corrective actions and measuring value
  - Develop alerting and reporting action time intervals
  - Assign organizational roles, responsibilities, and collective accountability

Ultimately, if the SIC system is implemented effectively, it will be able to achieve the many benefits described in Section 6. The capacity for SIC to result in continuous improvement is demonstrated in case studies in Appendix B.

7.1.3 Future State ("To-Be")

After establishing the baseline, those planning to implement SIC should define the desired future state (after successful SIC implementation). Because SIC is a method for continuous improvement, the primary change is the move from an open loop model to a closed loop model. In an open loop model, each shift is planned, executed, and completed. Progress data and results recorded during the shift are reviewed at the end of shift (or, in some cases, the end of the week or month) and are taken into consideration during planning for the next shift or short-term planning period (Figure 3).

In a closed loop model (Figure 4) deviations from the plan are reported and reviewed in real time and actions to respond to the deviations are prioritized and implemented during the next shift, or even during the current shift, effectively closing the loop.

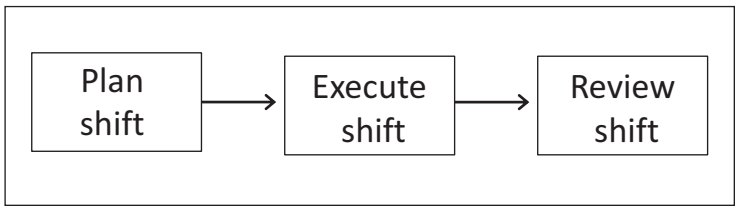

Figure 3. Open Loop Model of Shift Planning, Execution, and Review

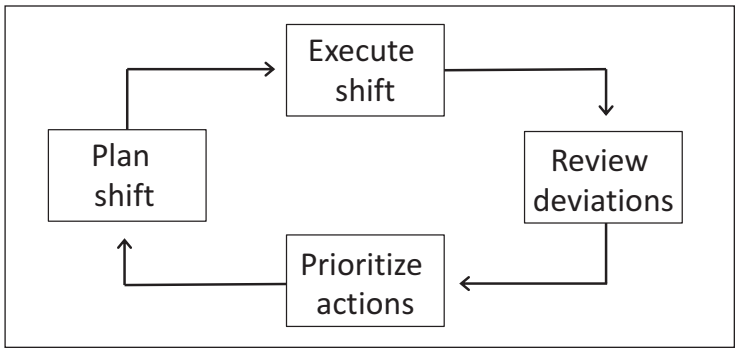

Figure 4. Closed Loop Model of Shift Planning, Execution, and Review

7.1.4 Short Interval Control Activities

This section describes activities and processes that are either enhanced by or the result of SIC implementation and outlines how, through these activities, the system can move from its current state—an open loop system with manual feedback—to its future state—a closed loop system with automatic or semi-automatic feedback.

7.1.4.1 Short-term plan The purpose of the detailed mine design is to ensure that the extraction of ore is sustained at the rate and quality (ore types, grade, treatability) required by the downstream processing steps to meet the business expectations. The orebody is divided into a sequence of blocks to be mined, the physical properties of each block are defined, and a short-term plan is developed to define the inputs and mechanisms required to achieve the desired output. The plan is then checked against the equipment availability to confirm its feasibility. In the current state, the short-term plan is updated at set timeframes (e.g., fortnightly or monthly), and these data are used to inform the next short-term plan. In the future state, SIC makes the planning process more efficient by measuring actual performance and equipment availability and using these data to modify the plan in real time (Figure 5).

7.1.4.2 Scheduling and execution A schedule outlines the production and service activities required to meet the short-term plan and provides a timetable for achieving them. Within SIC, the schedule takes work orders from the short-term plan and breaks them into more detailed, measurable components that can be used to track intrashift progress and provide decision support to the first line of supervision. Handheld devices and onboard instrumentation in equipment can interface with a monitoring system to record data and provide them to the control room in near-real-time. The impact of these data to the short-term plan is evaluated, and changes are made to the schedule, the short-term plan, and the mid-term plan as required (Figure 6).

7.1.4.3 Measurement The measurement process receives data about the detailed tasks contained in the schedule from handheld devices and onboard production equipment instrumentation. Elements of the schedule are updated and an analysis process is triggered that determines whether the latest progress update has resulted in any material deviation from the schedule. The measurement process also receives data on unplanned events (e.g., equipment breakdowns, approved ad hoc in-shift work), after which the impact is evaluated to determine whether these events will affect the schedule (Figure 7).

7.1.4.4 Analysis The analysis process has the capacity to provide near-real-time (depending on the data gathering frequency) reporting of actual operational results alongside historical results and the expected business result. KPIs using statistical rules are analyzed and trends identified. These results are prepared as a report or presented online as a current performance evaluation. Performance data are made available to operators to track their progress against the schedule, to first-line managers to track schedule delivery (the short-term plan), and to other stakeholders at the operation to ensure that the execution of the short-term plan is visible (Figure 8).

7.1.4.5 Decision support The decision support process helps front-line supervisors and operators make decisions based on quality, near-real-time information. Data on predefined job tracking metrics are collected and analyzed and corrective/alternative options to mitigate deviations

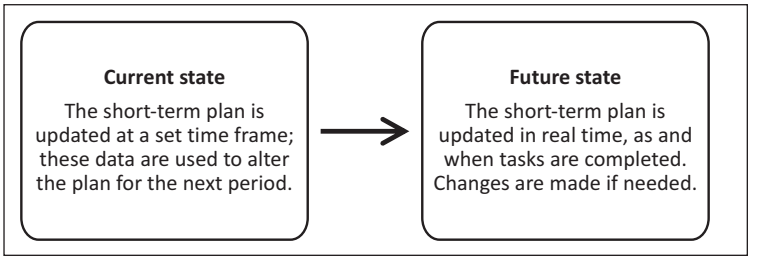

Figure 5. Short-term Planning in Current and Future States

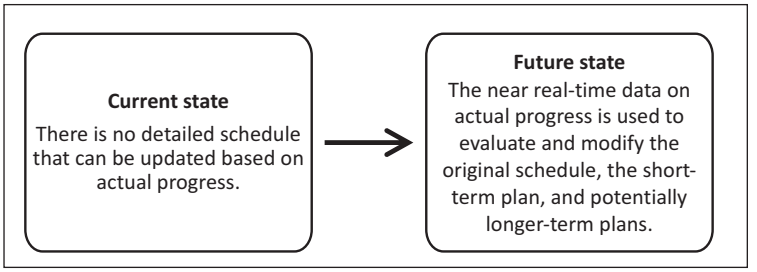

Figure 6. Scheduling and Execution in Current and Future States

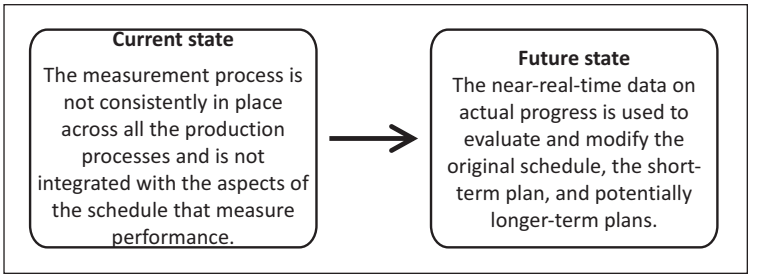

Figure 7. Measurement in Current and Future States

from the short-term plan are provided to operators via customized dashboards (e.g., tablet or on board; Figure 9). The information is then prioritized and ranked based on value using a value driver tree to allow the system, along with supervisors and operators, to make informed decisions based on a forecast of actions and impact on outcome.

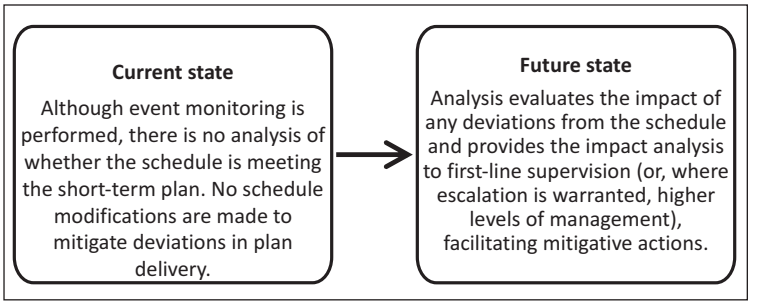

Figure 8. Analysis in Current and Future States

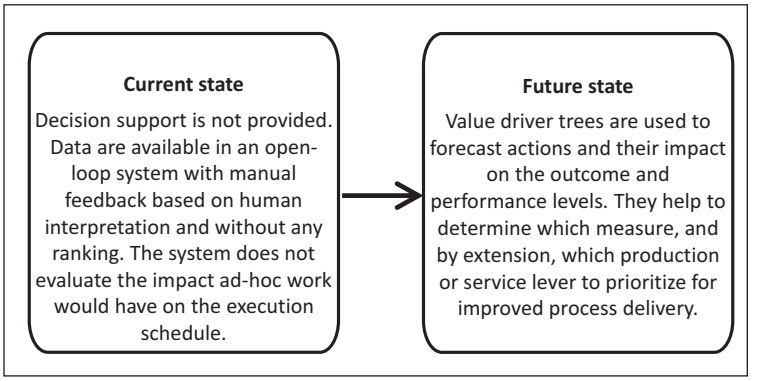

Figure 9. Decision Support in Current and Future State

7.2 Short Interval Control Processes

This section presents a series of figures and descriptions reflecting processes that can be used to investigate the impact of SIC on underground mining activities. This section also describes key actors in these processes and outlines their activity. Specific roles and responsibilities will vary depending on the mine organizational structure. This section identifies a single shift supervisor role that could be distributed in different ways. Some sites split shift management tasks between several roles. For instance, there could be a senior shift supervisor who is responsible for production and scheduling, while the primary responsibilities of individual shift supervisors are workplace safety and product quality. This makes it possible to ensure that tasks are performed on time and to the quality required while keeping the workforce safe.

See Appendix C for additional examples of how roles and responsibilities could be structured.

7.2.1 Long-Term Planning

Mine planning starts with long-term planning: Specialist geologists and engineers undertake design and planning activities, ensuring that a clear set of targets can be published that support the investment process for the mine. These targets are critical to determining how the deposits will be mined and what capital expenditure in infrastructure is needed to support the mining efforts. Long-term planning can take considerable time and is not within the scope of SIC.

7.2.2 Short-Term Planning

SIC processes come into play at the level of short-term planning. Short-term planning includes determining the resourcing required, the interactions that must be controlled, and the downstream requirements that must be achieved to meet the goals of the long-term plan (e.g., grades).

SIC begins once resourcing and conditions are known; every action can potentially affect the delivery of the short-term plan. The SIC process involves regularly assessing progress against a known plan and making decisions for future actions that are supported by those assessments. It also involves identifying risks early and implementing the appropriate mitigating actions to manage them.

Figure 10 shows the key stages of the mine planning chain. The dual arrows demonstrate the bi-directional flow of information: Every decision made at a given stage has implications for the stages before and after in the planning chain.

7.2.3 Weekly Planning

The short-term plan considers the areas to be mined and the required progress to meet targets set for the mine. Weekly planning allows an engineering resource to turn tasks in the short-term plan into activities that can be assigned resources (personnel, equipment) to execute the work and timelines for completion. By expanding the short-term plan into tangible activities, the planner can coordinate with the other departments within the mine, including maintenance, services, geotechnical, and processing, to develop a strong plan that is deliverable within the assigned timeframe. Although weekly planning is not a part of the SIC process itself, it sets the baseline that establishes production quantities and timing used to measure task completion. A strong weekly plan sets up the mine to be successful in the short-term plan and on target to meet the long-term plan.

The weekly planning process begins when the short-term plan is released and concludes with the release of an

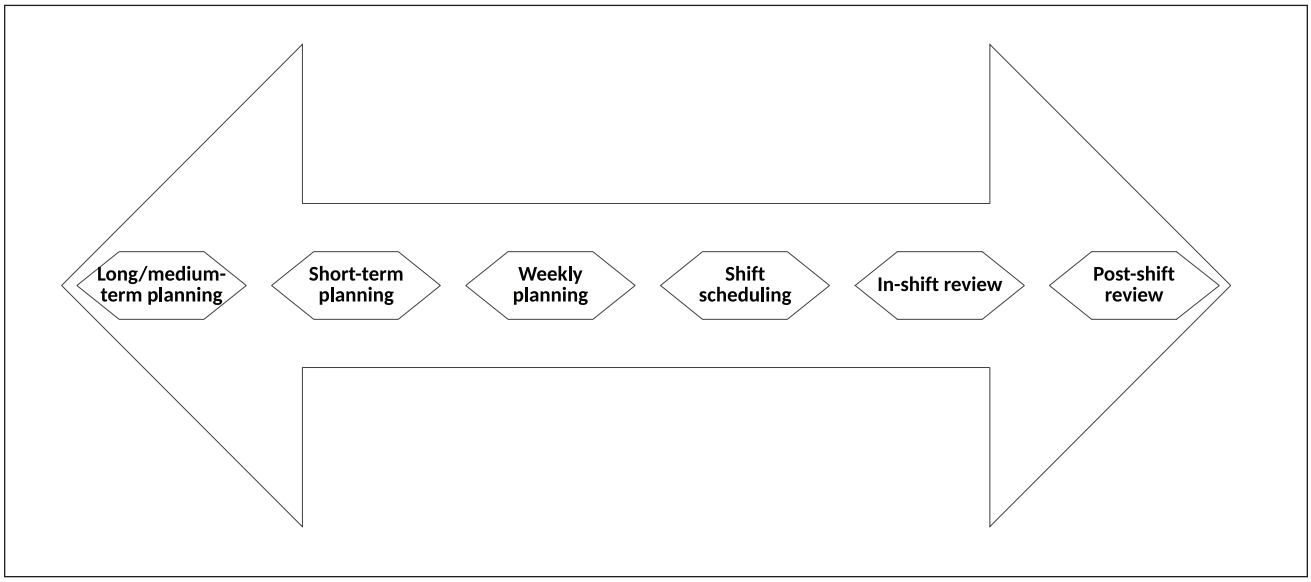

Figure 10. Mine Planning and Operational Control Chain in a Short Interval Control Environment

actionable schedule that supports all facets of the mining operation meeting their respective targets.

Figure 11 presents a workflow for the development of a weekly plan based on a short-term plan that includes three to six months of tasks and identifies key personnel, stakeholders, and systems that should be involved in the process. Dashed arrows represent interaction between people while dotted lines represent connection with systems in this figure and the other workflow figures (Figures 12–14). The primary actors in the weekly planning process are the short-term engineer and the production planner. Both primary actors are responsible for scheduling weekly activities based on the short-term plan and reporting back to stakeholders regarding work progress.

To create an achievable plan, the production planner must match the required targets for the period to the avail-

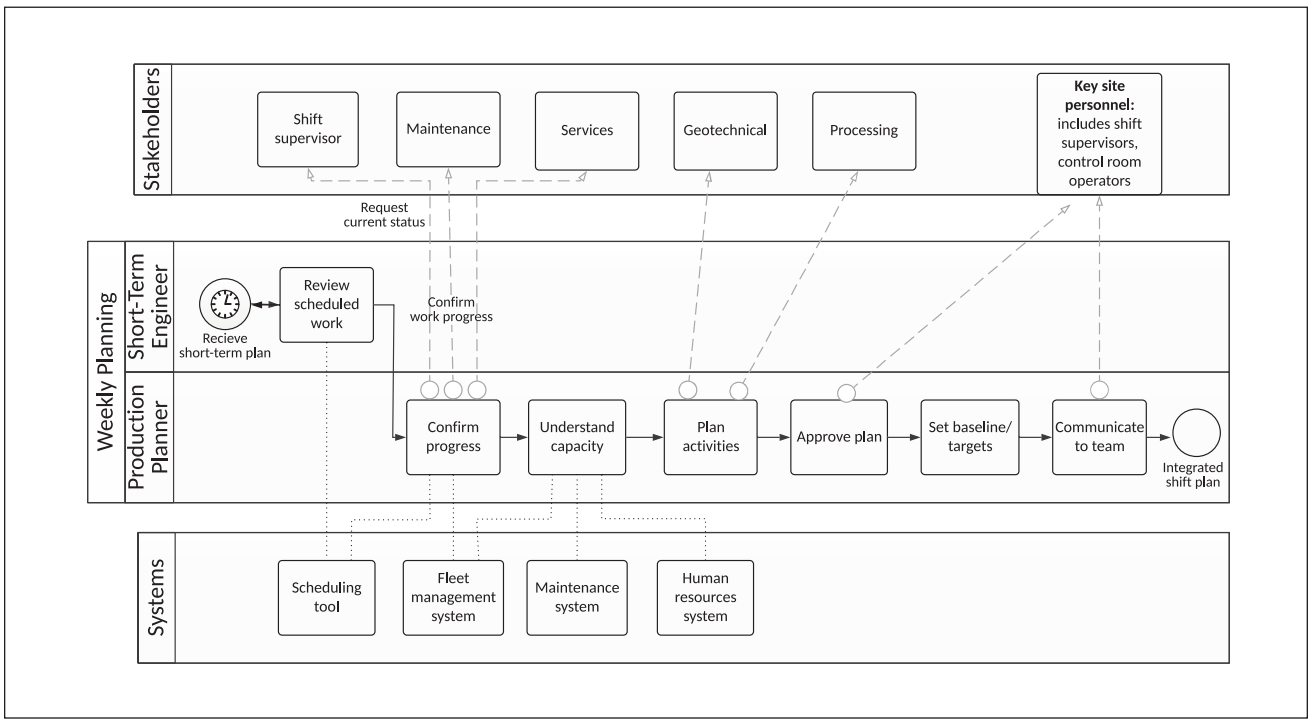

Figure 11. Weekly Planning Workflow

able equipment, people, and stockpiles (understanding capacity). Equipment operates at specific rates and changing the machine or type of machine will influence the crews' ability to meet the targets set out in the plan; consideration of this is required to develop a reasonable schedule. The production planner must liaise with other sectors of the mine to ensure that the resources necessary to achieve the weekly plan are available. If the required resources are not available, then the plan will need to be re-engineered to achieve success within the available resources.

Once available resources have been identified, the activities must be reviewed and adjusted to ensure the maximum likelihood of reaching the target deliverables and goals. Then, key site personnel should complete a structured walkthrough of the weekly plan to determine that all activities have been correctly planned and are achievable based on current knowledge. Agreement from all parties is essential to avoid negative impacts to/from other sectors.

Following this approval, a baseline should be set so that progress can be monitored and deviations from the plan can be noticed and mitigated as soon as possible. Targets should be visible to system users to facilitate performance tracking. Once a baseline has been set, the weekly plan can be communicated to all stakeholders, especially shift supervisors and control room operators. After all key personnel have reviewed and accepted the plan, it is ready for implementation by operational crews.

Table 1 provides an overview of the activities performed by the primary actors during the weekly planning process and identifies key inputs, outputs, and issues that should be considered.

Table 1. Weekly Planning Activities

Action	Description	Inputs and Outputs	Issues
Receive short-term plan	The short-term engineer notifies the production planner that a short-term plan has been updated, refined, and approved and is ready to be reworked into the weekly plan	Input: The short-term plan	Understanding the contents and level of detail in the short-term plan will inform construction of the weekly plan
Review scheduled work	Outline the work required to achieve each task in the schedule	Output: A set of activities that can be assigned to various resources	Activities might not be standardized or could be subject to change based on conditions
Confirm progress	Confirm the current status of each activity (not started, on track, behind schedule, or ahead of schedule); provide progress/status reports to stakeholders	Output: A schedule that accurately reflects current progress in the mine	If progress is tracked manually, the information will need to be verified
Understand capacity	Liaise with other sectors of the mine to ensure that the resources necessary to achieve the weekly plan are available	Inputs: Maintenance plan, operator availability (subject to leave and overtime), current stockpile balances, service schedules Output: Schedule of achievable activities based on available resources	Incorporating the service crew plan is key to delivery because their work can be lengthy and cause delays on multiple fronts
Plan activities	Review all planned activities, including those of non-mining crews, and adjust the schedule to maximize the chance of delivering on target	Output: An expanded mining schedule that accommodates all other relevant schedules	
Approve plan	Complete a structured walkthrough of the plan with key site personnel to get agreement that all activities have been correctly planned and the plan is achievable based on current information	Output: Approved weekly plan	All parties must agree to the plan, otherwise it is likely to be negatively impacted by (or will negatively impact) the activities of other sectors
Set baseline/ targets	Set baseline with visible targets to facilitate performance tracking and identify and mitigate deviations early, ensuring that the plan is followed and targets are met. A baseline also records key metrics (e.g., KPIs).	Output: A plan that can be tracked visually to monitor progress, identify risks or deviations early, and facilitate mitigation actions	Targets should be visible to system users

Table 1. (continued).

Action	Description	Inputs and Outputs	Issues
Communicate to team	Communicate the schedule to all stakeholders, especially shift supervisors and control room operators	Output: An agreed schedule with clear activities, targets, and timelines	
Provide weekly plan to operations	All key personnel accept the schedule and it is ready for operational crews to implement	Output: A list of deliverables driven by the weekly and short-term plans	

7.2.4 Shift Scheduling

Shift scheduling is the process of assigning resources to the necessary work tasks for an upcoming shift. It begins when the oncoming shift supervisor arrives to plan the shift and ends when the shift is planned, resourced, and prioritized. In mines where there is a window between shifts for blasts, the supervisor will have a brief window to prepare the schedule. In mines operating without a window, shift scheduling must be completed before the end of the previous shift. It is essential that those involved understand the schedule and that there is clear communication between the supervisors of the previous and upcoming shifts. If unplanned activities or maintenance are identified by the previous supervisor, then the shift scheduling process will also include any necessary rescheduling to accommodate these deviations. Shift scheduling could be managed via radio calls between operators and control room operators, but the quality and clarity of communication could be compromised and crucial information could be lost.

Figure 12 presents a workflow for shift scheduling and identifies key actors in the process. This example is a mature process with input from several external systems.

Primary Actors

- Incoming shift supervisor
- Control room operator

Stakeholders

- Previous shift supervisor
- Maintenance
- Services
- Control room
- Operators

Systems

- Weekly plan
- Fleet management system (FMS)
- Maintenance system
- Action plan
- Human resources system

Before planning for the next shift, the shift supervisor must review the prior shift's performance report, with partic-

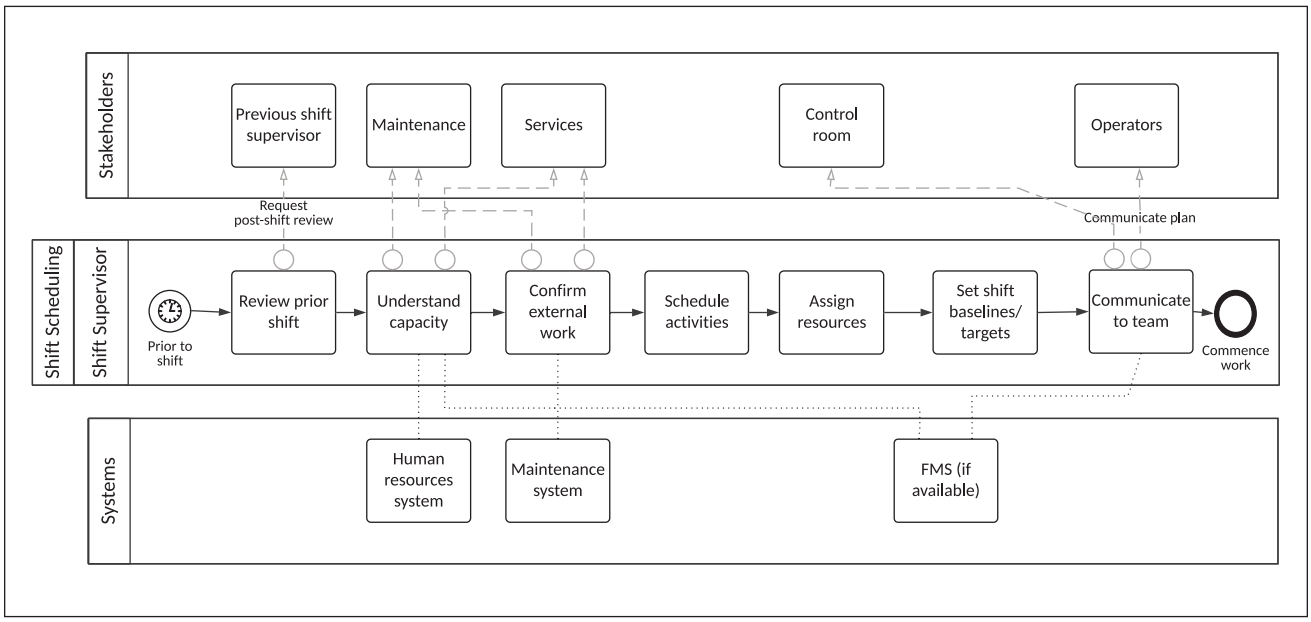

Figure 12. Shift Scheduling Workflow

ular attention to what progress had been made, activities that were not completed or were moved to the upcoming shift, resource performance and working conditions, and locations where crews from other sectors (e.g., services) are working. If there is no break between shifts, this review might not include the most up-to-date information.

Once the progress is reviewed, the shift supervisor must determine what resources are available for the next shift. The availability of specific equipment, what operators are assigned to the shift, and the safety of the zones where workers will be stationed during the shift must be determined. Equipment status reports should be reviewed by the shift supervisor to determine what equipment is out for maintenance or expected to require maintenance and the location of additional available equipment to replace machines that are offline. An operator status report will indicate which personnel are present for the shift and if any have their time limited by law (e.g., if they are working overtime or are contractors). To ensure worker safety during the shift, a location inspection might have been completed during the previous shift (and might even be a statutory requirement). Identified hazards should have been reviewed, mitigated, and communicated to the next shift supervisor. Location inspection reports should also be reviewed.

Before the shift supervisor can make plans, they need to gather information about external work that could affect the schedule, such as maintenance, service availability, and other mining activities (e.g., exploration drilling). If external activities make some work locations defined in the weekly plan unavailable, then additional work areas and activities may need to be found to make up for the deficiency and meet targets. During the shift scheduling process, maintenance participation is to confirm that equipment scheduled for work during the upcoming shift are delivered to the shop as planned and if the equipment has not yet been delivered, that it will be. Unscheduled maintenance needs to be recorded when it occurs because early identification and response will enable better decision making in the future.

Once the capacity and external work limitations have been identified, the shift supervisor can look at the activities to be completed based on the weekly plan and create an activity list for each operator on the shift. These lists include prioritization where appropriate, that is, if equipment must be delivered to a location before a certain time, or if work must be completed in a specific order. Resources are assigned to activities based on the list of available resources. In a more mature environment, the assignment of operators to tasks can also include validation of operator competencies to ensure that each operator is assigned to tasks that they are best suited for. Maintenance may also advise prioritizing certain machines based on engine hours. If enough resources are not available to complete all tasks on the plan, some tasks might need to be pushed to the next shift. The result is a list of resourced tasks (operators and equipment assigned) to be completed during the upcoming shift.

Before shift activities can begin, the supervisor sets shift baselines so that progress can be monitored and deviations from the plan can be noticed and mitigated as soon as possible. Targets can also be set for the upcoming shift. This allows supervisors and control room personnel to monitor progress during the shift using KPIs and make adjustments to the work plan if necessary to meet shift targets.

With tasks identified, resources assigned, and a baseline in place, the shift supervisor can communicate the completed plan to the operators and control room personnel. If an FMS is used, the list of tasks for each machine can be sent directly to each machine for action. Table 2 describes the actions involved in the shift scheduling process, their key inputs and outputs, and issues to consider.

Many sites are now using or considering FMSs and task management systems. Fleet management is usually vendor aligned and focused on the data available from the machine. Task management is usually work-driven and based on data collected by the operator. Fleet management solutions for underground environments are maturing and are likely to become one of the best sources of quality data in the future.

Table 2. Shift Scheduling Activities

Action	Description	Inputs and Outputs	Issues
Review prior to shift	Shift supervisor reads the post-shift review from the previous supervisor and checks prior shift performance, with particular attention to: – Progress to plan – Unfinished activities – Resource performance – Conditions encountered – Working locations of other crews (e.g., services) – Activities moved to the upcoming shift	Input: Progress/performance report from the previous shift; comments from the previous shift	If shift scheduling must take place before the end of the previous shift, the shift supervisor might not have the latest information

Table 2. (continued).

Action	Description	Inputs and Outputs	Issues
Understand capacity	Shift supervisor checks reports on: – Equipment either in or expected to be in maintenance – Location(s) of available replacement equipment – Operators assigned to the shift and limitations on their time (e.g., overtime operators whose time might be limited by law or contractors working the shift) – Workplace safety (location inspections and incident reports)	Inputs: Equipment status report, operator status report, location inspections, hazard incident/mitigation report	Some or all of this information might not be available at planning time Location inspections might be a statutory requirement A failed location inspection can block access to a location
Confirm external work	The shift supervisor must collect and incorporate data from: – Maintenance, both scheduled and unscheduled – Services, to understand where to send machines based on services availability or repairs needed – Other mining activities such as exploration drilling (likely to be controlled by the geologists)	Inputs: Maintenance schedule, services schedule, and other external schedules (e.g., diamond drilling schedule)	If external work affects location availability, the shift supervisor will need to access additional work areas and activities to make up for the loss
Schedule activities	The shift supervisor creates a list of work tasks for each operator on the shift based on shift targets. This list includes notes about task prioritization (based on earlier decisions), such as if a machine is due for maintenance mid-shift and should be used first	Input: A list of all tasks scheduled for the upcoming shift Output: A list of all shift tasks assigned to each operator, prioritized based on external factors and weekly targets	Insufficient resources might prevent work from being completed
Assign resources	The known list of resources is used to match resources to tasks that are needed for the upcoming shifts. Inventory to support activities is planned to ensure it is available as required. In a more mature environment, assigning operators can also include validation of operator competencies. Maintenance may also advise prioritizing certain machines based on engine hours	Input: Full list of all available resources, list of all shift tasks assigned to each operator Output: Complete task list (each with a start time, duration, and end time) for the upcoming shift, with all tasks resourced (operators and equipment) according to availability and priority	
Set shift baselines/ targets	Baselines are chosen to allow staff to monitor progress and assess if the schedule conforms to the plan. Stretch targets set against KPIs can also be used to communicate shift and plan goals	Input: Complete task list of assigned work for the upcoming shift Outputs: A shift baseline that confirms the planned tasks and defines targets (optional) for the work in the upcoming shift	
Communicat e to team	Shift supervisor communicates the plan to all operators and control room personnel. If a FMS is present, the tasks (and associated comments) may be sent directly to each machine	Output: Assigned tasks are communicated to the team	

Task management solutions are available that can integrate operator input and machine data. Some mining operations are also building their own tablet-based solutions, which can be less expensive to implement and can be more easily aligned to site practices.

Some sites split shift management tasks between several roles. For instance, a senior shift supervisor is responsible for production and measures this against the baseline shift schedule, whereas the primary responsibilities of individual shift supervisors are workplace safety and product quality. This makes it possible to ensure that tasks are performed on time and to the quality required while keeping the workforce safe.

7.2.5 In-Shift Review

In-shift reviews are the essence of the SIC process. Regular reviews of scheduled activities are used to monitor work and assess progress, fulfilling the need for control and response. The intended outcome is increased productivity and minimized waste due to crews underperforming, doing

unplanned work, or encountering risks. On mine sites where SIC is implemented, in-shift reviews occur at regular, predetermined intervals throughout the shift and/or can be initiated by the shift supervisor or the control room operator as needed or when KPIs indicate a deviation exceeding a set tolerance. On less mature sites, the review might take place at shift changes, with actions applied to future shifts or plans. In manufacturing companies, review meetings take place in person at the work location; however, in the case of underground mining operations, the meeting is more likely to occur via radio contact because the work location might be impractical for all review team members to access.

To best understand how work is progressing, the update frequency and quality of the data captured should be known. In basic operations, data are available when communicated manually and reflect the quality of the operator input; these data are generally based on manual observation, sometimes guided by standardized shift logs.

Sites using task management will instruct the operators what work is to be performed with expectations set regarding time (e.g., expected duration and/or deadline), quantity (e.g., tonnes of ore), and quality (e.g., grades). In advanced operations, work orders and updates or adjustments are delivered to the operators by tablet- or console-based communication systems.

An FMS is not essential, but it has the potential to improve the quality of available data to support decision making over what might be available through manual fleet management. Introducing a control room allows the shift supervisor to focus on their key responsibilities, which include monitoring safety and managing mine activities to ensure that the assigned work is done correctly by an individual with the appropriate competencies. Some sites have found that scheduling key roles, such as the control room operator, on a shift plan that is staggered with respect to the rest of the workforce provides better continuity due to the overlap in personnel across operator shifts. A limiting factor here is the ability of the site to implement communication technologies throughout the workplace (e.g., Wi-Fi® at the face). If the appropriate technologies are available, then machines can communicate in near-real-time to the control room, facilitating faster and more accurate decision making. Frequent data updates allow decisions to be made mid-activity and facilitate early risk identification and mitigation.

The shift supervisor works with other key actors to monitor work task delivery. Progress since the last review is measured, tasks that are not being delivered as planned and risks that have emerged are identified, and an action plan is created to resolve any issues. The continuous PDCA loop is followed at this stage. Data that indicate progress, equipment productivity, work conditions, safety concerns, and issues that will delay work are vital to the process. The increased performance visibility delivered by tools such as an FMS can empower sites to react to triggers earlier and more quickly. Figure 13 presents a workflow for in-shift review and identifies key actors in the process.

Primary actors

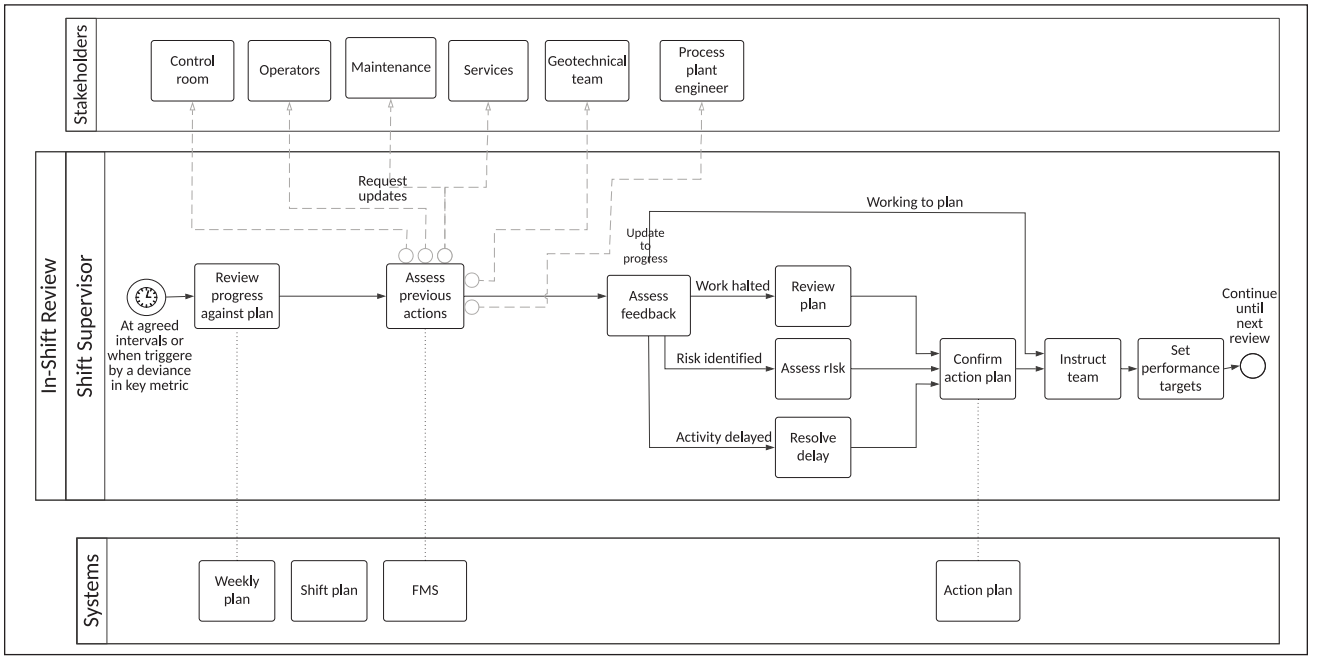

Figure 13. In-Shift Review Workflow

- Shift supervisor
- Control room
- Review team

Stakeholders

- Previous shift supervisor
- Maintenance
- Services
- Geotechnical team
- Process plant engineer
- Control room
- Operators

Systems

- Weekly plan
- FMS
- Maintenance system
- Action plan

Immediately prior to each review meeting, the shift supervisor gathers reports and data from all areas of the mine operation regarding the status of each activity listed in the shift schedule and weekly plan and any incidents and/or safety risks that have been identified. The action plan developed during the previous in-shift review is also reviewed, and each mitigation measure is assessed to determine if it had the desired outcome. Delays during the period are analyzed to identify patterns that might be fixable. Response/mitigation is determined for each activity listed in the plan, in accordance with the feedback that is received.

- Work is proceeding according to plan: No change required
- Work at a location has been halted: Review plan and determine if work can be restarted; only move resources to a new location if there is no other solution
- A risk has been identified that may require mitigation: Assess risk, rate the urgency, and determine a course of action to mitigate the risk
- A planned activity has been delayed: Resolve the delay, focusing on maintaining the shift schedule and staying on target. Only move the activity to the next shift if there is no other alternative.

The review team meets and, based on the status reports and required mitigation actions, reprioritizes work and produces a new action plan: A list of tasks and targets to be completed during the period until the next scheduled review. The activity rates set by the action plan are compared to the targets developed during weekly planning and shift scheduling to ensure that the targets remain achievable. Targets may be modified if necessary, but baselines remain the same. Once the new action plan is approved, all team members affected by the changes are notified and operators modify their work plan as required. Table 3 describes specific activi-

Table 3. In-Shift Review Activities

Action	Description	Inputs and Outputs	Issues
Review safety	Shift supervisor reviews safety reports, including incidents (actual and near misses) and upcoming activities that involve risk and creates an action plan for any items that require a response	Input: Safety feedback Output: Action plan	Timely communication of safety concerns affects how long it takes for the issue to be mitigated
Review progress against plan	Shift supervisor checks status reports from crew and equipment and assesses performance since the last meeting, with particular attention to – Progress to plan – Unfinished activities – Resource performance – Conditions encountered – Working locations of other crews (e.g., services) – Activities that have been moved to the upcoming shift	Input: Status reports from the crew, weekly plan, shift plan Output: List of discussion items for review meeting (if applicable)	If equipment is operating outside of communication areas, it might not be able to transmit status reports for review
Assess previous actions	Review changes made to the weekly and/or shift plan during the previous review meeting to determine if the changes resulted in the desired outcome Identify and analyze main delays during the work period to see if there is a pattern	Input: Action plan (output) from the last in-shift review Output: Assessment of effectiveness of mitigation actions	
Assess feedback	Review feedback from the mine to ensure that work is being performed according to plan. Potential responses are: – Work is proceeding according to plan – Work at a location has been halted – A risk has been identified that might require mitigation – A planned activity has been delayed	Input: Feedback from various sources (e.g., radio calls from the operators, comments on work cards, and updated data from a FMS)	Feedback data must be as current as possible to identify issues early (SIC). Outdated data may result in wasted effort

Table 3. (continued).

Action	Description	Inputs and Outputs	Issues
Work halted: Review plan	Shift supervisor assesses the reason for the halt, its impact on the schedule, and whether the equipment or operator assigned there needs to be reassigned to a new location. All effort must be made to resolve the issue in the current location and adhere to the shift schedule	Input: Feedback from work station; confirmation of location downtime	Only look for alternative work locations if a resolution at the assigned location is not possible
Risk identified: Assess risk	Shift supervisor assesses the impact of the risk, categorizes the risk based on urgency, and assigns risk mitigation. Possible risks are: – Risk to plan – Risk to personnel – Risk to equipment – Risk to the location or related location	Input: An identified risk Output: An action item to mitigate the risk	
Activity delayed: Resolve delay	Shift supervisor reviews the delay with the appropriate personnel and develops a mitigation plan to resolve it, with focus on maintaining the shift schedule and getting back on plan. Going to another location or moving activities to the next shift should only be considered if staying on schedule/on plan is not possible	Input: An identified delay Output: A mitigation plan for the delay	
Confirm action plan	Shift supervisor confirms an action plan that addresses all stoppages, delays, and risks. Any authorized additional work is added to the shift plan and the impact of that work assessed. Any costs of additional or emergency tasks are recognized and the details of the change are documented	Input: Mitigation items from previous tasks, weekly plan, shift schedule, progress reports Output: Action plan to form the basis for continued in-shift activities. To be reviewed at the next meeting	
Instruct team: Communicate plan	Communicate the new action plan, any new instructions, and associated relevant information to all personnel (e.g., control room operator, equipment operators) who are affected by the changes	Input: Action plan Output: Instructions to personnel	Note: This change can be communicated by any senior member of the team
Update performance targets	Review planned activities for the next working period and confirm they are achievable and in line with targets; if necessary, update the targets to reflect the change. Does not change any baselines; baselines are only modified/set as required for performance monitoring	Output: Updated rates and targets	

ties that form the in-shift review process, key inputs and outputs, and issues to consider.

7.2.6 Post-Shift Review

The post-shift review validates the work and decisions made during the just-completed shift using end-of-shift data to make informed assessments and decisions regarding future plans. The purpose is to understand what aspects of the shift schedule, weekly plan, and the short-term plan worked or did not work, using KPIs to assess the performance. The review should support better performance and decision making during the upcoming shift and informs the shift scheduling process (see Section 7.2.4). Figure 14 presents a workflow for post-shift review.

Primary actors

- Previous shift supervisor
- Control room operators

Stakeholders

- Incoming shift supervisor
- Maintenance
- Services
- Control room
- Operators

Systems

- Schedule and weekly plan
- FMS
- Maintenance system
- Action plan

At the end of each shift, the shift supervisor reviews the end-of-shift data, including performance, in-shift action plans, and issues that arose during the previous shift, and compares the progress made to the weekly and short-term plans to assess performance. They then create a report and task list for the upcoming shift that includes all tasks to be completed, all necessary instructions, the locations of key resources (equipment), an inventory list, safety concerns, maintenance and service requirements, and any other important information. This report is reviewed by the incoming shift supervisor

Table 4. Post-Shift Review Activities

Activity	Description	Key Inputs and Outputs	Issues
Review conformance to plan	Shift supervisor for the just-completed shift compares the shift schedule to the weekly and short-term plan with respect to performance and identify issues requiring review	Input: Weekly and/or short-term plan Output: Issues list for review	
Confirm action status	Shift supervisor compares the shift schedule to the latest action plan, confirms progress, and identifies required revisions	Input: Action plan Output: Updated action plan	
Understand issues	Shift supervisor reviews issues arising during the recently completed shift and determines the cause of each issue: – Failure to achieve progress to plan – Unfinished activities – Resource performance – Unexpected conditions – Other crews on site (e.g., services)	Input: Issues list Output: Updated action plan	
Revise planned tasks for the next shift	Create a task list for completion during the next shift that includes: – A review of each task with any necessary instructions/feedback. If a FMS with rate-based tasks is in use, review rates achieved or, if planned rates are not being achieved, make changes to better reflect current conditions if possible. – An up-to-date list of key equipment locations (a FMS can provide this) – A list of required inventory. – Maintenance and service requirements	Input: Weekly plan Output: Task list for upcoming shift	Monitoring and resetting rates are often most successful using a FMS. The frequency of data updates will significantly impact how this process is supported Future, more mature SIC systems may see this process driven by advanced AI and/or machine learning solutions

at the start of the shift scheduling process (see Section 7.2.4). The outgoing shift supervisor will also update the action plan, make a note of any issues that occurred during the shift and determine their cause, and make an assessment as to whether adjustments need to be made in the shift schedule, weekly plan or short-term plan. As previously noted, the baselines cannot change, but the targets are adjustable and using SIC, the information collected by each post-shift review can

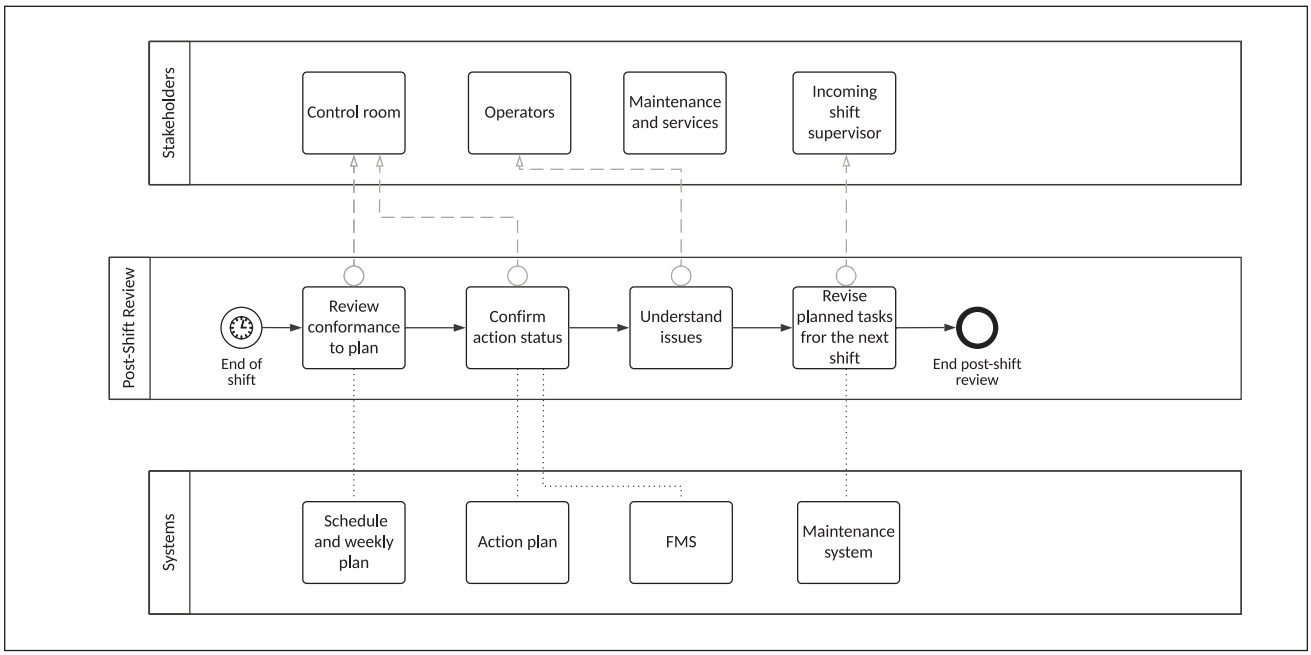

Figure 14. Post-Shift Review Workflow

help the system react quickly to changing circumstances. Table 4 describes activities involved in the post-shift review process, their key inputs and outputs, and issues to consider.

7.3 Data Enablement

Effective SIC relies on the collection and timely delivery of accurate information to decision makers. Enabling an organization to efficiently collect and deliver this information by applying digital technologies is commonly referred to as data enablement or digitalization. In underground mining, data enablement refers to the application of digital technologies to enable the capture and delivery of operational data to operations staff to enable more effective and timely operational decision making. This section presents considerations and questions to ask when implementing SIC in an operation.

How SIC captures, reports, and corrects deviations, and the timeframe in which it does this, will largely depend on the degree of digital enablement in the system, integration between systems, data analysis capabilities, and level of automation—its level of maturity. A basic SIC system might review and report on deviations from the plan at the end of each shift. Alternatively, a more sophisticated system could analyze and mitigate deviations in near-real-time and, where possible, initiate immediate corrective action during the shift. The complexity and ability of the SIC increases as the maturity level of the system increases:

Level 1: Basic: Manual data capture and end-of-shift reporting

Level 2: Foundation: Some digital data capture, though not in real time; no connectivity between systems

Level 3: Integrated: Multiple digital systems (including sensors, an FMS, digital asset management, safety applications) integrated for cross-system performance measures

Level 4: Decision-supported: Advanced analytics built into integrated operations; one source of information—everyone involved accesses up-to-date data from one interface configured to their role and responsibilities

Level 5: Semi-automated: Some decisions are made and resultant actions are executed by the system, with feedback and reporting to the responsible and accountable individuals.

Level 6: Highly automated: Closed loop, integrated AI system in which all data collection, analysis, and response is carried out by the monitoring program

The application of SIC to underground mining is discussed through the lens of the SIC maturity model, which is summarized in Figure 15.

Though SIC principles can be applied to all operational mining processes, the focus here is on technologies that enable SIC at the control room level. These technologies enable a centralized coordinator to optimize drill, load, blast,

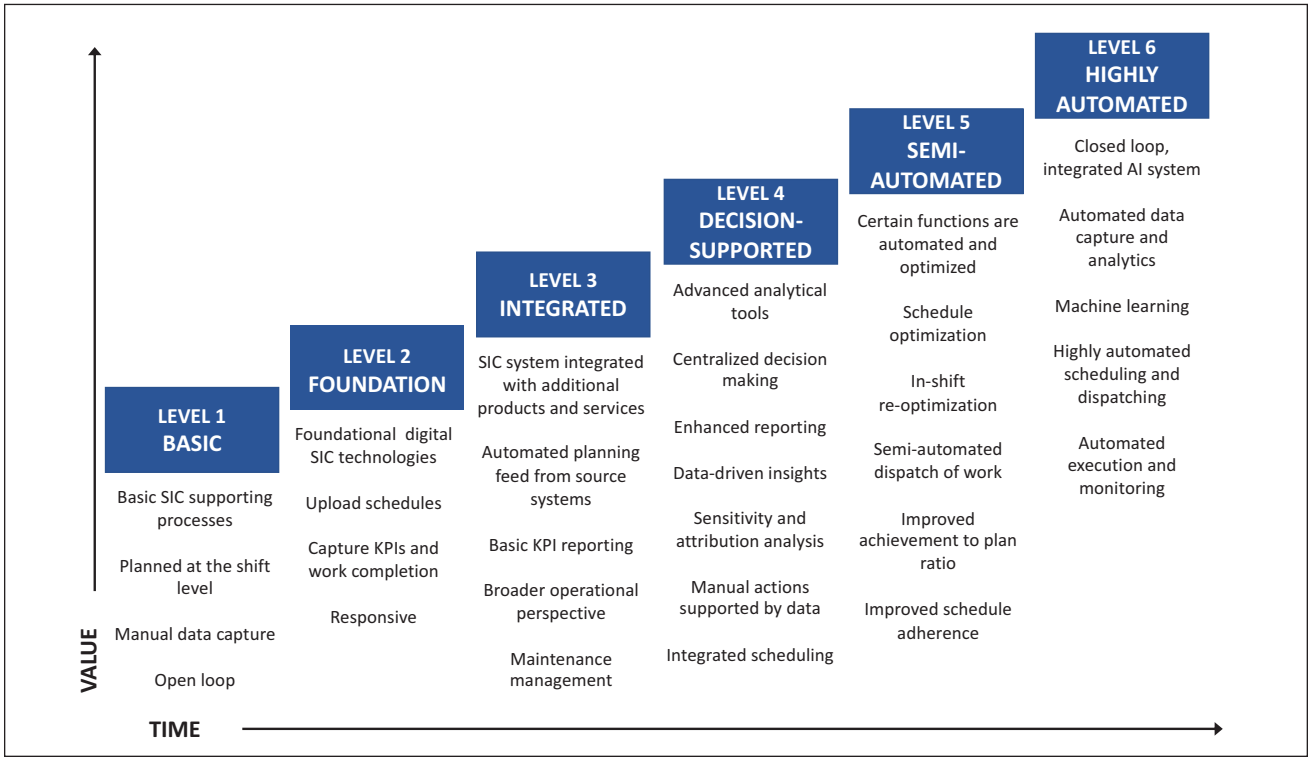

Figure 15. Short Interval Control (SIC) System Maturity Levels

muck, bolt, and transport production activities against functions like maintenance, mine planning, and logistics.

7.3.1 Level 1: Basic

An operation with basic SIC maturity is focused on implementing the fundamental processes required to support SIC and has not yet applied any significant digital technologies to enhance their operations. Operational data are typically collected manually by an operator on a paper form and submitted at shift change or through radio transmission.

7.3.2 Level 2: Foundational

Modern SIC leverages digital technologies to enable more efficient and effective decision making in underground operations. Introducing certain foundational technologies enables operations to more effectively plan, schedule, execute, monitor, control, and improve their operational practices.

Although the exact definition of level 2 might vary slightly from operation to operation, the generally accepted foundational technologies are outlined below.

7.3.2.1 Communications infrastructure A modern communications infrastructure is the foundational enabling technology for SIC. Modern communications technology enables connectivity throughout the mine, at the face, and with the surface. Communications infrastructure provides the avenue to move data between operations and activities, data stores, and decision makers. Many technologies are available that enable voice and data communications within mines. This is explored in greater depth in the GMG Underground Mine Communications Infrastructure guidelines (GMG, 2017a,b, 2019).

7.3.2.2 Mobile digital work management system Introducing mobile devices into the underground environment enables personnel to both retrieve and capture pertinent information related to the shift, making it possible to schedule tasks, track task progress, report delays, and locate critical equipment and consumables. Some work management systems allow certain functions to be performed in offline mode because connectivity underground is not guaranteed. The work management system can be integrated with location services to provide operations personnel with accurate resource location information.

7.3.2.3 Location services Underground mining takes place in a global positioning system (GPS)-denied environment, so indoor positioning system (IPS) technologies are required to locate operational assets (personnel, equipment, supplies and materials, semi-fixed assets). An IPS can use a range of technologies including Wi-Fi, long-term evolution (LTE®), radio frequency identification (RFID) tracking, beacons, Bluetooth® low energy (BLE), LiDAR, ultra-wide-band, and more to provide precision ranging from more than 50 m down to the millimetre level. Location services can also be integrated into dashboards to visually display asset locations in real time.

7.3.2.4 Equipment telemetry Telemetry refers to automated technological processes for communicating measurements and other data between remote locations and receiving equipment. Operations can leverage equipment telemetry to provide more accurate and timely updates of activity progress compared to what is possible using manual operator updates and facilitates a better understanding of equipment status and health.

7.3.2.5 Collaboration software To ensure clear communication, mines at the foundational maturity level use collaboration software that makes tasks and activities visible to the control room and to front-line team members concurrently. Collaboration software provides the following:

Reports (high detail, low reporting frequency) composed primarily of text and tabular data but can also include visual components, often containing significant detail covering multiple business areas and segments of the value chain across multiple pages. Reports are often used to review the activities from a specific time period (a shift, a day, a week, a month, or a year). This level of detail makes reports very useful for disseminating comprehensive operational information; however, the volume of information and broad coverage makes them less than ideal for monitoring progress in real time.

Dashboards (low to medium detail, medium to high reporting frequency) typically present the most important information and KPIs required to achieve specific business objectives to the operator on a single screen. Dashboards use data visualizations (e.g., line charts, histograms, pie charts, radial gauges) to make complex information easier to understand, focusing on driving decision making rather than informing. Dashboard update frequencies can vary significantly based on information needs and data availability. They can be updated in near-real-time, making them a useful tool for anyone that needs to actively monitor multiple operational parameters or KPIs.

Data-driven notifications (low detail, real-time reporting frequency), which can take many forms, including email, short message service (SMS), and in-app messaging. Notifications are typically event driven (specific conditions must be met for a notification to be sent). Notifications are most often used when narrowly focused, but critical operational information must be delivered to specific individuals in real

time; for example, an email is sent to the shift supervisor when a miner flags a delay or deviation from plan.

7.3.3 Level 3: Integrated

Integrating disparate data sources and services with the SIC system introduces additional data into the decision-making processes. Integration enables operational personnel to incorporate a broader operational perspective when making decisions. There are many sources of data that can optimize SIC decision making, including computerized maintenance management systems, corporate human resources systems, enterprise resource planning (ERP) systems, FMSs, supervisory control and data acquisition (SCADA) systems, mine planning software, seismic systems, and others. At this maturity level, data from many systems are often integrated into a single platform to provide one source of the truth, enabling new business capabilities beyond SIC.

7.3.4 Level 4: Decision-Supported

Decision-supported operations leverage advanced analytical tools to provide centralized decision-making capabilities and further improve the operation. With an integrated (and preferably interoperable) system, it becomes possible to apply analytical tools and incorporate integrated scheduling so that the control room personnel can make decisions with better data-driven insight. Functions for decision support could include schedule optimization planning and scheduling for all operational activities (e.g., production, maintenance, inspection, logistics) and in-shift schedule re-optimization. For effective SIC, it is important to respond to data inputs and revise the schedule during the shift whenever possible. Decision-supported analytics can process in-shift data based on recognized deviations (e.g., tasks taking longer than expected, equipment downtime) and help to optimally re-allocate available resources.

7.3.5 Level 5: Semi-Automated

As an operation integrates its discrete operational systems and centralizes its decision-making processes, opportunities are created to automate and optimize certain functions, enabling further improvements to the accuracy, speed, and effectiveness of their operation-wide decision making and orchestration. As decision-supported analytics become more automated, scheduling and rescheduling actions function with less manual input, further optimizing and speeding up the process.

In a semi-automated system, integrated execution and direct dispatching becomes possible. Integrated execution extends integrated scheduling capabilities by allowing a central system to dispatch instructions to lower level systems (FMSs, work management systems, and computerized maintenance management systems, SCADA systems) based on human-defined parameters and algorithmically optimized schedules. Direct dispatching improves instruction accuracy because communication occurs directly between the SIC system and lower level systems.

7.3.6 Level 6: Highly Automated

The highly automated scenario is the logical successor to a semi-automated solution. As the name implies, a highly automated operational system is one that requires some, though limited, human intervention and only in scenarios for which the system cannot arrive at an appropriate solution and for validation purposes. Having highly automated scheduling, execution, monitoring, and control of mine site operational activities provides further improvements in accuracy, effectiveness, and speed of operation-wide activity coordination. It is worth noting that, at the time of writing, the GMG working group is not aware of an operation that has achieved this level of maturity.

7.3.7 Recommended Contextual Reading

Within the data enablement section, technologies related to underground communications, data management, and analytics have been mentioned, but are not explored in depth. The following sources can provide useful context on these topics:

- Wireless communications: The GMG guideline suite on underground mine communications infrastructure (2017a, b, 2019). Three parts, "Positioning and Needs Analysis" infrastructure (2017a, b, 2019) "Scenarios and Applications," and "General Guidelines" are available at https://gmggroup.org/guidelines/.
- Data security: de Guise (2017). GMG also has future work planned on cybersecurity.
- Information management: Bytheway (2014)
- Data analytics: Jones (2018)
- Data quality: Redman (2001), Sadiq (2013)
- Data cleansing: Rahm and Do (2000)

8. IMPLEMENTATION

8.1 Introduction

A common challenge experienced by operations during the SIC implementation process is that competing priorities, lack of on-site knowledge or experience, and the need to process large quantities of information can hinder the decision-making process. Given that SIC is enacted when

operations do not go according to plan, collective accountability and teamwork is critical to ensuring effective and successful SIC, so that all areas of the operation are considered.

SIC implementation requires changes to activities, process flows, and reporting for multiple operators across multiple disciplines (processes and activities are covered in more depth in Section 7.2). Change management is also addressed in Section 8.3.1 but should, from the outset, be written into the methodology for defining and developing SIC through engagement with those affected, responsible, and accountable. Governance and transparency are important elements of measuring, understanding, and reporting the success of SIC and its impact on continuous improvement (see Section 8.4). Descriptions of SIC-specific roles and responsibilities are presented in Appendix C.

To secure innovative thinking and support from within all operational, management, and corporate levels, those implementing SIC should:

- Engage with operational teams from the outset using a cross-departmental approach to gather requirements, ideas, concerns, and aspirations from all stakeholders
- Focus initially on high-priority areas, including considering safety risks and identifying hazards and exposure risks
- Review operational and financial performance to identify delays/unplanned downtime in order to determine value loss and opportunities to unlock additional value
- Establish a baseline to ensure that success and impact can be tracked and measured

Successful SIC implementation requires detailed planning and preparation. The mine site must develop a clear strategy and timeline. SIC is a holistic process with many components, and there are many decisions to be made. Those implementing SIC need not only to decide what specific elements and which SIC levels to implement, but they also need to decide how to implement it. All decisions that can be made during the planning stage must be made as early as possible because openly communicating all the changes early in the process is key to getting approval from stakeholders.

Although every mine will have different requirements and objectives, a clear path to a well-defined destination will simplify the project implementation. SIC is a useful tool, but it is not a cure-all for a mine that is poorly planned and managed or has low equipment availability. The aim of this section is to delineate a general path and provide considerations for various stages of SIC planning and deployment.

This SIC implementation process can be undertaken at the same time as implementing other technological advances such as autonomous systems or Wi-Fi. Implementing SIC, however, requires significant time and effort. If a mine site chooses to implement SIC in parallel with other projects, budgeting and scheduling will need to be done properly and carefully so as not to overwork employees and equipment.

Figure 16 presents many of the activities and outcomes of the implementation process.

8.2 Culture

To get the most from SIC adoption and the best return on the investment, it is important to have the right organizational culture in place. If the mine culture is not one of accountability, where target-setting and reporting against targets on a shift-by-shift basis is not already standard practice, introducing a SIC system may be met with resistance.

Establishing a culture of accountability can be accomplished by having shift supervisors set daily targets as part of the lineup processes, check in regularly throughout the shift for updates on progress and delays, follow up at the end of shifts to compare productivity and performance against targets, and discuss what could have been improved with a focus on continuous improvement rather than penalty. Ultimately, having this kind of culture of accountability in place will speed up the adoption and acceptance of any SIC system.

8.3 Planning

Detailed change management and project planning needs to be undertaken prior to implementation to ensure that the software, projects, technologies, processes, and people are sufficiently ready for SIC. These plans should also be reviewed regularly throughout implementation to incorporate necessary adjustments based on unexpected situations.

8.3.1 Change Management Plan

Introducing SIC is a change that influences all levels of the organization. A clear and transparent change management plan to manage the process through all stages is critical. Visible management support and commitment, such as executive sponsorship, are critical for successful change implementation. Such support adds credibility to the entire process. Prosci® (2018) identifies clear and visible executive support as the most important contributor to successful change implementation.

Engaging champions at all organizational levels from the outset can encourage the rest of the employees to support the change. Selecting these individuals should be done carefully; champions should not only include early

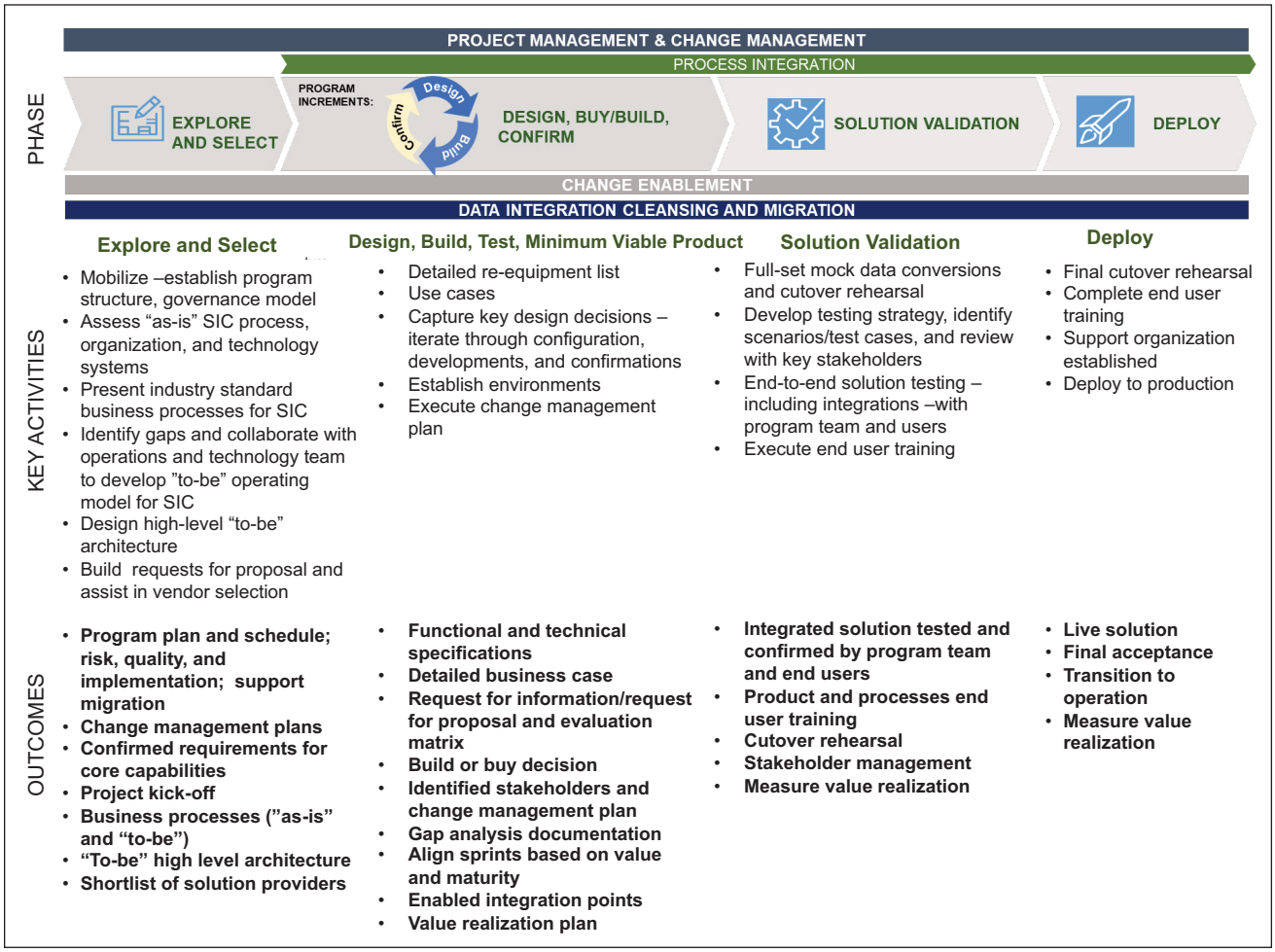

Figure 16. SIC Design, Development, Testing, and Scale (modified with permission from a figure courtesy of Accenture)

adopters who tend to be open to new technology, but also individuals who might not typically champion new technologies or processes. For example, gaining the early support of an influential supervisor who is not always eager to change can help others who might be resistant to the change to see that new processes and new technology can work. Because various champions at different organizational levels will have different ideas and interpretations, there needs to be a single responsible person or decision maker on site. This person will be responsible for analyzing data, ideas and interpretations and recommending actions. It is also valuable for user adoption/compliance to have a single on-site person to contact with questions and concerns about the incoming system, someone who can dispel rumours or misgivings and disseminate facts.

A well-developed communication plan is also vital to implementation. Communication should occur early and often, and it should address questions and concerns that are important to the front-line staff (operators) and supervisors. Connecting with what is important involves discerning how the technology or SIC process will benefit front-line staff and supervisors by making their jobs easier or helping them to achieve desirable results. For example:

- Increased production might result in increased staff bonuses
- Increased productivity could lower production costs and improve mine life and sustainability

Finally, all employees need to be actively involved and engaged throughout the change process. If there is resistance or minimal enthusiasm, especially on the part of superintendents and managers, it can delay or weaken the process and reduce the value delivered. Ensuring that those affected can make positive contributions will help create a culture that is open to change. An example of how to engage the workforce is presented as a project roadmap in Section 8.3.3. A case study on lessons learned about change management is included in Appendix B.

8.3.2 Scope of Work

The project needs to have a clear scope that outlines how the organization will implement SIC. Site officials need to review any scope, especially one prepared by consultants,

to make sure they are getting what they need and are aware of what is required of them. For a project of this size, it is worth having a third-party review of the plan to ensure that nothing important is missed.

Defining clear objectives will help the organization determine the appropriate SIC system to design and implement and what infrastructure will be required to support it. There are many potential benefits the organization could be seeking (e.g., improved adherence to mine plan and schedule, improved task coordination, increased face utilization, reduced delays). It is also essential that all parties agree on objectives and what they mean. For example, if corporate wants a tool to prevent supervisors from spending too much time solving small problems, but the site managers are looking for a better problem-solving tool, the end result may be less useful tools for both.

The scope must also establish high-level operational requirements. Organizations will need to specify for whom the system is intended: Will the system be only for production and development crews, will it also include construction and service groups, and to what extent will maintenance be involved? Sites will need to complete this step before and after developing organizational charts with clarity on new roles and responsibilities (see Section 7.3 and Appendix C). Similarly, the scope must also define the equipment on which the site will initiate the system (a single piece of equipment, one type of equipment, or the entire fleet).

Data handling processes must also be defined. A clear data management plan will reduce the risk of the system becoming overloaded and will also guide how the organization develops standardized reporting. Data considerations include:

1. Who collects and enters data (only supervisors, or also front-line staff)
2. Where and how data will be stored
3. What aspects of the data require analysis
4. To whom analyses will be presented
5. Digital maturity of the system
6. Single application programming interfaces (APIs) or integrated platform

Site officials will also need to decide the specific interval duration between plans and instructions and the targeted continuous improvement responsiveness. Defining the interval and response process will, in turn, establish the level of planning and scheduling and the communications infrastructure requirements (e.g., how close to the face to install communications).

8.3.3 Project Roadmap

Once the "To-Be," or future state, has been determined, a roadmap can be drafted based on input from operational, information management, and technology teams. The roadmap will estimate both capital and operational expenditures, indicate what will be possible within the budget, and provide an acceptable and realistic timeframe.

This stage of implementation applies to operational process and management changes as well as technological ones; therefore, change management is key to effective implementation. End users and those who will be responsible and accountable for processes and tools need to be involved from the outset so that they can offer input on how the "To-Be" state will be defined. Identified champions should also be involved in roadmap definition. Ultimately, the roadmap will be a useful tool for keeping the workforce engaged and informed about what is expected to happen and when and will help to manage expectations. To accomplish this, the roadmap should be accessible by all levels in the organization and should include:

1. How the roll out will take place (i.e., one function at a time or one area of the mine at a time)
2. A clear schedule (meeting timelines maintains engagement)

8.4 Deployment

During SIC deployment, site officials should set clear expectations about the timeline so that all staff members are informed and remain engaged throughout the process. The process requires at least one fully dedicated person responsible for on-site development and implementation; this individual can help to guide others through the process and manage expectations. SIC implementation is a multistep process and one which evolves with increased maturity; the benefits are not necessarily immediate and some productivity improvements can take several months for the value to materialize.

Site managers will also need to ensure that the appropriate mine infrastructure is in place and the capability to manage real-time communications and large amounts of data might need to be built. Pushing incomplete or beta-version software out before the infrastructure is ready is likely to lead to frustration. The appropriate IT service and support structure also need to be in place for the new software; this can require increases in the IT department budget to provide additional personnel, training in the new software, and potentially purchasing and training in new hardware to support the data flow (e.g., servers). If operators are provided with devices such as tablets, management will need to allow time to set them up with the appropriate permissions and other criteria. Installing the underground communications network will need to keep pace with mine development, so fibre-optic cable and access portals will be required as part

of the regular service extensions. For further information, see Appendix B, which includes a case study with lessons learned on implementing an operations management system.

Because processes will change and performance will be measured differently, rewards and bonuses will need to be adjusted. This potential adjustment is best communicated early and transparently as part of the change management process so that the workforce understands the impact on them as individuals and as teams. Most incentive systems, aside from safety incentives, are quantitative and based on measurable quantities of material mined. With SIC in place, more emphasis should be placed on compliance to plan and getting the right data to the right people at the right time. In addition, new KPIs such as heading utilization might be prioritized over equipment utilization and must be accommodated accordingly in the incentive structures.

8.5 Ongoing Review and Updating

The end goal of SIC is continuous improvement and when SIC is implemented, sites will need to regularly review and assess the objectives (as outlined in the scope) and whether or not they are being met, updating them as needed. Regularly assessing and updating processes to reflect updated objectives is also recommended. For success, sufficient thought and effort put into the weekly plan and short-term schedule at a level of detail that optimizes benefits will be required. The schedule should be integrated between operations and mobile maintenance (and ideally between electrical and fixed plant as well) and have the approval of all stakeholders. The success of SIC implementation also needs to be understood through the lens of governance and transparency and measured not only by the productivity of the mine but also by the efficiency of its stakeholders and key roles engaged in SIC.

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APPENDIX A: LEAN MANUFACTURING CONCEPTS APPLIED TO THE IMPLEMENTATION OF SHORT INTERVAL CONTROL IN UNDERGROUND MINING

Lean manufacturing is a methodology for making a process more streamlined by eliminating waste and inefficiency. The concept can be applied to SIC in underground mining. Examples relevant to mucking are provided throughout.

Within any process, activities can be classified as:

1. Value-added
2. NVA but necessary
3. Waste (seven forms)

Value-added tasks are tasks for which the customer is willing to pay. These tasks can be characterized as physically changing the product. For example, in mucking, value-added activities include:

1. Mucking out a stope
2. Loading a truck with ore
3. Loading ore into an ore pass from a scoop
4. Tramming ore to an ore pass
5. Dumping ore into a grizzly from a truck

NVA tasks are tasks that must be completed in order for value-added tasks to occur. The customer is not willing to pay for these tasks, but they must still be completed. For example, in mucking, NVA activities include

1. Fueling scoops and trucks
2. Pre-operation preparing equipment
3. Tramming to/from stope
4. Obtaining/sourcing supplies
5. Performing stope pre-operation and post-operation procedures (for safety)
6. Maintaining equipment

It is desirable to make NVA tasks as efficient as possible.

Waste activities are those that neither add value nor must be completed in order for value-added tasks to occur. The objective is to eliminate waste wherever possible or to reduce the impact of waste activities if they cannot be completely eliminated. Waste can be classified into seven categories, known by the acronym TIMWOOD:

- **U**ransportation: If more transportation occurs than is necessary. In mucking, this can be double-handling of ore or waste (for example, re-muck to truck).
- **J**nventory: If there is too much, too little, not enough of what is required, or too much of what is not required. In mucking, for example, having too much oversized material to be processed.
- **N** otion: If more motion occurs than what is required to get the job done. In mucking, this could be multiple moves by a scoop to load a truck.
- **X** aiting: In mucking for example, this could be waiting to dump or waiting for another piece of equipment to pass.
- **P**verproduction: If more is produced than what is required (getting out of sequence to the mine plan). In mucking, this could mean mucking a stope beyond the shift tonnage target, potentially taking away time from other planned tasks that require a scoop.
- **P**verprocessing: Making the task more complicated than required. For example, providing incomplete work instructions to an operator.
- **E**efects: If a task is not done right the first time.

Within SIC, the objective during a shift is to maximize the value-added activities by minimizing time associated with NVA and eliminating wasteful activities (as defined under TIMWOOD). Within scheduling and shift monitoring activities, all activities and subsequent actions should reflect this line of thinking. Data gathered from SIC execution along with structured problem solving drives the continuous improvement process of eliminating waste and minimizing NVA impact.

The purpose of SIC in underground operations is to strengthen the control and response pillar of the stability platform. The stability platform comprises the following elements used to address these three major inefficiencies (variation, waste [TIMWOOD], and overburden on individuals):

- Standard work: The current best practice to execute a task
- Workplace organization: The necessary tools, equipment and information on hand to perform a task
- Control and response: The ability to respond to a deviation in plan as close in time as possible to the event ("action before damage")

The above three pillars are underpinned by effective engagement of the workforce because driving and rewarding the desired behaviour will only make the above principles work; otherwise, they remain concepts only with lack of traction.

APPENDIX B: CASE STUDIES

B.1 Business Case for Short Interval Control at Boliden

For years, the ability to predict production and minimize downtime has been an expectation in the manufacturing sector; thus, manufacturing facilities have had the benefit of being able to predict, monitor, and observe productivity in their operations. Underground mining operations have yet to embrace similar activities because there is an industry-wide perception that predicting downtime and improving productivity is not feasible when the conditions and work environment are unpredictable, as they are in underground mining.

At Boliden in 2003, a vision to move toward the "transparent mine" began taking shape. Using simple paper tools to create a basic SIC system, Boliden started on a path to better understanding what was happening in their operations. Since then, they have taken a number of steps to get to where they are today: A mining company that is highly regarded for their ability to effectively predict productivity and mitigate and understand delays. Though they are not perfect, Boliden has built a culture of diligence to understand, evaluate, and act on the causes of deviations between planned and actual work. Table B1 shows the actions Boliden took to move from their initial state to where they are now. Initial states identified for change included problems to be solved and opportunities for improvement. End states include the results and benefits of each implemented change.

The two major concepts that support the business case of adopting SIC in a mining operation are

1. Believe in the transparent mine: The company must believe that the mine and mining operations can be made transparent and have the right people in the right places to implement the process, help make improvements to solve challenges, and take advantage of opportunities on a daily basis.
2. Recognize the need for a culture change: There must be explicit recognition that the current culture (i.e., the way the company interacts, sets expectations, and manages work) needs to change for the mine to transform into the transparent and predictable ore manufacturing facility that it can be.

Table B1. Changes Made During Short Interval Control (SIC) Implementation at Boliden

Initial state	Actions	End state
Increasing productivity	Conduct a value flow to analyze and identify: – Customer value for production process – How each part of the production chain contributes to creating value Design SIC to follow up on key tasks that enable success	– An increased production rate due to increased productivity – Reduced variance in production – Improved plan adherence
Unreliable plan/variable production schedule	Create an integrated plan (for production, maintenance) Design SIC up to follow plan according to: – Yesterday's results – Today's challenges – Tomorrow's challenges Use SIC meetings to act to fulfill today's/tomorrow's plan	Improved ability to execute production according to set plan by: – Improving the areas were deviation occurs (PDCA) – Ensuring everyone in the organization knows what is expected from them, which will give focus and direction

B.2 Change Management Lessons Learned at PACE – Partners in Achieving Change Excellence

The following case study (Table B2) describes lessons learned from change management processes associated with implementing SIC. PACE – Partners in Achieving Change Excellence is a consultancy that partners with the mining industry to help companies implement change and adopt new technological solutions. This case study draws from their experiences with change management at two mine sites: One site is an example of poor change management and the second is an example of good change management.

Table B2. Lessons Learned During Change Management at Two Mine Sites

Activity	Site 1: Example of poor change management	Site 2: Example of good change management
Awareness: Initial messaging	Messaging about the need for change was not targeted at or designed for the specific working groups affected by the change The "what's in it for me" messaging was a more generic explanation of how SIC might benefit productivityThe site general manager shared this messaging at a site-wide meeting but not all groups were present	A full communications and behavioural assessment was completed to design a communication strategy to identify and specifically target the individual reasons for change resistance – Posters were designed and placed in key locations and videos and frequently asked questions were created to target specific reasons for resistance – Messaging was presented by the site general manager at every lineup meeting, ensuring that all personnel received the information
Awareness: Change leadership	Change management was led by an offsite business leader who was only on site once a week to deliver a change management presentation	Change management was led by a guiding coalition of on-site champions and supervisors who demonstrated the system's use and value at in the field and at lineup meetings
Desire: Designing the content of change management tools and techniques	A designer from a well-known consulting company worked with the business leader and some supervisors to design elaborate PowerPoint slides and posters	A full communications and behavioural assessment was completed to design a communication strategy to identify and specifically target the individual reasons for change resistance – Informative posters were designed and placed in key locations – Short idea-sharing opportunities were inserted into the daily lineups
Knowledge: Technology alignment	Workers were provided with tablets; however, the onsite Wi-Fi was patchy. The workers were not made aware that the tablets would only work in certain areas, which caused some dissidence and loss of trust in the tool	Workers were provided with tablets; however, the onsite Wi-Fi was patchy. This was clearly communicated to the workers and visual displays were installed to remind workers where they could or could not get a Wi-Fi connection
Ability: Skills assessments	Skills assessments were not explicitly carried out	Skills assessments were carried out and those needing additional help were identified and paired with a mentor on their crew
Reinforcement: Reporting out	Minimal reporting of the data generated from the tablets (mainly because there was very little); no plan to use the data was clearly articulated	Frequent "change huddles," or team progress meetings, were implemented and huddle boards (visual management tools, that are updated frequently to track progress) were installed to display the collected data

B.3 Operations Management System Lessons Learned at Glencore

Glencore is a diversified natural resources company with mine sites all over the world. The following case study (Table B3) describes implementing an operations management system and the lessons learned from the process.

Table B3. Operations Management System Lessons Learned at Glencore

Category	What happened	Lesson
KPI-based design and establishing minimum viable product	Application requirements were based on capturing data and measuring compliance to the plan. Insufficient attention was paid to which roles would consume the data/information and which roles would use the data to measure compliance to plan. Visibility of compliance to plan reporting was not prevalent within the operation. This affected accountability and user adoption throughout the SIC process.	A KPI-based design, with established owners and responsibilities, will help ensure that SIC data are consumed and increase user acceptance of the application value at all levels. Establish and adhere to a minimum viable product scope. Display information in prominent locations, particularly for those responsible for taking action. Ensure all users are looking at the same data and have enough training to interpret it correctly.
Stable mining processes and change management	Requirements were gathered before the contracted mining developer was fully entrenched in the project and were based on the mine owner's best practices. Sessions were held with the contractor to determine requirements; however, these requirements deviated from the actual mining processes.	To avoid rework in design and development, ensure mining processes are fully established. This can be difficult if mine owners and contractors are integrated in mine development. Do not try to rush delivery before processes are documented and approved. As a first step, assess work processes and re-engineer them as required to support digital SIC implementation. Use manual or digital/mobile shift schedules/logs/miner task progress. Only move to an application (custom or off the shelf) when the level of user adoption/compliance and content quality is satisfactory. Ensure end users are engaged in work process engineering and application design as early as possible. Establish a mechanism for continuous improvement initiatives generated by application data. For example, identify who is responsible for analyzing data and recommending actions.
Management systems	Developed processes were not clearly defined at project start-up. Issues were compounded by using offshore developers, where there were time zone differences and communication challenges.	Ensure that the management systems for application administration and maintenance are established early in the project. Define administrative and maintenance roles and responsibilities by user group. Define the process for application enhancement requests Establishing these clear systems, roles, and processes facilitates clearer communications.
Mobile technology complexity	The mobile platform went through major changes during the development phase of the project, such as migration from BlackBerry® to iOS® for mobile devices and adoption of AirWatch® as the mobile device management software. Data loss occurred in underground areas with weak Wi-Fi.	Providing a secure, mobile platform is important. Requirements for device management, firewall security, and mobile operating system upgrade management should be considered. Establishing technology processes early will help prevent data loss and remove the need for changes later in the process. Be aware of the complexities of data syncing in areas of low Wi-Fi signal strength. Even when there is a connection, it might not be strong enough for some applications to function correctly in online mode.
Low code development platforms	A rapid mobile application development platform was used to build the application.	Rapid mobile application development platforms provide an easy way to deliver simple mobile applications quickly; however, consideration should be given to building a native application or using a hybrid development platform such as .Net/Xamarin® to provide the flexibility required to deliver applications that use complex logic.

B.4 Continuous Improvement Case Study: Greater Visibility, Control, and Efficiency at AGCO

This material is provided by Dassault Systemes Software Inc. (2014). The full case study and details can be found on the Dassault Systems website at https://www.3ds.com/customer-stories/single/agco/

To meet production and quality targets and control costs, manufacturing has strived to improve manufacturing operations management (also known by the abbreviation MOM) to optimize the performance of business processes that see inputs of material and labour turned into outputs and, finally, finished products. Through monitoring and analysis, manufacturing has found ways reduce variation by making the processes more efficient and predictable. To this end, manufacturing execution systems (MESs, sometimes referred to as MOM systems or MOM platforms) are widely used in the manufacturing industry. SIC is a process that strengthens MESes by offering increased stability and control at the shift level.

Story and Readiness

AGCO, the world's largest manufacturer of tractors and third largest supplier of agricultural machinery, decided to build the world's most modern tractor factory, capable of producing 20,000 tractors per year.

Work on the new, $300M factories in Marktoberdorf, Germany (gear boxes and tractors) and Bäumenheim, Germany (cabins and hoods) began in 2010 with system implementation tasks completed in parallel; this meant they could be operational on the same opening day: September 3, 2012. Workers at the existing plants were trained on the new system using simulations, allowing them to practice what they would be using after the move.

A Lean Approach

Existing factories had grown and evolved over decades of producing tractors and agricultural equipment using a mix of equipment and facilities. AGCO decided to make a bold move and start fresh with modern technologies in their new facilities to avoid being encumbered by past limitations.

The new facilities were designed with a lean manufacturing approach in mind: Minimum inventory on the plant floor, instant communications to keep work and material replenishments flowing, and the latest technology for a highly flexible production environment.

Using a Manufacturing Execution System

Workers in the new plant have ready access to the latest schedules and priorities, can order materials or report issues, and are able to call up documentation and specifications right at their workstations through online displays.

The new AGCO factories use an MES to capture real-time production data (order start, stop, duration, and set-up time) to enable quick visibility of all production activity with drilldown options to the machine level. The system supports finite scheduling based on restricted resources while optimizing set-up time (reduced nonproductive time). Delivery times from suppliers and subcontractors are synchronized to these schedules to minimize inventory and yet ensure the right materials are available when needed.

1. The MES manages and communicates machine alarms and process values (e.g., temperature) for management action, historical analysis, and process and quality control.
2. The system includes a production dashboard that displays continuously updated key measurements (KPIs) for management review.
3. The system automatically captures machine/production states (running, downtime, and set-up) and integrates with quality management software for scrap and inspection data.
4. Work orders are downloaded from the ERP system, which is in turn updated with production information and results from MES in a seamless closed loop.

Benefits

1. AGCO has documented a doubling of overall production volume without a reduction in efficiency, as measured by fixed-cost KPIs (efficiency and productivity) or production time and variable cost per unit; the result is an increased profit margin.
2. With increased transparency, the company now enjoys improved allocation and utilization of capital invested for machines.
3. Standardized, reliable, and objective process performance data such as production times, set-up times, and nonproductive times have allowed better management of valuable capital equipment and product quality.
4. Monitoring, improving, and accelerating the machine maintenance processes have reduced downtime and led to lower operating costs.
5. Consistent, automated data acquisition and KPI calculation¾including comparisons across sites¾provides greater transparency on the shop floor in support of waste elimination and performance improvements.

Statistics

1. Tractor assembly capability doubled (to 16 units per line) with no efficiency reduction
2. Increased new product introductions to one "pilot" per month; tractors consist of 10,000 components; new models have up to 60% new parts

3. Assembly-line productivity is projected to increase by 8% in the first year and by 25-30% during the first three years
4. Reduced "takt time," the rate of completing a project to meet demands, to below 10 minutes
5. Improved OEE by 22% in the first year in core competence machining area

Applications to Mining

Using a similar approach to the one discussed above could help to manage the following key areas of instability that the mining industry often faces:

- Planning: Not all required tasks/activities are planned sufficiently
- Scheduling: Not all planned tasks are robustly scheduled based upon specifications (e.g., sequence, time, duration, tonnes, grade, maintenance, safety, regulatory compliance)
- Execution: Not all scheduled tasks are completed or tracked to specifications (e.g., sequence, time, duration, tonnes, grade, maintenance, safety, regulatory compliance)

By focusing on tactical and operational control, mining companies can achieve increased stability and conformance to plan. Even though mining faces some factors such as geology and weather conditions that manufacturing does not, variation in mining activities can still be reduced by adopting the ISA-95 architecture for manufacturing enterprise control system integration (Table B4; International Society for Automation, 2010a,b, 2012, 2013a, b). Many elements of manufacturing operations management (level 3, Table B4) could be adapted to mining, and many mining companies are starting to implement mining execution systems. Effective use of planning and operational data can provide quick insight into how well activities are performed, enabling fast adjustments as operating conditions change. The analytics this approach enables will also drive continuous improvement.

A mining execution system enables superior work management through increased visibility and control over performance. It does this through up-to-the-minute tracking and management of mining and processing activities, equipment, maintenance, labour, support, and other inputs and outputs to provide:

- The ability to update activities and tasks between scheduling cycles
- Real-time visibility of capacity, availability, and performance
- Enhanced ability to manage activities, tasks, and priorities to account for changes in production and unexpected events
- Communication of new and updated work orders instantly wherever they are required
- Assurance that activities and tasks are completed to specification (e.g., sequence, time, duration, tonnes, grade, maintenance, safety, regulatory compliance)
- Efficient handover of incomplete activities and tasks between shifts

An additional level of stability is enabled when scheduling can be connected to the mining execution system to achieve SIC. When continuous feedback loops become part of the scheduling process for production, blending, waste, maintenance, and support schedules, adjustments can be rapidly made to keep production on track. With wireless infrastructure, the mining execution system can gather data from any part of the mine, even underground, and dispatch work orders digitally to employees in real time.

Work processes can be standardized when business process modelling capabilities are available in the mining execution system. Although some mining companies have undertaken great efforts to document procedures, it is difficult to ensure that they are followed if they remain on paper and are filed away. Through mining execution systems, work instructions, reviews, and approvals become routine and consistent because they are embedded in employees' job tasks. This ensures better execution every day, month, and quarter.

Table B4. Description of ISA-95 Control Levels (International Society for Automation, 2010a) and Activities

Level		Systems	Activities
Level 1 Sensing	Process control	Sensors/Actuators	Data generation, input monitoring
Level 2 Monitoring and supervising		Programmable logic control (PLC), SCADA	
Level 3 Manufacturing operations management (MOM)		MES	Scheduling, tracking, mitigation actions, dispatching, execution
Level 4 Business planning and logistics		ERP System	Short- and long-term planning, resourcing, identifying risks

APPENDIX C: SHORT INTERVAL CONTROL ROLES AND RESPONSIBILITIES

Although SIC processes follow a basic template (presented in Section 7.2), the actual structure will look different for each mine with different organizational structures and personnel roles. The following examples demonstrate options for structuring SIC-related roles and responsibilities in the underground mining environment.

C.1 Example 1

This example shows interactions between the following parties deliver a functioning operation, from short-term and weekly plans to intra- and intershift processes:

- General supervisor responsible for higher level supervision at the site
- Shift supervisor
- SIC supervisor/operator
- Short-term/daily task scheduler

The example represents a possible structure for a larger mining operation. It includes several different supervisory (general supervisor, shift supervisor, and SIC supervisor/operator) and administrative (task scheduler) roles that could potentially be done by one or two individuals in a smaller operation.

C.1.1 Superintendent (Production, Development, Maintenance)

End of shift

- Participate in a review with shift and SIC supervisors to share and understand issues encountered during the shift and what mitigation actions were taken
- Review the shift actuals with respect to the short-term/daily plan to understand deviation (i.e., management by exception)
- Determine which activities should be pushed to next shift, and what issues need further problem solving and resolution according to set criteria

Problem solving

- Lead problem solving on re-occurring issues; resolve and implement countermeasures
- Manage database of in-progress countermeasures to ensure successful completion
- Ensure that KPIs belonging at the production level are under control and engage in a problem-solving routine if KPIs are out of control

Planning

- Work with mine planners and the short-term task scheduler to determine what activities need to be done on a weekly basis
- Check for conflicts between activities and assess for chances of successful completion

Coaching

- Routinely provide regular interactions and coaching shift and SIC supervisors to support desired supervisory behaviour. This is done at the surface during regular meetings and through regular underground reviews.

C.1.2 Shift Supervisor (Production, Development, Maintenance)

End of shift

- Participate in a review with the SIC supervisor and superintendent to share and understand issues encountered during the shift and what mitigation actions were taken
- Review the shift actuals with respect to the short-term/daily plan to understand deviation (i.e., management by exception)
- Work with oncoming supervisors (SIC and shift) to determine what activities should be pushed to the next shift (support lineup creation)

Problem solving

- Participate in problem-solving activities (during the shift) to address recurring issues and support countermeasure determination and implementation

During the shift

- Work with the SIC coordinator to determine and/or confirm actions to be taken when tasks deviate from the schedule.

Planning

- During the shift, inspect future headings and other workplaces to identify work required (tools, equipment, and resources) to meet the schedule
- Add feedback data to short-term/daily task scheduler

Coaching

- Routinely engage with and coach operators (provide positive feedback). Engage in problem-solving activities within workplace to find short- and long-term solutions to issues.

C.1.3 SIC Supervisor/Operator

Pre-shift

- Support the shift supervisor in creating the crew lineup and use data from short-term and weekly schedules to create the shift schedule and monitor shift performance. Shift schedules include production, development, and maintenance activities.

Monitor shift performance

- Monitor and coordinate production activities with respect to the shift plan

- Using a predetermined logical format, determine when tasks are off schedule (management by exception), and assign countermeasures in collaboration with the shift supervisor

Data collection and problem solving

- Based on real-time and historical data, prepare end-of-shift reports and/or support the shift supervisor in their creation
- Prepare an action-card-type document with the level of detailed data to be used in future problem-solving activities.

End of shift

- Participate in a review with the shift supervisor and to share and understand issues encountered during the shift and what mitigation actions were taken
- Review the shift actuals with respect to the short-term/daily plan to understand deviation (i.e., management by exception)
- Working with incoming supervisors (SIC and shift), determine what activities should be pushed to next shift (support lineup creation)

C.1.4 Short-Term/Daily Task Scheduler

Weekly shift plan

- Using the short-term schedule and weekly plans from production and development and maintenance departments, coordinate work/tasks to develop an integrated shift plan with work broken down by shift

Problem solving

- Participate in problem-solving activities to address recurring issues and support countermeasure determination and implementation

Review weekly shift plan

- Lead review of the weekly plan and compliance to the overall short-term schedule
- Determine and lead longer term actions to address re-occurring problems in plan preparation and design

C.2 Example 2

The following example presents the roles and responsibilities of the control room supervisor, shift supervisors, operators, and superintendent of a mine. This facility is operating at least a foundational (level 2) SIC maturity and provides tablets to all employees to disseminate information, collect data, and monitor progress.

C.2.1 Control Room Supervisor

The control room supervisor is responsible for the overall management of information flow within the mine. This includes integrating and aligning shift schedules (production, maintenance, services), managing data flow within the operation, monitoring shift progress and performance, managing deviations, and facilitating information transfer between shifts. Table C1 describes the specific tasks that are the responsibility of the control room supervisor at this mine.

C.2.2 Shift Supervisor

The shift supervisor is responsible for resourcing shift activities based on short-term and weekly goals and performance during the previous shift(s). They monitor shift performance and work with the control room supervisor and other personnel to determine and implement mitigation measures. Table C2 describes the specific tasks that are the responsibility of the shift supervisor at this mine.

C.2.3 Operators

Operators are the individuals controlling the mine equipment and collecting real-time data. They report back to the shift supervisor and the control room. The operators working at this mine have a number of pre-shift and in-shift responsibilities. Table C3 describes the specific tasks that are the responsibility of operators at this mine.

C.2.4 Superintendent

The superintendent provides oversight for all operations and production activities in the mine. They oversee scheduling and monitor the control room performance. Table C4 describes the specific tasks that are the responsibility of superintendent at this mine.

Table C1. Control Room Supervisor Roles and Responsibilities in a Mine with Level 2 (Foundational) or Greater SIC Maturity

Schedule shift	– Add unscheduled production tasks to the integrated shift schedule – Add any service/maintenance not yet in the maintenance scheduling software to the production scheduling software manually input delays – Change resource assignment for production tasks affected by deviations – Identify resource conflicts that occur because of unscheduled production or maintenance tasks – Line up tasks for each shift schedule using the production scheduling software (to present to operators in pre-shift briefings, known as lineouts in North America) – Ensure that the shift and weekly production targets are aligned with the short-term production targets – Ensure all tasks are received on the employee tablets
Monitor shift performance	– Continually review task, machine, and workplace statuses throughout the shift – Report all issues with underground tablets and communications systems – Log IT service requests for any SIC systems issues. – Flag task deviations by observing progress in production scheduling and/or other software – Monitor priority and non-priority task duration to ensure targets can be met – Monitor status of scheduled tasks in the production scheduling and/or other software and respond to deviations – Manually update tasks where tablets are not operational using data entry capabilities – Identify possibilities to relieve congestion and bottlenecks – Identify opportunities to improve tonnage and work with supervisors to implement solutions
Manage deviations	– Prioritize tasks where there is a deviation from the plan using the defined priority procedure – Calculate production losses caused by task deviations – Capture breakdown, delay, and other deviation history using production scheduling software – Identify opportunities to change shift schedules and calculate impact on shift performance – Propose changes to the production, maintenance, and service shift schedule – Communicate the impact of deviations to the shift supervisor and discuss the possible changes to the integrated production schedule – Escalate events and deviation that cannot be resolved by the supervisors to the superintendent – Generate work order requests for all deviations that require non-urgent work
Prepare and hand over shift	– Summarize shift performance at the end of each shift – Review the end-of-shift reports to ensure data integrity – Update upcoming shift schedule using the end-of-shift status reports and the production scheduling software – Propose updated shift schedule and review it with the shift supervisor(s) – Identify possible change to the production, maintenance, and service shift tasks
Planning	– Advise technical services personnel of progress in the current weekly schedule – Assist technical services personnel to define the upcoming weekly schedule prior to uploading it to the shift management – Continually update planned targets (quantity and duration/deadline) based on active locations and provide feedback to technical services planners – Review uploaded weekly schedule in the production scheduling software to ensure it is aligned to production requirements

Table C2. Shift Supervisor Roles and Responsibilities in a Mine with Level 2 (Foundational) or Greater SIC Maturity

Schedule shift	– Review previous shift performance and weekly schedule progress to date – Review draft of upcoming shift schedule from the control room supervisor – Review possible changes to the shift schedule proposed by the control room supervisor – Review the updated shift schedule and task line up (lineout) to ensure adherence to weekly schedule – Assign equipment to all production tasks – Assign employees to all production tasks
Monitor shift performance	– Ensure all tasks are performed safely and according to company standards – Monitor priority and non-priority task durations using tablet and apps to ensure the shift targets can be met – Monitor status of scheduled tasks on tablet and apps – Monitor all deviations identified by the control room supervisor – Inspect all workplaces to ensure that the reported task performance is accurate – Identify opportunities to improve tonnage and work with the control room supervisor to implement solutions
Manage deviations	– Investigate the root cause of all task deviations – Investigate options to resolve production task deviation – Consult with maintenance/service shift supervisors to determine if required work is urgent or non-urgent – Advise control room supervisor on the best course of action to mitigate production task delays – Implement changes to the production schedule as requested by the control room supervisor – Define action plans to resolve production delays and deviations – Monitor task deviation action plan progress

Table C3. Operator Roles and Responsibilities in a Mine with Level 2 (Foundational) or Greater SIC Maturity

Pre-shift	– Ensure tablet and required apps are operating correctly – Ensure that the tasks received on the tablet are the same ones communicated during the pre-shift meeting (lineout) – Report any tablet issues to the control room supervisor during the pre-start machine check
In-shift	– Communicate all breakdowns and delays immediately as they occur (via tablet or radio) – Communicate symptoms of breakdowns and delays to the relevant shift supervisor – Report breakdowns and delays of event completion (tablet, radio, telephone or written log) – Update task progress for all tasks listed in the tracking app – Use the radio system to report task progress to the control room when tablets are not available or are offline – Notify control room supervisor and shift supervisor when a breakdown or delay is corrected – Respond to the supervisor action plans and report progress to the control room, supervisor, and other crew members as required

Table C4. Superintendent Roles and Responsibilities in a Mine with Level 2 (Foundational) or Greater SIC Maturity

Scheduling	– Ensure shift scheduling is completed prior to the shift pre-shift briefings (lineouts) – Ensure shift scheduling delivers the weekly forecast/schedule – Ensure that the weekly schedule delivers the monthly (short-term) forecast and that it is baselined/frozen, ideally 7+21 – Ensure all forecasts are available for inclusion in the weekly schedule – Ensure priorities are maintained
Monitoring	– Monitor the response time to task deviations – Monitor the number of unscheduled tasks created and take steps to minimize – Monitor the number of emergency tasks created and take steps to minimize – Monitor and measure compliance to weekly baseline schedule and take corrective actions as needed
Planning	– Review productivity rates on a regular basis and update planning variables as needed – Define priority and escalation procedures