MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 01:
Introduction

Lecture 01:
Introduction to automation

CONCEPTS COVERED

- Basic of automation
- Advantages of automation
- Disadvantages of automation
- Examples of automation
- Mining automation maturity model
- Types of automation
- Implementation approaches for automation
- Role of automation in mining Industry

Automation

- Automation involves employing logical programming commands and mechanized equipment.
- It aims to replace human decision-making and manual command-response activities
- It enhances productivity by optimizing processes.

Advantages of Automation

- Automate hard or monotonous tasks performed by human operators.
- Replace humans in dangerous environments with extreme temperatures, radiation, or toxicity.
- Simplify tasks beyond human capabilities, such as handling heavy loads or manipulating tiny objects.
- Increase production speed and reduce labor costs compared to manual operations.
- Implement automation for quality checks, reducing the production of out-of-tolerance parts and ensuring consistency.

Disadvantage of Automation

- Not all tasks can be automated due to current technological limitations.
- Tasks like product assembly with inconsistent component sizes or those requiring manual dexterity are challenging to automate.
- Automation is cost-effective for tasks that are repeatable, consistent, and high in volume.
- Some tasks may be more expensive to automate than to perform manually.
- A skilled maintenance department is crucial for servicing and maintaining automation systems.
- Neglecting maintenance can lead to lost production and the production of defective parts.

Examples of Automation

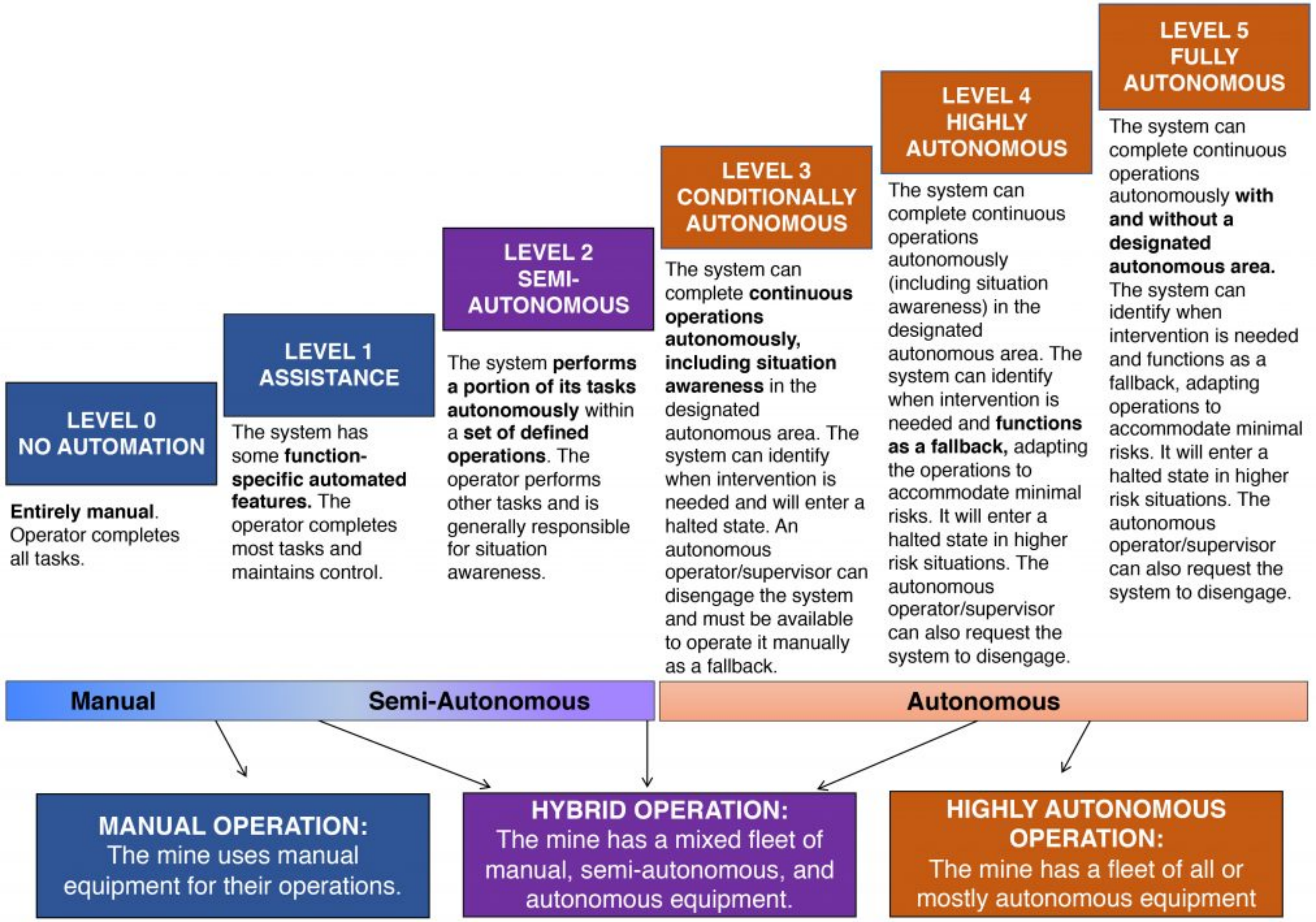
Industry
Drilling Systems
Haulage Systems
Automated Excavators and Loaders
Dust Suppression Systems

Drilling Systems

Haulage Systems

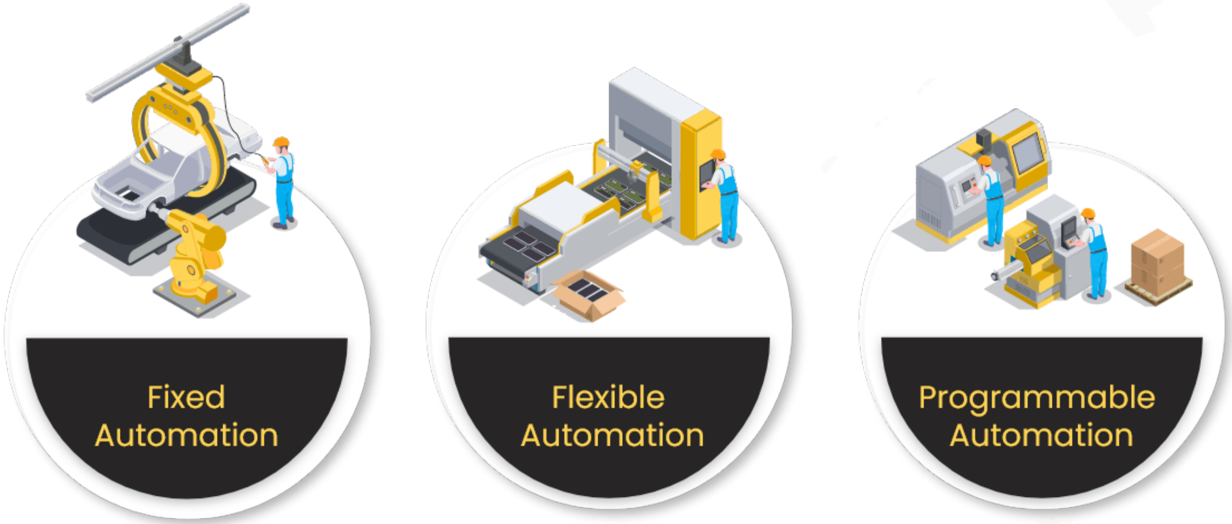
Dust Suppression Systems

Mining Automation Maturity Model



Types of Automation

Automation
- Fixed automation
- Programmable automation
- Flexible automation



Question 1

01. What is the primary objective of automation in mining, considering its aim to replace human decision-making and manual command-response activities?

Answer :

The primary objective of automation in mining is to improve efficiency by replacing human decision-making and manual command-response activities with automated systems. This shift aims to reduce errors, enhance safety, and increase overall operational effectiveness.

Fixed automation

Fixed automation refers to the use of special purpose equipment to automate a fixed sequence of processing or assembly operations. It is typically associated with high production rates and it is relatively difficult to accommodate changes in the product design. This is also called hard automation.

Fixed automation - Conveyor belt system

Fixed automation

Advantages

- Maximum efficiency.
- Low unit cost.
- Automated material handling—fast and efficient movement of parts.
- Very little waste in production.

Disadvantages

- Large initial investment.
- Inflexible in accommodating product variety.

Fixed automation

Example: Conveyor Belt System

- **Conveyor belt systems are utilized for fixed automation in mining.**
- **These networks facilitate the transportation of minerals from mining locations to processing areas.**
- **With predefined operations and a fixed path configured.**
- **Extreme efficacy with repetitious duties, such as transporting bulk materials.**
- **Reduces deviations from predefined paths.**
- **Improves overall mining material transport efficiency.**

Programmable automation

- Programmable automation involves equipment designed to adapt to specific product changes.
- Processing or assembly operations can be altered by modifying the control program.
- Well-suited for "batch production," typically manufacturing products in medium lot sizes at regular intervals.

Advantages

- Flexibility to deal with variations and changes in product.
- Low unit cost for large batches.

Disadvantages

- New product requires long set up time.
- High unit cost relative to fixed automation.

Programmable automation

Example: Drilling Machines with Programmable Controls

Programmable automation in mining can be exemplified by drilling machines equipped with programmable controls. These machines can be programmed to perform specific drilling patterns and adjust parameters such as depth and angle. This flexibility allows miners to adapt the equipment to different geological conditions and ore bodies.

Flexible automation (Soft automation)

In flexible automation, the equipment is designed to manufacture a variety of products or parts, and very little time is spent on changing from one product to another. Thus, a flexible manufacturing system can be used to manufacture various combinations of products according to any specified schedule. With a flexible automation system, it is possible to quickly incorporate changes in the product or to quickly introduce a new product line.

Advantages

- Flexibility to deal with product design variations.
- Customized products.

Disadvantages

- Large initial investment.
- High unit cost relative to fixed or programmable automation.

Flexible automation (Soft automation)

An example of Flexible automation in mining is autonomous haul trucks.

- **Operate without direct human intervention.**
- **Adapt to changing conditions in the mining environment.**
- **Navigate dynamic terrains, and avoid obstacles.**
- **Optimize routes using real-time data.**
- **Improves efficiency and safety in mining operations**

FrontRunner

Question 2

02. In the context of automation, what does "logical programming commands" refer to?

a. Human decision-making processes

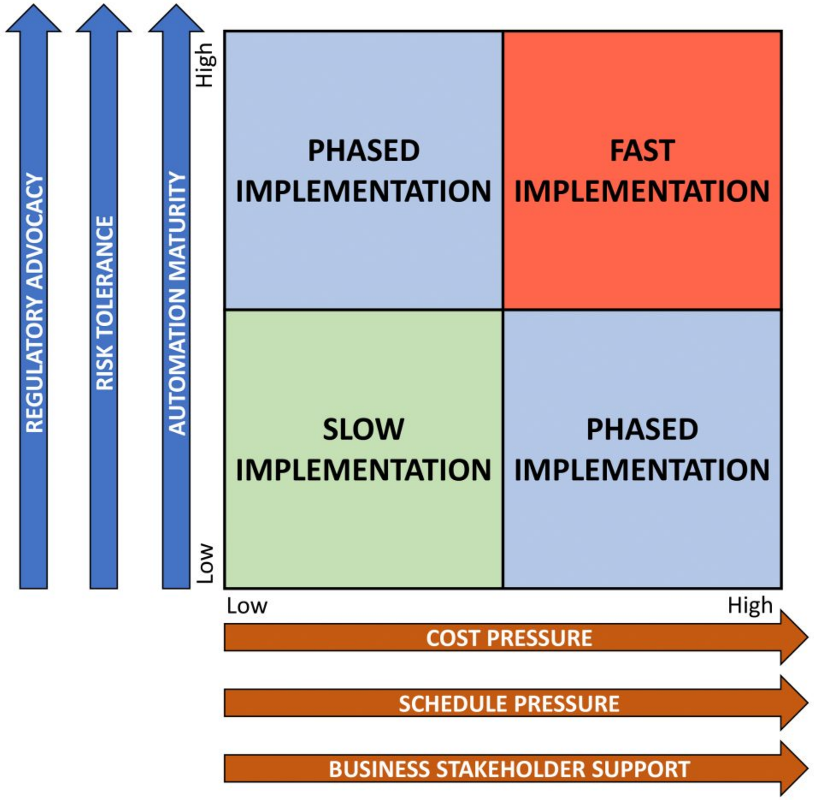
b. Mechanized equipment optimization

c. Manual command-response activities

d. Programmed instructions for automated systems

Answer d. Programmed instructions for automated systems

Implementation Approaches for Automation



Slow implementation strategy

- Lower risk associated with the approach.
- Higher cost involved.
- Implementation extended over a long time period.
- Multiple checkpoints included (e.g., concept, trials, multiple releases).
- Allows incorporation of research and development efforts by the mine.

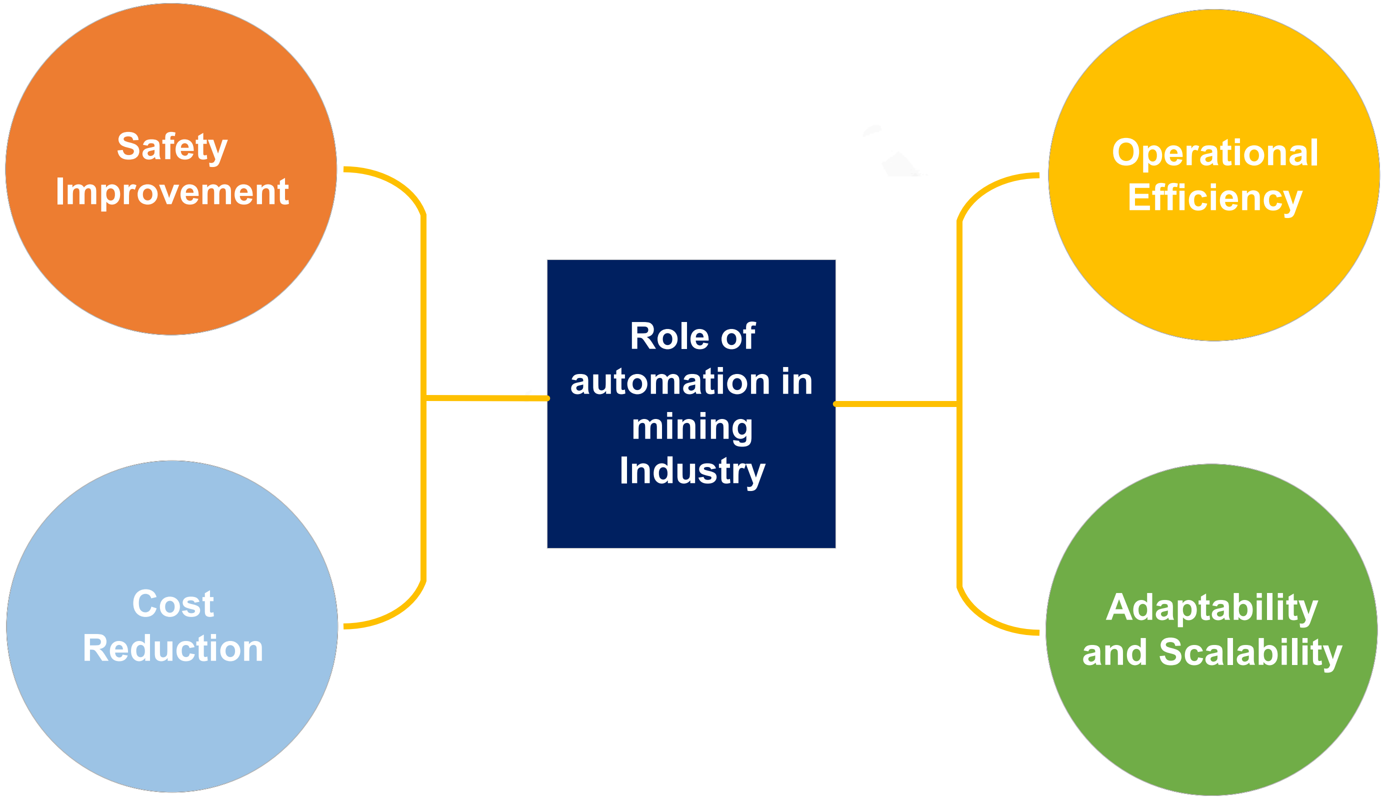
Phased implementation strategy

- Medium risk associated with the approach
- Medium cost involved
- Implementation completed in paced stages
- Two or three checkpoints included
- Involves a mix of mature and agile solutions

Fast implementation strategy

- Higher risk associated with the approach
- Lower cost involved
- New system completely replaces the old one
- Involves implementing mature commercial solutions

Role of Automation in Mining Industry



REFERENCES

- Gupta, A., Arora, S., Westcott, J. R. (2016). Industrial Automation and Robotics: An Introduction. Germany: Mercury Learning and Information.
- Lamb, F. (2013). Industrial Automation: Hands On. United States: McGraw Hill LLC.
- Yaghini, A., Hall, R., & Apel, D. (2022). Autonomous and Operator-Assisted Electric Rope Shovel Performance Study. Mining, 2(4), 699-711. https://doi.org/10.3390/mining2040038
- https://www.mining-technology.com/sponsored/mining-conveyor-belt/
- https://www.e-mj.com/features/condition-monitoring-of-critical-mining-conveyors/
- https://www.epiroc.com/en-za/newsroom/2023/the-autonomous-smartroc-d65mk2-outperforms-manually-operated-drill-rigs

REFERENCES

- https://www.smsequipment.com/en-ca/advanced-technologies/smart-mining/autonomous-haulage-systems/
- https://datenwissen.com/blog/ai-in-manufacturing-automation/
- https://www.applanix.com/news/blog-gnss-for-autonomous-haulage-systems-ahs-in-deep-open-pit-mines/
- https://www.maddisonwatertech.co.uk/services/dust-suppression-systems/
- https://polymathian.com/news-media/blogs/making-the-most-of-autonomous-mining-system/

CONCLUSION

- Comprehensive overview of automation, covering basics, advantages, and disadvantages.
- Real-world examples illustrating practical applications in the mining industry.
- Emphasis on setting specific aims for different automation levels and their implementation.
- Exploration of various types of automation, highlighting the versatility and adaptability of automated systems.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Module 01:
Introduction

Lecture 01:
Principle of automation and strategies

CONCEPTS COVERED

- Principle of automation
- Different strategies for automation
- Automation migration strategy
- Engineering design management framework

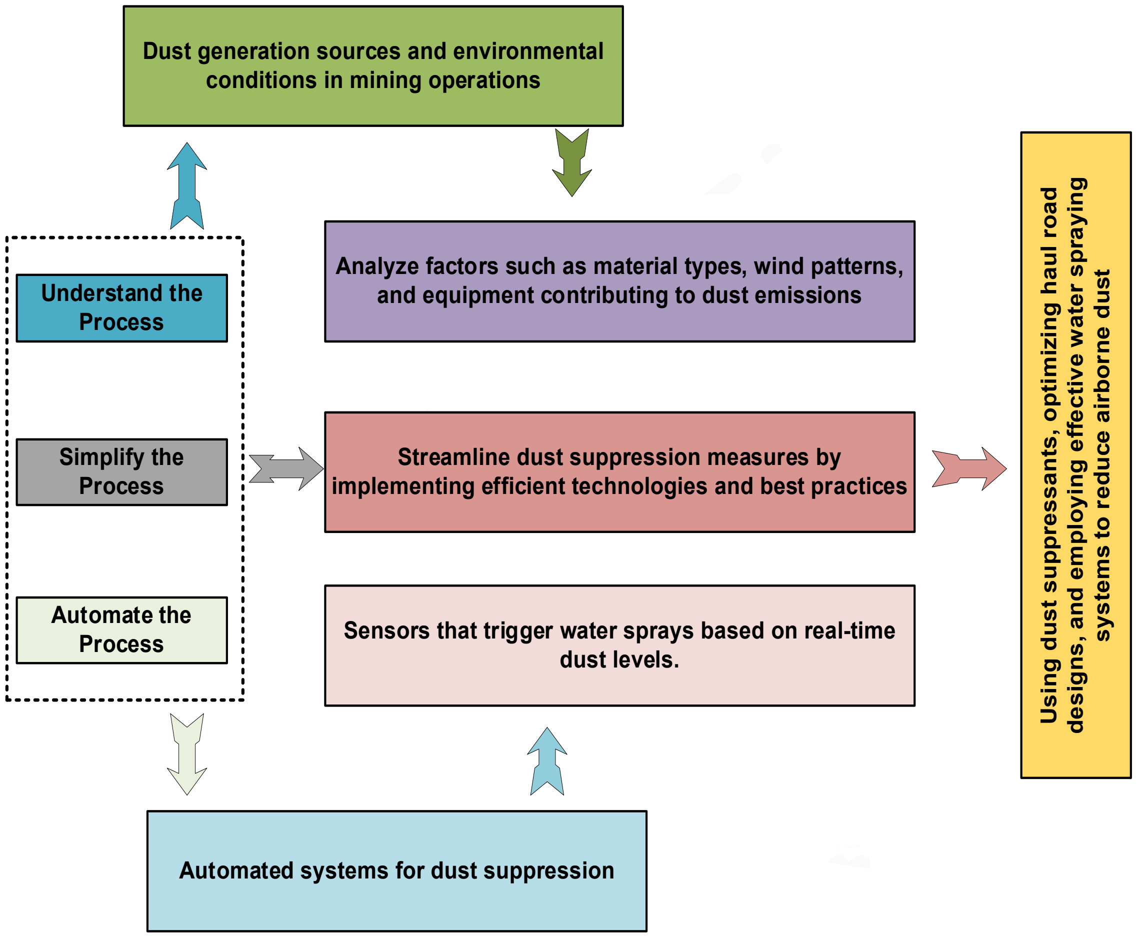
Principles of Automation

The USA Principle is a common approach to automation projects

USA stands for:

- **Understand the existing process**
- **Simplify the process**
- **Automate the process**

Optimizing Dust Suppression in Mining



Strategies for Automation

Specialization of operations.

Simultaneous operations.

Combined operations.

Integration of operations.

Increased flexibility.

Improved material handling and storage.

On-line inspection.

Plant operations control.

Computer Integrated Manufacturing.

Process control and optimization.

Specialization of operations

The first strategy involves the use of special purpose equipment designed to perform one operation with the greatest possible efficiency . This is analogous to the specialization of labor, which is employed to improve labor productivity.

Example - Automated Water Sprinkler Systems

Specialized automated systems control the release of water in response to environmental conditions, effectively mitigating airborne dust and improving overall air quality in the mining area.

Automated Water Sprinkler Systems

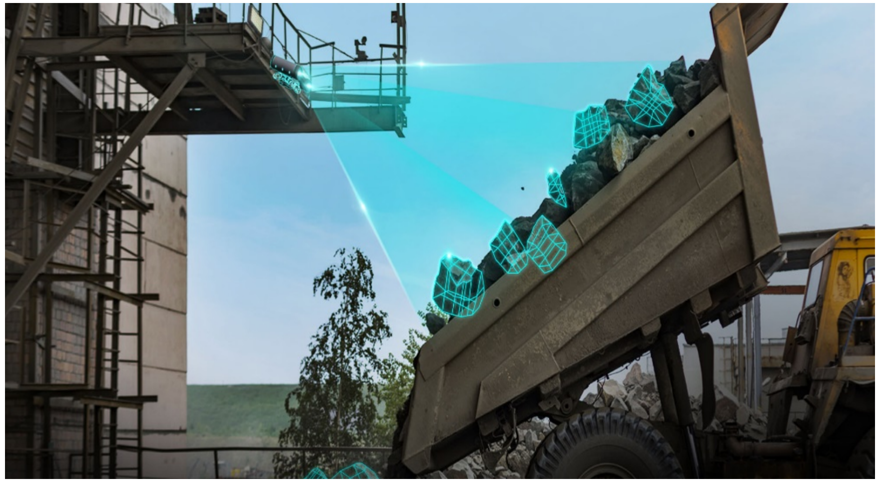
Simultaneous operations

- Extending the combined operations strategy involves simultaneously executing the combined operations at one workstation.
- The result is a reduction in total processing time, enhancing efficiency in the manufacturing process.

Example – Fragmentation analysis

- **BlastIQ FRAGTrack: Fragmentation Control solution**
- **Purpose: Capture and reporting of fragmentation data in mining operations**
- **Goal: Improve overall outcomes of fragmentation processes**
- **Mechanism: Utilizes automated triggering for capturing high-quality images**
- **Application: Conveyor belt and dig face of a muck pile**

Simultaneous operations



Combined operations

- Production is a series of operations with complex parts often requiring numerous processing steps.
- Combined operations strategy aims to minimize distinct machines or workstations, consolidating operations at a single machine.
- Performing multiple operations at one machine reduces the need for separate machines, saving setup time.
- This strategy results in reduced material handling effort, non-operation time, waiting time, and overall manufacturing lead time.

Combined operations

Example: Real-time ore sorting

Operating mines - Saloro’s tungsten mine in Barruecopardo, Spain.

TOMRA's XRT technology can identify and differentiate between valuable minerals and waste rock based on their atomic density. This allows for real-time sorting on conveyor belts, maximizing the recovery of valuable minerals like copper, gold, and tungsten while minimizing waste.

Integration of operations

- The strategy entails connecting multiple workstations into a unified mechanism.
- Automated work handling devices facilitate part transfer between stations, minimizing the need for separate work centers.
- Multiple workstations enable simultaneous processing of several parts, leading to an enhanced overall system output.

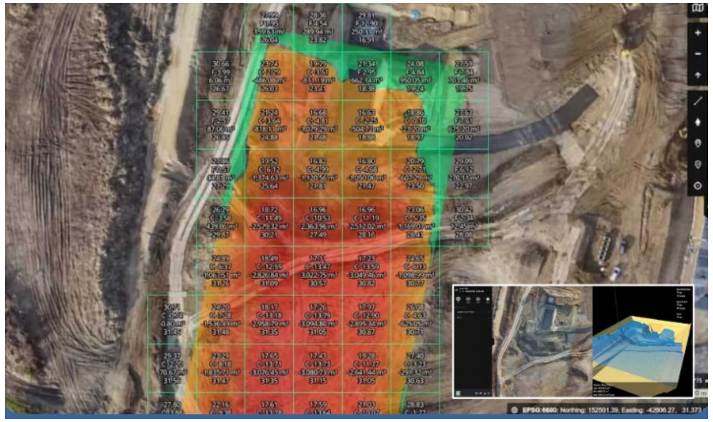
Automated systems like conveyor belts streamline mineral transfer between processing stations in mining, reducing work centers. This enables simultaneous processing of various ores, enhancing overall mining efficiency and output.

Increased Flexibility

This strategy optimizes equipment use in job shops and medium-volume scenarios by employing flexible automation. The goal is to minimize setup and programming time for production machines, resulting in reduced manufacturing lead times and less work-in-process.

Example- Drone-powered Surveying and Inspection in Mining **Company- Terra drone**

Real-time data: Instead of waiting for manual surveys, engineers have instant insights, enabling immediate action on safety hazards, equipment issues, and production bottlenecks.



Improved Material Handling and Storage

A great opportunity for reducing non-productive time exists in the use of automated material handling and storage systems. Typical benefits include reduced work-in-process, shorter manufacturing lead times, and lower labor costs.

Examples - Automated Haulage Systems (AHS)

Mining company using AHS - Rio Tinto

Driverless trucks: These trucks use GPS and LiDAR technology to navigate mine haul roads autonomously, eliminating the need for human drivers and reducing the risk of accidents.

Benefits

- **Reduced accident risk**
- **Eliminates human drivers**
- **Increased efficiency**
- **Improved safety for other workers**

Question 1

01. How does the utilization of specialized equipment in mining operations enhance overall efficiency and productivity?

Answer

The utilization of specialized equipment in mining operations enhances efficiency and productivity by tailoring machinery to specific tasks. This targeted approach minimizes downtime, optimizes resource use, and streamlines processes, ultimately contributing to overall operational effectiveness

Question 2

02. In what way does linking workstations align with technological advancements in mining?

A. By resisting innovation

B. By discouraging automation

C. By leveraging automation and smart technologies

D. By promoting manual intervention

Answer C. By leveraging automation and smart technologies

On-line Inspection

Traditional quality inspection occurs after completing the process, resulting in the production of any poor-quality items before detection. Integrating inspection into the manufacturing process allows real-time corrections, minimizing scrap and improving the product's overall quality as per designer specifications.

Plant operations Control

- Controls individual manufacturing processes
- Focuses on plant-level control for more efficient coordination of aggregate operations
- Implementation involves extensive computer networking within the factory

Computer-Integrated Manufacturing (CIM)

- Involves extensive use of computer systems, databases, and networks
- Integration spans across the entire enterprise
- Aims to unify factory operations and business functions

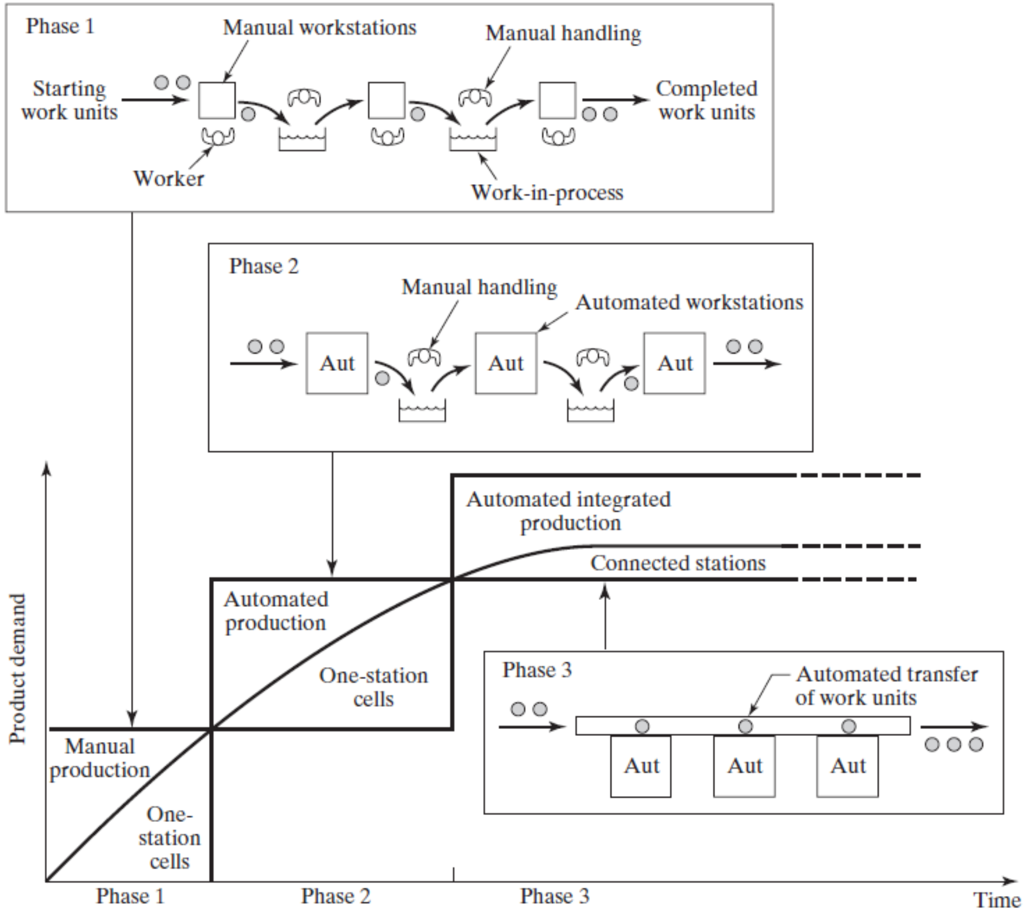
Process Control and optimization.

This includes a wide range of control schemes intended to operate the individual processes and associated equipment more efficiently. By this strategy, the individual process times can be reduced and product quality can be improved.

Example - bucket wheel excavator

Advanced control systems in bucket wheel excavators optimize digging in real-time, reducing cycle times, improving material extraction efficiency, and ensuring equipment longevity. Integrated safety features enhance overall operational safety.

A Typical Automation Migration Strategy.



Phase 1: manual production with single independent workstations.

Phase 2: automated production stations with manual handling between stations.

Phase 3: automated integrated production with automated handling between stations.

Question 3

03. What does the term "integrated production" imply in the context of Phase 3 of the automation migration strategy?

A. Independent workstations

B. Automated handling between stations

C. Fully manual production

D. No interaction between workstations

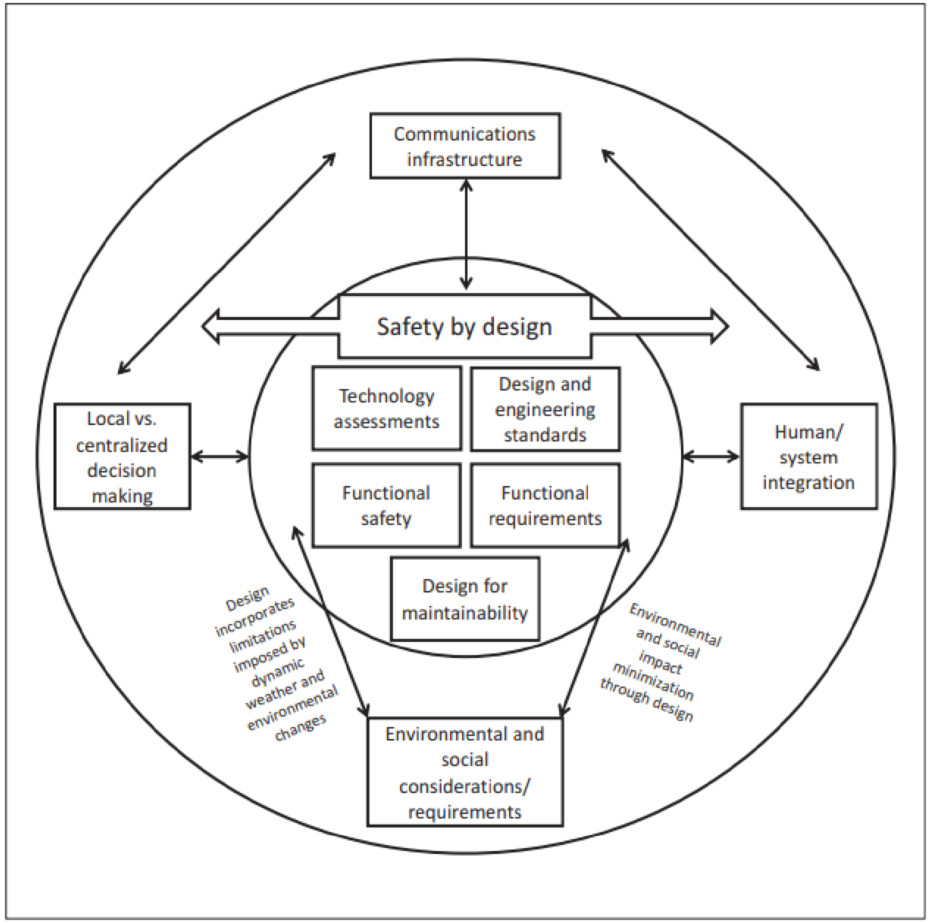
Answer B. Automated handling between stations

Engineering Design Management Framework

A strong design management framework improves OEE (Overall Equipment Effectiveness) and enables safe and predictable production results by

- Reducing safety risks and resulting delays
  - Embedding safety controls fail to a safe level of operations
- Maximizing asset availability
  - Minimizing breakdowns and failures
  - Allowing maintenance activities to be conducted within the planned hours
- Ensuring equipment utilization conforms to the plan
  - Minimizing production delays
  - Ensuring the mining equipment performs and delivers to production targets

Engineering Design Management Framework for Implementing Autonomous Systems



Design Management Plan

A design management plan must be developed and agreed upon by all stakeholders upfront (including the autonomous system supplier) and should include:

- Acceptance and performance criteria
- Agreement on how the design will be verified and approved (i.e., verification approach, quality management plans)
- Risk assessment approaches.
- A document deliverables list with both internal and external stakeholders.

Configuration Management

A comprehensive configuration management system must be employed for changes that are introduced through implementing autonomous systems, including:

- **Operational and maintenance practices**
- **Design specifications**
- **System changes (e.g., software updates, upgrades, parameters) that affect mine design**
- **Data collection and integration**
- **End of life/obsolescence considerations for long-term installations**
- **Risk transformation**

REFERENCES

- Gupta, A., Arora, S., Westcott, J. R. (2016). Industrial Automation and Robotics: An Introduction. Germany: Mercury Learning and Information.
- Lamb, F. (2013). Industrial Automation: Hands On. United States: McGraw Hill LLC.
- https://www.brainkart.com/article/Automation-Principles-and-Strategies_6375/
- https://www.miningmagazine.com/transport/news/1262635/lace-%E2%80%99-conveyor-belt-commissioned
- https://www.equipmentworld.com/construction-equipment/video/14953372/meet-the-31-million-pound-bucket-wheel-excavator-the-largest-land-vehicle-ever-built
- https://www.orica.com/Products---Services/Mining-Services/BlastIQ/Solutions/fragmentation-control

REFERENCES

- https://www.orica.com/news-media/2022/orica-expands-its-fragmentation-monitoring-solution-with-fragtrack-crusher
- https://www.tomra.com/en/mining/media-center/news/2023/tomra-mining-xrt-technology-delivers-significant-grade-improvement-at-saloros-tungsten-mine
- https://terra-drone.net/global/solution/survey/
- https://polymathian.com/news-media/blogs/making-the-most-of-autonomous-mining-system/
- https://gmggroup.org/wp-content/uploads/2019/06/20181008_Implementation_of_Autonomous_Systems-GMG-AM-v01-r01.pdf

CONCLUSION

- Overview of fundamental principles of automation in the context of the mining industry.
- Exploration of various strategies employed in automating mining operations. Real-world examples illustrating successful implementations of automation in mining, showcasing increased accuracy and reduced human risk.
- Different phases involved in transitioning to automated mining processes
- Identification and discussion of challenges that may arise during the implementation of automation in mining.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Module 01:
Introduction

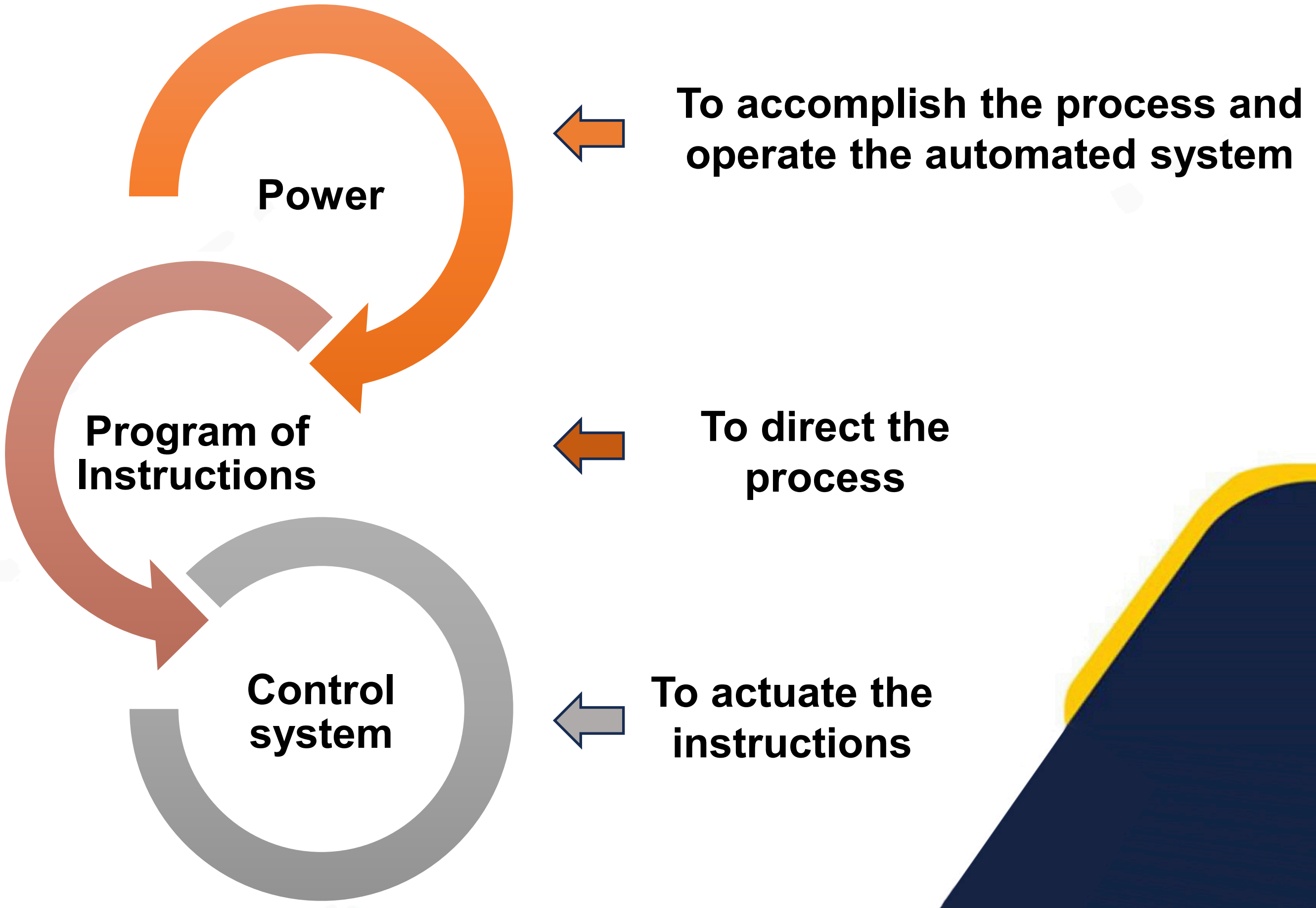
Lecture 02:
Elements of automated system

CONCEPTS COVERED

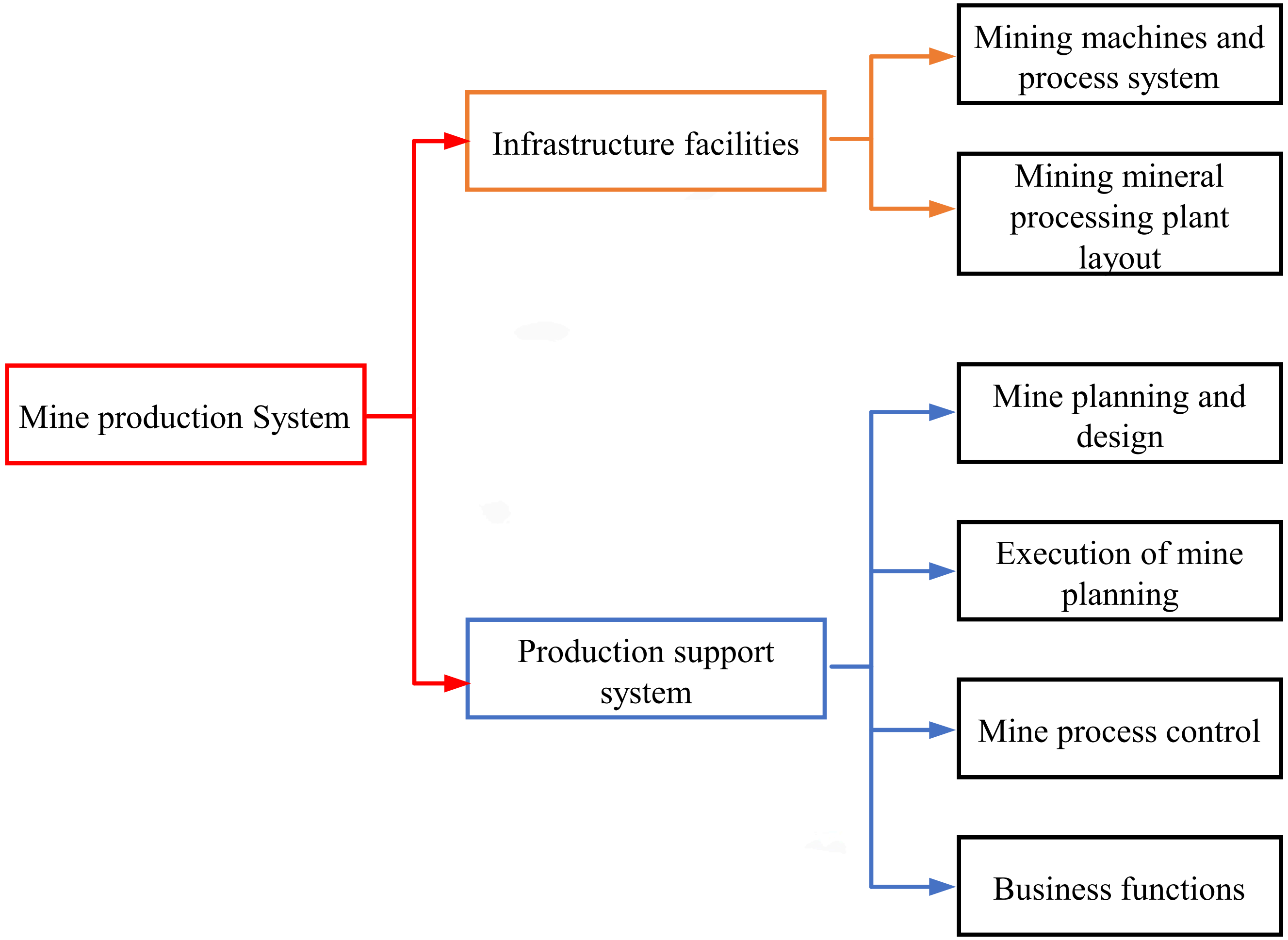
- Basics of automated system
- Mine production system
- Sequence of information-processing activities
- Opportunities for automation and computerization

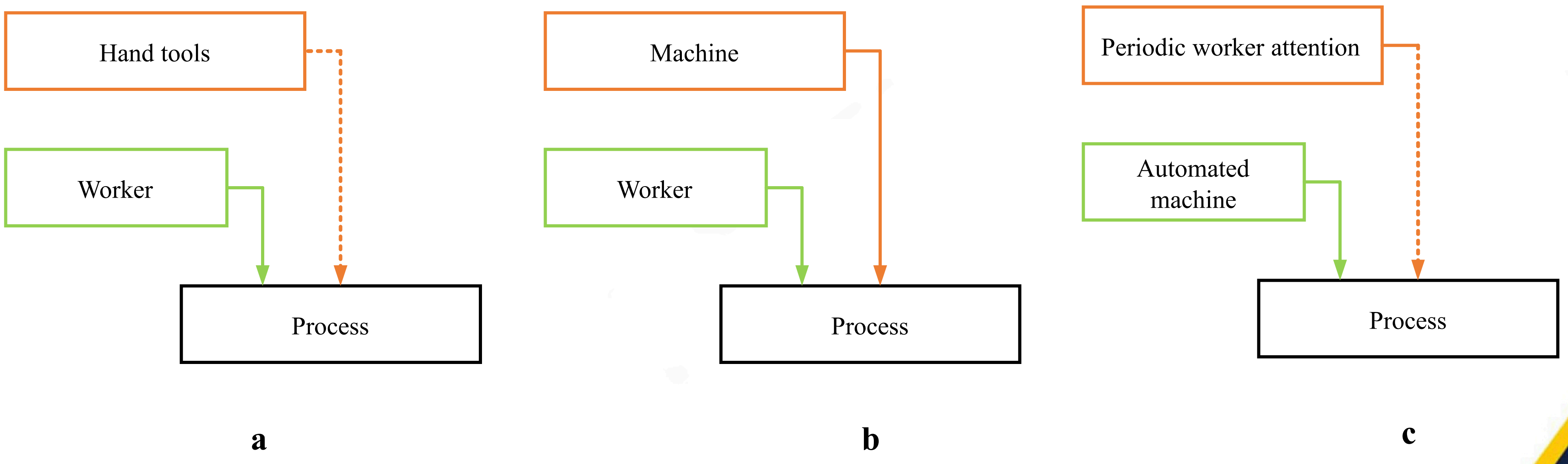
Elements of Automated Systems

- Power
- Program of Instructions
- Control system

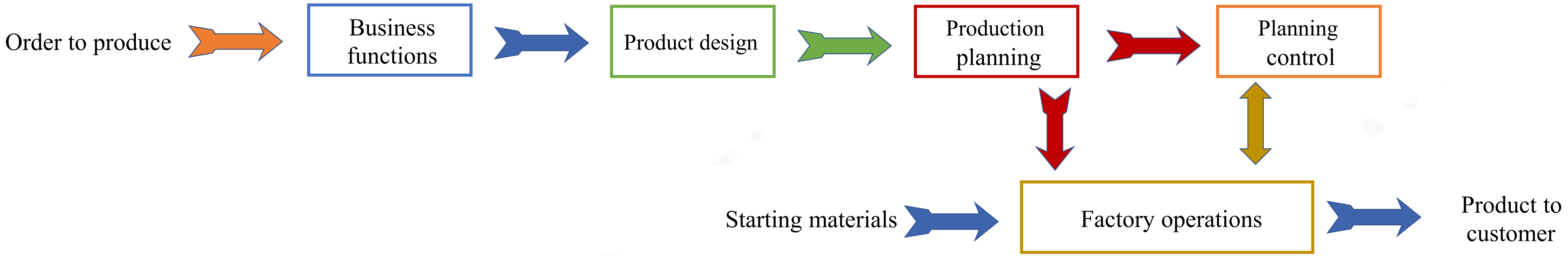


The mine production system consists of infrastructure facilities and production support systems

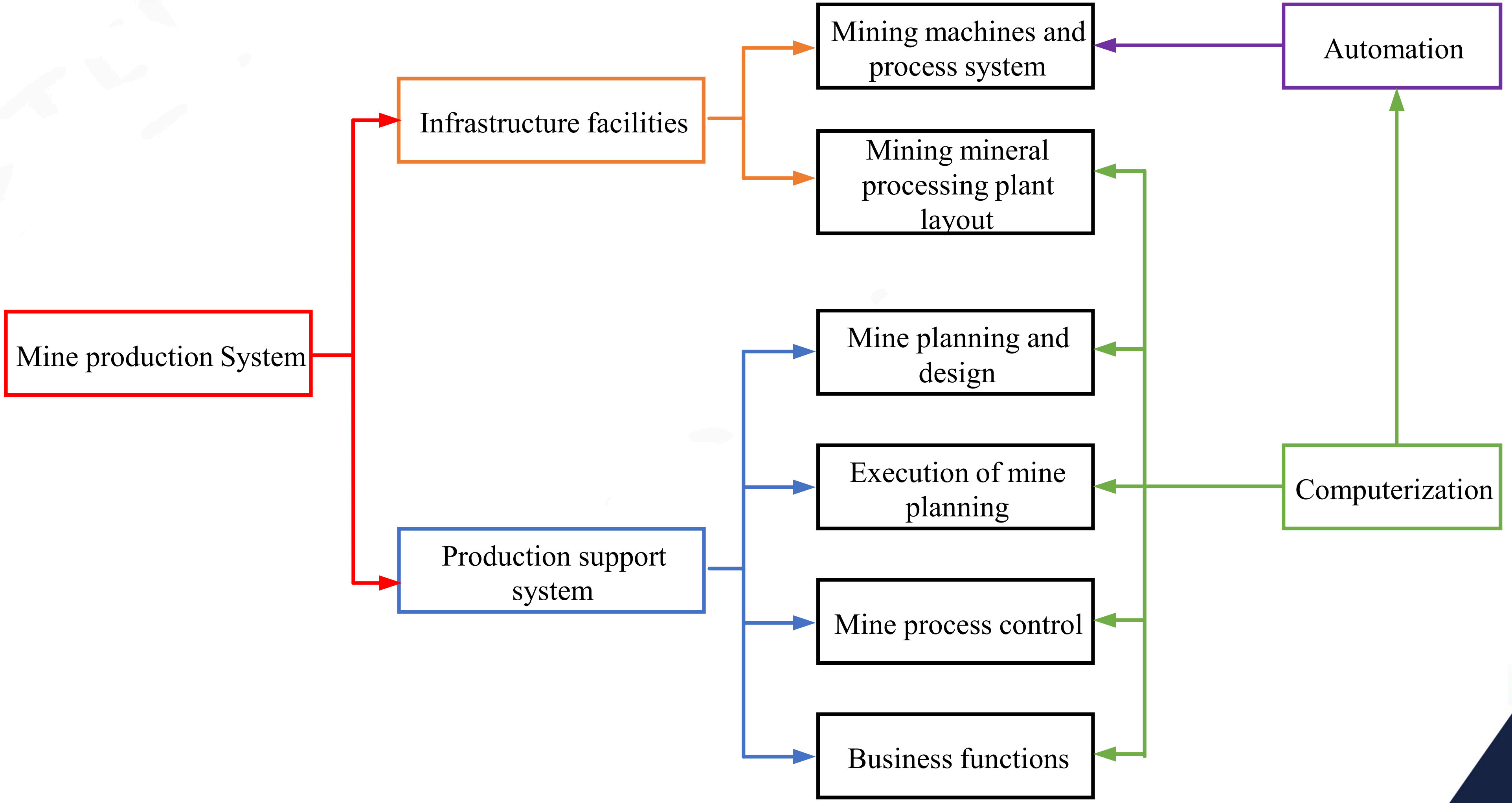




Three categories of production systems: (a) manual work system, (b) worker-machine system, and (c) fully automated system.

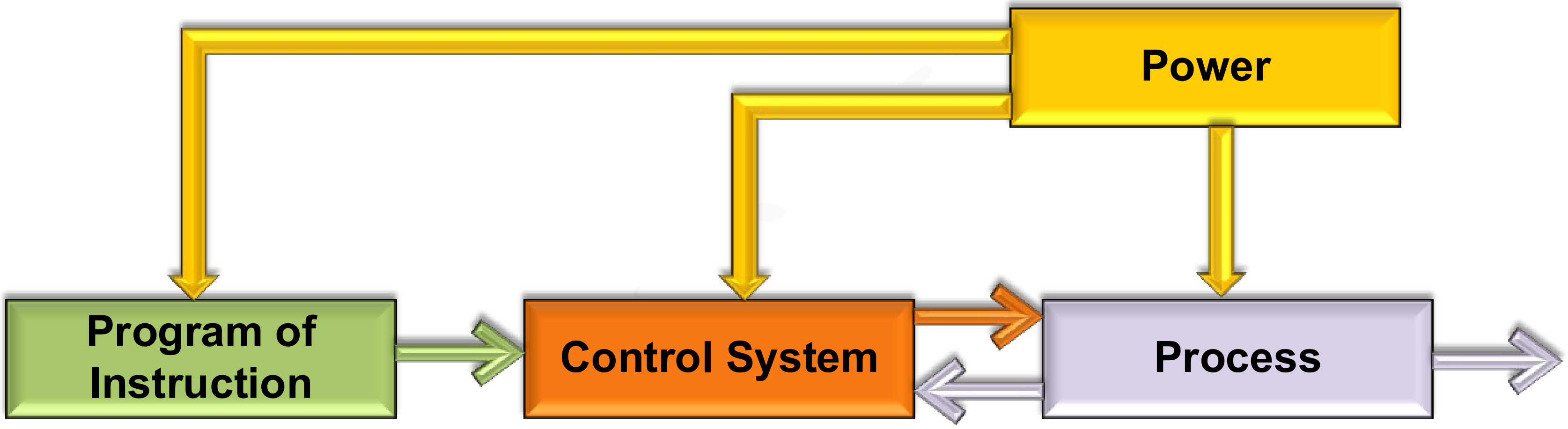


Sequence of information-processing activities in a typical manufacturing firm.



Opportunities for automation and computerization in a production system.

Elements of Automated Systems



Power to Accomplish the Automated Process

- Affordable electrical power is vital for industry.
- Electrical power easily transforms into various energy forms: mechanical, thermal, light, acoustic, hydraulic, and pneumatic.
- Low-level electrical power performs functions like signal transmission, information processing, and data storage and communication.
- Stored in batteries, electrical energy suits remote locations.

Power to Accomplish the Automated Process

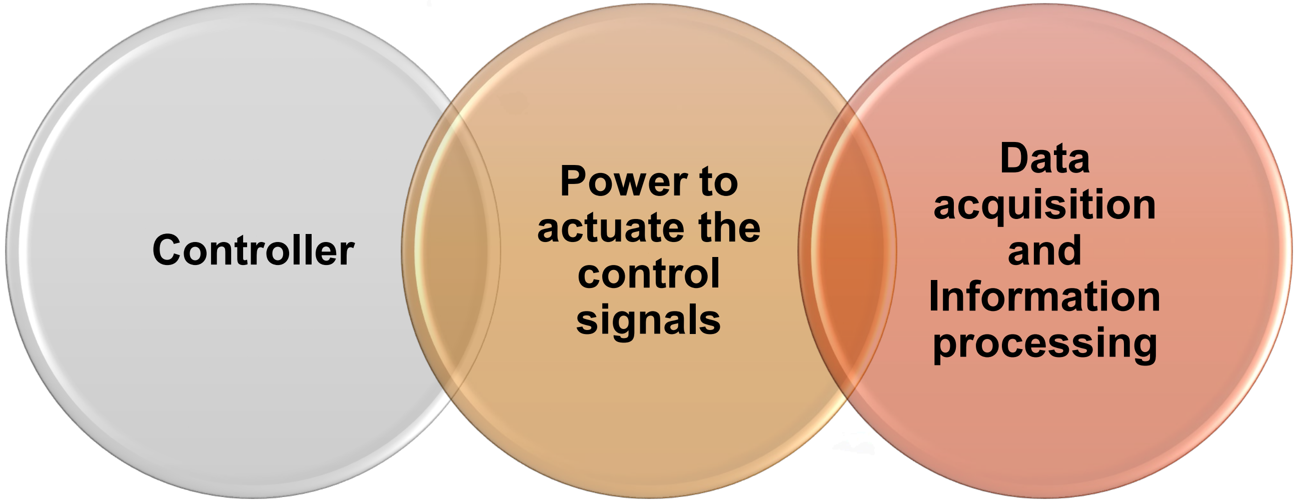
- Alternative power sources: fossil fuels, solar energy, water, and wind.
- Rare exclusive use in automated systems.
- Often used to drive the process, while electrical power controls automation.
- Example: Furnace heated by fossil fuels, but temperature and time cycle control is electrical.
- Some cases involve converting alternative source energy to electric power for both process and automation.

Power to Accomplish the Automated Process

Power for the Process

- "Process" in production covers the entire manufacturing operation on a specific work unit.
- It serves as the driving force propelling each stage of the manufacturing operation.

Power for the automation



Controller unit

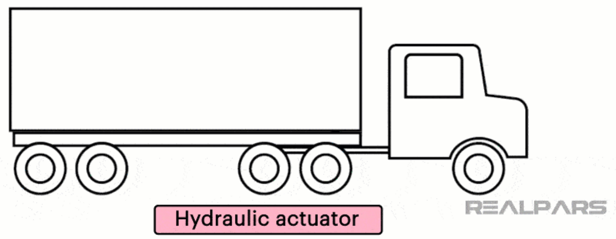
- Modern industrial controllers operate on digital computer technology.
- The essential functions of these controllers rely on a consistent supply of electrical power.
- This power is crucial for tasks such as reading program instructions, performing complex control calculations, and executing commands to actuating devices.
- The role of industrial controllers extends to automation, contributing to increased efficiency, accuracy, and overall system reliability.

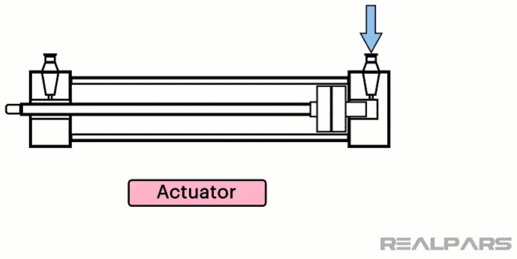
Data acquisition and information processing

- In most control systems, data must be collected from the process and used as input to the control algorithms.
- Additionally, process requirements may include keeping records of process performance or product quality.
- The functions of data acquisition and record-keeping in control systems require power, albeit in modest amounts.

Power to actuate the control signals

- The commands sent by the controller unit are carried out by means of electromechanical devices, such as switches and motors, called actuators.
- The commands are generally transmitted by means of low-voltage control signals.
- To accomplish the commands, the actuators require more power, and so the control signals must be amplified to provide the proper power level for the actuating device.





Program of Instruction

- Automated processes are guided by a program of instructions.
- Manufacturing operations, regardless of production scale, involve unique processing steps for each part or product style.
- Every part or product style undergoes one or more specific processing steps during the operation.
- These processing steps are carried out within a defined work cycle.
- The details of the work cycle, including specific processing steps, are outlined in a work cycle program, also referred to as part programs.

Question 1

- In an automated system, the program of instructions is responsible for

  A) Providing energy to operate the system

  B) Directing the process and tasks

  C) Monitoring system status

  D) Regulating feedback loops

  Answer: B) Directing the process and tasks

Question 2

Which element ensures the capability to accomplish the process and operate the automated system?

A) Control system

B) Program of instructions

C) Power

D) Feedback loop

Answer: C) Power

Questions 3

- **Explain the importance of seamless integration between the power, program of instructions, and control system for the overall reliability of an automated system.**

Answer:

Seamless integration ensures synchronized operation, preventing disruptions. For instance, a well-integrated control system can dynamically adjust power usage based on the program's demands, optimizing performance.

Work Cycle Programs

- In the simplest automated processes, the work cycle consists of essentially one step which is to maintain a single process parameter at a defined level.
- In complicated systems, the process comprises a work cycle with multiple steps that repeat consistently from one cycle to the next. This category predominantly includes discrete part manufacturing operations. A simplified sequence of steps typically involves:

  (1) loading the part into the production machine,

  (2) executing the process, and

  (3) unloading the part.

REFERENCES

- Gupta, A., Arora, S., Westcott, J. R. (2016). Industrial Automation and Robotics: An Introduction. Germany: Mercury Learning and Information.
- Lamb, F. (2013). Industrial Automation: Hands On. United States: McGraw Hill LLC.
- Groover, M. P. (2008). Automation, Production Systems, and Computer-integrated Manufacturing. India: Prentice Hall.
- https://www.realpars.com/blog/actuator-applications

CONCLUSION

- This lecture covered the fundamental aspects of automated systems, exploring their principles and constituent elements.
- Implementation of automated systems in the mining industry involves the integration of infrastructure facilities and production support systems.
- Different Categories of manufacturing systems.
- The lecture further explored the vast opportunities for automation and computerization across industries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Module 01:
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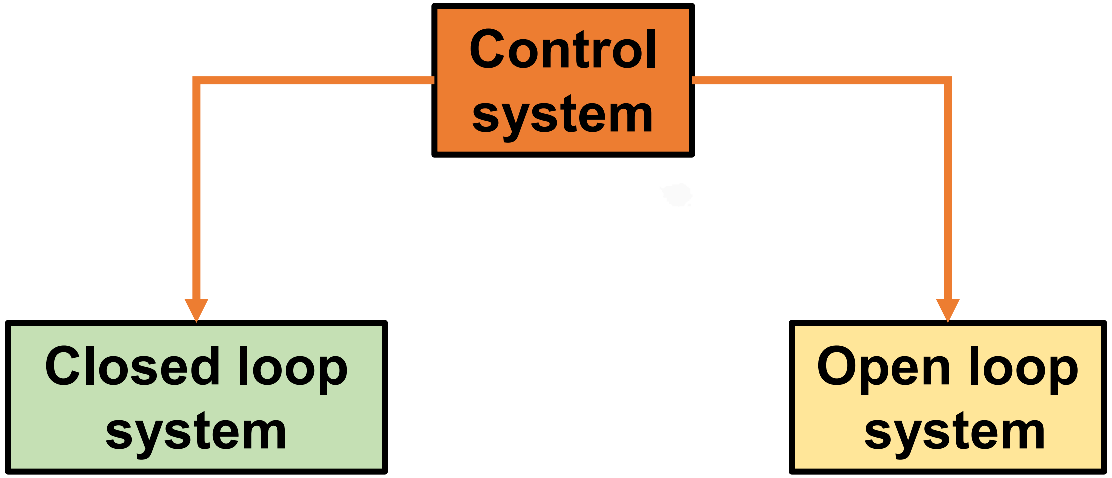
Elements of automated system

CONCEPTS COVERED

- Control system
- Open loop control system
- Closed loop control system
- Positive Impact of Automation
- Operational readiness and deployment for automation system

Control system

The control element of the automated system executes the program of instructions. The control system causes the process to accomplish its defined function.



Closed loop control system

A closed loop control system also known as a feedback control system, is one in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output into agreement with the input.

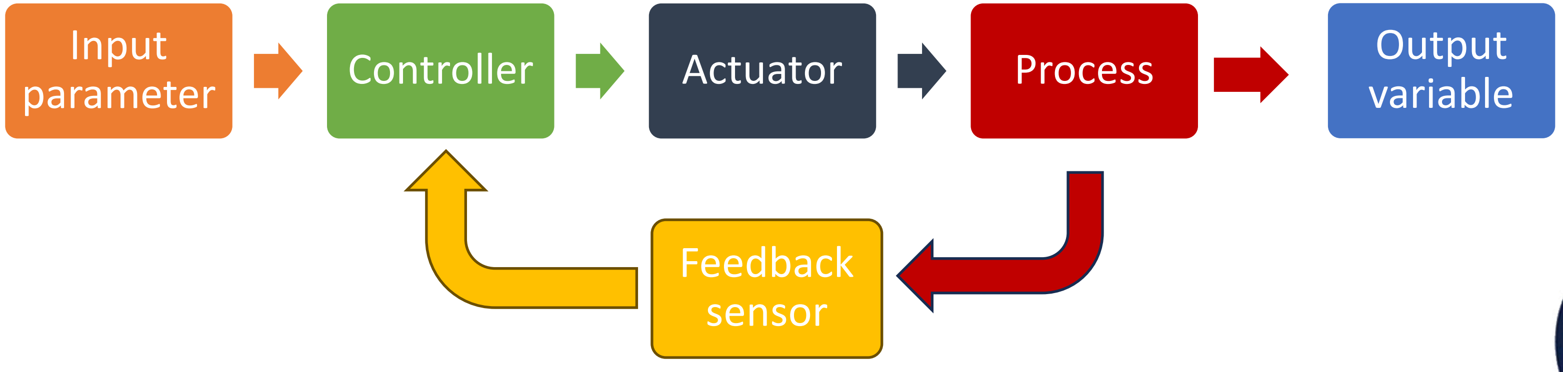
Closed loop control system consists of six basic elements:

Input parameter

- The input parameter, often referred to as the set point, represents the desired value of the output.

Process

- The process is the operation or function being controlled. In particular, it is the output variable that is being controlled in the loop.



Output variable

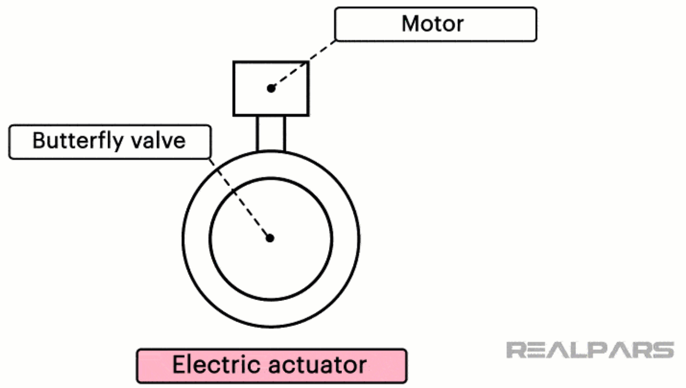
- The output variable is some process variable, perhaps a critical performance measure in the process, such as temperature or force or flow rate.
- A sensor is used to measure the output variable and close the loop between input and output, Sensors perform the feedback function in a closed loop control system

Controller

- The controller compares the output with the input and makes the required adjustment in the process to reduce the difference between them.

Actuators

- The adjustment is accomplished using one or more actuators, which are the hardware devices that physically carry out the control actions, such as an electric motor or a flow valve.
- Most industrial processes require multiple loops, one for each process variable that must be controlled.



Open loop control system

- In contrast to the closed loop control system, an open loop control system operates without the feedback loop.
- In this case, the controls operate without measuring the output variable. so no comparison is made between the actual value of the output and the desired input parameter. The controller relies on an accurate model of the effect of its actuator on the process variable.

- With an open loop system, there is always the risk that the actuator will not have the intended effect on the process, and that is the disadvantage of an open loop system. Its advantage is that it is generally simpler and less expensive than a closed loop system.

Open loop systems are usually appropriate when the following conditions apply:

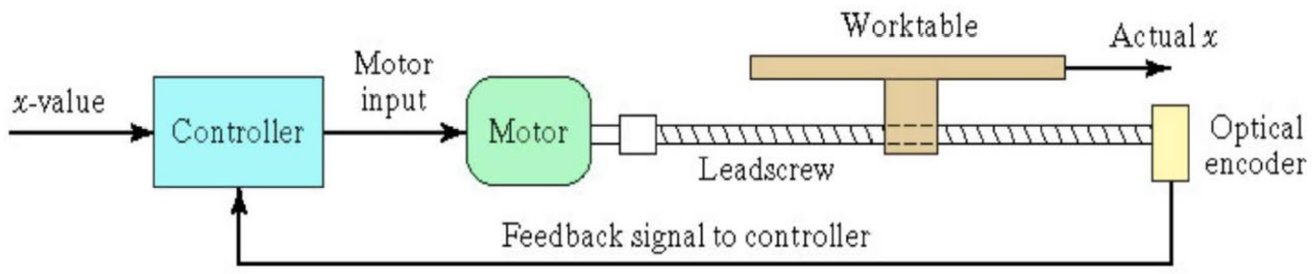
(I) The actions performed by the control system are simple,

(II) the actuating function is very reliable, and

(III) any reaction forces opposing the actuation are small enough to have no effect on the actuation. If these characteristics are not applicable, then a closed loop control system may be more appropriate.

Example for closed loop positioning system

- **In operation, the system is directed to move the worktable to a specified location as defined by a coordinate value in a Cartesian (or other) coordinate system.**
- **Most positioning systems have at least two axes (e.g., an x — y positioning table) with a control system for each axis. but our diagram only illustrates one of these axes. A dc servomotor connected to a leadscrew is a common actuator for each axis.**



- A signal indicating the coordinate value (e.g.. x-value) is sent from the controller to the motor that drives the leadscrew, whose rotation is converted into linear motion of the positioning table.
- As the table moves closer to the desired x-coordinate value, the difference between the actual x-position and the input x-value is reduced.
- The actual x-position is measured by a feedback sensor (e.g., an optical encoder). The controller continues to drive the motor until the actual table position corresponds to the input position value.

Example for open loop positioning system

- For the open loop case, no feedback loop is present and a stepper motor is used in place of the dc servomotor.
- A stepper motor is designed to rotate a precise fraction of a turn for each pulse received from the controller. Since the motor shaft is connected to the leadscrew, and the leadscrew drives the worktable, each pulse converts into a small constant linear movement of the table.
- To move the table a desired distance, the number of pulses corresponding to that distance is sent to the motor.

Question 1

In a closed-loop control system, why is the comparison between the output variable and input parameter essential?

A. To generate input parameters

B. To control the process

C. To drive the output into agreement with the input

Answer C. To drive the output into agreement with the input

Question 2

Why is the actuator considered a crucial element in a closed-loop control system?

A. It generates input parameters

B. It controls the process

C. It measures the output variable

D. It drives the output into agreement with the input

Answer B. It controls the process

Question 3

In terms of complexity and cost, how does an open-loop control system generally compare to a closed-loop system?

A. More complex and more expensive

B. More complex but less expensive

C. Less complex and less expensive

Answer: C. Less complex and less expensive

Positive Impact of Automation

Companies undertake projects in automation and computer-integrated manufacturing for good reasons, some of which are the following:

Increase labor productivity

- Automating manufacturing operation increases production rate.
- Automation leads to higher labor productivity.
- Greater output is achieved per hour of labor input.

Reduce labor cost

Increasing labor cost has been, and continues to be, the trend in the world’s industrialized societies. Consequently, higher investment in automation has become economically justifiable to replace manual operations. Machines are increasingly being substituted for human labor to reduce unit product cost.

Mitigate the effects of labor shortages

- The shortage of labor has prompted the development of automated operations.
- Automation is considered a substitute for insufficient labor in advanced nations.

Reduce or eliminate routine manual and clerical tasks

An argument can be put forth that there is social value in automating operations that are routine, boring, fatiguing, and possibly irksome. Automating such tasks improves the general level of working conditions.

Improve product quality

Automation not only results in higher production rates than manual operation, it also performs the manufacturing process with greater consistency and conformity to quality specifications.

Improve worker safety

- Automating a given operation involves transferring the worker to a monitoring role or removing them from the operation.
- This transition enhances safety by reducing the worker's active participation in the process.
- The Occupational Safety and Health Act (OSHA) of 1970 underscores the national objective of ensuring the safety and physical well-being of workers.
- OSHA has acted as an impetus for the adoption of automation to improve workplace safety.

Reduce manufacturing lead time

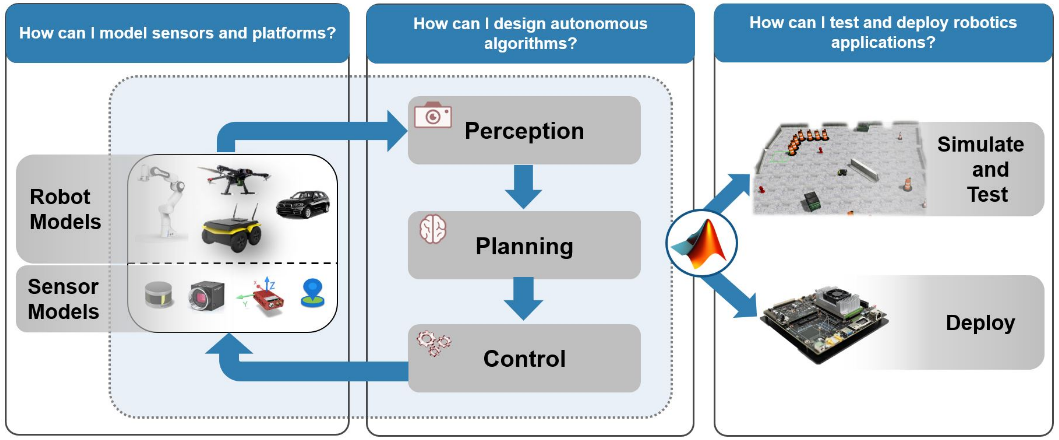
Automation helps reduce the elapsed time between customer order and product delivery, providing a competitive advantage to the manufacturer for future orders. By reducing manufacturing lead time, the manufacturer also reduces work-in-process inventory.

Accomplish processes that cannot be done manually

Certain operations cannot be accomplished without the aid of a machine. These processes require precision, miniaturization, or complexity of geometry that cannot be achieved manually.

Operational Readiness and Deployment For Automation System

- Introducing autonomous systems is a time-consuming process that involves planning, design, and implementation.
- Autonomous systems are complex, requiring the integration of multiple planning layers before deployment.



- The implementation of autonomous systems necessitates meticulous planning, but plans must also be adaptable to ongoing technological changes.
- This section addresses fundamental principles and considerations for implementing autonomous systems, covering mine planning, engineering design, and architecture.
- Additionally, it includes information on essential deployment and commissioning activities.

Several key factors must be established in advance

- The organization's reasons for automating a mine site.
- Determination of project scope and scale, including what components to automate, the level(s) of autonomous system/equipment maturity to implement, and planned autonomous operational maturity. These choices influence the required changes to the mine design and plan.
- Adoption of an implementation approach.
- Selection of a technological approach, which may involve integration with supplier(s), mature technology, or new technology.

REFERENCES

- Gupta, A., Arora, S., Westcott, J. R. (2016). Industrial Automation and Robotics: An Introduction. Germany: Mercury Learning and Information.
- Lamb, F. (2013). Industrial Automation: Hands On. United States: McGraw Hill LLC.
- Groover, M. P. (2008). Automation, Production Systems, and Computer-integrated Manufacturing. India: Prentice Hall.
- https://www.realpars.com/blog/actuator-applications
- https://gmggroup.org/wpcontent/uploads/2019/06/20181008_Implementation_of_Autonomous_Systems-GMG-AM-v01-r01.pdf

REFERENCES

- https://blogs.mathworks.com/autonomous-systems/2022/10/05/welcome-to-the-autonomous-systems-blog/

CONCLUSION

- Explored the fundamentals of control systems, highlighting their pivotal role in regulating and managing processes.
- Discussed the concept of open-loop control systems as well as closed-loop control systems.
- Explored the motivations behind automating systems, considering factors such as efficiency, precision, labor reduction, and improved safety as driving forces for the adoption of automation.
- Discussed the deployment for automation system


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 01:
Automated Mining Systems

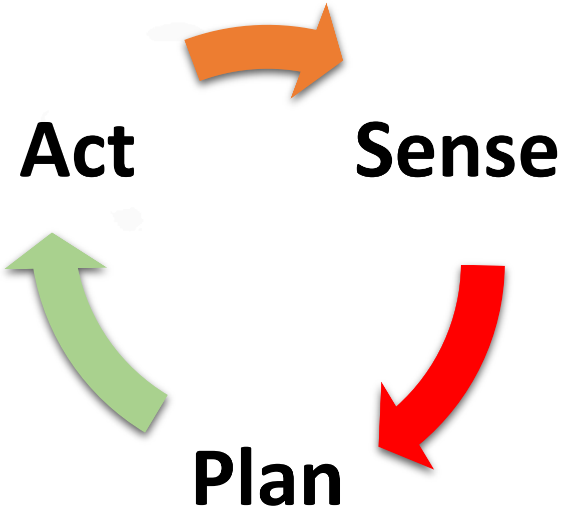
Lecture 03A:
Autonomous Haulage System

CONCEPTS COVERED

- Autonomous Driving
- Autonomous haulage systems (AHS)
- Sensors
- Benefits of Autonomous Haul Trucks to Mining
- Economic Analysis of Autonomous Haul Trucks
- Autonomous Haul Truck Manufacturers and Users
- AHS Haul Trucks Features
- Autonomous Haulage System Workflow
- Principles of Permission Control
- Conversion Capabilities

What is Autonomous Driving

Autonomous vehicles have the ability to drive from one location to another without guidance or assistance from a person. They do this by collecting data about their environment, understanding the data and taking appropriate actions. A variety of sensors collects data. On-board computers process the data and instruct the steering, accelerating and braking operations.



Autonomous haulage systems (AHS)

- Autonomous haulage systems (AHS) transform conventional haul trucks into unmanned vehicles.
- The technology incorporates wired and wireless networks, virtual infrastructure, servers, and a control center with standard desktop workstations.
- High precision GPS systems ensure 1 cm accuracy for all mobile vehicles within the autonomous system.

- Safety features include lidar and radar systems for obstacle detection and collision avoidance.
- Onboard supervisory logic governs the vehicle, allowing integration with other mine vehicles like light trucks, dozers, and loaders.
- Operators monitor the status of the autonomous haulage system and issue vehicle route following commands.
- Field operators update vehicle route information based on changes in the mining environment, such as breakdowns or obstacles on haul roads.

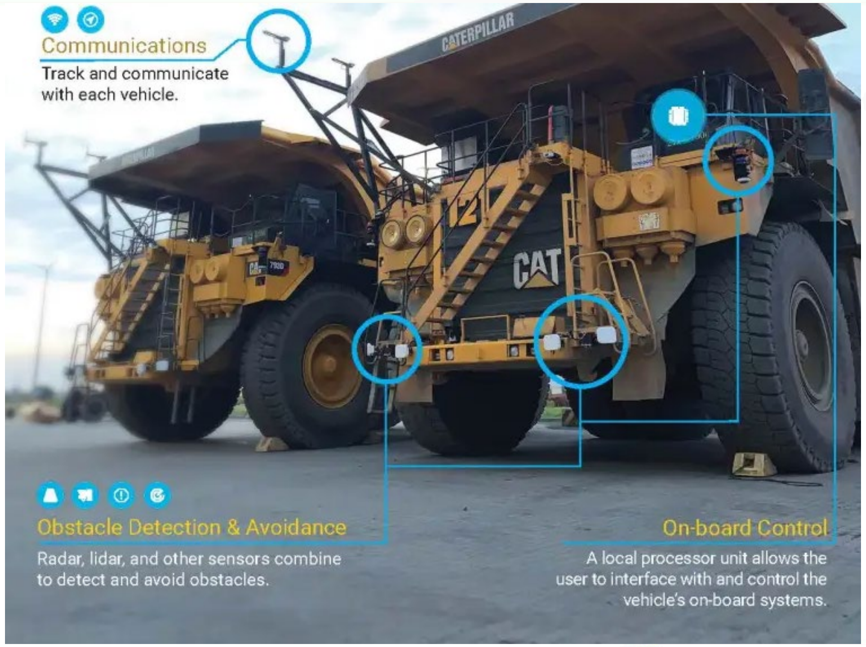
Additional considerations in AHS include

- Autonomous haulage systems have a higher risk profile than conventional vehicle operations.
- These systems rely on wireless technologies for safe production and operational control.
- Digital transformation within the mining industry has established rich connectivity to OT (Operational Technology) networks from enterprise systems.
- Existing relevant standards focus on safety, but cybersecurity is a minor consideration. These standards typically revolve around mitigating risks for personnel and functional safety.

Sensors

Main Sensors on Autonomous Vehicles

- Light Detection and Ranging (Lidar) Systems
  - Measure distance by emitting laser lights and analysing reflected light.
  - Can emit multiple lasers, and generate three-dimensional models of the environment.
- Radio Detection and Ranging (Radar) Systems
  - Provide specific types of information for autonomous vehicles.
- Visual Cameras
  - Contribute to the sensor array, each offering unique data.



Sensor Functions

- Each sensor gathers different types of information.
- Sensors have individual limitations.
- A variety of sensors positioned around the vehicle collect data based on their specific functions.

Prominence of Lidar Systems

- Lidar systems are prominently featured on autonomous vehicles.
- They play a crucial role in distance measurement and environmental mapping.

Benefits of Autonomous Haul Trucks to Mining

Mine haul trucks are massive and costly machines that typically operate 24 hours a day, ensuring continuous operation.

Advantages of Autonomous Operation

- **Increased Equipment Utilization: Without drivers, expensive equipment can operate continuously, eliminating idle time during breaks or between shifts.**
- **Higher Efficiency and Cost Savings: Autonomous trucks achieve equivalent work to manual ones, operating more efficiently with shorter cycles, reduced fuel consumption, and improved tire wear.**

Safety Benefits

- **Human Safety Improvement: Having fewer personnel in a hazardous mining environment enhances safety.**

Job Impact

- **Job Elimination and Creation: While the technology eliminates some jobs, it also creates new ones, with workers developing improved skills in safer workspaces.**

Economic Analysis of Autonomous Haul Trucks

Positive Economic Potential

- Implementation of autonomous haul trucks in mines has significant positive economic potential.
- The reduction in costs is observed in three major areas: improved productivity, reduced labor, and lower investment costs.

Productivity Gains

- Actual autonomous haul truck data reveals a 21% increase in haul truck productivity.
- Seven autonomous mine haul trucks could replace nine human-operated trucks, showcasing increased utilization.

Positive Economic Potential
Productivity Gains
Efficiency Improvements
Candidate Mines

Economic Analysis of Autonomous Haul Trucks

Efficiency Improvements

- **Fuel consumption shows a 6% improvement, and tire wear is enhanced by over 7.5%.**

Candidate Mines

- **Large mines in developed countries with higher wages are identified as primary candidates for adopting autonomous haul trucks, primarily for cost savings.**

Autonomous Haul Truck Manufacturers and Users

Testing and Implementation

- **Autonomous haul truck technology is undergoing trials and testing by multiple manufacturers and mining companies.**

Key Manufacturers

- **Komatsu, Caterpillar, and Hitachi are the three main haul truck manufacturers actively involved in developing autonomous technology.**

Komatsu AHT

Caterpillar AHT

Hitachi AHT

Collaborations with Mining Companies

- These manufacturers have collaborated with prominent mining companies, such as Rio Tinto, BHP, and Fortescue.
- The collaboration involves implementing autonomous technology in real mine operating environments.

Real-world Application

- The focus is on applying autonomous haul truck technology in practical mining operations to assess its effectiveness and feasibility.

AHS Haul Trucks Features

AHS haul trucks (AHTs) feature high-precision global navigation satellite positioning systems (HP GNSS), advanced sensors, and integrated controllers, enabling remote control from a central room for unmanned hauling.

Autonomous Operation

- **AHTs operate autonomously using high-performance wireless networks, including LTE.**
- **The autonomy allows for centralized control, with a single operator managing the entire fleet.**

Interconnected System

- **The interconnected system facilitates safe interactions between AHTs and manually operated equipment, such as loaders, dozers, graders, and light vehicles.**

Optimizing Mining Operations

- **The integration of autonomous haul trucks and manual equipment is designed to optimize overall mining operations, enhancing efficiency, safety, and coordination within the mining environment.**

Question 1

How do autonomous vehicles navigate between locations?

a) Human guidance

b) Sensor data analysis

c) Steering wheel control

d) Acceleration commands

Answer b) Sensor data analysis

Question 2

What type of networks do AHTs use for autonomous operation?

a) GPS

b) HP GNSS

c) Wireless networks, including LTE

d) Radar networks

Answer c) Wireless networks, including LTE

Question 3

What is the main goal of integrating autonomous haul trucks and manual equipment in mining operations?

a) Increasing manual labor

b) Reducing efficiency

c) Optimizing overall mining operations

d) Isolating autonomous systems

Answer c) Optimizing overall mining operations

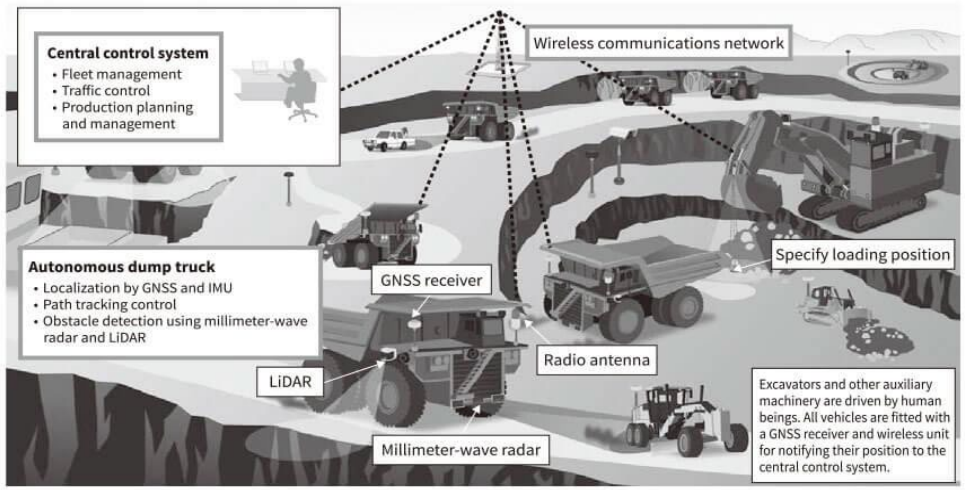
Autonomous Haulage System Workflow

Autonomous Driving Technology

- Driverless dump trucks utilize GNSS (Global Navigation Satellite System) and sensors for autonomous driving.

Central Control System

- A central control system employs wireless communications to manage operations and control traffic for the entire fleet of dump trucks.



AHS: autonomous haulage system GNSS: global navigation satellite system IMU: inertial measurement unit LiDAR: light detection and ranging

Coordination with Auxiliary Machinery

- Various auxiliary machinery, such as excavators, bulldozers, and graders, operated by humans, coexist at the mine site.
- These human-driven machines need to coordinate their operations with the driverless dump trucks for seamless and efficient mining processes

Principles of Permission Control

Vehicles are prevented from interfering with each other by controlling their movements, ensuring exclusive use of their permitted sections.

Permission Control Mechanism

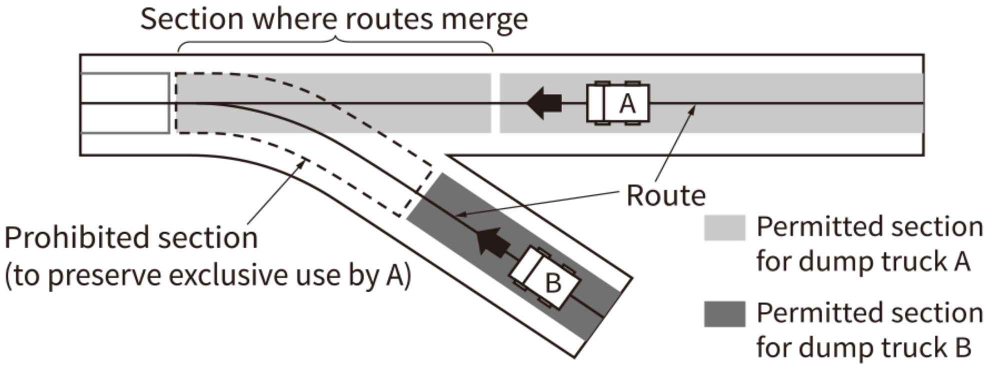
- Permission control divides the route into sections, allowing only one dump truck at a time to drive on each section.
- Dump trucks can drive through their current permitted section without continuous communication with the central control system.

Request and Grant System

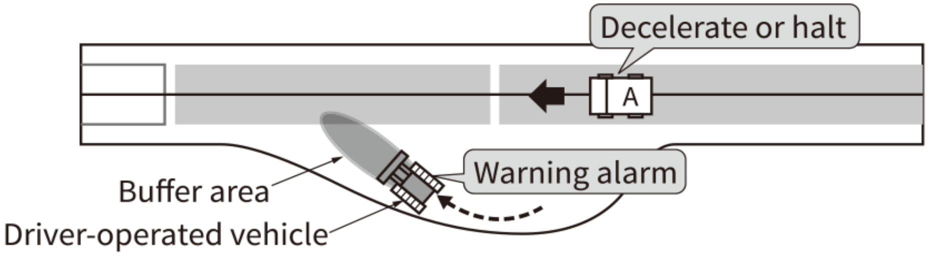
- When approaching the end of a section, the truck sends a request to the central control system for permission to enter the next section.
- If permission is granted, the truck continues its route; otherwise, access is denied, preventing potential collisions.

Example Scenario

- **Dump truck A already has permission, preventing dump truck B from entering, avoiding collisions.**



(1) Permission control for two dump trucks



(2) Permission control for dump truck and driver-operated vehicle

Management Exclusively for Autonomous Vehicles

- This management by permitted sections is tailored for autonomous vehicles, not employed for vehicles operated by drivers.
- Driver-operated vehicles are guided to avoid sections allocated to autonomous dump trucks.

Warning and Control Measures

- Driver-operated vehicles are equipped with terminals displaying sections allocated to autonomous dump trucks.
- In situations where the buffer area of a driver-operated vehicle overlaps with a section assigned to an autonomous dump truck, warnings are displayed, and the central control system may issue instructions to slow or stop the dump truck, ensuring safety and preventing collisions.

Benefits of Permission Control

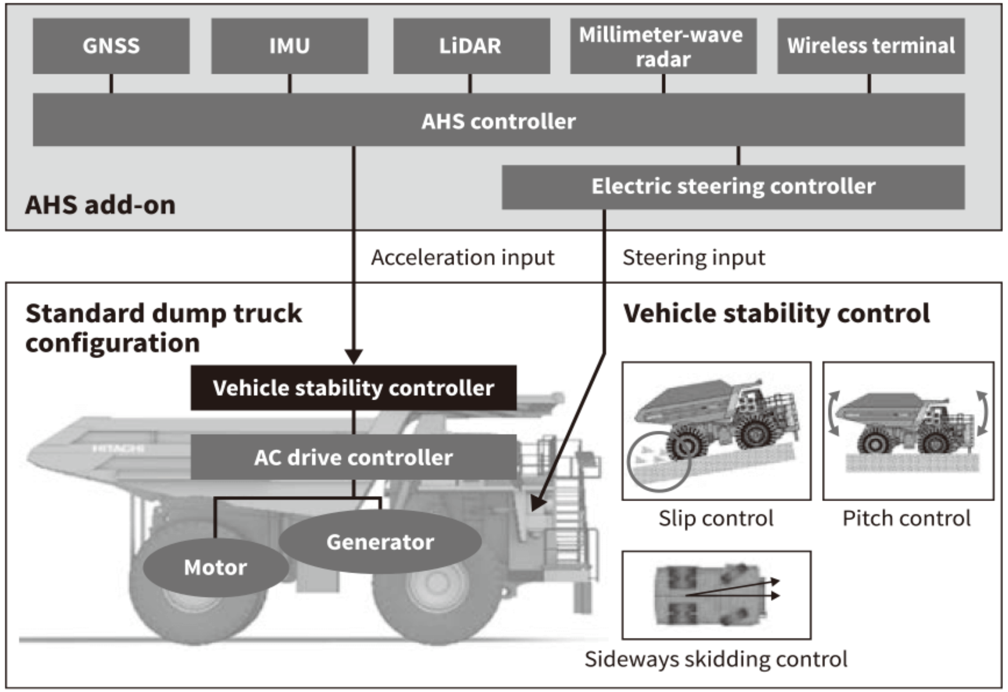
- Table 1 compares the vehicle control capacity of permission control and position-based techniques under various communication conditions.
- Permission control supports approximately 1.7 times more vehicles than a position-based control technique in the given example.
- The efficiency of permission control lies in its reduced demand for frequent position information updates, enhancing overall system scalability.

Table -1

Control method	No. of dump trucks	No. of driver-operated vehicles	Total
Control based on vehicle position	29	73	102
Permission control	50	125	175

Conversion Capabilities

A driver-operated dump truck can be converted to autonomous driving simply by using the vehicle stability control provided by an on board controller for this purpose.



AC: alternating current

REFERENCES

- https://www.hitachi.com/rev/archive/2018/r2018_01/10a07/index.html
- https://www.elprocus.com/radar-sensor/
- https://cranenetworknews.com/komatsu-first-to-operate-autonomous-haulage-system/
- https://s7d2.scene7.com/is/content/Caterpillar/C10338825
- https://southburnett.com.au/news2/2013/04/18/driverless-trucks-coming-to-meandu/
- https://www.google.co.in/books/edition/SME_Mining_Engineering_Handbook_Third_Ed/5uq-kdfHLWUC?hl=en&gbpv=0

REFERENCES

- Gaber, T., El Jazouli, Y., Eldesouky, E., & Ali, A. (2021). Autonomous haulage systems in the mining industry: Cybersecurity, communication and safety issues and challenges. Electronics, 10(11), 1357. https://doi.org/10.3390/electronics10111357
- https://mine.nridigital.com/mine_jul23/mining-electric-vehicles-decarbonisation
- https://gmggroup.org/wp-content/uploads/2022/12/MM-ISAC-Secure-Deployment-of-Autonomous-Haulage-Systems-Case-Study.pdf

CONCLUSION

- **Explored the multifaceted impact of Autonomous Haul Trucks, covering advanced sensors, economic considerations, and distinctive features.**
- **Emphasized the strategic significance of these vehicles beyond mere technological innovation, particularly in terms of safety, economic benefits, and efficiency in mining operations.**
- **Discussed the seamless workflow of an Autonomous Haulage System, highlighting the integration of various components and the necessity for synergy.**
- **The role of permission control, stressing the importance of a robust governance framework for managing access and ensuring security.**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MINE AUTOMATION AND DATA ANALYTICS

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Module 02:
Automated Mining Systems

Lecture 03B:
Autonomous haulage system

CONCEPTS COVERED

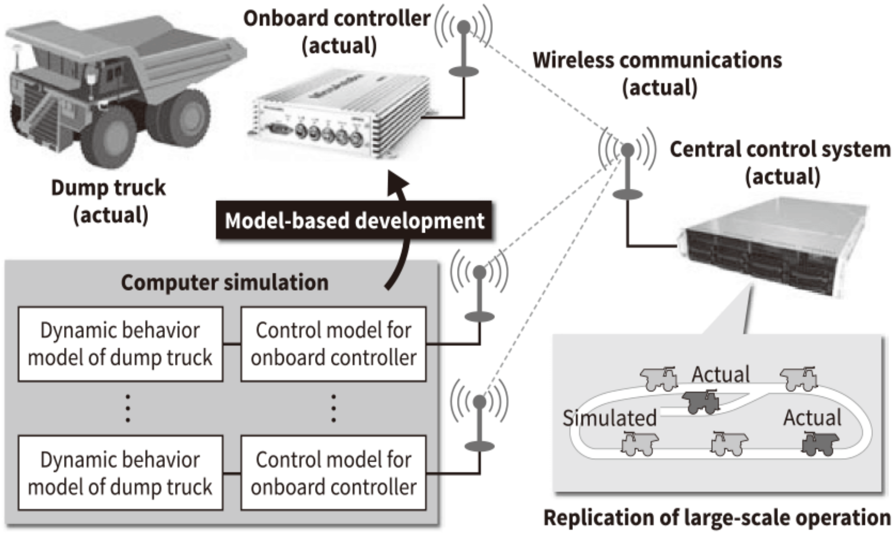
- Hybrid Simulator Integration for Efficient Development and Testing of AHS
- Comprehensive Test Site Configuration for AHS
- Different levels of System in AHS
- Challenges in Autonomous Haulage Systems in the Mining Industry
- Autonomous Haulage System - Risk Management Practices

Hybrid Simulator Integration for Efficient Development and Testing of Autonomous Haulage System (AHS) Technology

The development and testing of Autonomous Haulage System (AHS) technology involve replicating loading, hauling, and dumping operations with dump trucks.

Hybrid Simulator Setup

- **A hybrid simulator integrates an actual traffic control server and wireless communication units for transmitting commands to dump trucks.**
- **The dump truck part of the simulation utilizes a combination of real vehicles and simulators.**



Model-Based Development

- Onboard controller control logic is created using a model-based development method.
- The control model is initially developed on the simulator and then directly ported to the onboard controller, reducing development time.

Scalable Simulation

- The hybrid simulator can replicate and test mining operations with around 100 vehicles by modelling them as virtual dump trucks.
- This scalability enables thorough testing and validation of AHS technology in various scenarios.

Early Stage Traffic Control Testing

- A combination of actual and virtual dump trucks is used for early-stage testing of traffic control.
- This approach ensures the safety of real vehicles during testing while providing comprehensive insights into system functionality.

Comprehensive Test Site Configuration for Simulating and Evaluating Mine Site Operations

Test Site Configuration

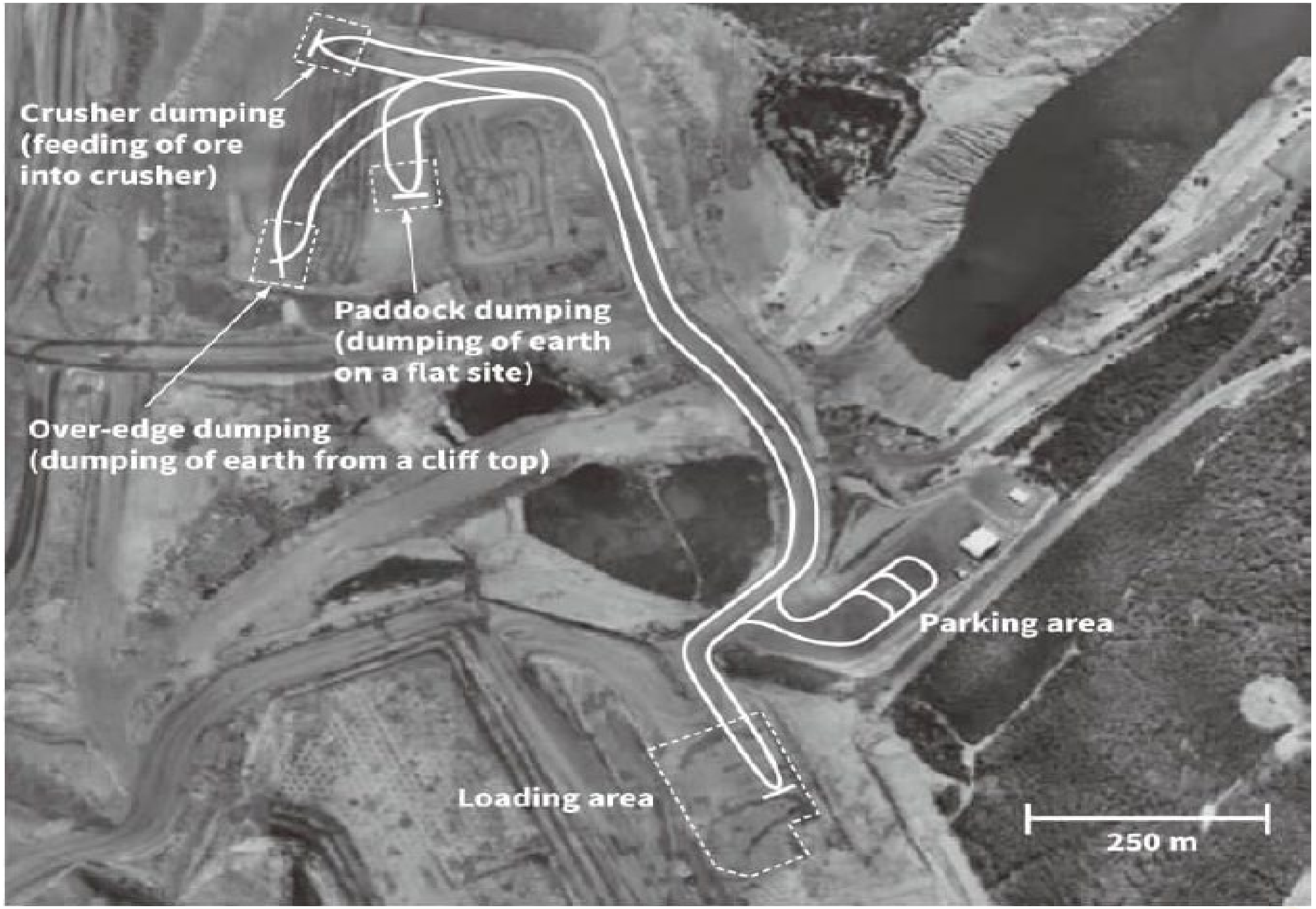
- The test site is organized with specific zones to replicate mine site operations.
- It includes one loading area and three distinct dumping areas.

Sequential Operations Replication

- The site is designed to faithfully emulate the sequence of operations observed at a mining site.
- This encompasses the loading, hauling, and dumping phases.

Loading Process

- **The loading area is dedicated to simulating the process of loading materials onto haul trucks.**



Hauling Phase

- Haul trucks transport loaded materials from the loading area to other locations within the testing facility.

Dumping Operations

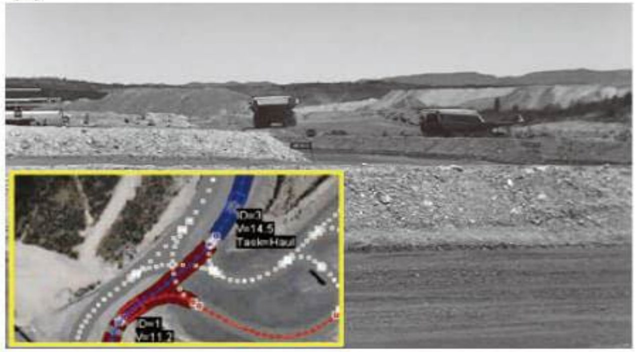
- Three distinct dumping areas are provided to replicate the dumping phase of mine site operations.

Comprehensive Testing Environment

- The configured layout facilitates thorough and accurate testing of the entire sequence of mine site operations.
- This setup enables the assessment of the performance and efficiency of systems involved in loading, hauling, and dumping processes.

(1)

(2)



(3)

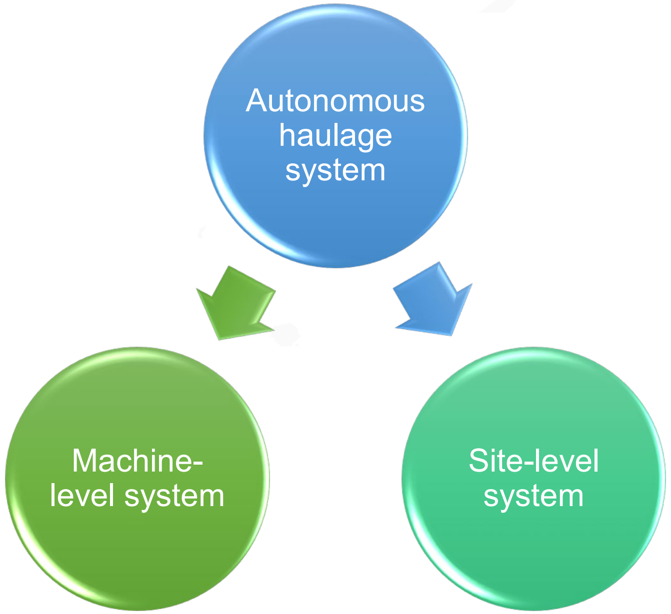
(1) shows a dump truck being positioned at a loading location specified by the excavator,

(2) shows permission control managing vehicles converging at an intersection, and

(3) shows a dump truck carrying earth.

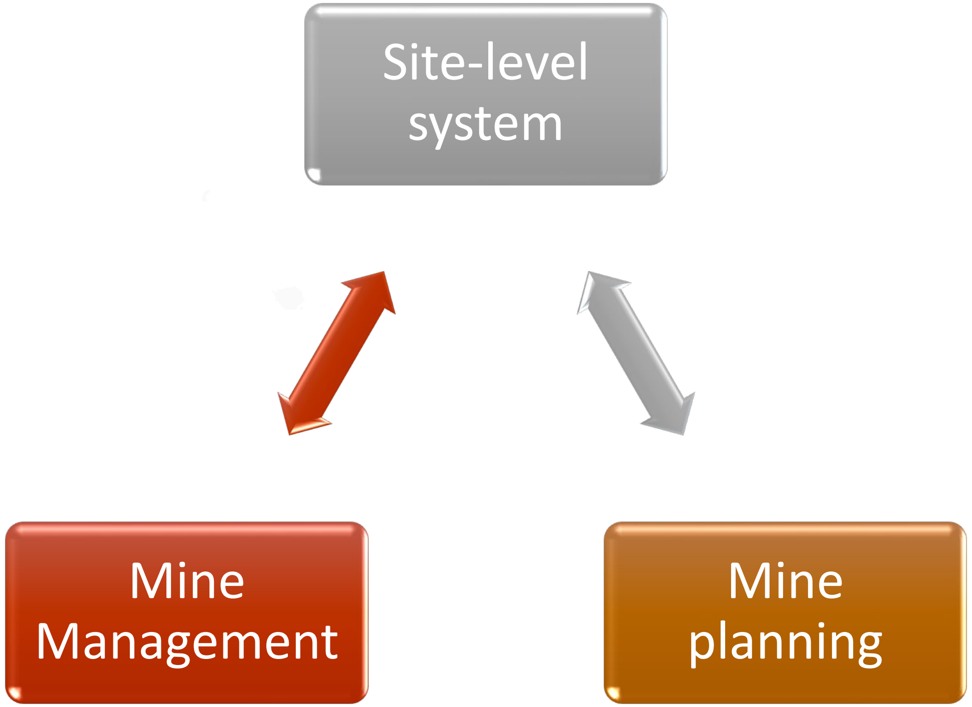
Autonomous haulage systems

Autonomous haulage systems are generally divided into two major divisions



Site-Level Automation

The site-level systems provide an interface between the human (and software-based) mine planners, provide data for business tracking, and provide optimization and control over the haulage system machines.



Mine planning

- Significant human interaction is essential for setting goals in mine planning.
- Goals include prioritizing production volume and considering significant cost factors such as fuel usage and the risk of machine damage.
- Another aspect involves prioritizing short-term production needs versus long-term mine efficiency.
- The challenge in mine planning lies in accurately translating both explicit and implicit goals into the automated mine management system.

Mine management

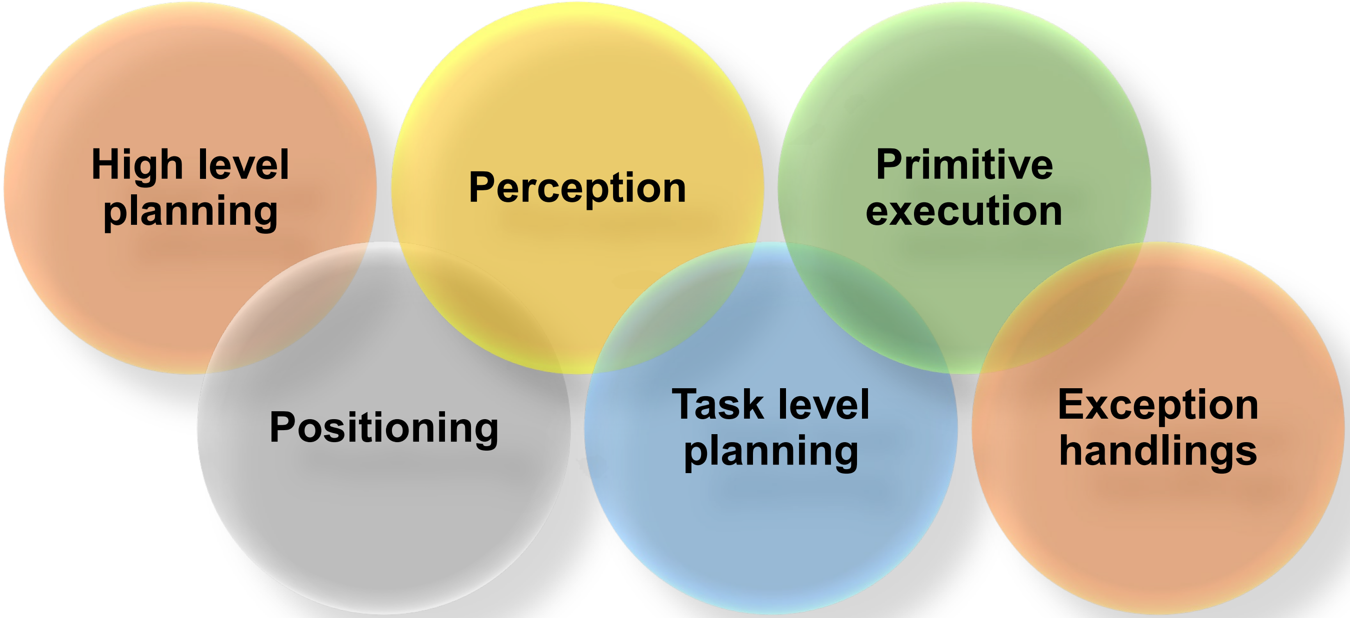
- A substantial amount of experience exists in the field of mine management systems.
- Despite this, the evolving landscape demands a new generation of mine management systems.
- The emerging need is driven by the requirements of autonomous systems within mining operations.
- The upcoming generation of these systems will necessitate more intricate mine models.
- Additionally, a host of new features will be essential to effectively manage autonomous equipment in mines.

Machine-Level Automation

Machine-level automation requires the ability to

- **Understand what tasks need to be accomplished (high-level planning), Determine location (positioning)**
- **Perceive the environment based on the location (perception)**
- **Based on the environment and position, plan future tasks to achieve the desired goals (task-level planning).**
- **Execute the planned primitives (primitive execution), and Handle exceptions.**

Machine-Level Automation



High-level planning

- Interpreting directions from the mine management system is a key aspect of high-level planning.
- The autonomous truck must select appropriate behaviours based on the provided directions.
- When directed to a load area, the truck needs to comprehend the path it should take.
- Validation of the chosen path is crucial to ensure accuracy and safety in execution.
- The autonomous truck must confirm that it possesses the necessary behaviours and capabilities to carry out the plan effectively.

Positioning

- Positioning involves determining the machine's pose, which includes its location and orientation.
- In the case of autonomous machines, having an accurate and reliable pose is crucial.
- While absolute accuracy is not always the top priority, accurately registering the machine's pose to the mine model is a necessary requirement.
- The process of positioning involves considering multiple types of positioning methods to meet the desired accuracy and reliability.

For aboveground applications, the most common real-time kinetic Global Navigation Satellite Systems (RTK GNSSs) are

a) RTK GNSS + machine sensors (such as odometers),

b) RTK GNSS + machine sensors + inertial,

c) RTK GNSS + machine sensors + inertial + perception-based positioning, and

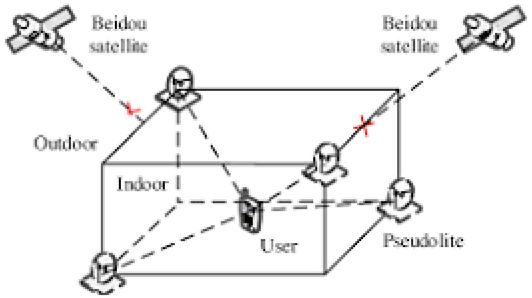
d) RTK GNSS + machine sensors + inertial + pseudolites (ground-based satellites or reference stations).

For belowground applications, the most common types of positioning systems are

a) Radio frequency (RF) based distance measurement,
b) Perception-based positioning + machine sensors, and
c) Perception-based positioning + machine sensors + inertial.

- Perception-based systems used in factories for over two decades and in mining for nearly ten years.
- RTK GNSS-based systems offer centimetre-level accuracy in construction for a decade.

- **RTK GNSSs need augmentation due to poor coverage, especially near poles and areas with blockage.**
- **Global government support is increasing, promising improved GNSS coverage with more satellite deployments.**
- **Inertial sensors plus odometry are a well-proven short-duration technology for GNSS augmentation.**
- **Other options include pseudolites and RF-ranging beacons for ground-based positioning, but they are costly to install and maintain.**



Pseudolites enforcing GNSS system

Perception

- Autonomous machines need a thorough understanding of their surroundings for object detection and occasional positioning assistance.
- The perception system relies on information from the mine model and positioning system for accurate object location reporting.
- Common forms of perception sensors include radar, laser, vision, and sonar.
- These sensors contribute to the machine's ability to interpret and navigate its environment effectively.
- A seamless integration of perception data with the mine model and positioning system enhances overall autonomous machine performance.

Perception sensors

Radar

- **Millimetre-wave radars, a recent development, offer object detection capabilities.**
- **Radar's strengths include long-range detection and the ability to penetrate dust and fog.**
- **However, radar has lower resolution compared to laser-based systems.**
- **Object detection size is influenced by radar cross section (RCS), determined by the object's projected area returning the signal.**

Question 1

What is the purpose of wireless communication units in the hybrid simulator?

a) Broadcasting traffic updates

b) Transmitting commands to dump trucks

c) Controlling virtual reality simulations

d) Monitoring pedestrian traffic

Answer b) Transmitting commands to dump trucks

Question 2

What does the perception system of autonomous machines rely on for accurate object location reporting?

a) Global weather reports

b) Satellite imagery

c) Mine model and positioning system

d) Historical data of the mining are

Answer: c) Mine model and positioning system

Laser sensor

- Laser systems offer the best resolution but can be affected by obscurants like dust and fog.
- Newer lasers address this limitation through multiple reflections from each point or time getting returns to mitigate interference from small, diffused particles (dust, fog, rain, and snow).
- The method's effectiveness diminishes as particle density increases.
- Retroreflectors, like tail lights or reflective tape, can be added to targets to significantly improve their visibility to lasers.

Task-level planning

- Task-level planning involves creating a sequence of tasks or behaviours to achieve a goal and is typically rule- or constraint-based.
- The nature of task planning depends on factors such as the goal type, the number of constraints, environmental variability, and the automated system's flexibility.
- Machine-level planning often includes tasks related to object avoidance.
- Object avoidance is a common and essential aspect of machine-level planning within automated systems

Primitive execution

- Executing planned primitives is a fundamental machine operation.
- Examples of these operations include drilling, tramming, loading, grading, stability control, dumping, and ripping.
- These operations typically involve continuous closed-loop control.
- They closely resemble human skills in machine operation.

Exception handling

Handling exceptions is the ability of an autonomous machine to recognize that it does not have the means or required primitive ability to handle the existing situation, and thus it resorts to fail-safe behaviour usually stopping and asking for help.

Challenges in Autonomous Haulage Systems in the Mining Industry

- **Autonomous Haulage Systems (AHS) function as Cyber-Physical Systems (CPS) and heavily rely on wireless communications, incorporating systems for object avoidance/detection, Global Positioning Systems (GPS) like GNSS, and artificial intelligence.**
- **Autonomous trucks (ATs) need constant wireless connectivity, vital for tracking in challenging terrains during AHS operations in mines.**

- The reliance on wireless technologies introduces challenges, including frequency interference, concerns about channel utilization for efficient communication, and the risk of signal jamming, impacting the reliability of communication links.
- Integration of Operational Technology (OT) and Information Technology (IT) in AHS increases vulnerability to cybersecurity issues.
- The combination of AHS with wireless tech and OT/IT integration presents operational and cybersecurity challenges requiring careful consideration during implementation and maintenance.

GPS Positions in Autonomous Haulage Systems: Understanding and Mitigating Realistic Threats

- Securing GPS positions is of utmost importance in Autonomous Haulage Systems (AHS).
- Classifying GPS attacks into two categories: spoofing and jamming, with a focus on their realistic nature.
- Spoofing is the act of intentionally misleading the correct location by creating a false signal. On the other hand, jamming uses sophisticated techniques such as nulling to eliminate GPS signals by transmitting encrypted negative signals, enabling covert attacks.
- The insufficient safeguarding of GPS data presents a significant safety risk, which could result in severe collisions within the AHS (Autonomous Highway System) setting.

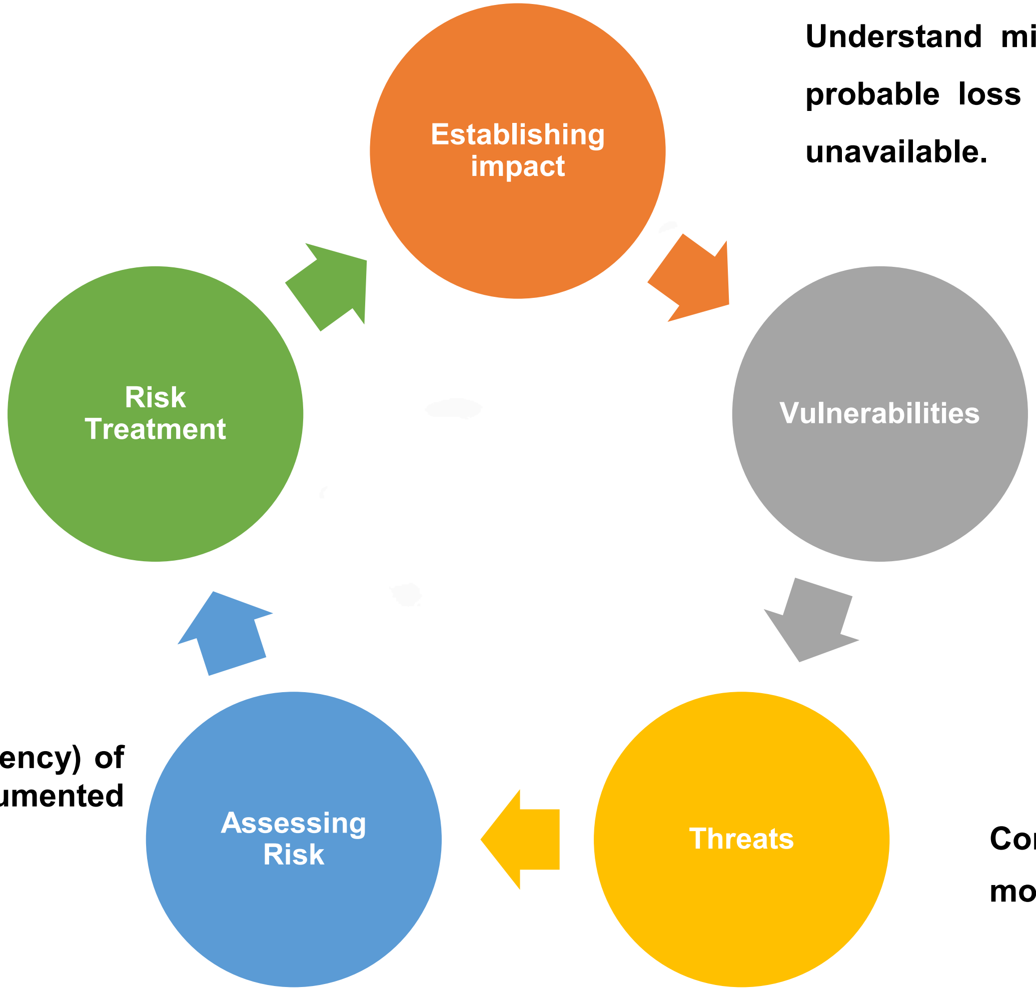
Autonomous Haulage System - Risk Management Practices

- Securing autonomous haulage systems comes down to understanding the risk relationships between operational assets used in the mining process and autonomous systems on which the processes are dependent. These dependencies can form potential safety, production, and regulatory compliance impacts and risks.
- Establishing good risk management practices including security requirements when new technology is introduced and it is crucial to securing autonomous haulage systems effectively

The five following risk management concepts are used for securing autonomous haulage systems

Understand mining process dependencies on OT and the probable loss that could occur if the dependent OT were unavailable.

Accept assessed risks or mitigate and apply controls

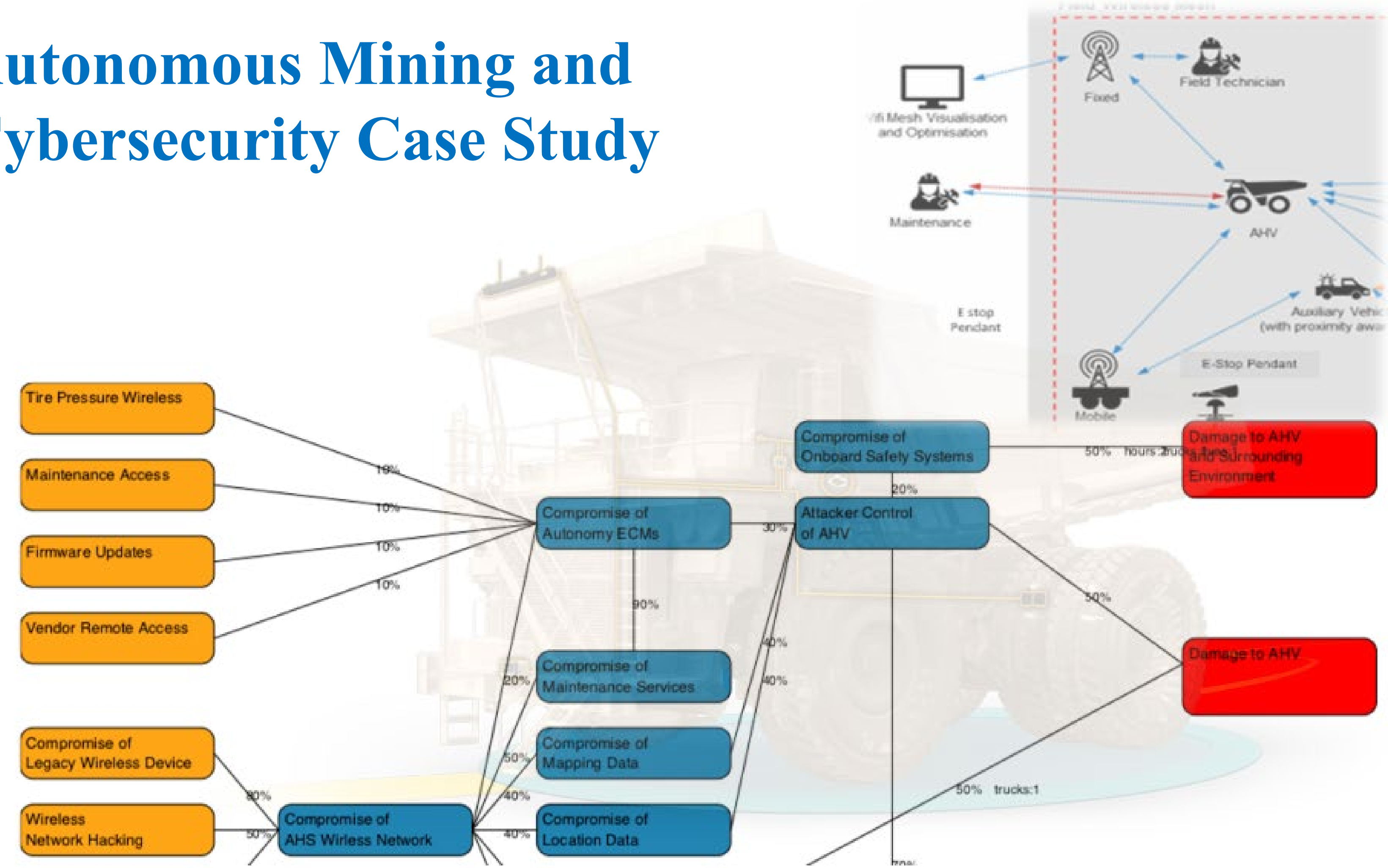


Inventory potential attack pathways and system exposure

Establish the likelihood (frequency) of a threat exploiting documented vulnerabilities

Conduct threat modeling.

Autonomous Mining and Cybersecurity Case Study



REFERENCES

- https://www.hitachi.com/rev/archive/2018/r2018_01/10a07/index.html
- https://www.elprocus.com/radar-sensor/
- https://cranenetworknews.com/komatsu-first-to-operate-autonomous-haulage-system/
- https://s7d2.scene7.com/is/content/Caterpillar/C10338825
- https://southburnett.com.au/news2/2013/04/18/driverless-trucks-coming-to-meandu/
- https://www.google.co.in/books/edition/SME_Mining_Engineering_Handbook_Third_Ed/5uq-kdfHLWUC?hl=en&gbpv=0
- Gaber, T., El Jazouli, Y., Eldesouky, E., & Ali, A. (2021). Autonomous haulage systems in the mining industry: Cybersecurity, communication and safety issues and challenges. Electronics, 10(11), 1357. https://doi.org/10.3390/electronics10111357
- https://gmggroup.org/wp-content/uploads/2022/12/MM-ISAC-Secure-Deployment-of-Autonomous-Haulage-Systems-Case-Study.pdf

CONCLUSION

- Explored the integration of hybrid simulators for streamlined development and testing of Autonomous Haulage Systems (AHS), emphasizing efficiency in the developmental phase.
- Discussed the configuration of comprehensive test sites tailored for AHS, recognizing the importance of realistic testing environments to validate system functionality.
- Examined the different levels of the system within Autonomous Haulage Systems, providing insights into the hierarchical structure and functionalities at various tiers.
- Addressed the challenges inherent in the implementation of Autonomous Haulage Systems in the mining industry, acknowledging and analyzing obstacles to their seamless integration.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

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Module 02:
Autonomous Mining Systems

Lecture 04 (A):
Automated drilling system

CONCEPTS COVERED

- Introduction to drilling
- Basic concept of drilling
- Overview of Autonomous drilling system
- Main system of autonomous drill
- Benefits of Autonomous Drilling System
- Basic Sensors for an Automated Drilling System
- Disadvantages of Drill Automation

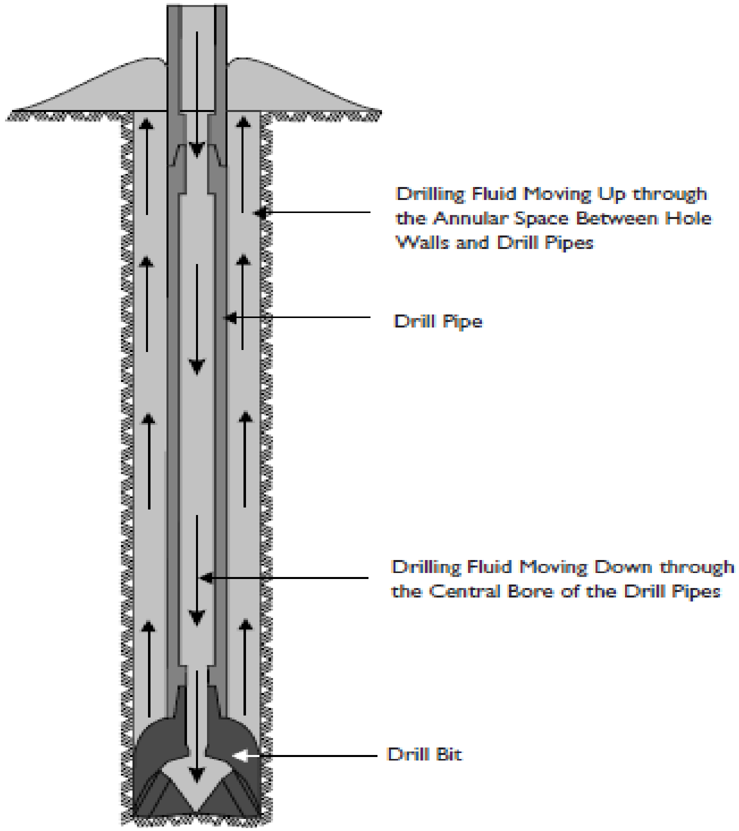
CONCEPTS COVERED

- Hole Navigation System (HNS)
- Measure While Drilling (MWD) Analysis
- Role of autonomous drilling in mining industry
- Automation drive drilling process
- Challenges in autonomous drilling system

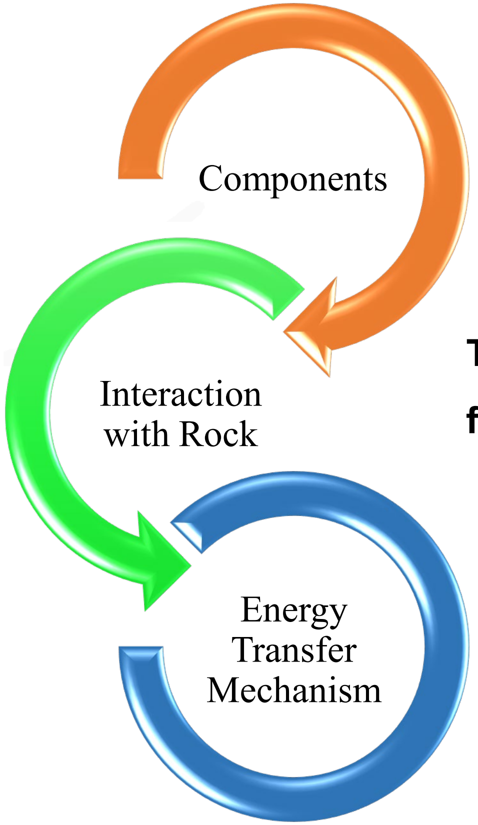
Introduction to drilling

Relatively large rotary drills may commonly be used in the mining industry for the drilling of holes in ore beds and strata. Large earth-boring machines, commonly known as blast-hole drilling rigs may be used in a process which involves mapping out a drill pattern, drilling a blast hole, and filling the blast hole with explosives. An individual blast pattern may typically consist of 50 or more holes, each hole containing a measured quantity of explosives required to fracture the strata as intended.

Basic concepts of drilling



Drilling Schematics



In drilling, a drill bit is attached to the lower end of a drill string, primarily composed of drill pipes.

The drill bit transfers energy to the rock, causing it to fracture during the drilling process.

The drill string consistently supplies energy to the drill bit, ensuring progressive rock fracturing at increasing depths.

Overview of autonomous drilling system

- Autonomous drilling involves unmanned drilling rigs controlled remotely, known as teleoperated rock drilling apparatuses.
- Autonomous mining operations encompass the use of unmanned drilling rigs, loading vehicles, and other mining vehicles collectively. These can be controlled externally from an overground control room using video cameras.

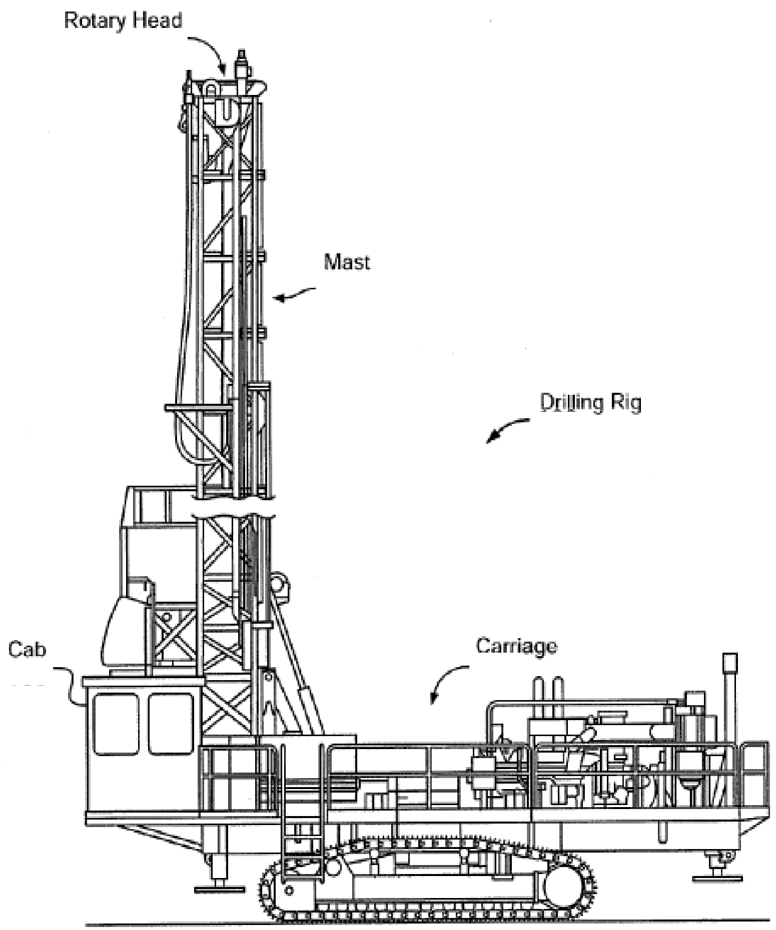
- Due to the absence of human involvement in autonomous drilling systems, data must be sensed and transmitted to a remote computing device for monitoring, analysis, and optimization of the drilling process.
- Autonomous drilling rigs may feature navigation systems, markings for remote control, collision avoidance capabilities, and other features enabling operation without a human onboard.

- Unmanned drilling rigs need high reliability to avoid human intervention, with the ability to recover from problems, replace used parts, and perform regular upkeep.
- Inexpensive and efficient solutions are required for collecting and transmitting data to the remote operator, necessitating software to control the hardware components of the drilling rig.

- The software must guide the drilling rig for blasthole drilling in specified locations, detect component failures and navigation errors, and log/report activities of the drilling rig.

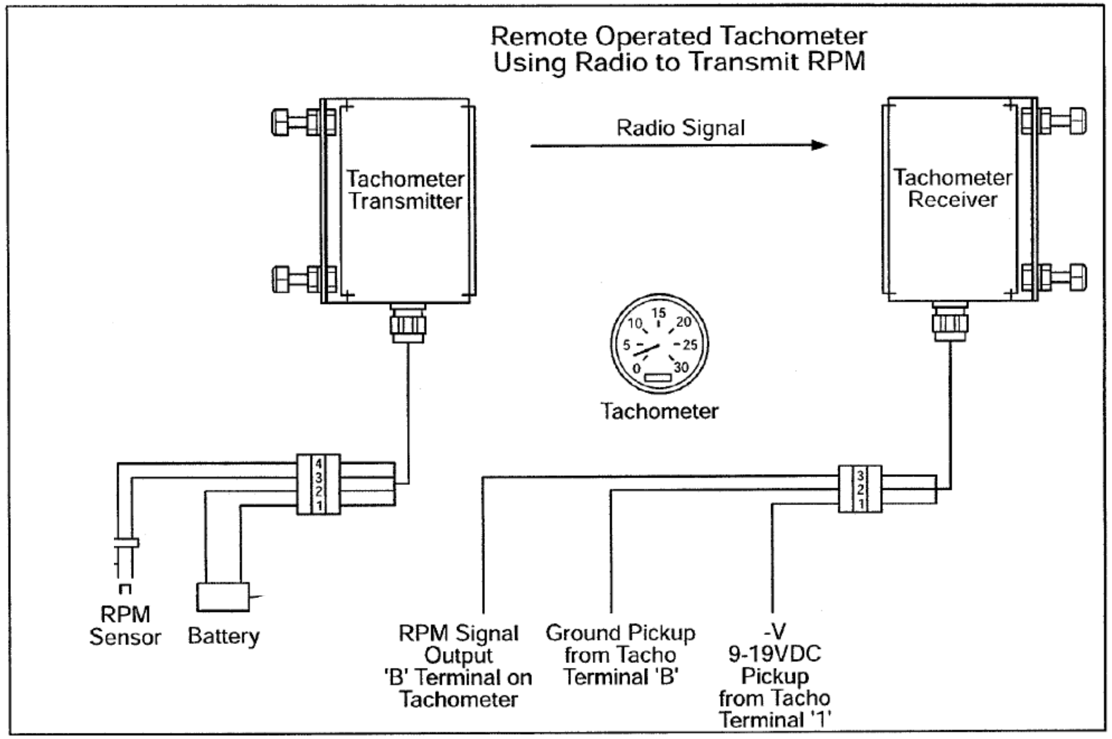
Main systems of an autonomous drill

1) **Radio Tachometer System**
2) **Downhole Sensing and Measuring**
3) **Laser Depth Counter**



Radio Tachometer System

An exemplary sensing and measuring instrument capable of wireless transmission of data in an autonomous mining drilling rig is a radio tachometer system that wirelessly transmits data using radio frequency signals.

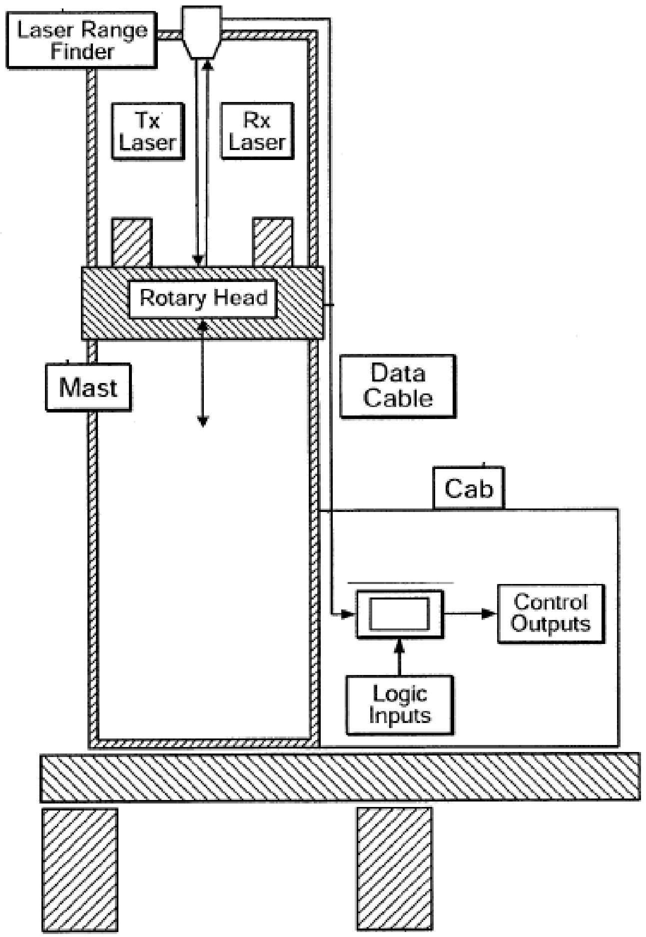


Downhole sensing and measuring

- In mining drilling rigs, which are mobile rigs placed on a moving tract, sensor information from tools and components obtained downhole can be processed and displayed semi-real-time. Because of the nature of mining operations, where numerous holes are drilled in a short period. Drill pipes are rapidly inserted and withdrawn from the earth.
- Due to the quick drilling and extraction process, surface and downhole measurements(such as vibration, pressure, and temperature) can be relayed semi-real-time.

Laser depth counter

The laser depth counter is designed to take measurements for calculating the depth of the drill hole, employing a laser range finder.



- The laser range finder uses a laser beam to determine the distance to a reflective object, such as the rotary head.
- The laser operates on a "time of flight" principle, sending a laser pulse in a narrow beam towards the object and measuring the time taken for the pulse to be reflected off the target and returned to the sender.
- The displacement of the object is calculated based on the time measurement obtained.

- Laser range finder positioned at the top of the mast and aimed at the rotary head measures the displacement of the rotary head as it travels up and down the mast.
- The raw data collected by the laser range finder includes the range of distances between the laser mounted at the top of the mast and the distance to the rotary head as it traverses the mast.
- This raw data can be relayed using a wireless transmission system on the drilling rig.
- The relayed data is subsequently used to compute the depth of the drilled hole and the penetration rates of the drill over time.

Benefits of Autonomous Drilling System

Better precision in the drilling process → Lower total cost per meter → Increased production per drill → Longer use of assets → Need for human operator reduces → Better hole stability → Better predictability of blast fragmentation

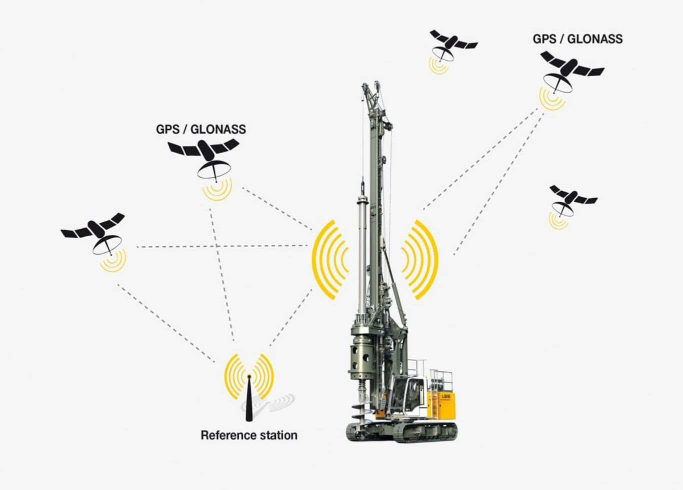
Basic Sensors for an Automated Drilling System

Drill-rig position

- High-precision Global Positioning Systems,
- Inertial measurement units, and
- Laser technology

Basic Sensors for an Automated Drilling System

High-precision Global Positioning Systems



- High-precision Global Positioning Systems (GPS) play a crucial role in autonomous drilling systems, providing accurate location data for precise control and monitoring of drilling operations. The use of advanced GPS technology enhances the efficiency, safety, and overall performance of autonomous drilling systems

Key aspects of high-precision GPS

- Positioning and Navigation
- Collision Avoidance
- Remote Monitoring and Control
- Path Planning and Optimization
- Drilling Zone Management

Drill-hole depth

1) Laser technology
2) String Encoders,
3) Wheel
4) Encoders, and
5) Magnetic Pulse

Drill-rig roll and pitch

Digital tiltmeters

Track speed

Track encoders

Drill-rotation velocity

1) Magnetic pickup on drill-drive gearbox, and
2) Flow meter on rotation hydraulic circuit

Tiltmeters

Disadvantages of Drill Automation

Although the advantages of automation are significant, there remain some disadvantages:

1) The automated drill is best suited to stable geology.
2) It can be slower than certain parts of the drill cycle as it maintains the level of accuracy required.
3) Sensor failure on the drill is common and could stop the whole system.
4) Detection of worn bits or drill-string failure can be difficult.
5) High-precision GPS may be difficult in deep pits and may require ground-based satellite augmentation.

Question 1

What is a key advantage of automation in surface blast-hole drill rigs compared to manual operation?

A) Lower productivity rates

B) Increased accuracy and repeatability

C) Greater manual control

D) Limited operational efficiency

Answer: B) Increased accuracy and repeatability

Question 2

What is essential for effective supervision of a drill rig when operated remotely?

A) Inadequate vision coverage

B) Limited use of prior geological knowledge

C) Adequate vision coverage

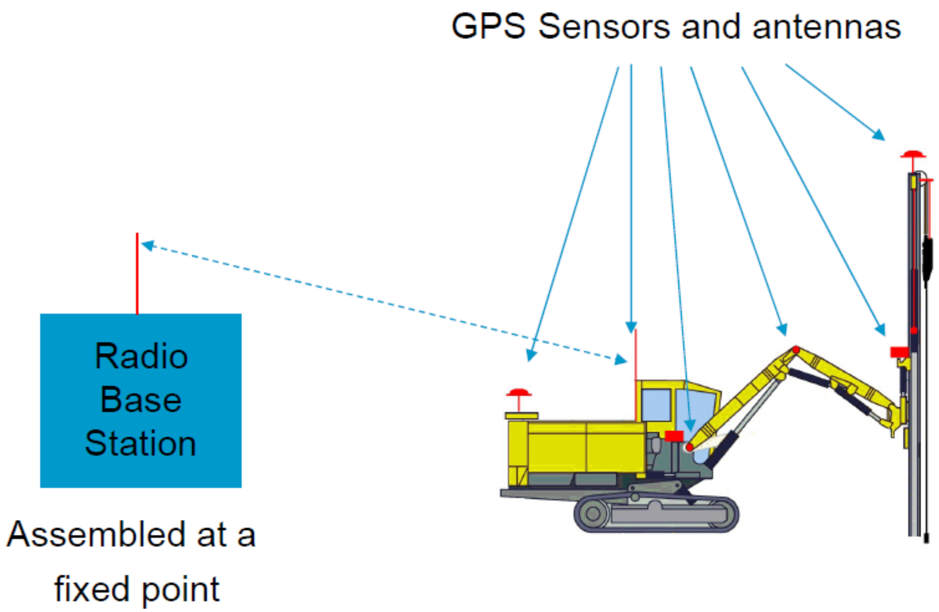
D) Complex movement path planning

Answer: C) Adequate vision coverage

Hole Navigation System (HNS)

The Hole Navigation System (HNS) is a key feature that enhances drilling efficiency by enabling faster setup, allowing for high-precision drilling in any weather conditions.

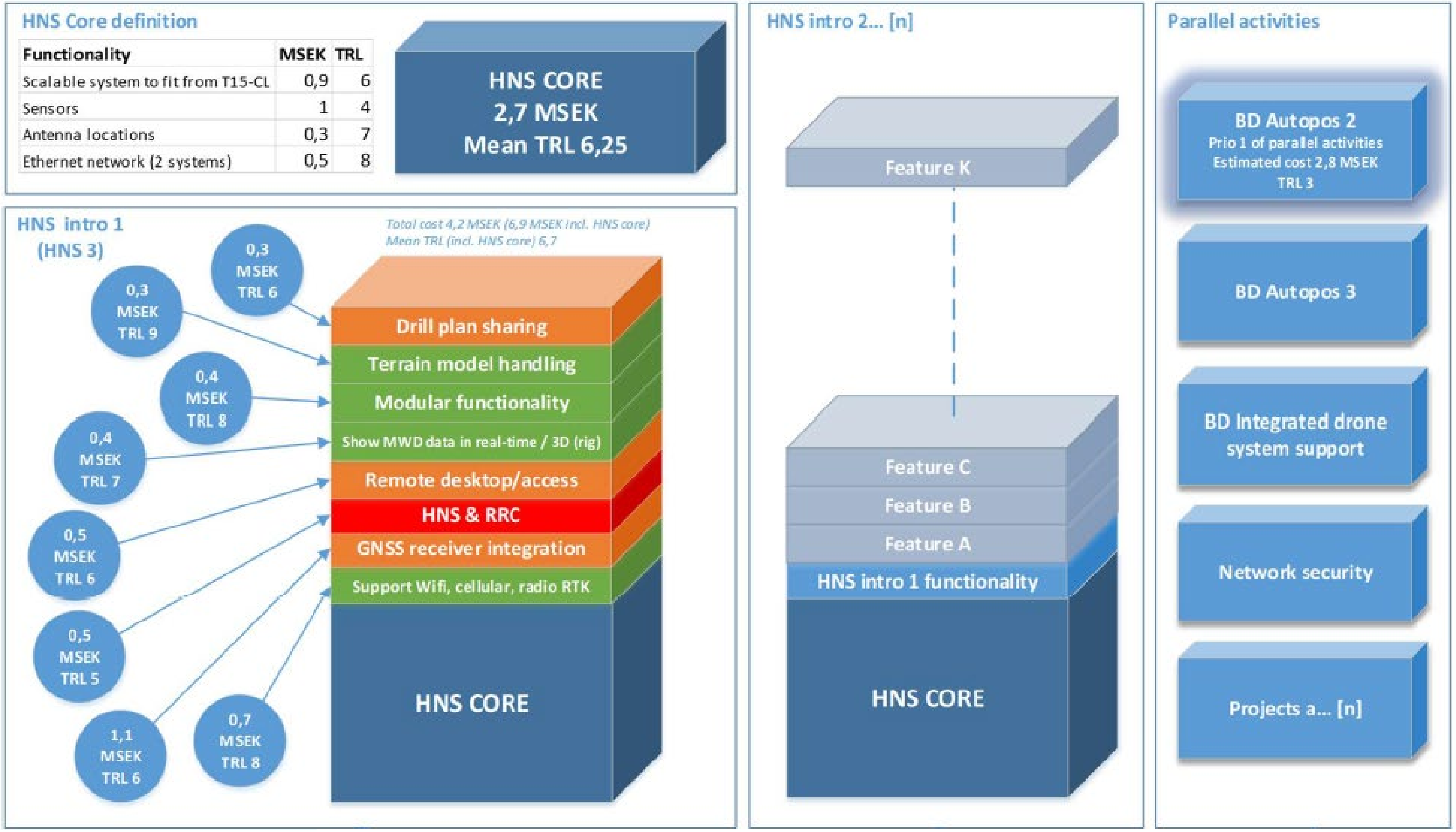
Hardware



- Base Station
- Moving Base Unit + Moving Base Antenna (receiver 1)
- Rover Unit + Rover Antenna (receiver 2)
- Radio Modem Unit + Radio Antenna
- Rig Inclinometer Sensor
- Boom Swing Encoder Sensor
- Boom Lift Encoder Sensor
- Boom Extension Encoder Sensor
- Feed Extension Encoder Sensor
- Feed Inclinometer Sensor
- Cradle Position Sensor
- Aim Device Angle Sensor
- ANMASK Display Unit

Extra sensors compared to a standard SmartROC

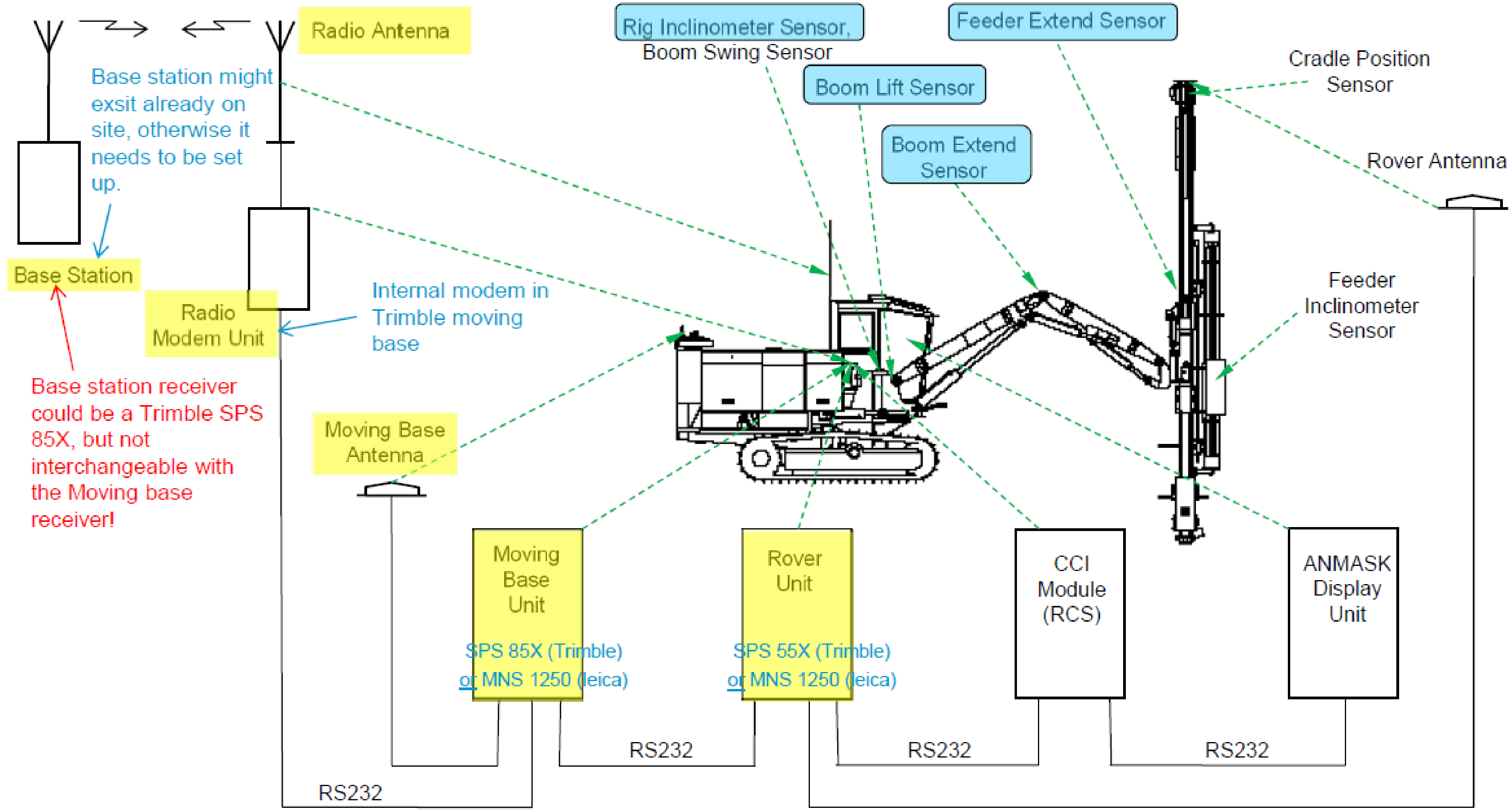
HNS hybrid solution



Epiroc HNS

Hardware location

New sensors compard to a standard SmartROC



Atlas Copco HNS

Base Station

- The base station is placed within the coordinate system and serves as a reference position for the rig to correct its positions, also known as RTK (real-time kinematic) fix.
- The base station is comprised basically of a GPS receiver and a radio unit.

working principle

During operation, the base station is sending out RTK data to the radio modem on the rig in order to correct the bit's position by adjusting the carrier phase frequency sent from the satellites.

Sensor Calibration

- Sensor calibration can be performed with the HNS system offline.
- If a Baseline error shows up during operation, it can serve as an indication that calibration is needed.

  Possible causes:

  - Sensor not calibrated
  - Different coordinate system in the receivers
  - Sensor error
  - Measurement error in the link model
- Calibration is also needed if the feed/boom has been exposed to heavy movements

Calibration of boom swing

For Volvo cabin

- **Set the boom swing straight forward in the longitudinal direction of the rig (measure with a roll-up measuring tape between the boom swing and cab until parallelity is achieved).**

For Bosal cabin

- **Use the boom pillar to make sure the alignment is right. Use the digital spirit level put it against the pillar and measure towards the boom making sure it is straight.**

Calibration of feed tilt and feed turn

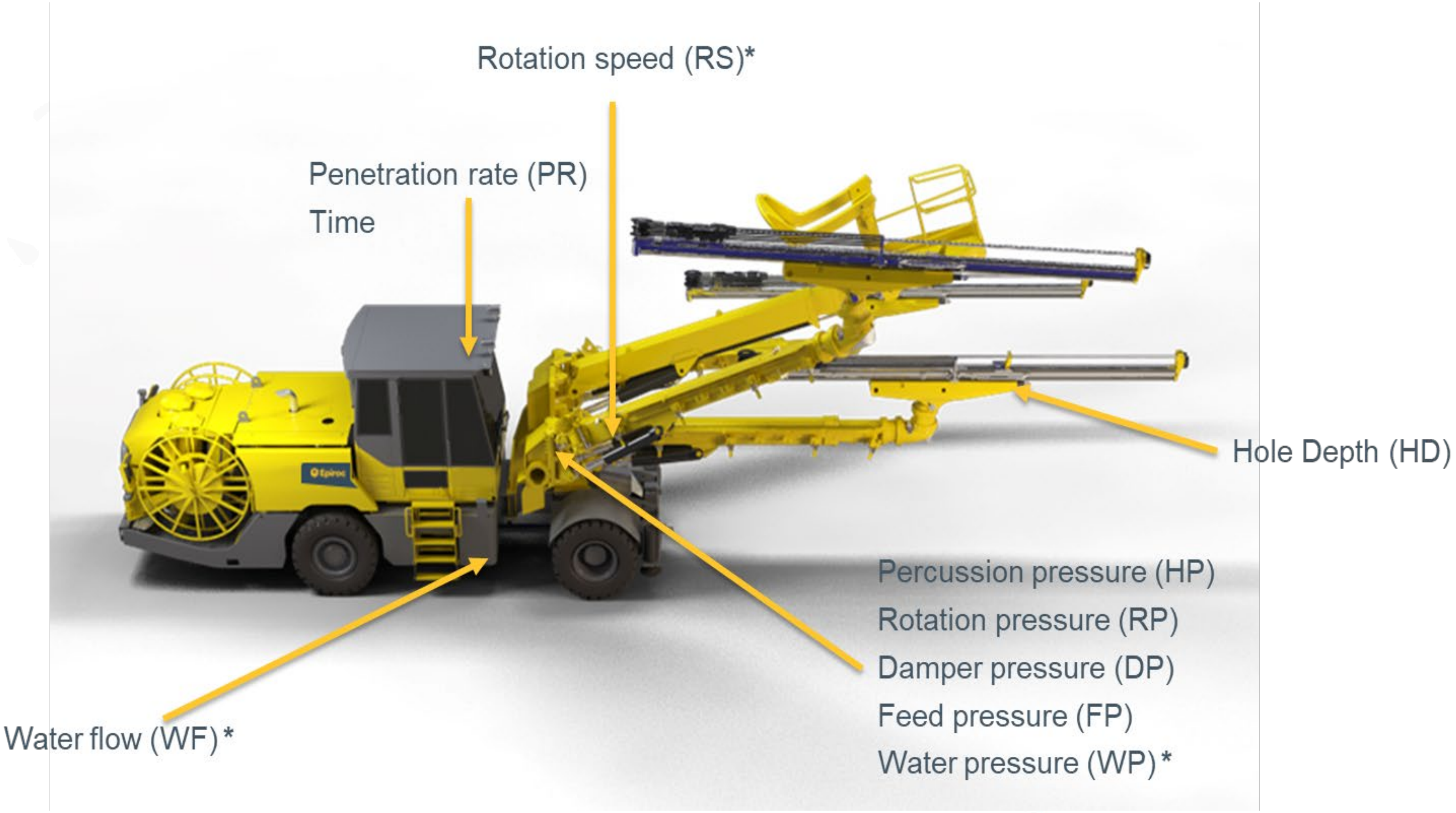
- Set the feeder in vertical position by positioning the feed tilt and feed turn to vertical position 0° using the electronic spirit level.

- Calibrate feed turn and feed tilt to 0 (zero) by pressing the calibration buttons for feed turn, and feed tilt respectively in the Calibration menu.

Measure While Drilling (MWD) Analysis

- **Measure While Drilling (MWD) is a method for identifying the properties in the rock by continuously recording all drilling parameters of importance during drilling.**

- **By means of analysis where operating variations due to the operator or the control system are removed, a detailed description of the mechanical properties of the rock, mass can be made.**


Rotation speed (RS)*
Penetration rate (PR)
Time
Hole Depth (HD)
Percussion pressure (HP)
Rotation pressure (RP)
Damper pressure (DP)
Feed pressure (FP)
Water pressure (WP) *
Water flow (WF) *

Epiroc MWD

MWD has several advantages:

- Very high degree of detail as data are recorded in all production holes.
- Very low cost as recording takes place automatically during normal production drilling.
- Very high data security as the recording takes place at the same time as drilling the hole and not afterward.
- Minimal disruption of production.

Role of autonomous drilling in the mining industry

- Operational Costs
- Fuel Efficiency

- Precision and Accuracy
- Continuous Operation

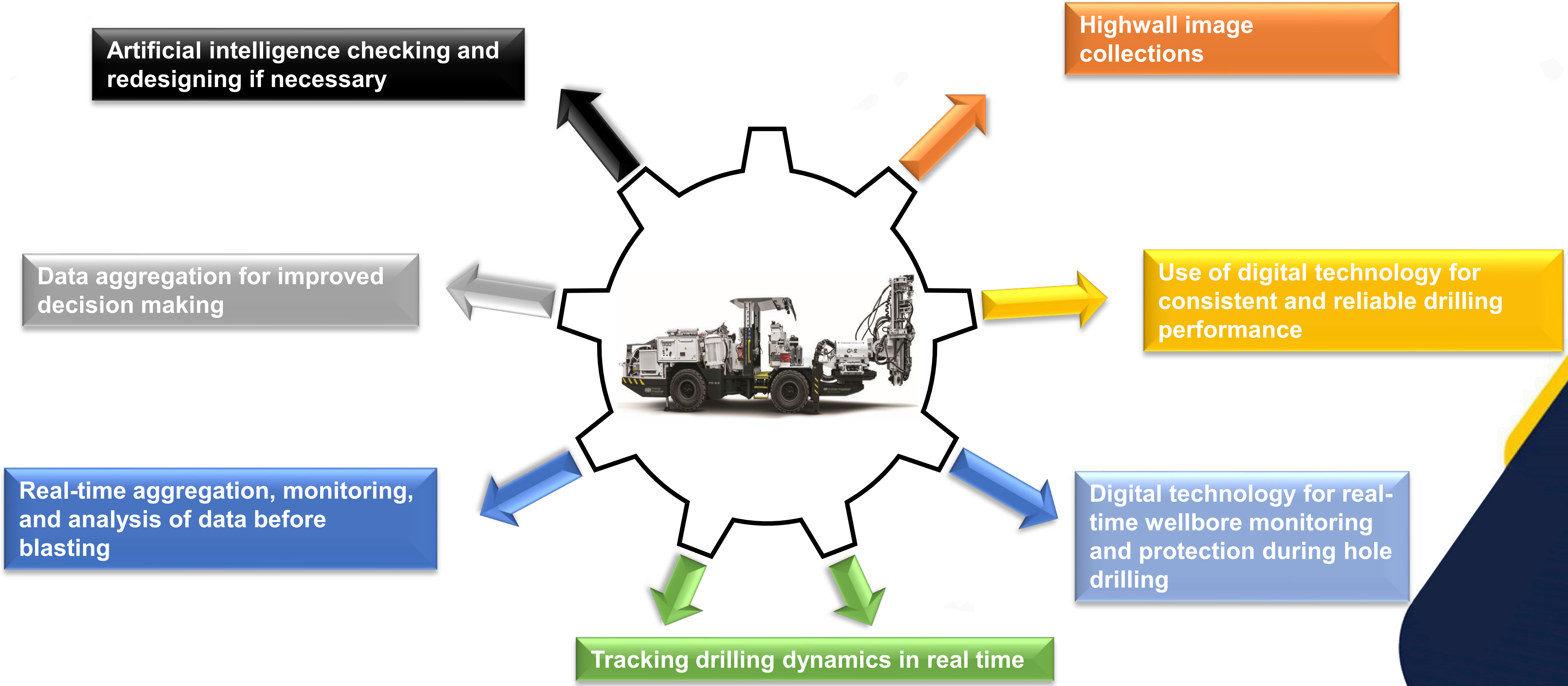
- Real-time Monitoring
- Predictive Maintenance

- Reduced Human Exposure
- Emergency Response

Automation drive drilling process

- The impact of digital technology on the entire drilling process, from highwall image collection to pre-blasting activity.
- Real-time monitoring of wellbores using digital technology during hole drilling for protection
- Utilization of artificial intelligence for tracking drilling dynamics in real-time and for verification and redesigning as needed
- Improved decision-making during the drilling process through data aggregation and thorough analysis before blasting

Automation drive drilling process



Challenges in Autonomous Drilling System

- Provision for Reliable Sensors in Extreme Conditions.
- Robust Wireless Communication for Remote Operations.
- Adequate vision coverage to supervise the rig remotely.
- Complex movement path planning.
- Integration with other mine equipment such as explosives trucks.

REFERENCES

- Bołoz, Łukasz, and Witold Biały. "Automation and robotization of underground mining in Poland." Applied Sciences 10.20 (2020): 7221, https://www.mdpi.com/2076-3417/10/20/7221
- https://www.google.co.in/books/edition/Rotary_Drilling_and_Blasting_in_Large_Su/3CLXF6PigB4C?hl=en&gbpv=0
- https://gamma.rocktechnology.sandvik/en/products/surface-drill-rigs/rotary-blasthole-drill-rigs/dr416i-rotary-blasthole-drill-rig/
- https://www.epiroc.com/en-us/products/drill-rigs/surface-drill-rigs/smartroc-d65
- https://www.flandersinc.com.au/drill-automation-products/
- https://www.google.co.in/books/edition/SME_Mining_Engineering_Handbook_Third_Ed/5uq-kdfHLWUC?hl=en&gbpv=0
- https://www.liebherr.com/en/usa/products/construction-machines/deep-foundation/digital-solutions/lipos/lipos.html#lightbox

REFERENCES

- Onifade, M., Adebisi, J. A., Shivute, A. P., & Genc, B. (2023). Challenges and applications of digital technology in the mineral industry. Resources Policy, 85, 103978, https://doi.org/10.1016/j.resourpol.2023.103978
- https://www.e-mj.com/features/advancing-art-of-autonomous-drilling/
- https://patentimages.storage.googleapis.com/bb/5d/5e/3732bf87c72ad6/US8836534.pdf
- HNS and MWD technical aspects in the drilling system taken from Atlas Copco and Epiroc websites.

Acknowledgment

We are grateful to TATA Noamundi Iron Ore Mines Management for sharing some of the information used in this lesson. We also acknowledge the help and material provided by the Executives of EPIROC working at TATA Noamundi mine site.

CONCLUSION

- Initiated with a foundational overview of drilling processes.
- Explored fundamental concepts underlying the drilling process.
- Introduced the concept of automated drilling systems, emphasizing technological advancements.
- Discussed the main systems of autonomous drill.
- Examined advantages such as efficiency and safety in adopting autonomous drilling.
- Explored the essential sensors integral to automated drilling systems.

CONCLUSION

- Introduced the Hole Navigation System, emphasizing its role in guiding drilling processes.
- Explored Measure While Drilling (MWD) analysis, highlighting its significance in real-time data collection during drilling operations.
- Explored the pivotal role of autonomous drilling in enhancing mining operations.
- Discussed how automation drives the drilling process, optimizing efficiency.
- Addressed obstacles and challenges in implementing autonomous drilling systems.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

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Module 02:
Autonomous Mining System

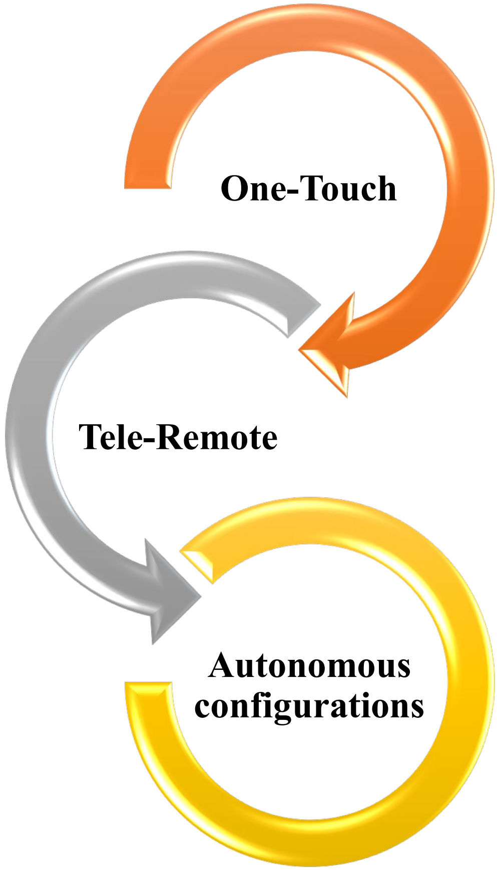
Lecture 04 (B):
Automated drilling system

CONCEPTS COVERED

- ARDVARC drill control system (ADS)
- ARDVARC drill control system operating modes
- ARDVARC system features
- Detailed overview of Autonomous Drill Rig
- Modes of Blasthole Drill Computerization
- Case studies of Autonomous Drilling System

Advanced rotary drill vector automated radio control (ARDVARC)

- The ARDVARC system includes



- Merges data management with One-Touch drill control for consistent performance.
- Operates up to 200m, enhancing safety by keeping the operator away from dangerous areas.
- Integrates automatic propel and positioning for remote autonomous operation while retaining One-Touch functionality.

- Drills within the system interpret pre-programmed blast designs and autonomously drill entire rounds with minimal or no human intervention.
- The system has the capability to anticipate and correct the drilling process.
- It provides comprehensive data on drill performance, health, strata mapping, and generates customized reports for maintenance and production.

ARDVARC Drill Control System Operating Modes

Semi-autonomous mode

- In semi-automated drilling, the machine operator manually guides the machine to each hole location.
- Initiating the One-Touch drill cycle is as simple as pressing a single button on the operator interface.
- The One-Touch drill cycle involves levelling, collaring, drilling, retracting the drill bit, and deploying jacks.

- After completing the cycle, the operator switches the machine to propel mode and moves to the next hole location, restarting the process.

- The operator retains the ability to take control of the automated drilling process at any time and can return the drill to autonomous mode.

- The ARDVARC system issues a message if the operator attempts an unauthorized action.

- These messages explain why the function cannot be completed and provide guidance on corrective actions.

Fully-autonomous mode

- The Autonomous system provides comprehensive autonomous control, incorporating hazard and obstacle detection and mitigation features, along with a remote monitoring station.
- With this system architecture, the operator can be relocated from the machine to a secure location.

- A single operator has the capability to monitor up to eight machines from a remote control room, only intervening to determine the sequence in which the pattern is drilled.

- This remote capability becomes particularly useful when drilling is required below an existing high wall or in proximity to the edge of a potentially unstable high wall.

ARDVARC System Incorporates Several Automation Features

Pipe-in-hole Protection

- Prevents the machine from entering propel mode when the drill bit is below the safe propel set point.
- Safeguards the drill string from bending.

Hole Quality Assurance

- Automatically detects the need for hole cleaning during the retraction phase.
- Measures the hole to ensure proper depth with each drilling cycle.

Hole Collar Quality Management

- Enables dynamic automated collaring to ensure collaring to competent ground.

All Stop

- Initiated when all machines currently in automated control mode need to be shut down.

Auto Levelling Functionality

- **Automatically levels the machine within +/-0.2 degrees on 95% of holes.**

Automatic Engine Shutdown

- **Initiates automatic shutdown in the event of a catastrophic system failure.**

Air Compressor Control

- **Regulates the air compressor's bit air pressure using electronic air regulation.**
- **Utilizes air pressure feedback to control bit RPM and pull-down pressure.**

Drill Energy Index

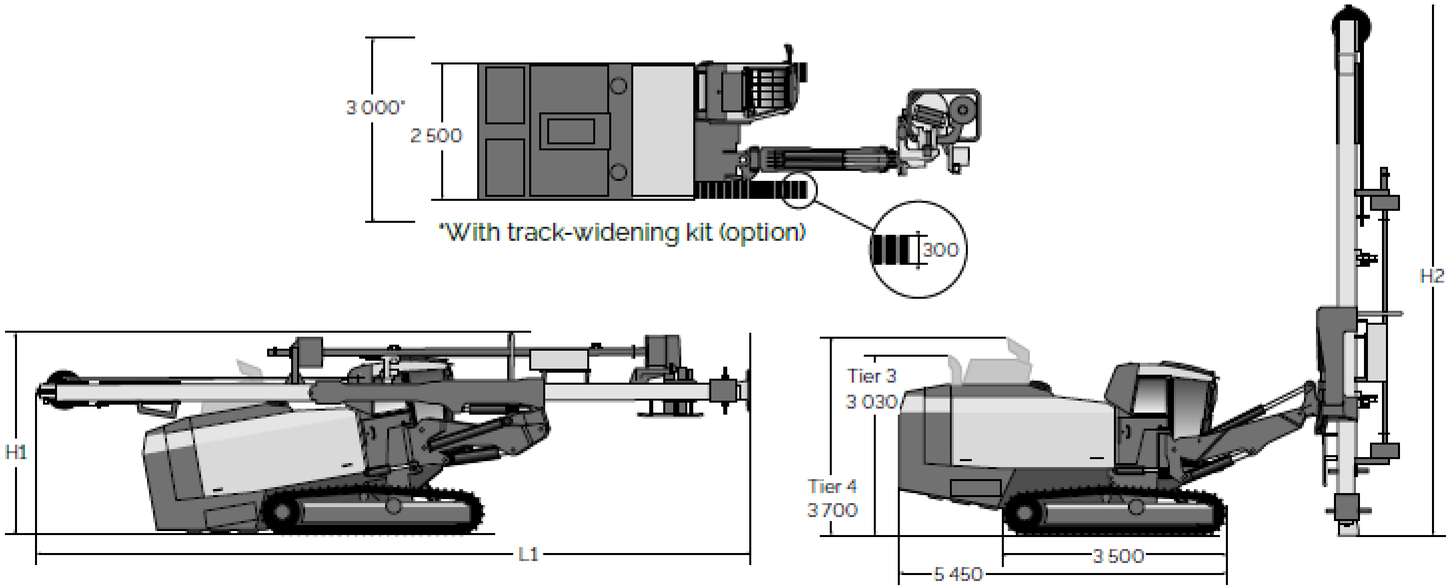
- **Dynamically adjusts drill parameters, such as pull-down and rotation.**

Detailed overview of Autonomous Drill Rig

Epiroc SmartROC D65

- The SmartROC D65 incorporates cutting-edge automation technology to facilitate drilling in various scenarios, including production blast, pre-split, and buffer holes.
- The drill offers reverse circulation options for in-pit grade control.
- The Hole Navigation System (HNS) is a key feature that enhances drilling efficiency by enabling faster setup, allowing for high-precision drilling in any weather conditions.

- The utilization of HNS helps in minimizing production costs by optimizing drilling and blasting operations, improving fragmentation, and reducing the quantity of explosives required.
- HNS eliminates the need for manual marking and surveying of hole positions, contributing to significant improvements in efficiency and safety on the bench.



Advantage SmartROC D65

Reduced Fuel Consumption

- The SmartROC D65 integrates intelligent control systems for compressor load and engine rpm, leading to a significant reduction in fuel consumption. This innovative approach ensures optimal energy utilization, promoting cost-effectiveness and environmental sustainability.

Rugged and Efficient Design:

- The SmartROC D65 is designed with ruggedness and efficiency, having high availability, and flexibility

Consistent Productivity through Automation

- **Automated drilling and rod handling features are key elements contributing to the SmartROC D65's ability to maintain consistent productivity.**
- **By automating these critical processes, the drill minimizes downtime, enhances operational efficiency, and ensures a steady workflow.**
- **This automation capability is pivotal in achieving reliable and predictable drilling outcomes.**

Sandvik DR416i Blasthole Drill

- **DR416i blast-hole drill offers a single-pass capacity of 21m or 69ft**
- **Specifically designed for large-diameter rotary drilling with pipe diameters ranging from 270–406 mm.**
- **The DR416i combines power and intelligence for efficient drilling operations.**
- **The drill offers a scalable solution, from onboard automation to fully autonomous operation.**
- **The drill is capable of fully autonomous operation, offering a high level of automation.**

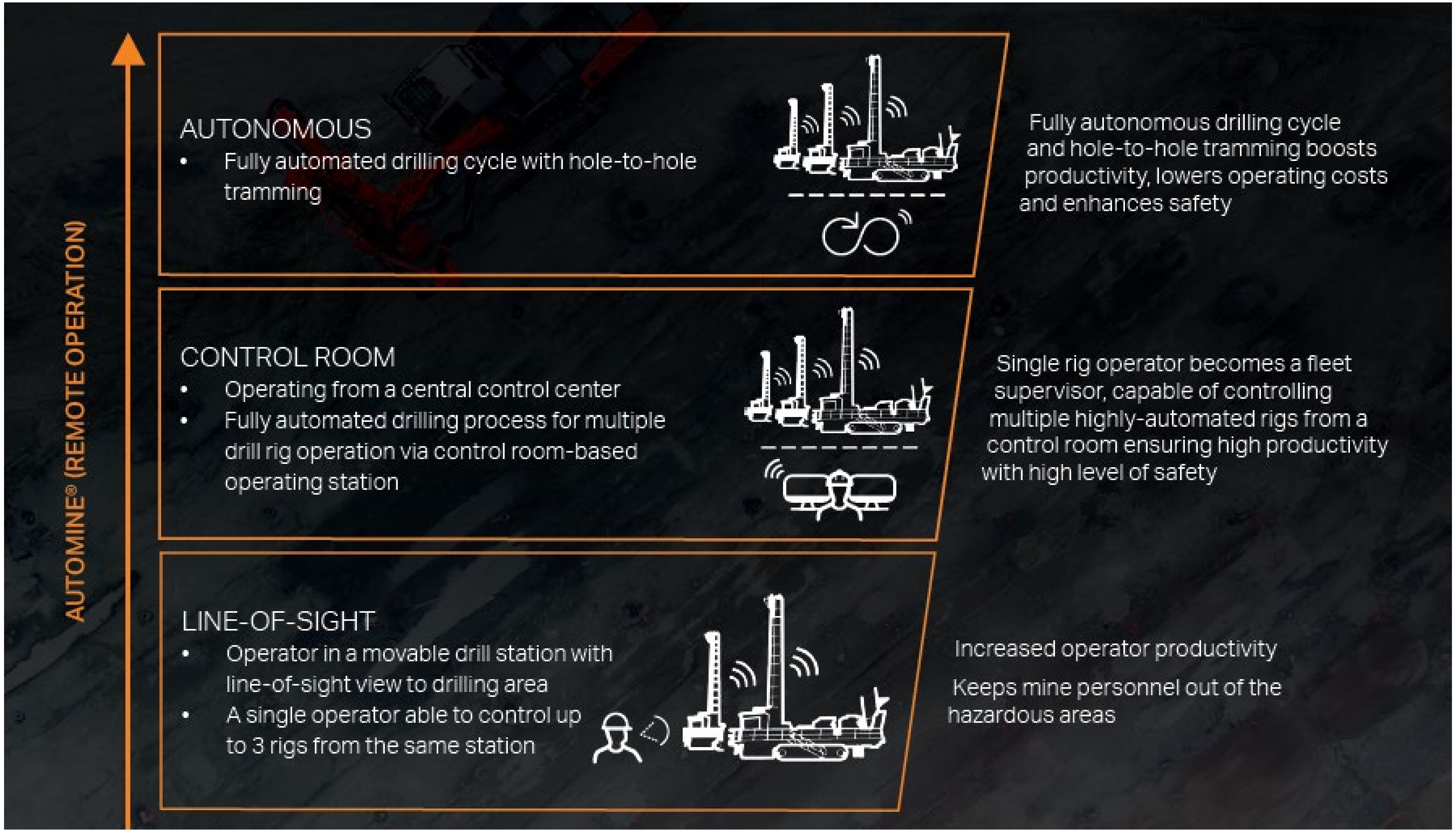
Key Features

AUTOMATION

1) iDrill Performance produces consistently clean, precision-drilled holes delivering improved fragmentation, downstream throughput, and asset utilization.
2) iDrill Navigation provides accurately and safely positions the rig in the correct location to produce clean holes, improving blast accuracy, fragmentation, and downstream throughput.

OPERATOR ENVIRONMENT

1) Full Visibility of Drilling Operation
2) Ergonomically-Designed Shock Mounted Cab
3) Function Lockout Fail-Safe Programming
4) Touchscreens for Ease of Operation



Sandvik Automine

Question 1

What is the role of Hole Quality Assurance in the ARDVARC system?

a) Enabling dynamic collaring

b) Initiating all-stop mode

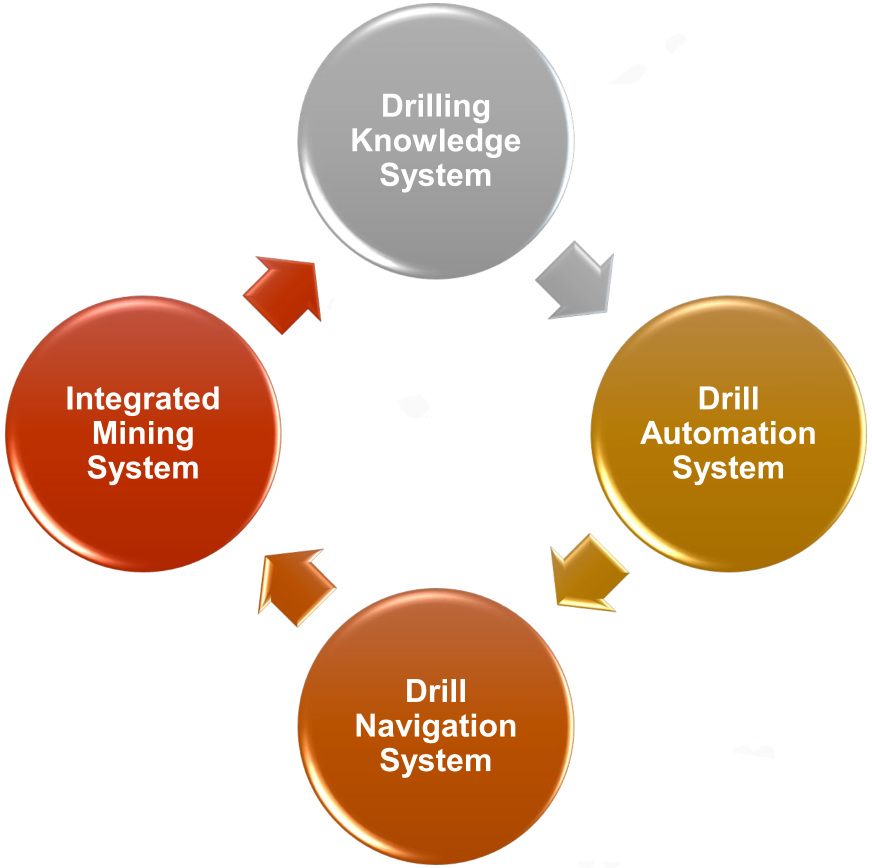
c) Detecting the need for hole cleaning during retraction

d) None of these

Answer: c) Detecting the need for hole cleaning during retraction

Modes of Blasthole Drill Computerization

Full-fledged computerization of a blast hole drill usually consists of four subsystems as follows



Drilling Knowledge Systems

- The objective, is to get data about the drilling operation and the material being drilled.

Drill Automation System

- The objective of a drill automation system is to introduce automation in various activities to be carried out in a drilling cycle. Means of introducing automation in rod handling, levelling, and drilling have been in existence for a long time.

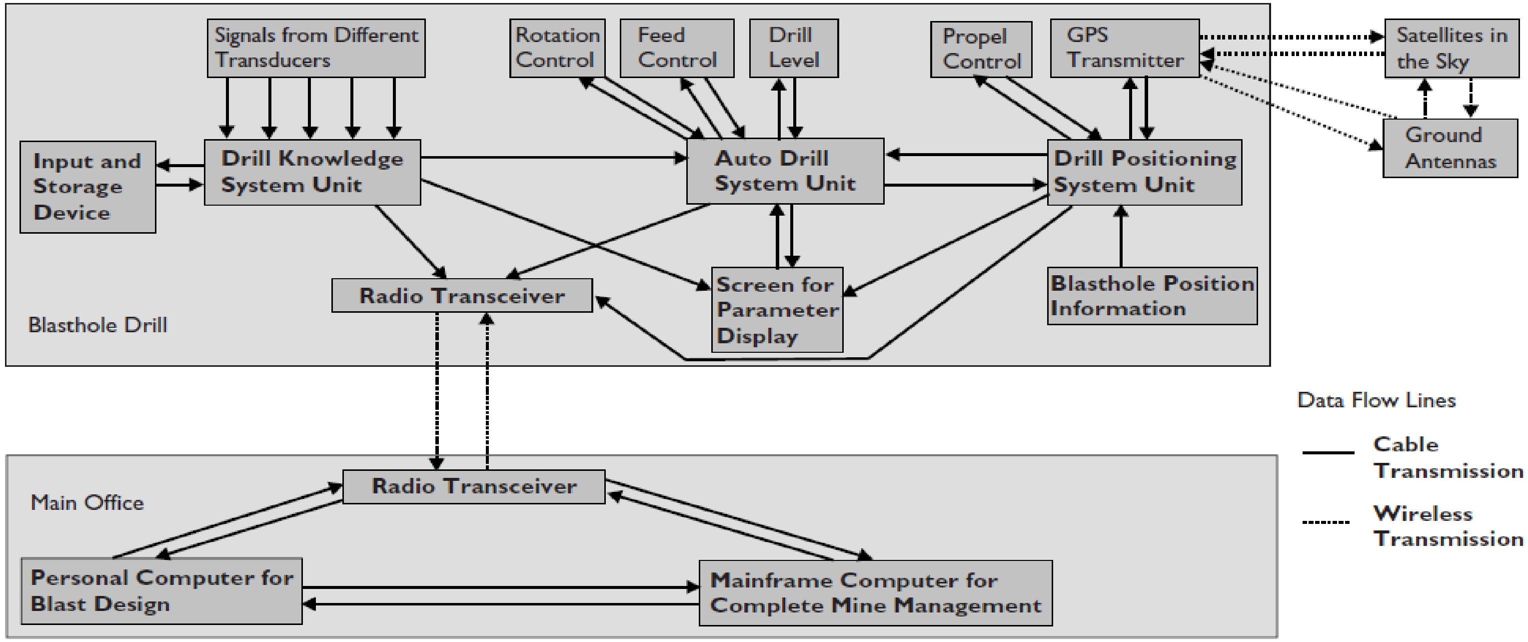
Drill Navigation System

A aims at automating the tramming activity of the drilling cycle.

Integrated Mining System

Finally, the ultimate objective of controlling all the operations of all the equipment used in the mine. To achieve this, it is essential to channel some output from the drilling activities to the activities of other mining equipment.

For computerization of the entire mining operations through an integrated mining system, many other pieces of production equipment in the mine, such as shovels, dumpers, wheel loaders, draglines, dozers and other blasthole drills must be equipped. Very specialized software must be used to coordinate and control all this equipment. This software needs improvements and modification from time to time.



Schematics of data flow in rotary blasthole drill equipped with drill knowledge, auto drill and GPS positioning system.

Question 2

What is required for the computerization of the entire mining operations through an integrated mining system?

A) Exclusion of certain production equipment

B) Inclusion of specialized software

C) Limited coordination between equipment

D) Ignoring improvements in software

Answer: B) Inclusion of specialized software

Case study 1

Introduction

- Mine Master, in partnership with the AGH University of Science and Technology, has successfully developed two innovative modular drilling machine monitoring systems. These systems are the result of their combined expertise and aim to significantly enhance productivity in drilling processes.

Case study 1

System Development

Collaborative Effort

The development of the monitoring systems stemmed from the collaborative efforts between Mine Master and AGH University, leveraging their collective experiences in drilling process automation.

Modular Design

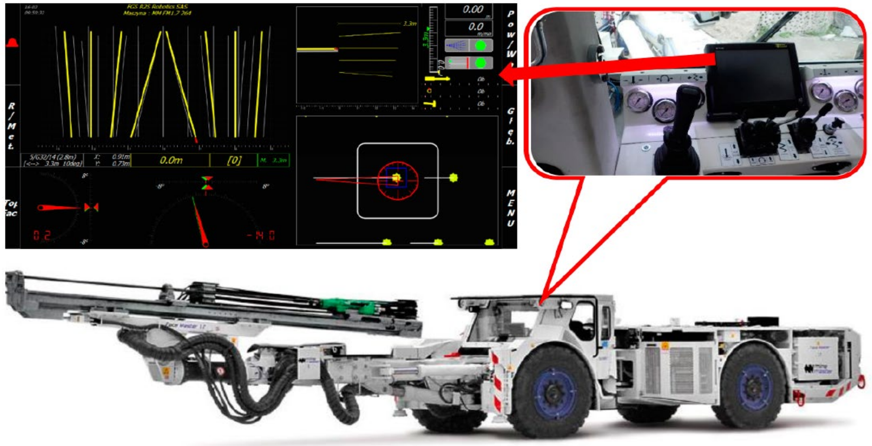
The monitoring systems were strategically designed with a modular approach, allowing for flexibility and adaptability to different drilling scenarios.

Case study 1

Initial Focus: Face Master 1.7 Drill Rigs

Drilling Parameter Monitoring

- **The initial phase focused on monitoring drilling parameters and drilling frame settings for Face Master 1.7 drill rigs. This was crucial for aligning the drilling process with the assumed blasting pattern, optimizing efficiency.**



Case study 1

Diagnostic Systems Implementation

- **As a natural progression, diagnostic systems were integrated to monitor the drive system and hydraulic system of the machines. This step further enhanced the overall monitoring capabilities of the drilling systems.**

Impact on Productivity

Decisive Impact

The monitoring systems were specifically designed to have a decisive impact on achieving the assumed productivity levels. By providing real-time insights and control, these systems contribute to optimized drilling operations.

Case study 1

Comprehensive Machine Control

Drilling Process Control

The monitoring systems offer control over the drilling machines not only during the drilling process but also extend to transportation to and from the workplace. This includes navigation on roads with a slope of up to 15 degrees, ensuring seamless machine operation across various terrains.

Case study 2 - West Angelas Iron Ore Mine

Introduction

Automating surface blast-hole drill rigs has proven to be a game-changer, delivering superior accuracy and repeatability compared to manual operation. Remote supervision enables a single operator to control multiple drills simultaneously.

Case study 2

Precision and Repeatability

Automation ensures drilling accuracy and repeatability, matching manual productivity levels while reducing errors.

Field Trials

Trials on an 80-ton Terex SKSS16 drill equipped with an automated system demonstrated substantial improvements in accuracy compared to manual operation.

Case study 2

Comparative Analysis

Over a 9-week period, the remotely supervised drill, utilizing the automated system, outperformed manual drills by completing over 90% of all holes in automation mode.

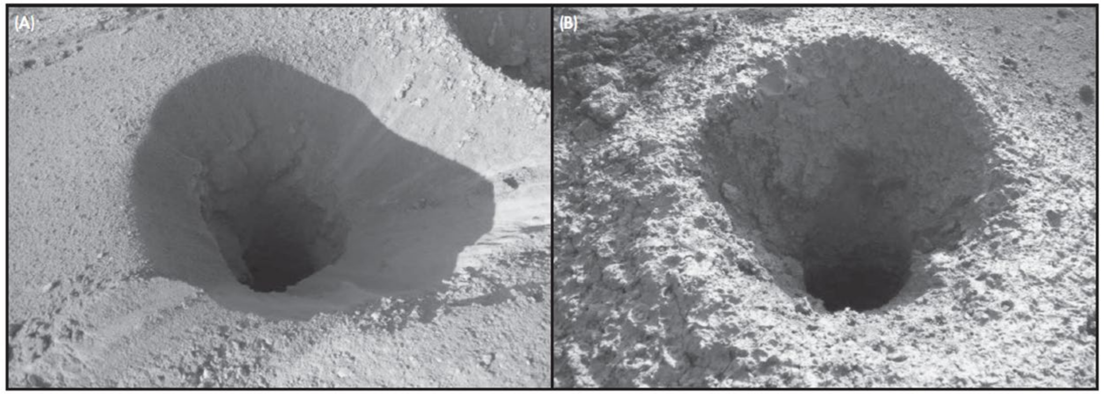
Training Efficiency

Automating drilling approaches reduces training time for new operators, enabling them to reach proficiency comparable to expert drillers

Case study 2

Geological Stability

The automated drill maintains stability in varying geological conditions, adapting drilling techniques for consistent performance.



Source: McHugh 2009.

Figure Comparison of drill collars between (A) manual and (B) automated drill holes

The automated drill, as depicted in the figure, demonstrates the ability to maintain a stable collar in the given geological conditions by appropriately injecting the correct amount of water

REFERENCES

- Bołoz, Łukasz, and Witold Biały. "Automation and robotization of underground mining in Poland." Applied Sciences 10.20 (2020): 7221, https://www.mdpi.com/2076-3417/10/20/7221
- https://www.google.co.in/books/edition/Rotary_Drilling_and_Blasting_in_Large_Su/3CLXF6PigB4C?hl=en&gbpv=0
- https://gamma.rocktechnology.sandvik/en/products/surface-drill-rigs/rotary-blasthole-drill-rigs/dr416i-rotary-blasthole-drill-rig/
- https://www.epiroc.com/en-us/products/drill-rigs/surface-drill-rigs/smartroc-d65
- https://www.flandersinc.com.au/drill-automation-products/
- https://www.google.co.in/books/edition/SME_Mining_Engineering_Handbook_Third_Ed/5uq-kdfHLWUC?hl=en&gbpv=0
- https://www.liebherr.com/en/usa/products/construction-machines/deep-foundation/digital-solutions/lipos/lipos.html#lightbox

CONCLUSION

- Introduced the ARDVARC Drill Control System.
- Explored various operating modes of the ARDVARC system.
- Highlighted the multiple automation features integrated into the ARDVARC system.
- Detailed overview of autonomous drill rigs, highlighting the technological components and functionalities that contribute to their autonomy in drilling operations.

CONCLUSION

- Examined the various modes employed in the computerization of blasthole drills, illustrating the adaptability and versatility of these systems in different drilling scenarios.
- Discussed two case studies of autonomous drilling systems.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 02:
Autonomous Mining System

Lecture 05 (A):
Fleet Management System

CONCEPTS COVERED

- Fleet Management System (FMS)
- Aim of Fleet Management System (FMS)
- Advantages of Fleet Management System
- Disadvantages of Fleet Management System
- Fleet Management Systems: A Global Perspective

CONCEPTS COVERED

- FMS Workflow
- Fleet Management Systems Work Setups
- Types of Fleet Management Systems
- Benchmark Truck Dispatching Model

Fleet Management System (FMS)

A fleet management system in a mining operation is a decision-making system that makes real-time decisions for handling material in a surface mine. FMS obtains the required information regarding the status of the operation from the database and makes decisions accordingly. The decisions are then implemented in the operation and the FMS is called again whenever a new decision is required.

Aim of Fleet Management System (FMS)

Aim of Fleet Management System (FMS)

Optimizing Mine Production

- The fleet management system (FMS) is essential in the mining sector. It focuses on optimizing mine production.
- Utilizes real-time data for making informed decisions.
- Aims to enhance overall output in the mining industry.

Real-time Data Utilization

- The FMS's primary function is leveraging real-time data.
- Involves collecting and analyzing information as it becomes available.
- Enables quick adjustments and improvements in operational efficiency.

Minimizing Stock Handling

- **Essential objective of the FMS: Minimize stock handling.**
- **Aims to reduce operational costs.**
- **Ensures a streamlined and efficient workflow in mining operations.**

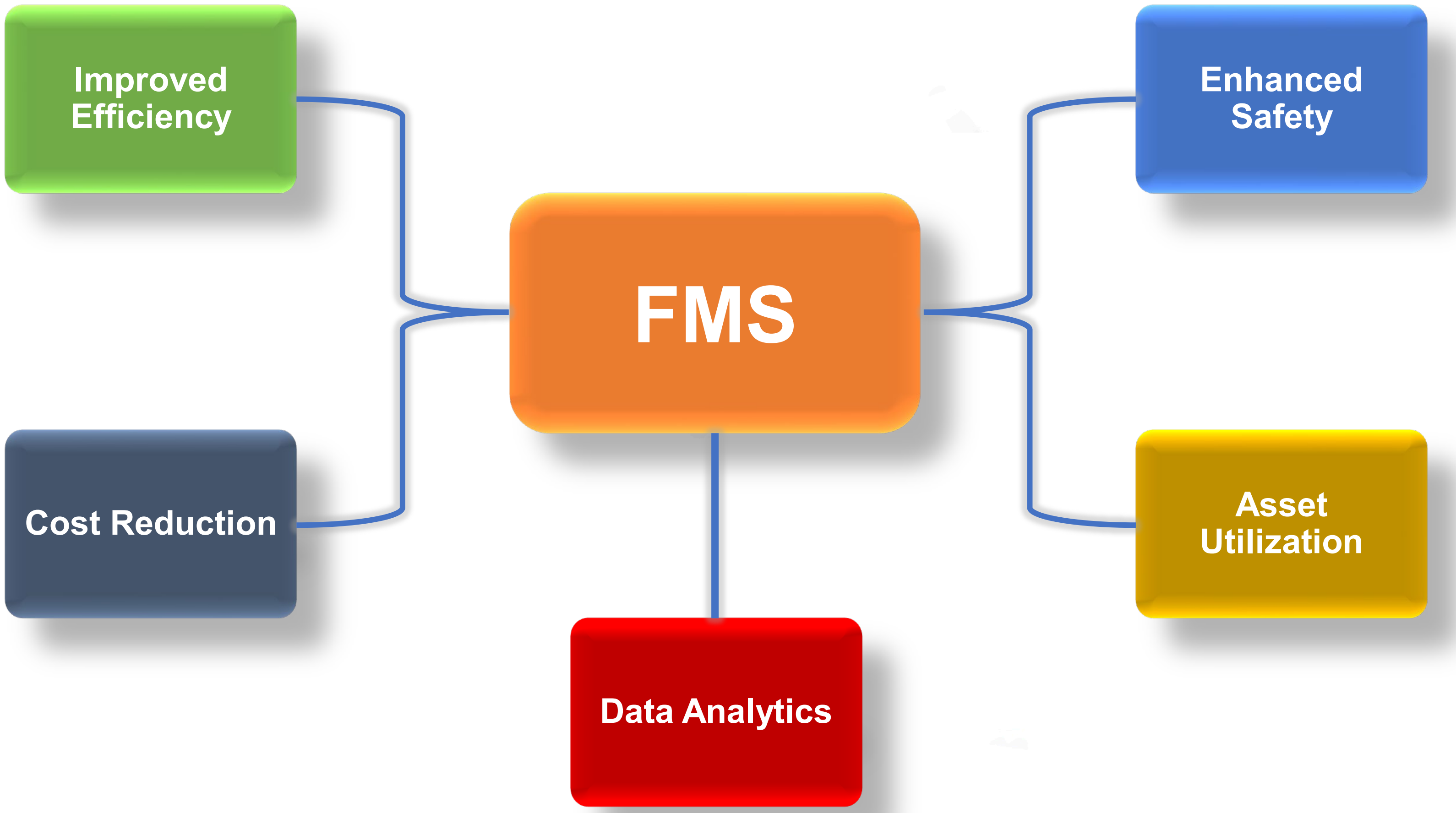
Maintaining Planned Processing Rates

- **FMS designed to ensure processing plant receives materials at planned rate.**
- **Aims to avoid bottlenecks in the production process.**
- **Contributes to a more consistent and predictable workflow.**

Quality Mixing Constraints

- FMS addresses meeting quality mixing constraints.
- Involves managing and controlling material composition.
- Aim is to meet specific quality standards.
- Ensures final product meets required specifications.

Advantages of Fleet Management System



Improved Efficiency

- Real-time monitoring allows for better coordination of mining activities.
- Optimized route planning and scheduling lead to reduced idle time and increased operational efficiency.

Cost Reduction

- Fuel consumption can be optimized by monitoring and controlling vehicle speed and engine performance.
- Maintenance costs can be minimized through predictive maintenance and condition-based monitoring.

Enhanced Safety

- Real-time tracking and monitoring contribute to better safety management.
- Proactive alerts and warnings can prevent accidents and improve overall safety.

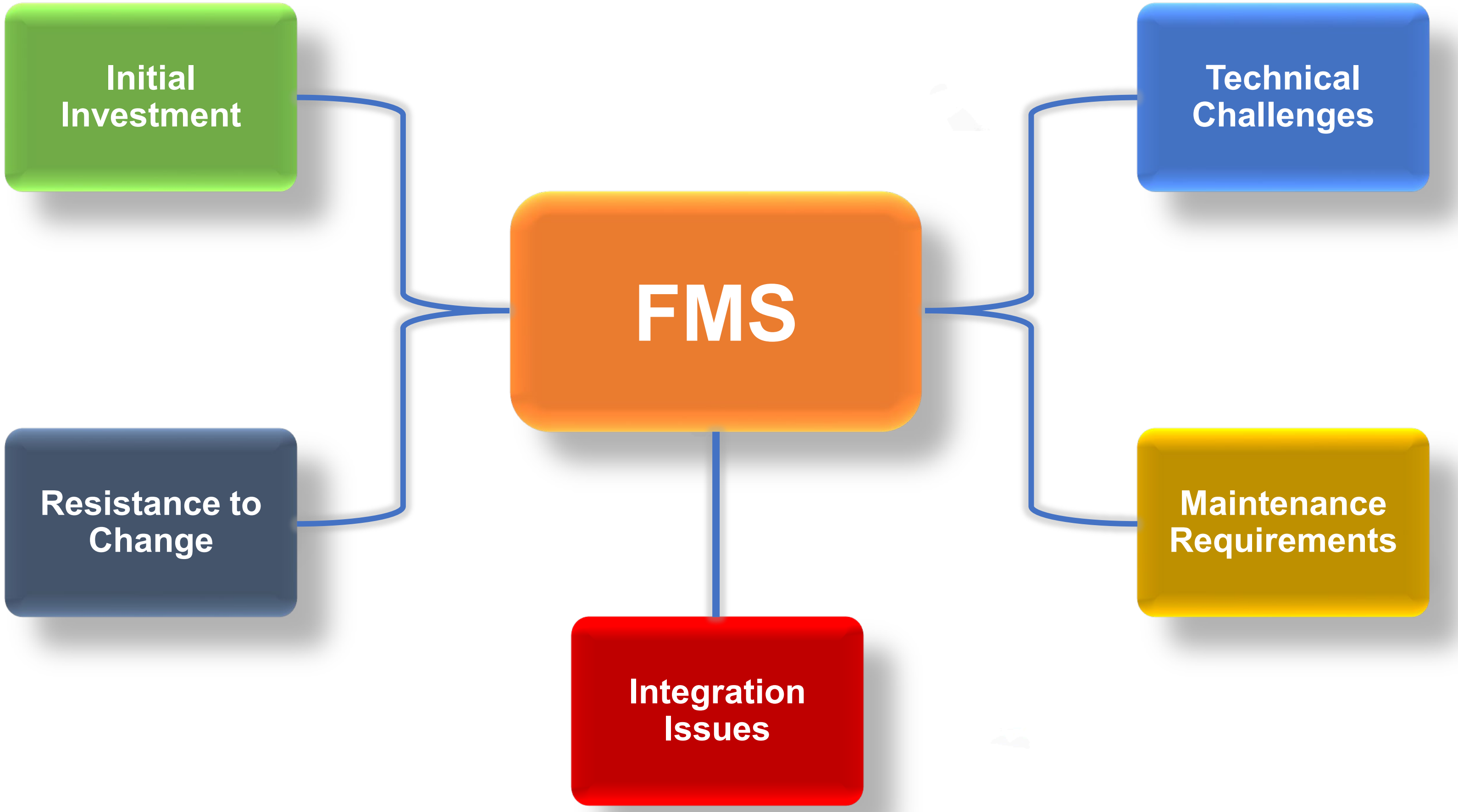
Asset Utilization

- Optimal use of equipment and vehicles, reducing downtime and increasing overall productivity.
- Improved allocation of resources based on real-time data.

Data Analytics

- Data collected by the FMS can be analyzed to identify trends, patterns, and areas for improvement.
- Informed decision-making based on accurate and up-to-date information.

Disadvantages of Fleet Management System



Initial Investment

- **Implementation of a Fleet Management System involves significant upfront costs, including hardware, software, and training.**

Resistance to Change

- **Employees may resist the adoption of new technologies, leading to challenges in implementation and training.**

Technical Challenges

Technical issues such as system malfunctions, software glitches, or connectivity problems can disrupt operations.

Maintenance Requirements

The system itself requires regular maintenance and updates to ensure optimal performance, adding to ongoing costs.

Integration Issues

Integration with existing systems and processes may pose challenges, leading to potential disruptions during the implementation phase.

Question 1

What does the fleet management system do with the information obtained from the database?

a) Archives it for historical analysis

b) Collaborates with other industries

c) Utilizes it for employee evaluations

d) Makes real-time decisions accordingly

Answer: d) Makes real-time decisions accordingly

Fleet Management Systems: A Global Perspective

Leading Providers

Noteworthy companies include Modular Mining Systems, Jig-saw Software, Wenco, and Dynamine TATA Services Consulting.

Complex Demands Addressed

Their solutions are designed to meet the intricate demands of contemporary mining operations

Commonly Adopted Systems

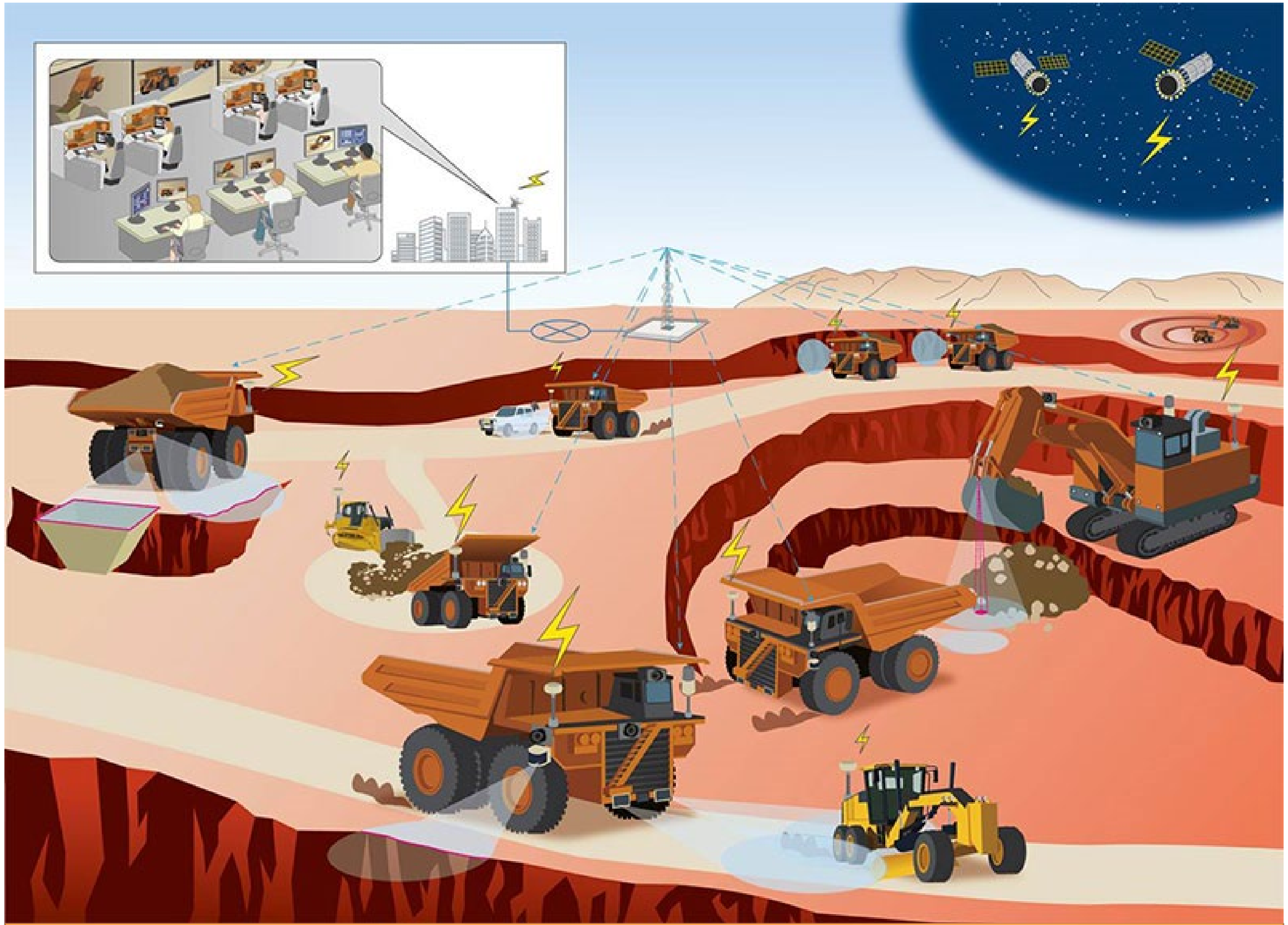
Micromine Pitram, Viste, and CAT® MineStar emerge as the most widely adopted fleet management systems

Evolutionary Significance

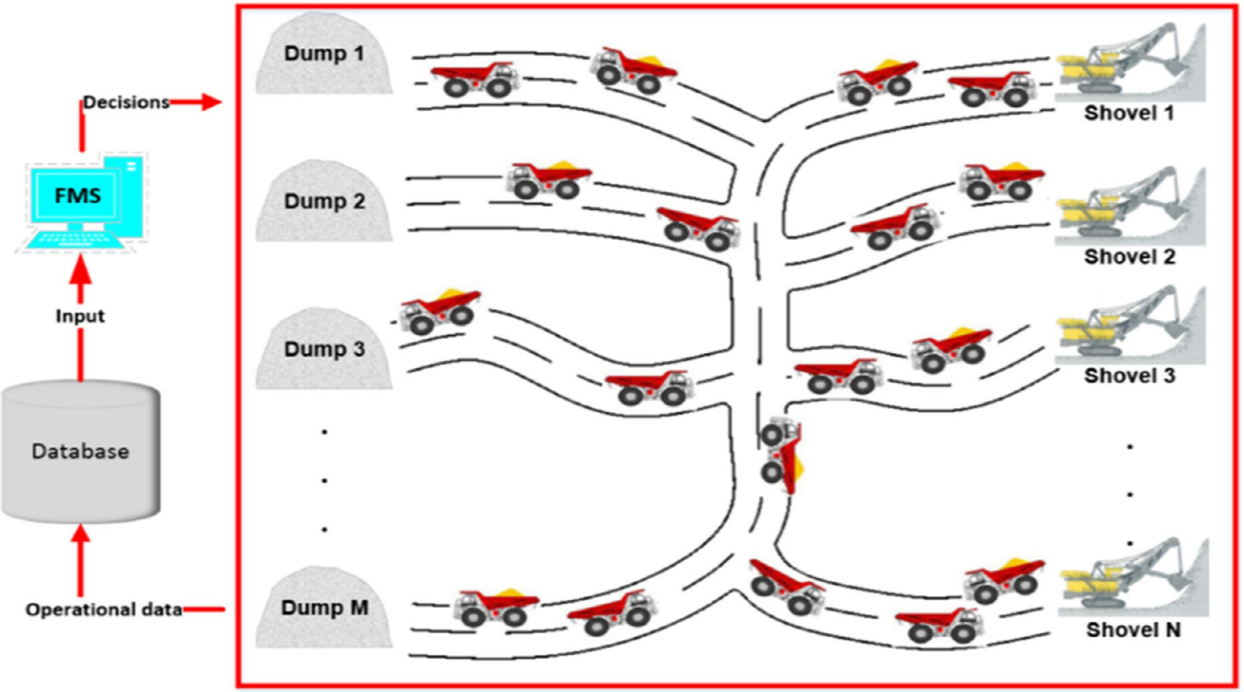
As the mining industry evolves, these solutions play a crucial role in shaping and defining modern mining operations.

FMS Workflow

- A Fleet Management System (FMS) for a mine site is a suite of specialized software running on ruggedized hardware.
- Using GPS and a wireless radio network, the FMS tracks and monitors production, maintenance, and safety in mine.
- At the top, we have the control center, connected to the wireless network and a GPS satellite network. The wireless network sends signals to equipment, which is fitted with onboard computers. The equipment sends back data including location, payload, ore quality, cost codes, etc.



Fleet Management System Workflow



Schematic of the surface mining operation and how it communicates with the FMS.

Main decisions to be made by the FMS is to dispatch trucks to the shovels. This decision should be made in a way that meets the production requirement with the minimum deviation and maximizes the productivity of the active equipment, including both loaders and transporters.

Question 2

How does the Fleet Management System prioritize the dispatch of trucks to shovels?

a) By choosing the shovels with the shortest route

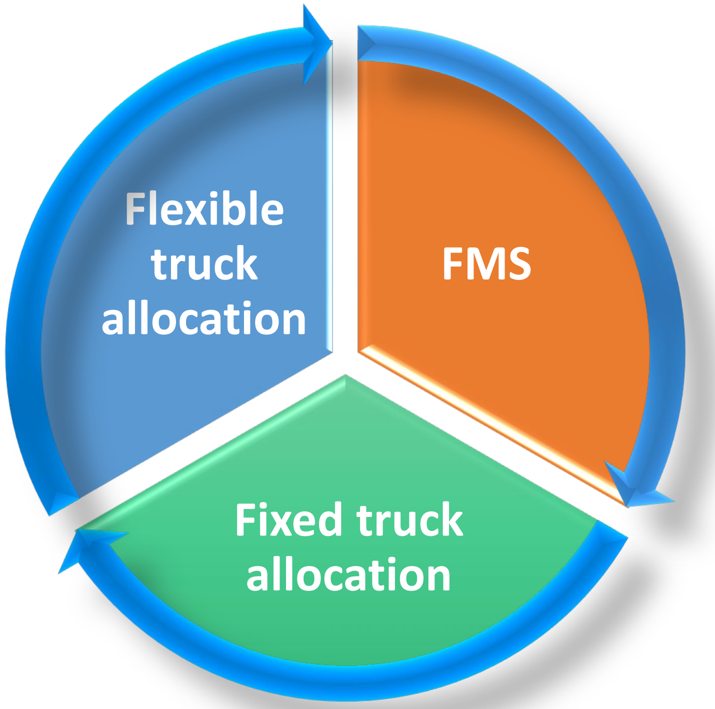
b) Randomly selecting trucks for dispatch

c) Ensuring the trucks are arranged by colour

d) Meeting production requirements with minimal deviation and maximizing equipment productivity

Answer: d) Meeting production requirements with minimal deviation and maximizing equipment productivity

Fleet Management Systems Work Setups



Fixed Truck Allocation

- At the beginning of each shift, a set of trucks is assigned to specific transportation routes.
- Allocation is based on various criteria, including production requirements and the availability of trucks in the fleet.
- Trucks remain locked to their designated paths throughout the shift period.
- Path assignments are typically static unless there is a breakdown or a critical event occurs.
- This method provides stability but lacks adaptability to changing conditions.

Criteria for Allocation

- Allocation decisions are influenced by factors such as production needs and the availability of trucks.
- The criteria for assigning trucks to specific paths aim to optimize efficiency and resource utilization.

Base Method for Performance Evaluation

- The fixed truck allocation method serves as a foundational approach for evaluating the performance of other algorithms and operational strategies.
- Researchers use it as a benchmark to assess the effectiveness and efficiency of proposed modifications and innovations in mining logistics.

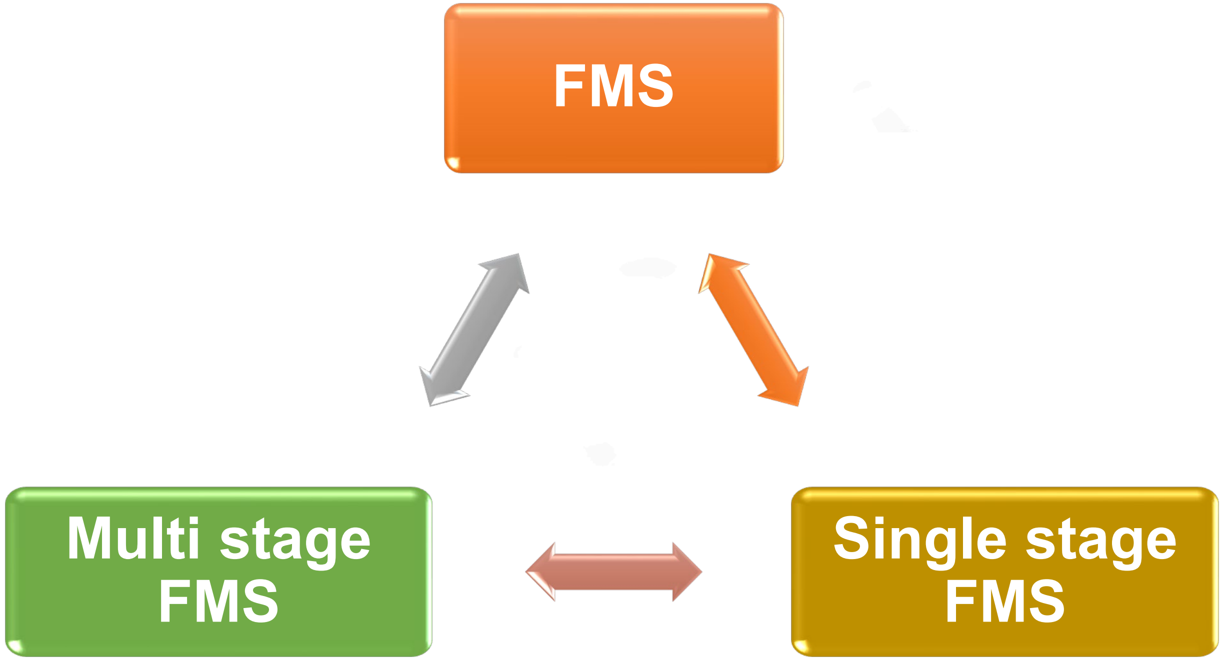
Flexible Truck Allocation

- Flexible truck allocation involves assigning a number of available trucks in the fleet to a specific working shovel at the beginning of the shift.
- Unlike traditional allocation methods, these trucks are not dedicated to a single shovel or route during the shift.
- Instead, they receive new assignments from the dispatching system after loading at shovels and tipping at dumping destinations.

- Flexible truck allocation has been shown to significantly improve the productivity of mining operations.
- It has been reported a 13% increase in production at the Bougainville Copper Mine through the use of flexible truck allocation.
- The Barrick Goldstrike Gold mine experienced a 10–15% improvement in productivity, and a 10% growth in iron ore production was observed.

- Additionally, the Quintette Coal mine reported a 10% increase in production with flexible truck allocation.
- A simulation study of the Sungun Copper mine operation, demonstrating an 8% increase in mine productivity with the implementation of a flexible allocation strategy compared to a fixed allocation.

Types of Fleet Management Systems



Single Stage FMS

Shortest Path Identification

The single-stage Fleet Management System (FMS) is designed to identify the shortest paths connecting loaders to their respective destinations.

Optimal Trip Calculation

It determines the optimal number of truck trips needed for each available path, optimizing efficiency and minimizing travel time.

Historical Significance

Hauck developed FMS in 1973, represents one of the earliest instances of this technology, and operates on a single-stage approach, contributing to the foundational development of Fleet Management Systems.

Multi Stage FMS

Most mining Fleet Management Systems (FMS) adopt a multi-stage approach for their operation.

Sequential Sub-Problems

The multi-stage approach involves solving three sequential sub-problems, with each stage building upon the solution of the previous one.

a.) Shortest Path Identification

- The first sub-problem focuses on finding the shortest paths that connect all the sources to their respective destinations.

b.) Optimal Material Production

- In the second stage, the goal is to determine the best possible amount of material to be produced for each identified path.

c.) Truck Dispatching

- **The final sub-problem involves dispatching trucks to shovels based on the solutions obtained from the previous stages, completing the multi-stage process.**

Visualization

The process is depicted in Figure, illustrating the interconnected nature of the three sequential sub-problems in the multi-stage approach.

Benchmark Truck Dispatching Model

- The real-time dispatching model in the benchmark FMS is the backbone of Modular Mining DISPATCH.
- The model follows the m-trucks-for-1-shovel strategy.
- In the m-trucks-for-1-shovel strategy, m trucks that need to be assigned in the near future are considered for one needy shovel.
- The model requires two lists: the list of needy shovels and the list of available trucks.

- The list of needy shovels, which are the operating shovels behind their production schedule, is ordered based on the next time a needy shovel needs truck assignment.
- The list of available trucks is ordered based on their next availability.
- The first truck in the available trucks list is assigned to the shovel on top of the needy shovels list.
- After the first truck is assigned, the shovel moves to the bottom of the list.
- The model repeats the same procedure until all available trucks are assigned to the needy shovels.

REFERENCES

- Bnouachir, H., Chergui, M., Machkour, N., Zegrari, M., Chakir, A., Deshayes, L., ... & Medromi, H. (2020). Intelligent fleet management system for open pit mine. International Journal of Advanced Computer Science and Applications, 11(5), 327-332.
- Chaowasakoo, P., Seppälä, H., Koivo, H., & Zhou, Q. (2017). Improving fleet management in mines: The benefit of heterogeneous match factor. European journal of operational research, 261(3), 1052-1065, https://doi.org/10.1016/j.ejor.2017.02.039
- Moradi Afrapoli, A., & Askari-Nasab, H. (2019). Mining fleet management systems: a review of models and algorithms. International Journal of Mining, Reclamation and Environment, 33(1), 42-60. https://doi.org/10.1080/17480930.2017.1336607
- Afrapoli, A. M., Tabesh, M., & Askari-Nasab, H. (2019). A multiple objective transportation problem approach to dynamic truck dispatching in surface mines. European Journal of Operational Research, 276(1), 331-342. https://doi.org/10.1016/j.ejor.2019.01.008

CONCLUSION

- Explored the fundamental concepts of Fleet Management Systems, emphasizing their role in optimizing the operations of vehicle fleets.
- Defined the objectives and goals of a Fleet Management System, illustrating how these systems contribute to enhancing efficiency, safety, and overall fleet performance.
- Discussed the advantages and disadvantages of FMS and its importance.
- Provided an overview of the workflow within a Fleet Management System, detailing the processes involved in monitoring, tracking, and managing a fleet of vehicles.

CONCLUSION

- Classified and discussed different types of Fleet Management Systems, showcasing the diversity and adaptability of these systems to meet specific industry needs.
- Introduced a benchmark model for truck dispatching within Fleet Management Systems, emphasizing best practices and efficiency benchmarks.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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MINE AUTOMATION AND DATA ANALYTICS

By

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Module 02:
Autonomous Mining System

Lecture 05 (B):
Fleet Management System

CONCEPTS COVERED

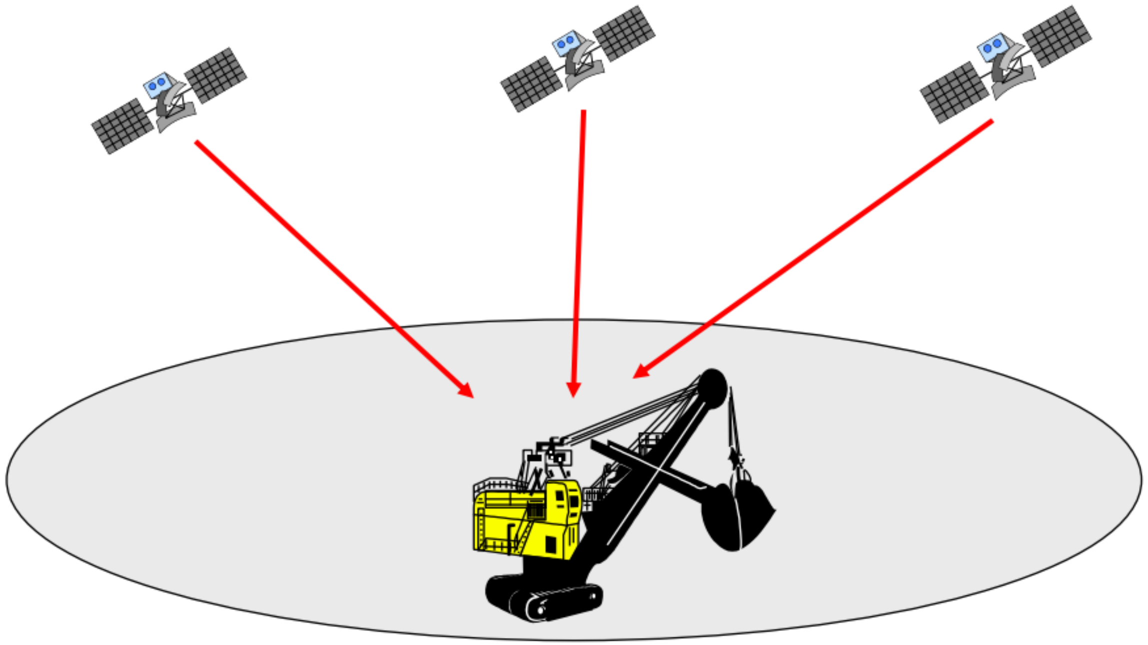
- Fleet management system (FMS) operation
- Mining supply chain with a fleet management system
- Industrial Fleet Management Systems
- Shortest path system

CONCEPTS COVERED

- Production optimization system
- Real-time dispatching
- Industrial mine fleet management systems examples
- Dynamine fleet management systems

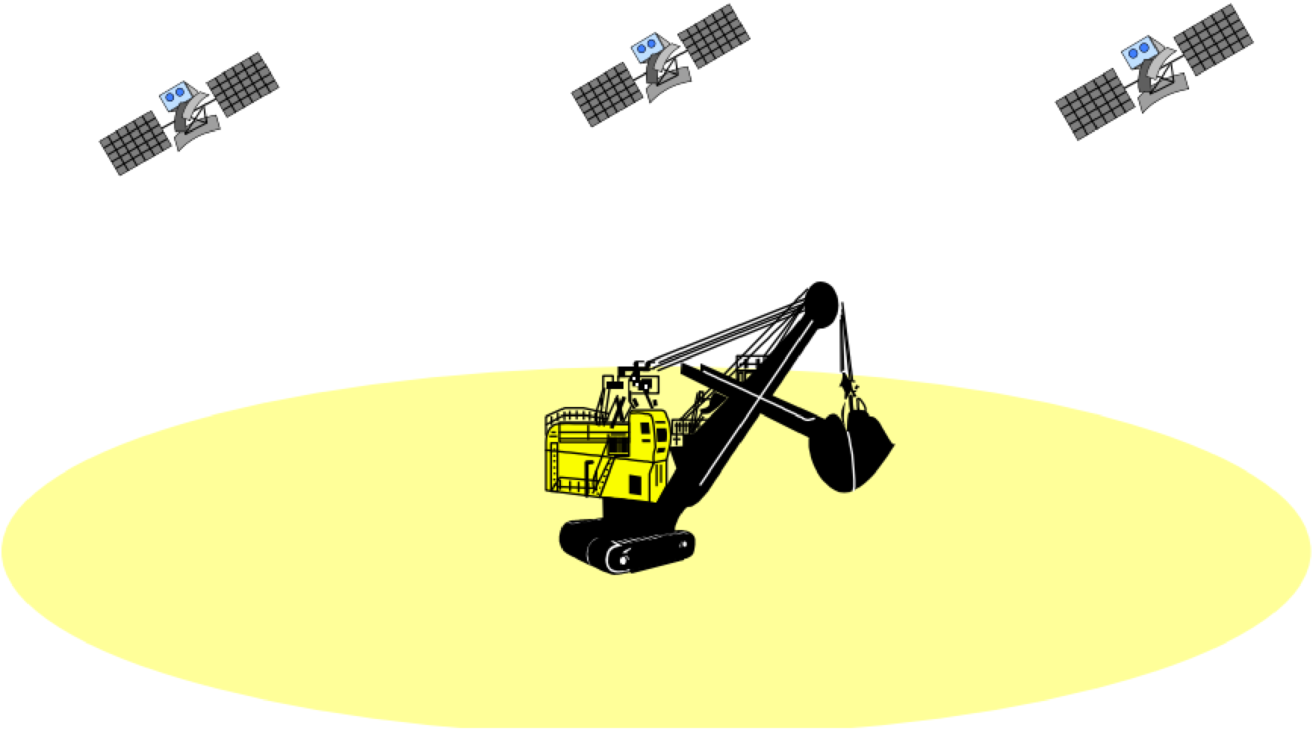
Fleet management system (FMS) operation

1.) GPS identifies the exact position of the loading machine.



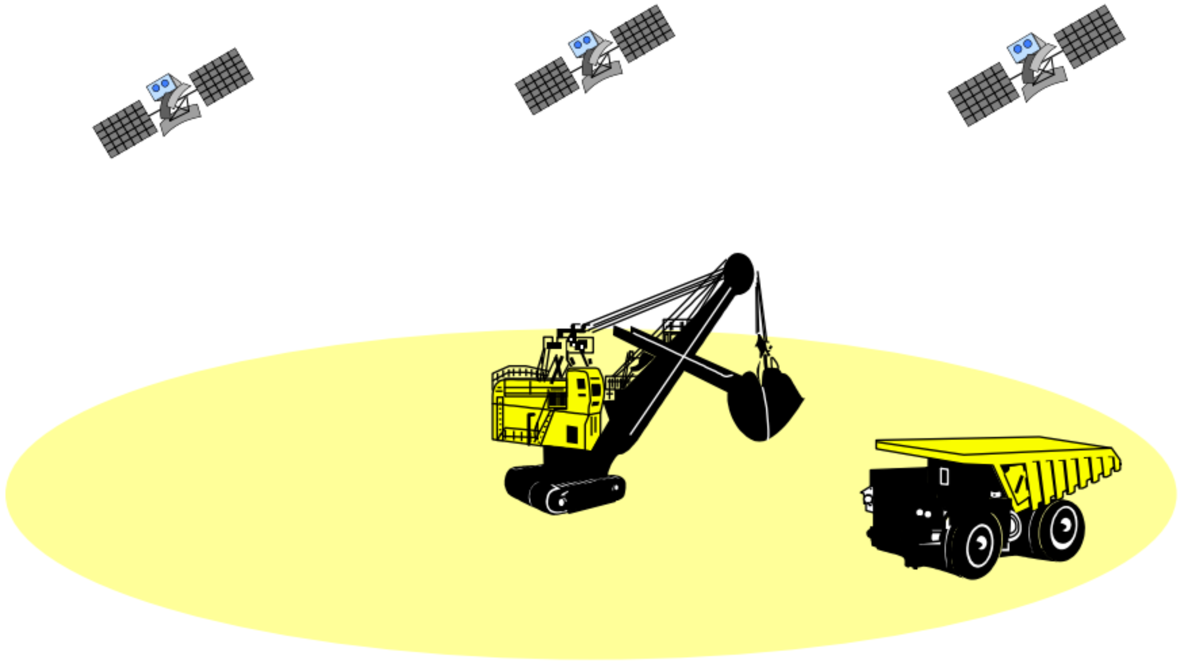
Fleet management system (FMS) operation

2.) Using the GPS position as a center point, the FMS System defines a “Waiting Zone” around the loading machine.



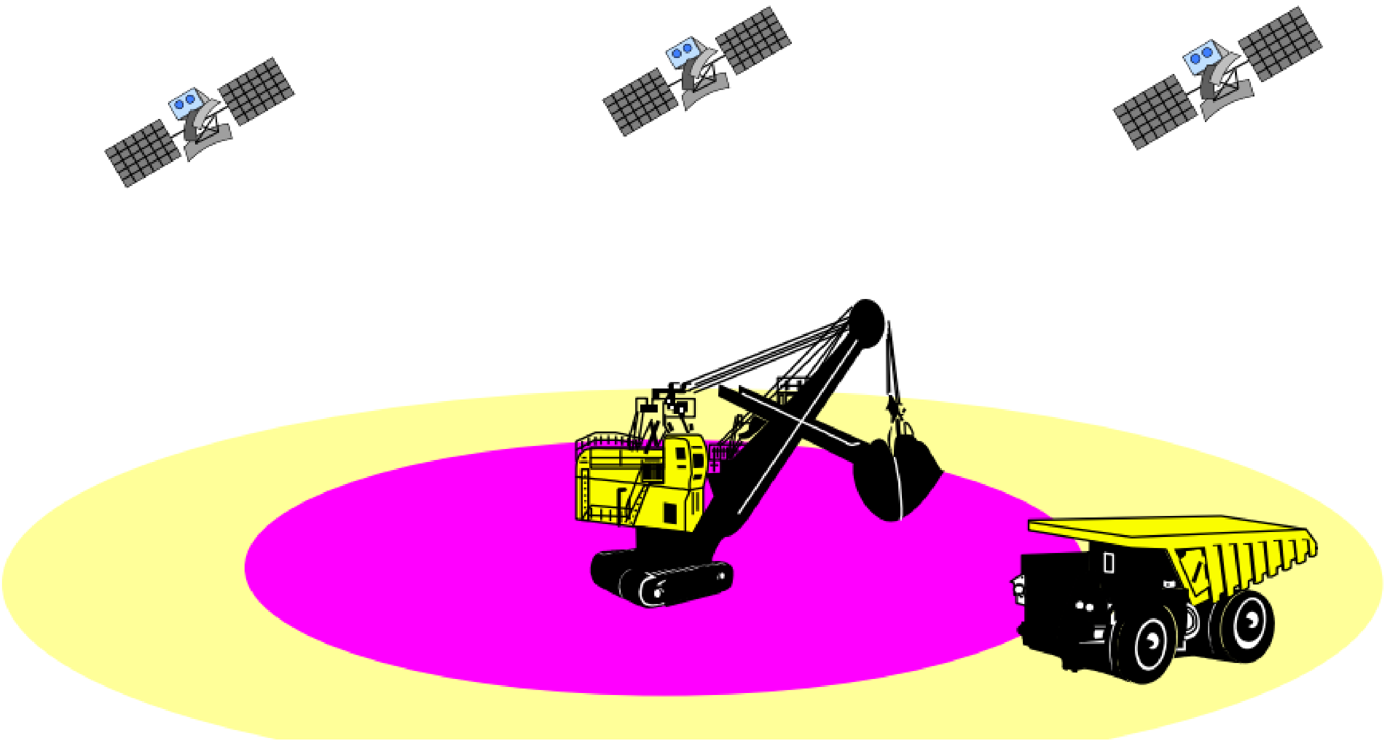
Fleet management system (FMS) operation

3.) When a truck enters the Waiting Zone and stops, its status automatically changes to Waiting.



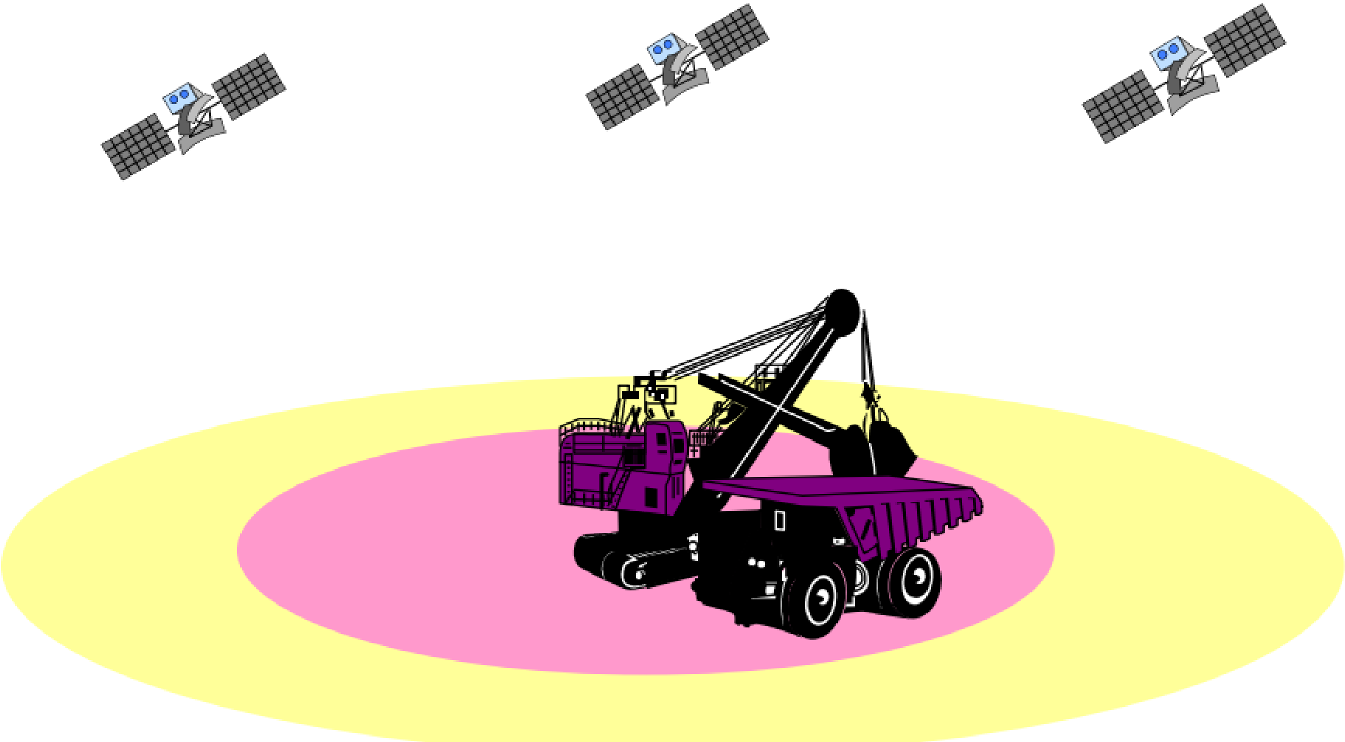
Fleet management system (FMS) operation

4.) The software also defines a smaller, virtual zone inside of the Waiting Zone. It is called the "Loading Zone".



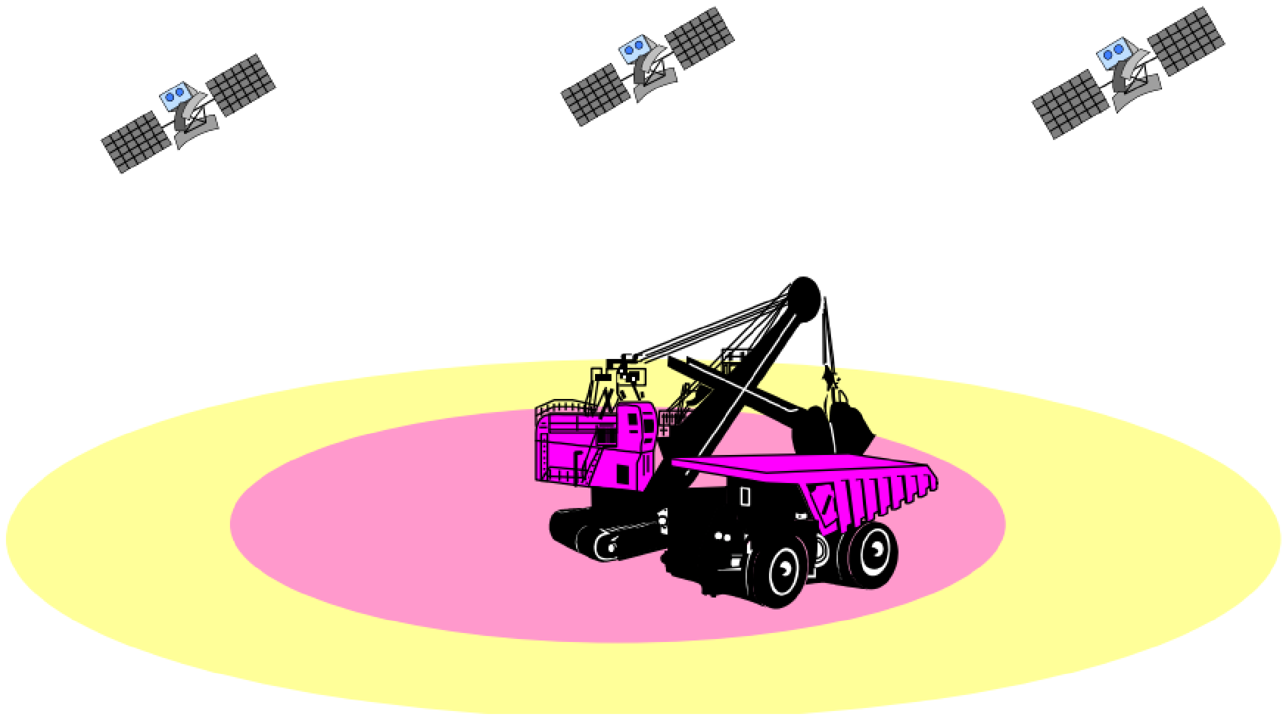
Fleet management system (FMS) operation

5.) When the truck enters the Loading Zone, its status and that of the loading unit automatically change to Spotting.



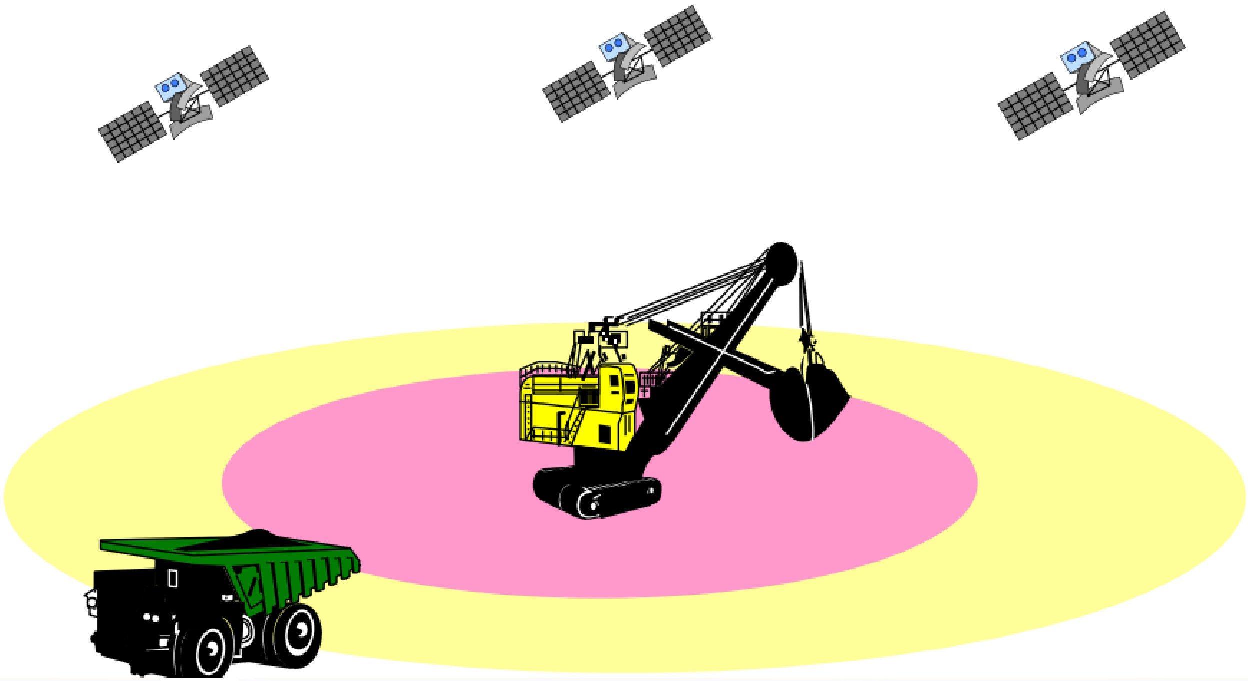
Fleet management system (FMS) operation

6.) When the truck Stops, its status and that of the loading unit automatically change to Loading.



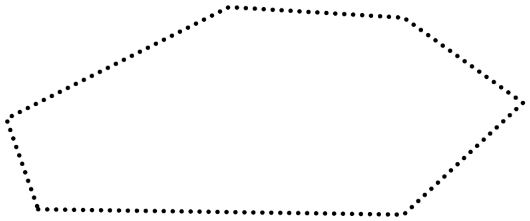
Fleet management system (FMS) operation

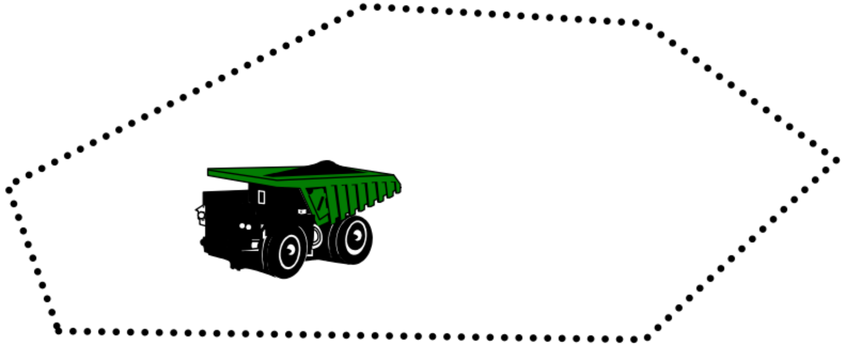
7.) When the truck leaves the Loading Zone and attains a certain speed, its status changes to Hauling. This triggers the status of the loading machine to change back to Waiting.



Fleet management system (FMS) operation

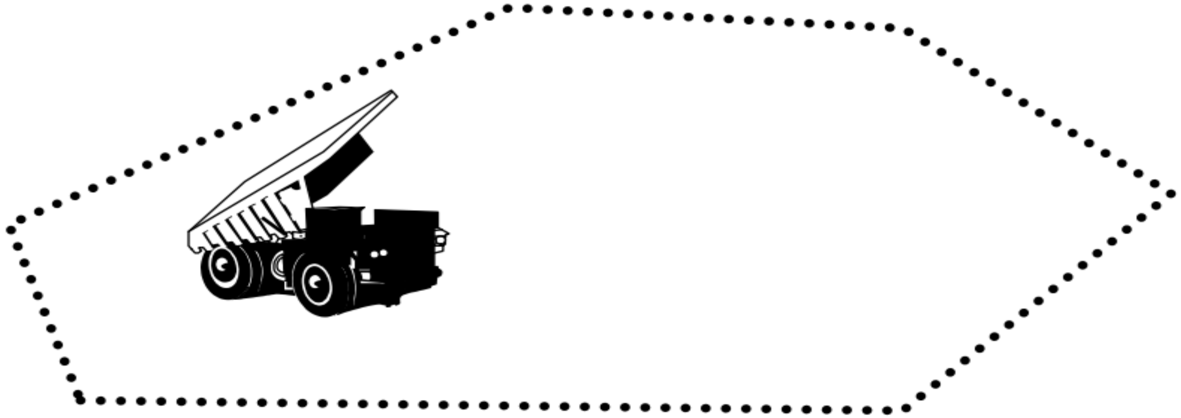
- The position of each waste dump, crusher or stockpile is defined in the FMS System by its GPS coordinates. Each can have the form of a circle or a polygon (square, rectangle, trapezoid, hexagon, etc.).
- When a truck arrives at a dump destination, the System confirms that it corresponds with the assigned destination.





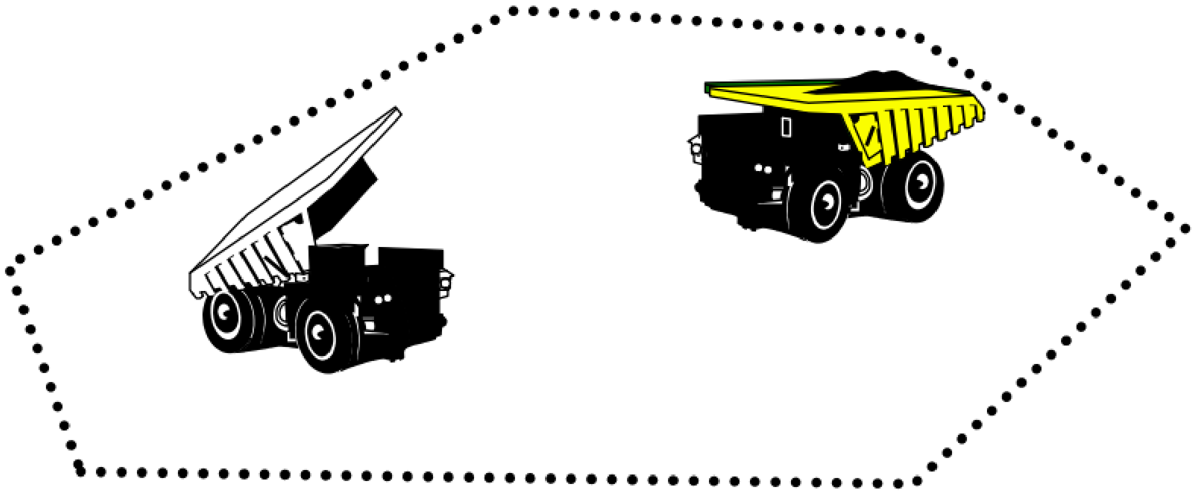
Fleet management system (FMS) operation

- When the operator tips the box, the status of the truck becomes Dumping and soon thereafter Empty. Then the truck receives a new destination (shovel or loader) for the next haul cycle.



Fleet management system (FMS) operation

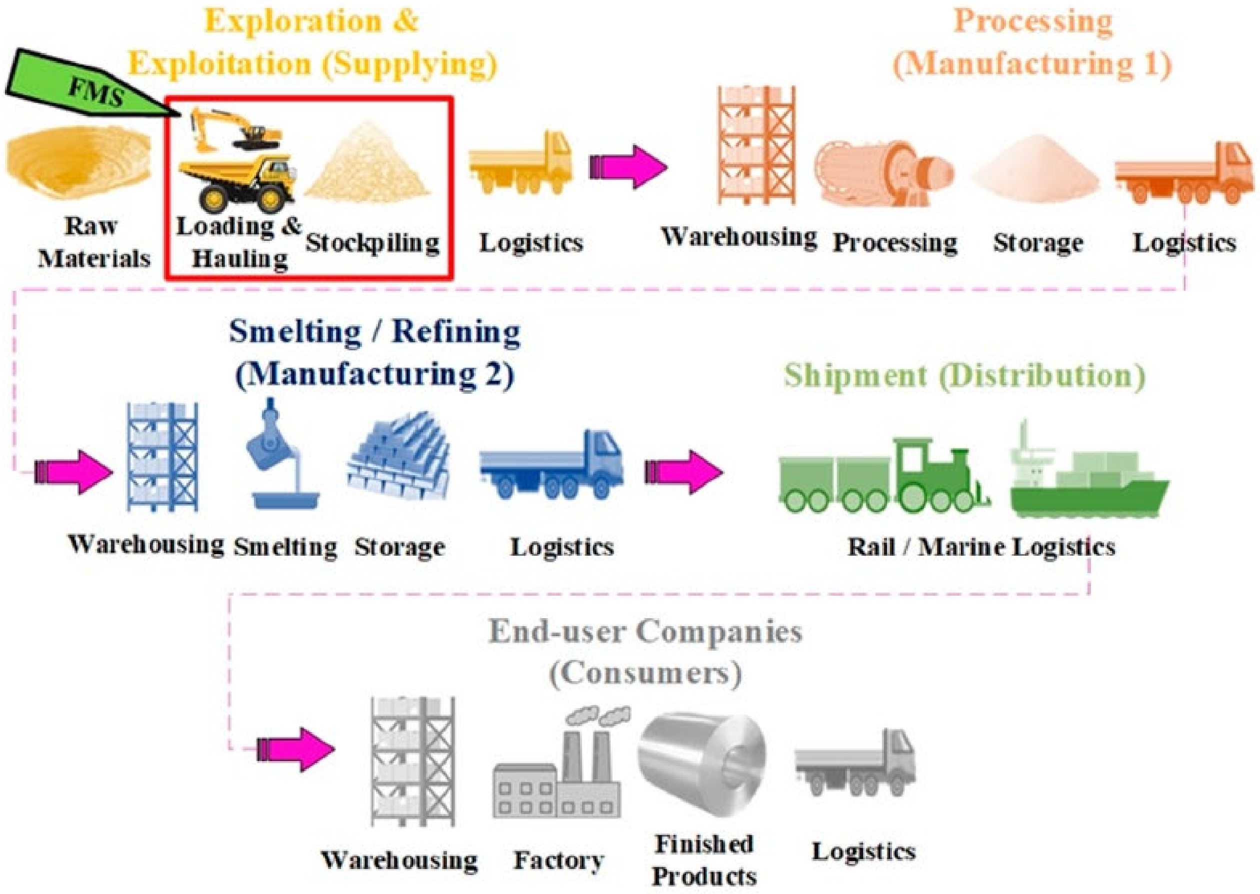
- If a second truck arrives at the dump destination and stops while the first truck is dumping, the status of the second truck becomes Waiting.



Holistic mining supply chain embedded with a fleet management system (FMS)

- FMSs operate at the operational level of mine planning hierarchy.
- FMSs have a nested relationship with logistics and supply chain management.
- The mining supply chain includes exploration/exploitation, materials handling, maintenance, and distribution chains.
- Exploration/exploitation chain is the base supplier, covering activities from exploring reserves to outbound logistics.

Holistic mining supply chain embedded with a fleet management system (FMS)



Holistic mining supply chain embedded with a fleet management system (FMS)

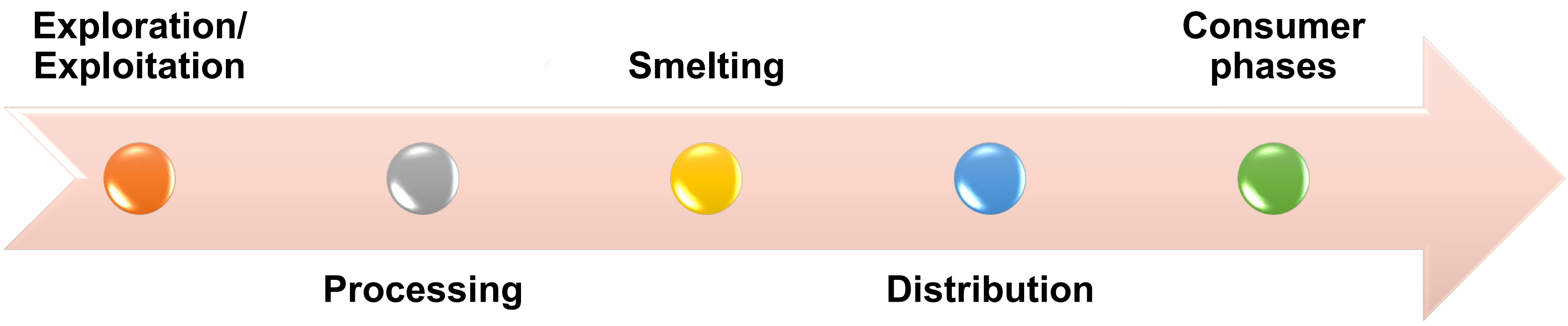
- FMS handles materials handling, stockpiling, dispatching, and dumping commands in the mining network.
- Mining FMS tasks include maintenance, fuel management, and provision of feed for the primary crushing plant.
- Preliminary mining phases like exploration and development can be separate value chains.
- Mined ores undergo treatments in a processing plant, leading to concentrate production.

Holistic mining supply chain embedded with a fleet management system (FMS)

- Concentrate is processed in smelting or refinery plants to extract base or precious minerals.
- Distribution chain delivers the cargo by land, rail, or marine logistics to buyers.
- Purified minerals in end-user factories mark the end of the mining supply chain.
- The last value chain can create another supply chain with downstream industries.
- Every enterprise aims to sell its commodity directly to the end user, but obstacles may arise.

Holistic mining supply chain embedded with a fleet management system (FMS)

Mining supply chain comprises five distinct phases



Holistic mining supply chain embedded with a fleet management system (FMS)

- FMS enhances exploration/exploitation phase for raw material extraction.
- Real-time monitoring and data-driven decisions optimize vehicle routes and extraction processes.
- GPS technology tracks vehicles for efficient exploration in mineral-rich areas.
- Telematics in exploitation phase monitor equipment, fuel usage, and health in real time

Holistic mining supply chain embedded with a fleet management system (FMS)

- **Early issue detection and maintenance extend machinery lifespan.**
- **Predictive analytics in FMS forecast maintenance needs, reducing downtime.**
- **Real-time data sharing supports prompt decision-making.**
- **FMS contributes to better resource allocation, strategic planning, productivity, and cost reduction.**

Surface Mining Value Chain Analysis

- The combined effect of technology development and an FMS on the efficiency and profitability of a mining unit along its exploitation value chain has been illustrated in figure below and described in Table

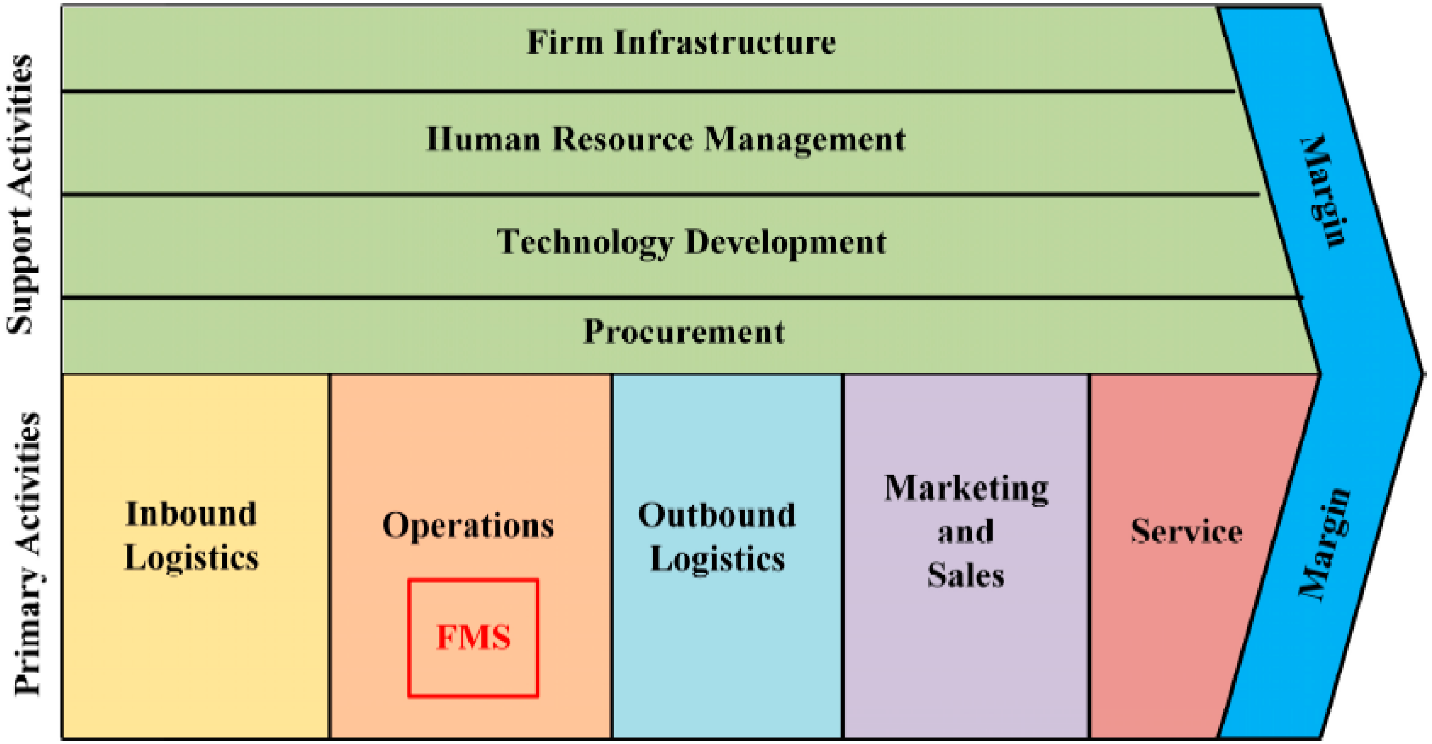
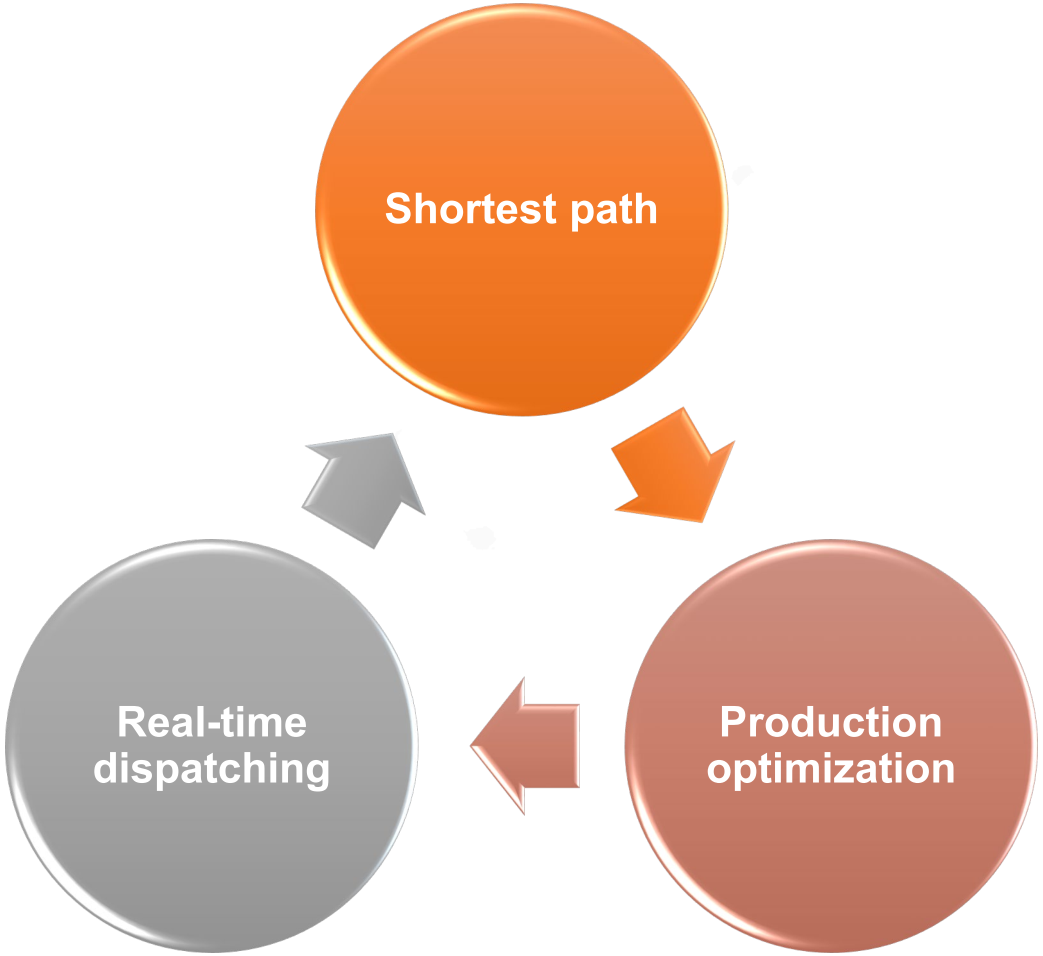


Table- Description of various activities along the exploitation value chain

Type	Activities	Description
Support activities	Firm infrastructure	Finance, accounting, legal permits, buildings, equipment.
	Human Resource Management	Recruiting, training, career development, fringe benefits, retention, compensation, safety and health assessment.
	Technology Development	Mining 4.0 enablers (Data mining, robots, simulation, system integration, Internet of Things, cyber security, cloud computing, augmented reality, artificial intelligence, digital twin, cyber-physical systems, quantum computing, 3D printing, research and development, autonomous vehicles, drones, etc.).
	Procurement	Supplier management, negotiation, and subcontracting of equipment and services.
Primary activities	Inbound logistics	Utilities (e.g., fuel, electricity), spare parts, explosives, errands (e.g., food, office affairs).
	Operations	Development of new working faces, drilling, blasting, loading, hauling, stockpiling, crushers' feeding.
	Outbound logistics	Ore dumps management, grade control, blending, order handling, invoicing, and shipment.
	Marketing and sales	Multimedia advertisement, domestic and international exhibitions, branding, sales analysis, and market research.
	Services	After-sales services in case of grade fluctuations, consulting.

Industrial Fleet Management Systems



Shortest path system

- Shortest path was defined as the shortest travel-time route from loading to the tipping point.
- use Dijkstra’s algorithm of finding the shortest to select the best route of connecting shovels to their destination.

Production optimisation and truck allocation

- As the first step, it fixes the shovels location by implementing a combinatory mixed integer linear programming (MILP) model with respect to available trucks and the objective of maximising the production subject to quality constraints.
- In the second step of the algorithm, represent the truck travel plan between shovels and dumping points by solving a non-linear programming (NLP) model.

The model’s objective function consists of three components:

(1) shovel production objective - computed shovel production,

(2) available truck hours – computed truck hours – which includes truck waiting time as well; and

(3) penalty for the deviation of the produced ore material from the blending objectives.

Real-time dispatching

- Real-time decision-making on the destination of trucks in a mining operation was first used in the early 1960s with implementation of radio communication tools to link between dispatcher and trucks operators in a fixed truck allocation mine.
- However, based on the utilization of the modern computer, real-time fleet management in mining operation systems are divided into three major categories, locked-in or fixed allocation, semi-automated, and fully automated systems.

Locked-in Method: No effort for dispatching transportation units.

Semi-automated Dispatching: Divided into two classes: passive and active.

- Passive: Computer displays current mine operation information without involvement in decision-making.
- Active: Computers use current mine status as inputs, process them based on predefined models, and suggest assignments for dispatchers.

Automated Dispatching:

- Data on current mine status, equipment condition, and position are collected in a main computer server. Assignments are sent to trucks after solving heuristics or mathematical programs.

Question 1

What does the term "shortest path" refer to?

a) The most scenic route

b) The route with the least number of turns

c) The shortest travel-time route from loading to the tipping point

d) The route with the fewest obstacles

Answer: c) The shortest travel-time route from loading to the tipping point

Question 2

What technological advancement facilitated real-time decision-making in the early implementation for truck destination in mining operations?

a) GPS technology

b) Radio communication tools

c) Satellite communication

d) Morse code

Answer: b) Radio communication tools

Industrial mine fleet management systems

DISPATCH fleet management systems

Company - Modular Mining Systems

Number of mines installed – Over 200

Main claimed features

- Haulage Optimization
- Qualifications Management
- Fuel Service Management
- Auxiliary Equipment Management
- Remote Supervision
- Payload Analysis
- Ore Blending Control
- Real-Time Web Reporting

Jmineops fleet management systems

Company - Leica Geosystems

Number of mines installed – 130

Main claimed features

- Universal Software Platform
- Ability to harness any industry standard IP-based wireless network
- Identical onboard SQL databases & office server that replicate in real-time
- Distributed database architecture.
- Instantaneous data relay
- Real-time compliance control
- Automated cycle logic

Wencomine fleet management systems

Company - Wenco Mining Systems

Number of mines installed – 65

Main claimed features

- **Real-time views of location and activity for all equipment at the mine**
- **Assignments sent to operators based on current mine parameters**
- **Operators kept on task with onscreen work**
- **Details status of all shovels, trucks, drills, dozers, and other equipment monitored**
- **Ongoing events monitored with customizable, real-time alerts**

Dynamine fleet management systems

Company - TATA

Main claimed features

- **Minimising the cycle time for open pit mine operations and improving mine productivity**
- **Efficient queue management and monitoring of mobile assets**
- **Effective visualization throughout the operational boundaries within a mine**
- **Ability to integrate with mine surveys, mine planning and enterprise applications**

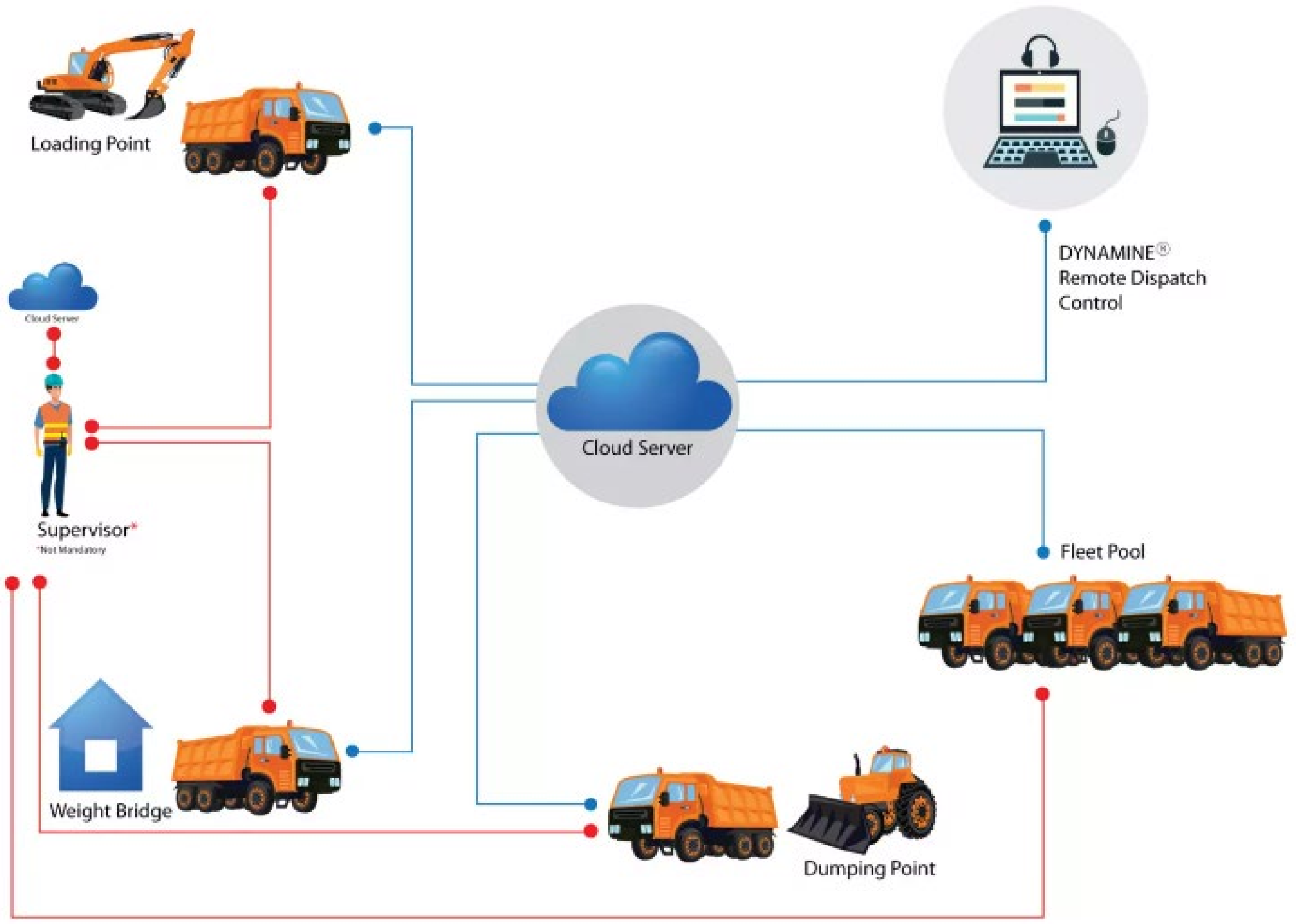
Dynamine fleet management systems

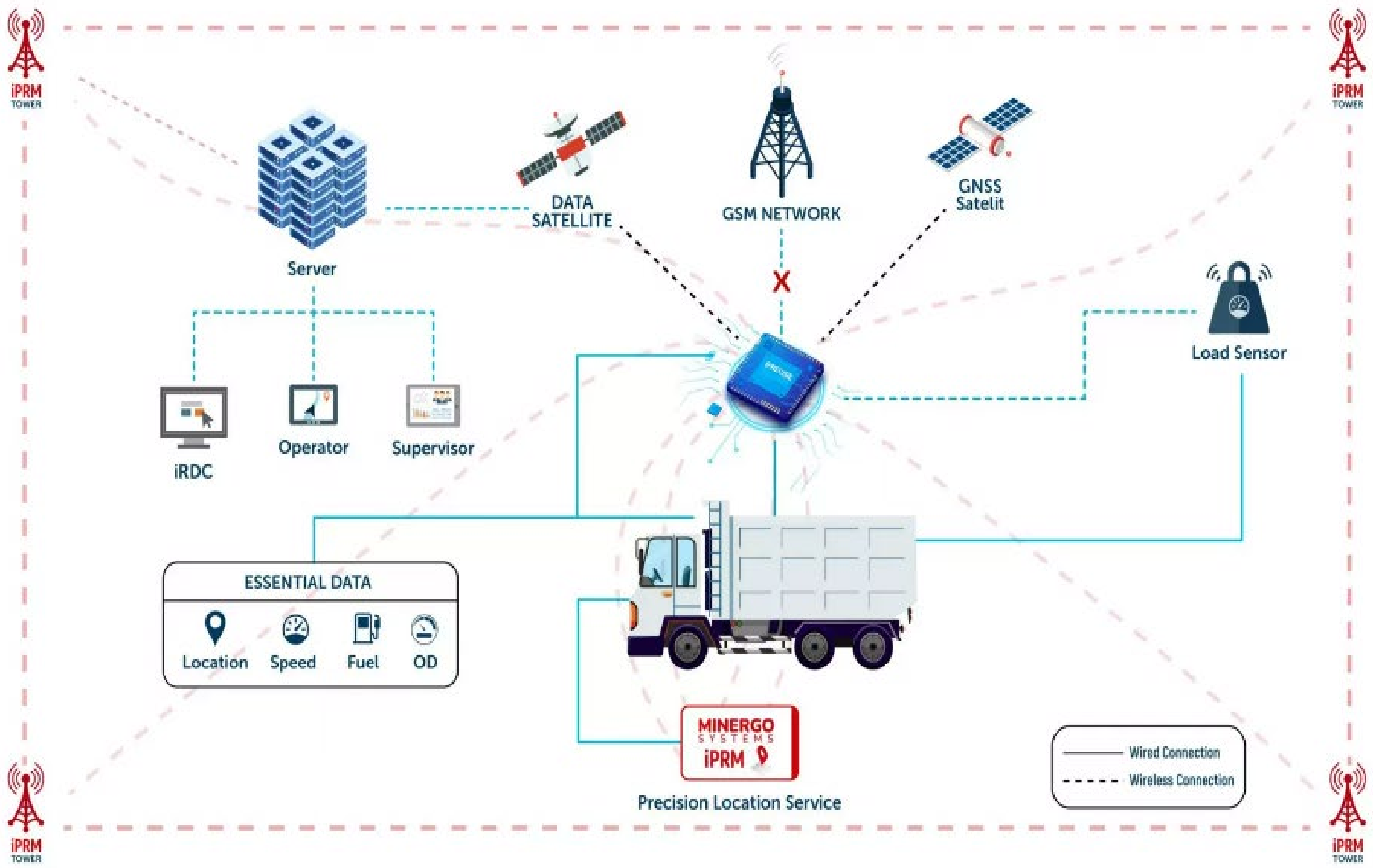
DYNAMINE is platform to manage the daily haulage operations of mining materials outside the pit and also very effective for long-distance hauling. The system has many useful functions to utilize the fleet more effectively.

DYNAMINE is equipped with advanced tools:

- **Intelligent Remote Dispatch Control.**
- **Telematics technology.**
- **Satellite for data collection.**
- **Integrated mobile app for field workers and others.**

Dynamine Control system




iPRM TOWER
iPRM TOWER
Server
DATA SATELLITE
GSM NETWORK
GNSS Satelit
X
Load Sensor
iRDC
Operator
Supervisor
ESSENTIAL DATA
Location
Speed
Fuel
OD
MINERGO SYSTEMS
iPRM
Precision Location Service
Wired Connection
Wireless Connection
iPRM TOWER
iPRM TOWER

MODULES

i-RDC

i-RDC (Intelligent Remote Dispatch Control) a module for managing haul fleets and monitoring assignments to operators on site.

Advantages of i-RDC include:

- Lightweight application, easy to install, operating system based on web applications.
- User friendly so that it is easy to use by authorized dispatchers.
- Connected to applications on android-based smartphones or industrial tablets and can be widely used anywhere.
- Easy to navigate and operate easily to be able to monitor various haulage activities.
- Ability to provide control, visibility and consolidate fleets operated by third parties (vendors).
- Able to integrated with third party systems.
- Customizable as needed.

i-Precise

- A telematics system that allows dispatcher to tracks the trucks, fuel, navigation, driver records and driver performance, resulting in optimal fuel usage and asset utilization.
- Routes can be optimized to reduce mileage and fuel usage, which also keeps costs proportional.
- i-Precise is a module embedded into the truck dashboard to monitor the position and health of the vehicle in real time.

Question 3

How does the telematics system contribute to optimal fuel usage and asset utilization?

a) By reducing the number of trucks

b) By optimizing routes and monitoring driver performance

c) By increasing vehicle speed

d) By minimizing navigation features

Answer: b) By optimizing routes and monitoring driver performance

I-Drive

- i-Drive is an application used by operators in the field.
- Information about tasks, routes, and other relevant instructions will be contained in I-Drive.
- In some applications i-Drive limits the intensity of the operator's touch to the buttons that appear above the interface screen for the purpose of maintaining safety.
- I-Drive can be operated on an industrial tablet or smartphone.

Benefits of using Dynamine

Improved Efficiency

DYNAMINE helps to optimize haul truck operations, reducing downtime and increasing haul truck utilization, leading to improved overall efficiency.

Better Dispatch Management

DYNAMINE provides real-time visibility into haul truck activity, enabling dispatchers to manage the movement of haul trucks more effectively and reduce delays.

Benefits of using Dynamine

Improved Load Management

The system is used to assign loads to haul trucks based on factors such as truck availability, load size, and haul truck capacity, helping to optimize load management and reduce inefficiencies.

Data-driven Decision Making

The system provides detailed data and analysis of haul truck utilization, including factors such as average cycle time, idle time, and haul truck productivity, enabling data-driven decision-making and continuous improvement of haul truck operations.

REFERENCES

- Bnouachir, H., Chergui, M., Machkour, N., Zegrari, M., Chakir, A., Deshayes, L., ... & Medromi, H. (2020). Intelligent fleet management system for open pit mine. International Journal of Advanced Computer Science and Applications, 11(5), 327-332. https://dx.doi.org/10.14569/IJACSA.2020.0110543
- Chaowasakoo, P., Seppälä, H., Koivo, H., & Zhou, Q. (2017). Improving fleet management in mines: The benefit of heterogeneous match factor. European journal of operational research, 261(3), 1052-1065, https://doi.org/10.1016/j.ejor.2017.02.039
- Moradi Afrapoli, A., & Askari-Nasab, H. (2019). Mining fleet management systems: a review of models and algorithms. International Journal of Mining, Reclamation and Environment, 33(1), 42-60. https://doi.org/10.1080/17480930.2017.1336607

REFERENCES

- Afrapoli, A. M., Tabesh, M., & Askari-Nasab, H. (2019). A multiple objective transportation problem approach to dynamic truck dispatching in surface mines. European Journal of Operational Research, 276(1), 331-342. https://doi.org/10.1016/j.ejor.2019.01.008.
- https://www.slideshare.net/AgungeDuke/dynaminepkdeckfeb2023bgpdf

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CONCLUSION

- Explored the operational aspects of FMS
- Explored FMS tailored for industrial applications, focusing on optimizing fleet operations.
- Discussed the implementation of the shortest path system for efficient route planning in industrial fleets.
- Explored systems aimed at optimizing production within industrial fleet management, enhancing overall efficiency.

CONCLUSION

- Highlighted the significance of real-time dispatching in industrial fleet management for agile decision-making.
- Provided examples of FMS tailored for industrial mines, showcasing practical applications in the mining sector.
- Introduced Dynamine as an example of a fleet management systems with a focus on dynamic optimization in industrial contexts.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

Prof. Radhakanta Koner
Department of Mining Engineering
Indian Institute of Technology (Indian School of Mines) Dhanbad

Module 03:
Introduction to Maintenance Management System in Mining

Lecture 06 (A) :
Introduction to CMMS

CONCEPTS COVERED

- Introduction to Maintenance
- Types of Maintenance
- Maintenance management
- Fundamental steps of maintenance management
- Computerized maintenance management system (CMMS)
- Benefits of CMMS
- CMMS subsystem or modules
- CMMS software models

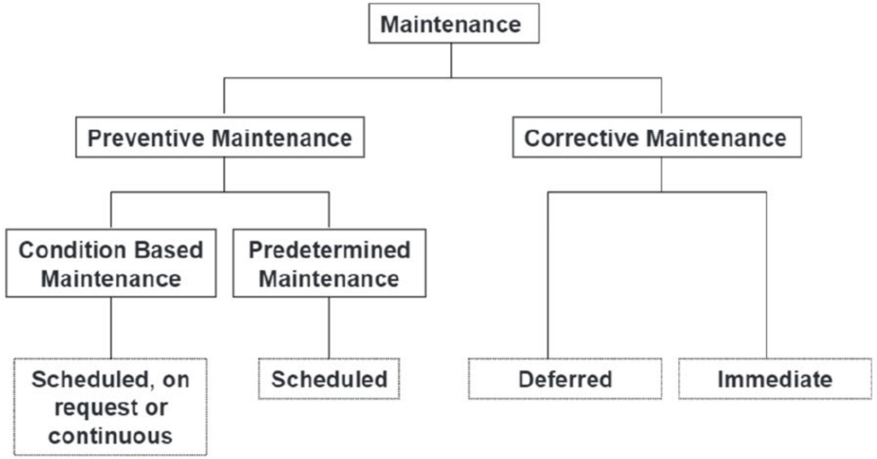
CONCEPTS COVERED

- CMMS software
- New trends in the CMMS or enterprise asset management industry
- EAM vs. CMMS
- Introduction to Asset Performance Optimization
- Challenges in Asset Management for the Mining Sector
- Benefits of CMMS Solutions for Mining Companies
- Key Features of CMMS for the Mining Industry
- Implementing CMMS in Mining Operations
- Future Trends in CMMS for the Mining Industry

Maintenance

Maintenance refers to the systematic and organized control of activities necessary to preserve a facility in its original condition, ensuring it retains its productive capacity over time.

Types of Maintenance



Corrective maintenance

Preventive maintenance

Corrective maintenance

- Corrective maintenance is carried out reactively after a fault has been recognized. It aims to restore the equipment in question into a state in which it can again perform a required function.
- Depending on the maintenance plan corrective maintenance can be either planned or unplanned.

- Planned corrective maintenance is typically result of a run-to-failure (RTF) maintenance plan where no maintenance is performed on the asset until the failure event.
- Unplanned corrective maintenance is typically the result of a breakdown not stopped by preventive maintenance.
- Based on the fault and the business conditions corrective maintenance can either be done immediately after the fault occurs or it can be delayed and performed later.

Preventive maintenance

- Preventive maintenance is performed proactively before the equipment fails. It intends to reduce the probability of failure or degradation of the functioning of an item.

Predetermined maintenance

Predetermined maintenance is done based on established maintenance programs for intervals of time or units of use. The programs are typically provided by equipment manufacturers and are based on their knowledge of the failure mechanisms and mean-time-to-failure (MTTF) statistics for the equipment and its parts.

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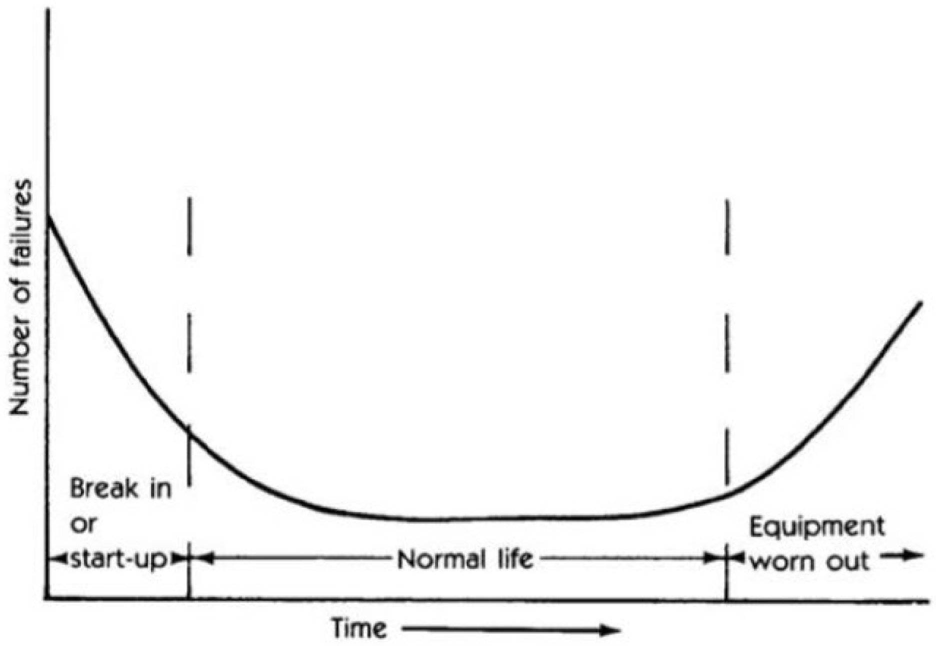


Figure-Typical bathtub curve

- The failure probability is typically higher when the equipment or part is new or worn out.
- This MTTF or bathtub curve is shown in Figure. Predetermined maintenance does not guarantee that the equipment does not fail and often leads to unnecessary repairs since the programs are based on failure statistics and not on the actual condition of the equipment.
- Managing predetermined maintenance can be complex since each equipment can have multiple maintenance programs and companies can have a large number of equipment.

Condition Based Maintenance

- Condition-based maintenance tries to predict failure. It is based on regular monitoring of the condition, operating efficiency, and other indications of the system.
- The monitoring can be done either on-site or remotely via a network connection to the equipment. Monitoring can be done continuously, or it can be scheduled to happen at predetermined intervals.
- Condition-based maintenance is the most complex maintenance type to implement but can be the most economical one since only the parts needing repair or replacement are maintained.

Question 1

How is monitoring conducted in condition-based maintenance?

a) On-site only

b) Remotely only

c) Both on-site and remotely

d) Continuously

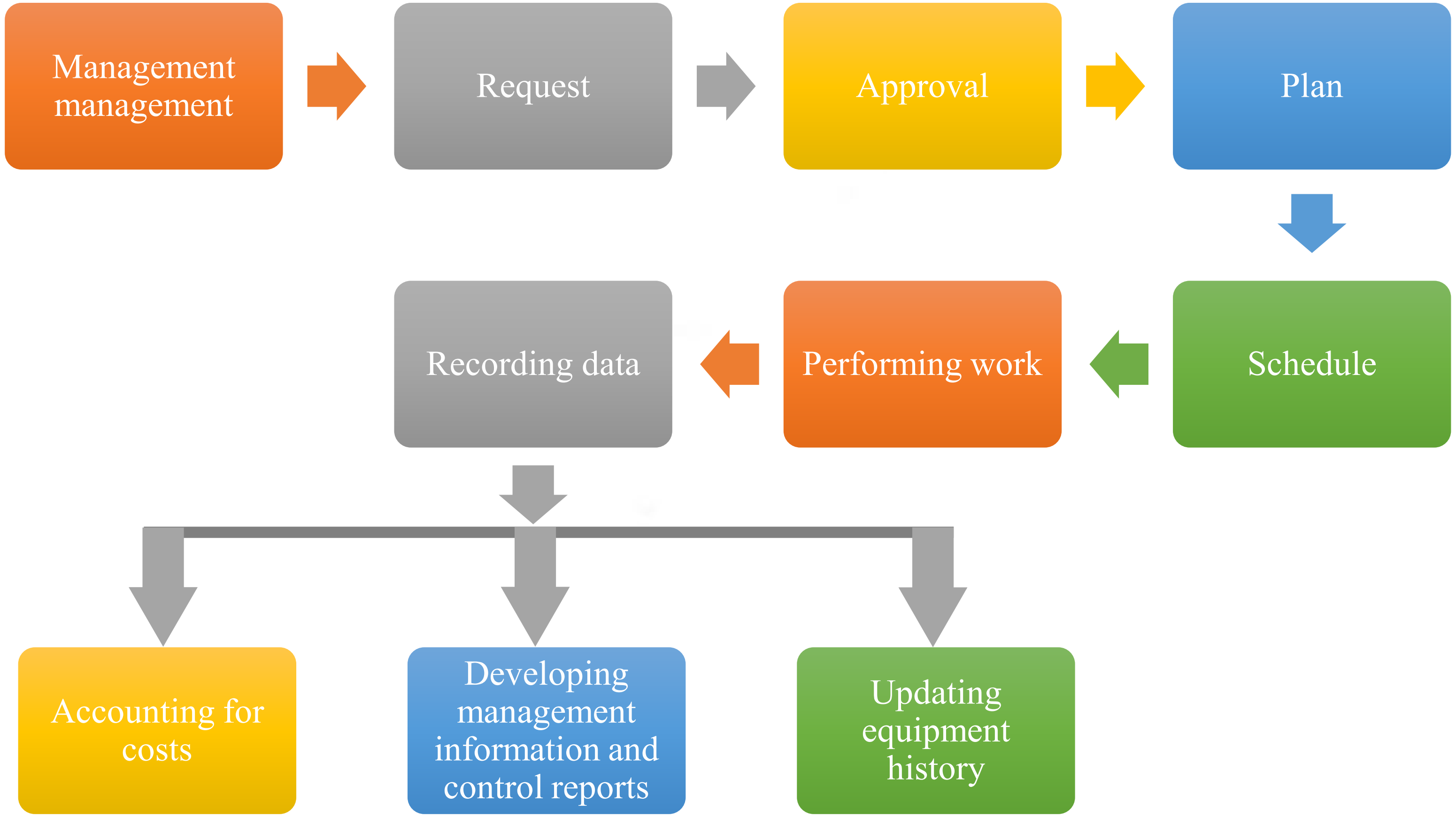
e) Only at predetermined intervals

Answer: c) Both on-site and remotely

Maintenance Management

Initially, maintenance management was a manual, time-consuming task. However, it has evolved into a Computerized Maintenance Management System (CMMS), a software that centralizes planning, tracking, measuring, and optimizing all aspects of a maintenance program.

Fundamental steps of maintenance management



Computerized maintenance management system (CMMS)

A combination of different modules that combine in one comprehensive solution.

Used by maintenance professionals across different industries.

CMMS = Computerized Maintenance Management System

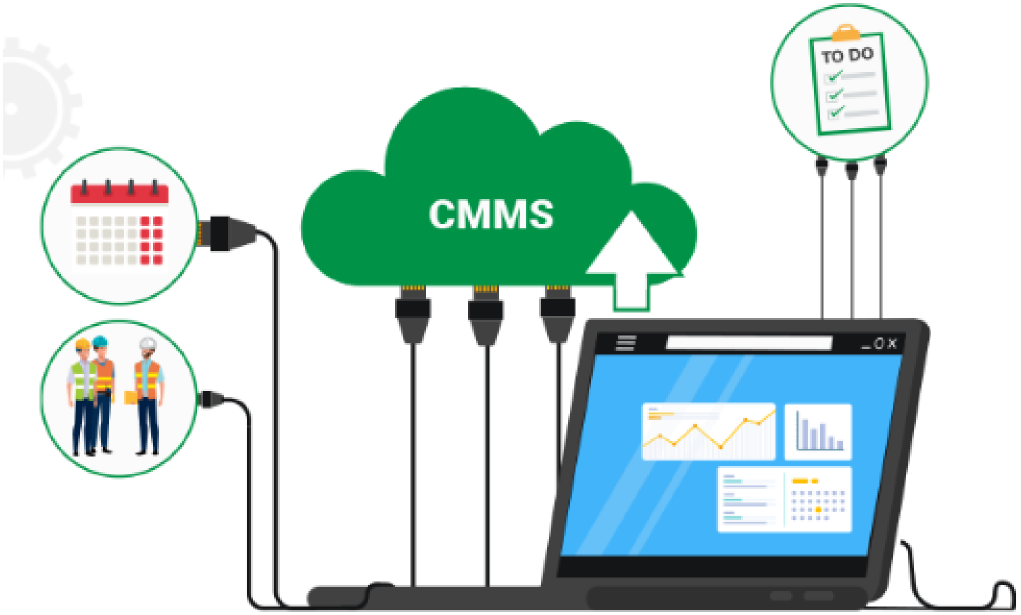
Digital solutions used on a computer/mobile device,

Used to plan, organize, track, and optimize maintenance work.

Computerized maintenance management system (CMMS)

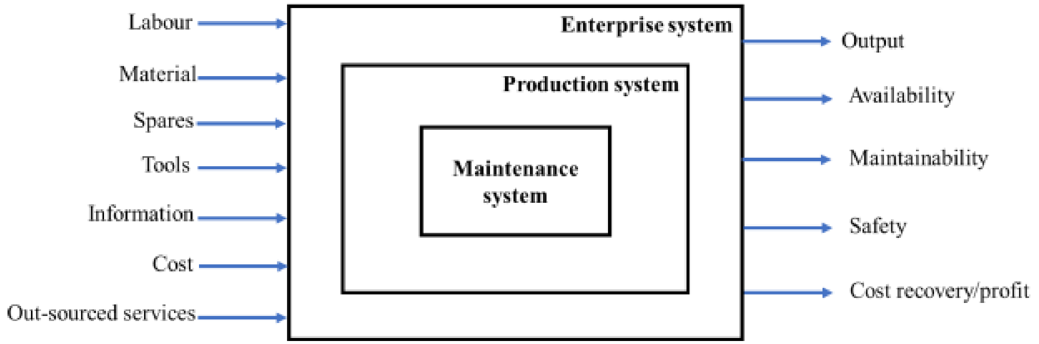
A computer-managed maintenance system is an integrated set of computer programs and data files designed to provide its user with a cost-effective means of managing massive amounts of maintenance, inventory control, and purchasing data.

- It helps in systematic planning, execution, and control of maintenance activities.
- It provides a cost-effective way to manage human and capital resources.
- CMMS is a transformation from a paper-based working environment to a computerized digital storage. It helps to eliminate the recording of paperwork.



Input and output model for an enterprise

- Figure below highlights the resources which need to be managed in an enterprise. It can be seen from the figure that maintenance is the sub-part of enterprise and production system. Maintenance systems have high importance as both depend on it.
- CMMS software helps to manage resources such as labor, spares, tools, information, cost, and outsourced repair activities. These inputs result in production output, availability, maintainability, and the safety of assets.



Question 2

What does CMMS (Computerized Maintenance Management System) primarily aim to achieve?

A) Increase paperwork in the working environment.

B) Maintain the traditional paper-based record-keeping system.

C) Facilitate the transition from a paper-based to a computerized digital storage system.

D) Discourage the use of digital storage for maintenance records.

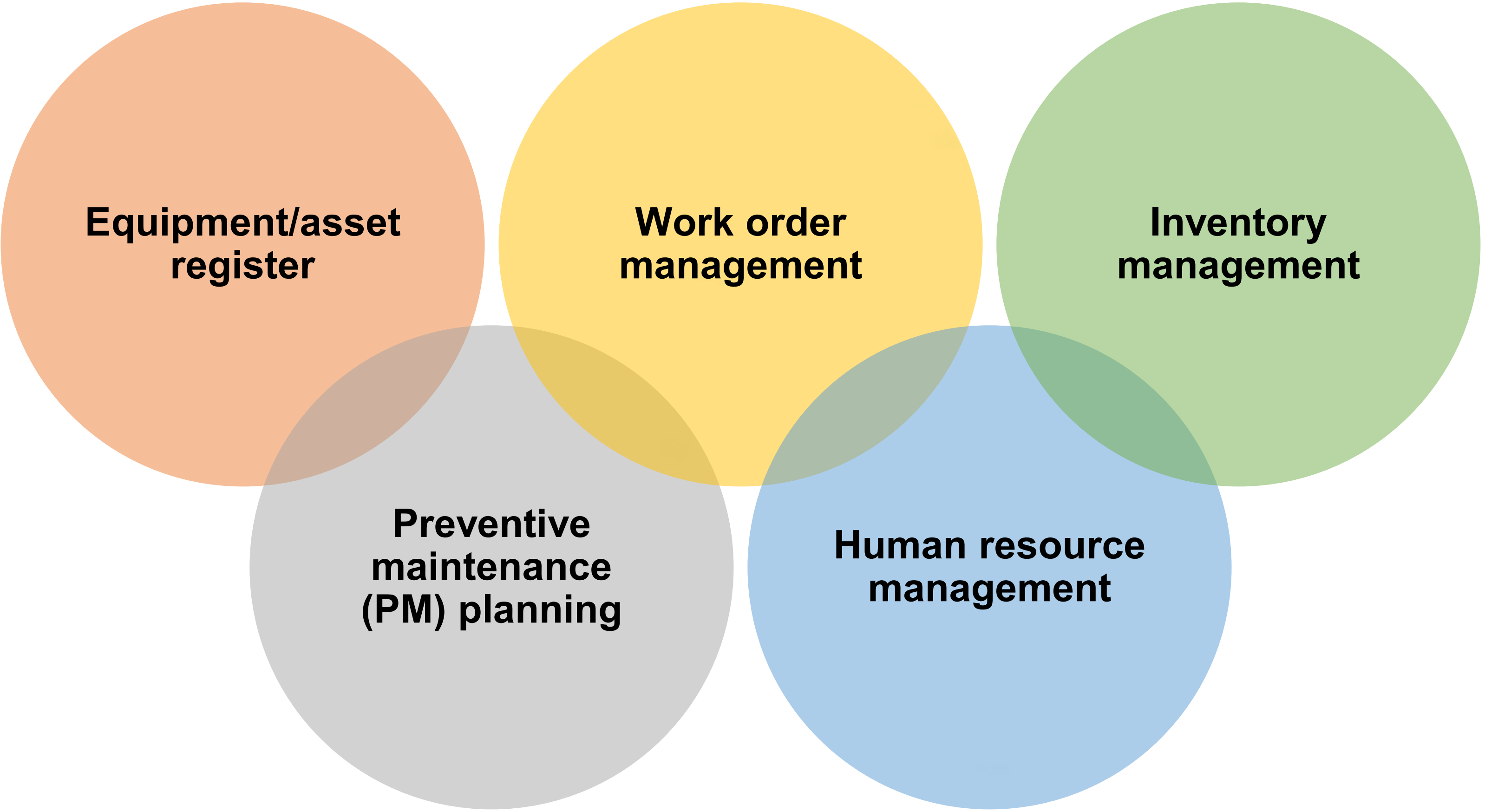
E) Promote a hybrid approach of paper and digital record-keeping.

Answer: C) Facilitate the transition from a paper-based to a computerized digital storage system.

Benefits of CMMS

- Reduce maintenance backlog
- Reduce maintenance cost
- Reduce overtime
- Reduce follow-up a time to repairs
- Reduce outsourced contract maintenance work
- Improve maintenance planning and scheduling
- Improve maintenance service tracking
- Improve technician and service engineer performance
- Improve technician and supervisor planning

CMMS subsystem or modules



Equipment/asset register

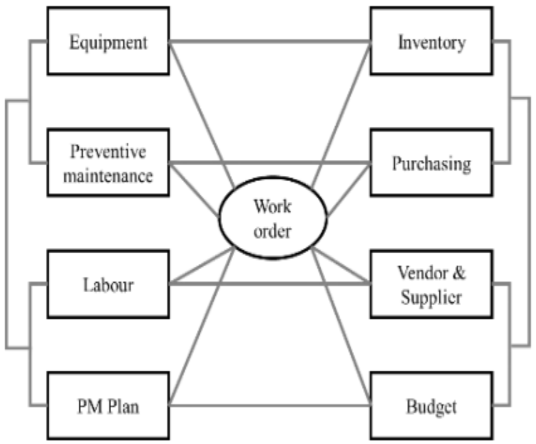
- It is a database of all the equipment in the plant.
- All maintenance activities are linked to an asset. So, it is linked to all other databases such as Preventive maintenance (PM) planning, inventory, and purchase

Preventive maintenance (PM) planning

This module contains the PM plan for the registered assets/ equipment based on the maintenance checklist and frequency.

Work order management

- The work order is the backbone of the CMMS system.
- A work order can be generated by planned PM or unplanned maintenance activity.
- All modules are connected and updated through a work order.



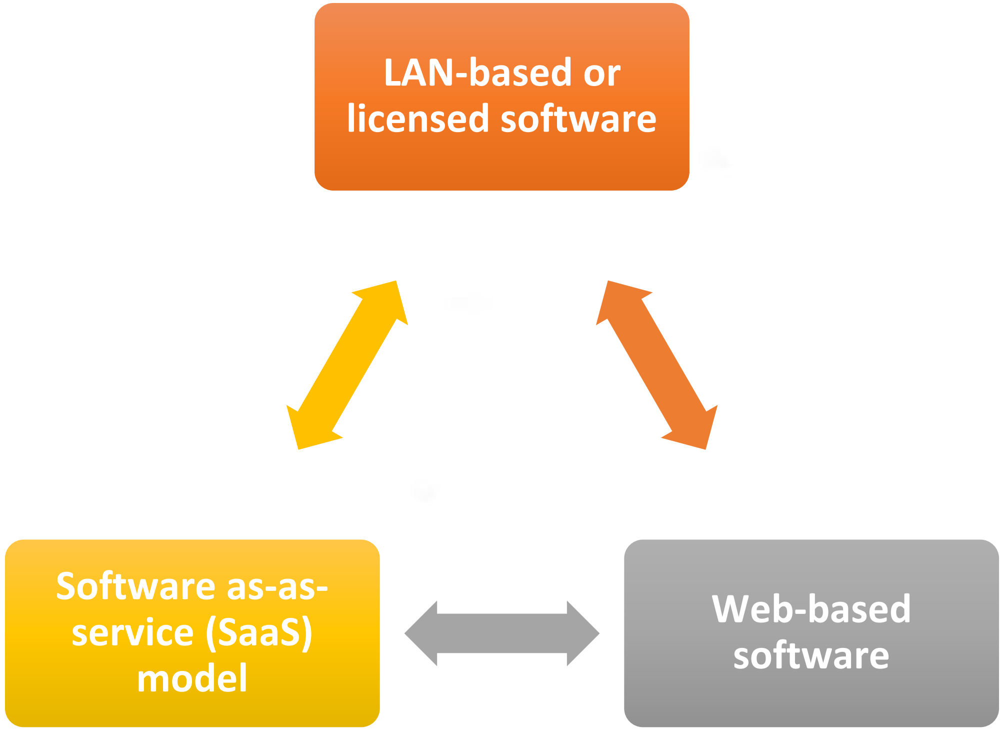
Human resources

It Includes personnel and technicians who carry out maintenance work activity.

Inventory management

It includes warehousing, purchase, and ordering of spare parts.

CMMS software models



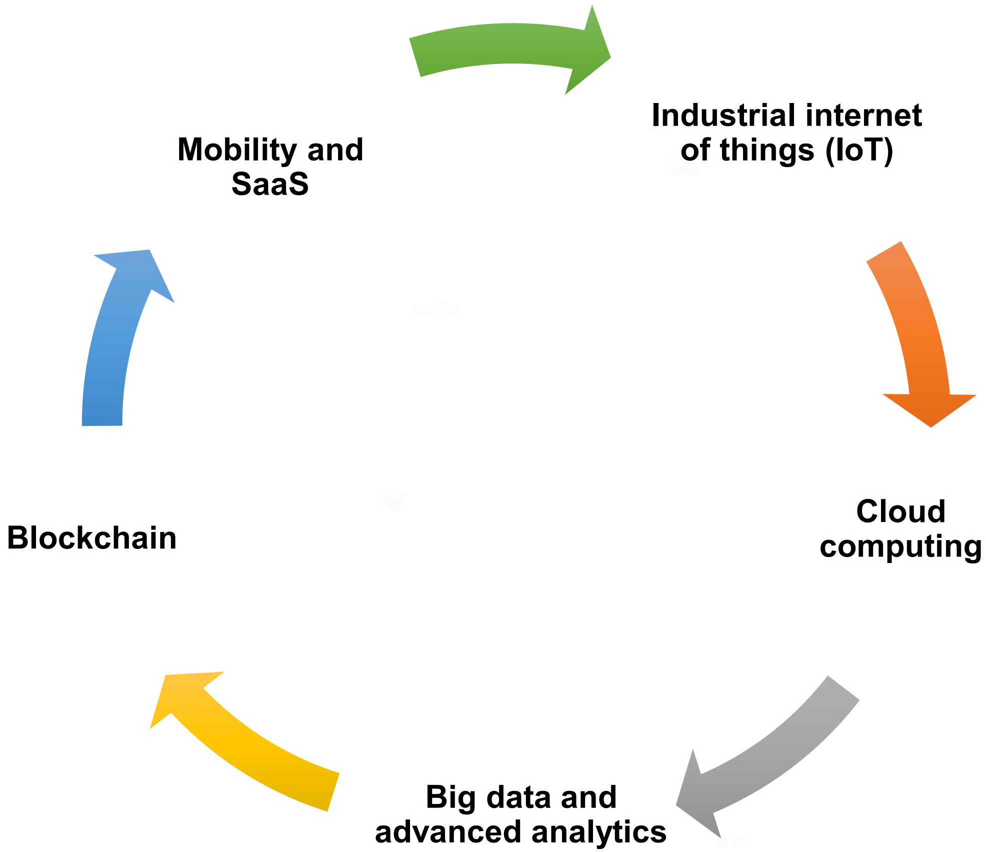
- The LAN-based software is purchased by the company and all the data is stored on the company servers, major maintenance of parts is carried out by company IT staff or with the help of a service vendor.
- Web-based software is available through monthly or yearly subscription. Data is stored in cloud storage and all maintenance activities are carried out by the software provider. In the next decade, LAN-based CMMS software will be preferred by large organizations while small organizations will prefer SaaS-based solutions.

CMMS software

CMMS software vendors can be categorized into two major groups tier 1 and tier 2

Tier 1	Tier 2
SAP	Avantis (Schneider Electric)
IBM Maximo	Oracle
Infor LN	Mainsaver
IFS	eMaint
	Fiix

New trends in CMMS or enterprise asset management industry



- Industrial Internet of things (IoT) uses industrial Ethernet for connected devices concept.
- Cloud computing and big data analytics include the processing of a large amount of data for predictive analytics using machine learning algorithms.
- Blockchain technology is helping asset management to capture all transactions and change in the state of the equipment.

EAM vs. CMMS

- (Enterprise Asset Management) EAM and CMMS were both developed to help maintain and optimize assets but their scope and impact differ and have evolved over time.
- Modern EAM solutions take essential CMMS functionality and expand and integrate it across the core areas of the business, addressing the complete lifecycle of assets, from initial research and capital planning to eventual disposal or recycling.

EAM vs. CMMS

- EAM solutions leverage technologies like AI, machine learning, and advanced analytics to provide real-time insights into asset performance and maintenance needs – and can be customized to meet the specific needs of different industries and organizations.

- So while CMMS remains a useful and important tool, modern EAM solutions are better equipped to handle complex and dynamic business needs and deliver a more agile approach to asset management, helping to best optimize asset usage, reduce costs, and maximize return on investment.

Introduction to Asset Performance Optimization

In the mining industry, the efficient performance of assets is critical for achieving operational excellence and maximizing productivity. Asset Performance Optimization refers to the strategic use of technology, data-driven insights, and maintenance practices to enhance the reliability, availability, and performance of mining assets.

Understanding the Importance of Asset Performance in the Mining Industry

- Mining companies heavily rely on their assets to carry out various operations, such as excavation, transportation, and processing. The optimal performance of assets directly impacts the overall efficiency and profitability of mining operations.

Role of CMMS Solutions in Enhancing Asset Performance

- Computerized Maintenance Management System (CMMS) solutions play a crucial role in optimizing asset performance. These advanced software tools help mining companies efficiently manage maintenance activities, plan preventive maintenance, and monitor asset health in real-time.

Key Objectives of Asset Performance Optimization

- The primary objectives of Asset Performance Optimization are to reduce downtime, minimize maintenance costs, improve equipment reliability, and extend the lifespan of mining assets. By achieving these goals, mining companies can maximize their return on investment and ensure sustainable operations.

Question 3

What are the primary objectives of Asset Performance Optimization in mining?

A) Increase downtime and minimize maintenance costs.

B) Improve equipment reliability and minimize return on investment.

C) Extend the lifespan of mining assets and maximize maintenance costs.

D) Achieve sustainable operations and decrease equipment reliability.

E) Reduce downtime, minimize maintenance costs, improve equipment reliability, and extend the lifespan of mining assets.

Answer: E) Reduce downtime, minimize maintenance costs, improve equipment reliability, and extend the lifespan of mining assets.

Challenges in Asset Management for the Mining Sector

The mining industry faces various challenges in effectively managing its diverse and extensive asset portfolio.

These challenges can hinder asset performance and lead to increased maintenance costs and downtime.

- **Managing a Vast and Complex Asset Portfolio**
- **Dealing with High Maintenance Costs and Downtime**
- **Ensuring Regulatory Compliance and Safety Standards**
- **Addressing the Impact of Environmental Factors on Assets**

Managing a Vast and Complex Asset Portfolio

Mining operations typically involve a wide range of assets, including heavy machinery, vehicles, conveyor systems, and processing equipment. Managing this vast and complex asset portfolio can be overwhelming without proper tools and strategies.

Dealing with High Maintenance Costs and Downtime

Maintenance costs can constitute a significant portion of a mining company's expenses. Unscheduled downtime due to asset failures can disrupt production schedules and result in financial losses.

Ensuring Regulatory Compliance and Safety Standards

The mining industry is subject to strict regulatory requirements and safety standards. Non-compliance can lead to penalties and reputational damage.

Addressing the Impact of Environmental Factors on Assets

Mining assets are exposed to harsh environmental conditions, such as extreme temperatures, dust, and moisture. These factors can accelerate wear and tear, leading to premature asset failures.

Benefits of CMMS Solutions for Mining Companies

Implementing CMMS solutions in mining operations can yield numerous benefits, enhancing equipment reliability, maintenance efficiency, and overall asset management.

- Improved Equipment Reliability and Availability
- Enhanced Maintenance Planning and Scheduling
- Real-time Monitoring and Condition-Based Maintenance
- Streamlined Inventory and Spare Parts Management
- Data-Driven Decision Making and Predictive Analytics

Improved Equipment Reliability and Availability

CMMS solutions enable mining companies to implement effective preventive maintenance programs, reducing the likelihood of unexpected breakdowns and improving equipment reliability and availability.

Enhanced Maintenance Planning and Scheduling

CMMS tools provide advanced planning and scheduling features, allowing maintenance teams to optimize work orders, allocate resources efficiently, and reduce downtime.

Real-time Monitoring and Condition-Based Maintenance

With IoT integration, CMMS solutions enable real-time monitoring of asset performance and condition-based maintenance, allowing for timely interventions and minimizing equipment failures.

Streamlined Inventory and Spare Parts Management

CMMS systems help streamline inventory management by providing accurate asset data, ensuring the availability of spare parts when needed, and reducing inventory holding costs.

Data-Driven Decision Making and Predictive Analytics

CMMS solutions leverage data analytics and predictive maintenance algorithms to identify patterns, detect anomalies, and provide data-driven insights for informed decision-making.

Key Features of CMMS for the Mining Industry

CMMS solutions designed for the mining industry offer a comprehensive set of features tailored to meet the specific needs of asset-intensive mining operations.

- Asset Tracking and Historical Maintenance Data
- Work Order Management and Task Assignment
- Preventive Maintenance and Inspection Checklists
- Integration with IoT Sensors and Predictive Maintenance
- Mobile Access and Remote Workforce Management

Asset Tracking and Historical Maintenance Data

CMMS systems track the complete maintenance history of mining assets, including past work orders, repairs, and inspections. This historical data helps in identifying recurring issues and planning preventive maintenance.

Work Order Management and Task Assignment

CMMS solutions streamline work order management, enabling maintenance teams to create, assign, and track tasks efficiently. This feature ensures that maintenance activities are carried out promptly and in a structured manner

Preventive Maintenance and Inspection Checklists

CMMS platforms allow the creation and scheduling of preventive maintenance tasks, along with detailed inspection checklists. Regular inspections and maintenance activities help prevent unexpected breakdowns and extend asset life.

Integration with IoT Sensors and Predictive Maintenance

CMMS solutions can integrate with IoT sensors and other data sources to gather real-time asset performance data. This integration enables predictive maintenance, allowing mining companies to address potential issues before they escalate.

Mobile Access and Remote Workforce Management

Mobile CMMS applications enable technicians to access maintenance information on the go, carry out inspections, and update work orders in real-time. Remote workforce management ensures efficient collaboration among team members.

Implementing CMMS in Mining Operations

The successful implementation of a CMMS system in a mining operation requires careful planning, stakeholder involvement, and change management.

- Assessing the CMMS Implementation Readiness
- Selecting the Right CMMS Solution for Specific Mining Needs
- Developing a Comprehensive Implementation Strategy
- Training and Skill Development for Maintenance Teams
- Overcoming Resistance to Change and Ensuring Adoption

Assessing the CMMS Implementation Readiness

Prior to implementation, mining companies should assess their readiness for CMMS adoption. This involves evaluating existing processes, data quality, and the availability of resources.

Selecting the Right CMMS Solution for Specific Mining Needs

Choosing a CMMS solution that aligns with the unique requirements of mining operations is essential. Key factors to consider include scalability, integration capabilities, and industry expertise of the vendor.

Developing a Comprehensive Implementation Strategy

Successful CMMS implementation requires a well-defined strategy that includes setting clear goals, establishing timelines, allocating resources, and defining roles and responsibilities.

Training and Skill Development for Maintenance Teams

Proper training and skill development are crucial for ensuring that maintenance teams can effectively use the CMMS system and leverage its features to the fullest.

Overcoming Resistance to Change and Ensuring Adoption

CMMS implementation may face resistance from employees accustomed to traditional maintenance practices. Effective change management is necessary to overcome resistance and ensure adoption.

Future Trends in CMMS for the Mining Industry

The mining industry is evolving, and future trends in CMMS solutions are poised to revolutionize asset management practices.

AI and Machine Learning for Predictive Maintenance

Advancements in AI and machine learning will enable more accurate predictive maintenance, minimizing asset failures and optimizing maintenance schedules

Advanced Data Analytics for Performance Optimization

CMMS solutions will leverage advanced data analytics to provide deeper insights into asset performance, enabling proactive decision-making.

Robotics and Automation in Asset Management

The mining industry may witness the integration of robotics and automation technologies to handle routine maintenance tasks and inspections.

Cloud-Based CMMS Solutions and Scalability

Cloud-based CMMS platforms will become more prevalent, offering scalability and easy access to data for geographically dispersed mining operations.

REFERENCES

- Bagadia, K. (2010). Computerized Maintenance Management Systems Made Easy: How to Evaluate, Select, and Manage CMMS. United Kingdom: McGraw Hill LLC. https://www.google.co.in/books/edition/Computerized_Maintenance_Management_Syst/UNeYRMCXG3oC?hl=en&gbpv=0
- Robatto Simard, S., Gamache, M., & Doyon-Poulin, P. (2023). Current Practices for Preventive Maintenance and Expectations for Predictive Maintenance in East-Canadian Mines. Mining, 3(1), 26-53.
- https://uis.brage.unit.no/uis-xmlui/bitstream/handle/11250/2561926/Ashraf_Waqas.pdf?sequence=1
- https://www.theseus.fi/bitstream/handle/10024/139395/laurila_jari.pdf;jsessionid=099663C2A6ABD27585541BA8399F65D2?sequence=1

REFERENCES

- https://www.maintwiz.com/blog/maximizing-asset-performance-cmms
- https://limblecmms.com/cmms/
- https://adaptahome.co.uk/product/planned-preventative-maintenance/

CONCLUSION

- Discussed about the maintenance and its types.
- Introduced the concept of managing maintenance processes in various industries.
- Explored the foundational steps involved in effective maintenance management.
- Introduced the Computerized Maintenance Management System (CMMS).
- Examined the advantages, such as enhanced efficiency and streamlined maintenance processes.
- Explored the different functional modules within a CMMS.
- Discussed various models of CMMS software applications.
- Introduced the software used for implementing CMMS.
- Explored emerging trends in the CMMS and Enterprise Asset Management (EAM) industry.
- Highlighted the distinctions between Enterprise Asset Management and CMMS systems.

CONCLUSION

- Introduced the concept of optimizing asset performance for efficiency.
- Addressed challenges specific to asset management in the mining sector.
- Examined the advantages of Computerized Maintenance Management Systems in mining operations.
- Explored essential features tailored for the mining industry within CMMS solutions.
- Discussed the process of integrating CMMS into mining operations for improved efficiency.
- Explored evolving trends shaping the future of CMMS in the mining industry.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

MINE AUTOMATION AND DATA ANALYTICS

SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 03:
Introduction to Maintenance Management System in mining

Lecture 06 (B) :
Enterprise resource planning (ERP) system

CONCEPTS COVERED

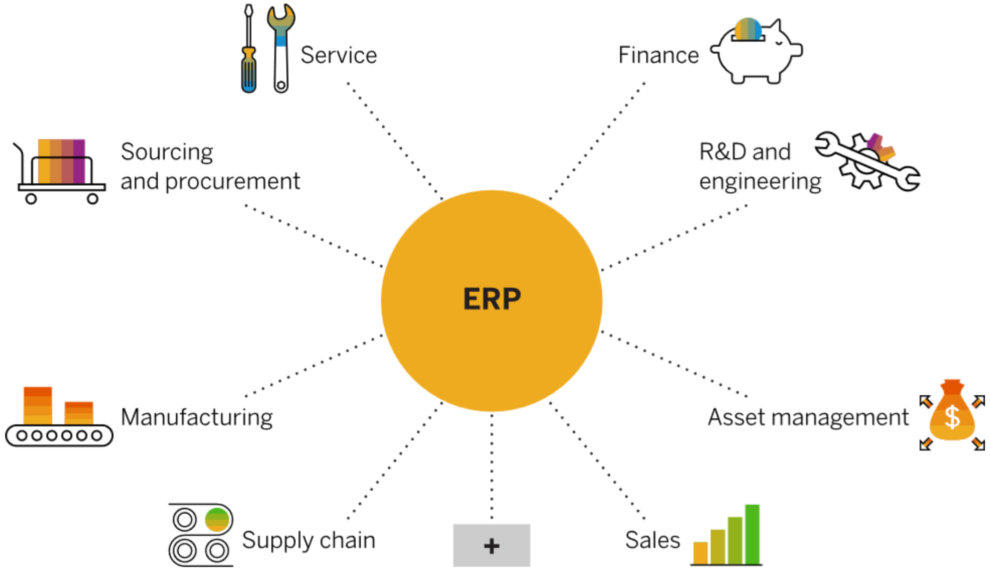
- Introduction to Enterprise resource planning (ERP) system
- Why is ERP important
- CMMS vs ERP
- Benefits of ERP
- Types of ERP deployment
- Fundamental features of enterprise resource management systems
- ERP software
- ERP Integration

CONCEPTS COVERED

- Drawbacks of the ERP systems
- Modules of ERP
- ERP operations
- Effect of the Industry 4.0 on ERP Systems
- What is ERP for the Mining Industry
- Features of ERP for the Mining Industry
- Benefits of Using ERP for the Mining Industry

Enterprise resource planning (ERP) system

An enterprise resource planning (ERP) system is a business management system that comprises integrated sets of comprehensive software, which can be used, when successfully implemented, to manage and integrate all the business functions within an organization.



- These sets (comprehensive software) usually include a set of mature business applications and tools for financial and cost accounting, sales and distribution, materials management, human resource, production planning and computer-integrated manufacturing, supply chain, and customer information.
- These packages have the ability to facilitate the flow of information between all supply chain processes (internal and external) in an organization.

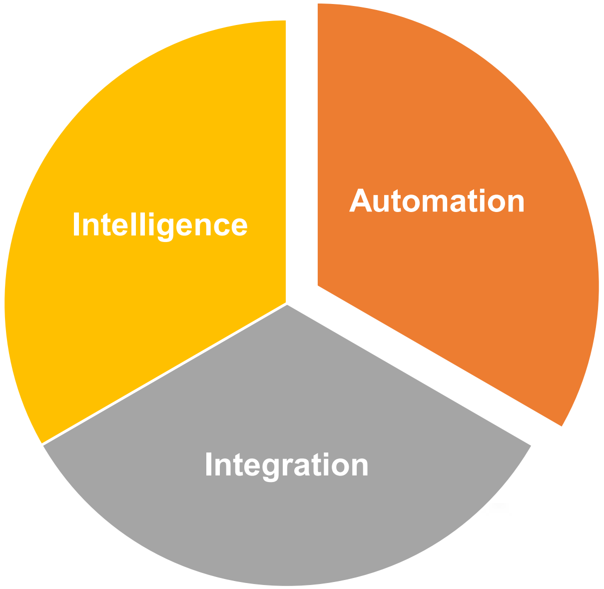
ERP packages touch many aspects of a company's internal and external operations. Consequently, successful deployment and use of ERP systems are critical to organizational performance and survival.

The most important attributes of ERP are its abilities to:

- Automate and integrate business processes across organizational functions and locations.
- Enable implementation of all variations of best business practices with a view towards enhancing productivity.
- Share common data and practices across the entire enterprise in order to reduce errors.
- Produce and access information in a real-time environment to facilitate rapid and better decisions and cost reductions.

Why is ERP important?

ERP is the central nervous system of an enterprise. An ERP software system provides the automation, integration, and intelligence that is essential to efficiently run all day-to-day business operations.



CMMS vs ERP

Computerized Maintenance Management System (CMMS) and Enterprise Resource Planning (ERP) systems are both software solutions that play crucial roles in the management of business operations. However, they serve different purposes and focus on distinct aspects of an organization.

Primary Purpose:

CMMS

Primarily designed for the management of maintenance activities and assets. It helps in scheduling preventive maintenance, tracking equipment, managing work orders, and ensuring the overall efficiency of maintenance processes.

ERP

A comprehensive system that integrates various business processes, including finance, human resources, procurement, manufacturing, and more. ERP aims to provide a unified platform for managing and optimizing overall business operations.

Scope

CMMS: Focuses specifically on maintenance-related tasks, such as equipment upkeep, work order management, and inventory control.

ERP: Encompasses a broader range of business functions beyond maintenance, including finance, supply chain management, customer relationship management (CRM), and human resources.

Modules

CMMS

Typically includes modules for preventive maintenance, work order management, asset tracking, inventory management, and sometimes health and safety compliance.

ERP

Comprises modules for finance, procurement, production planning, inventory management, HR, CRM, and more, depending on the specific ERP system.

Integration

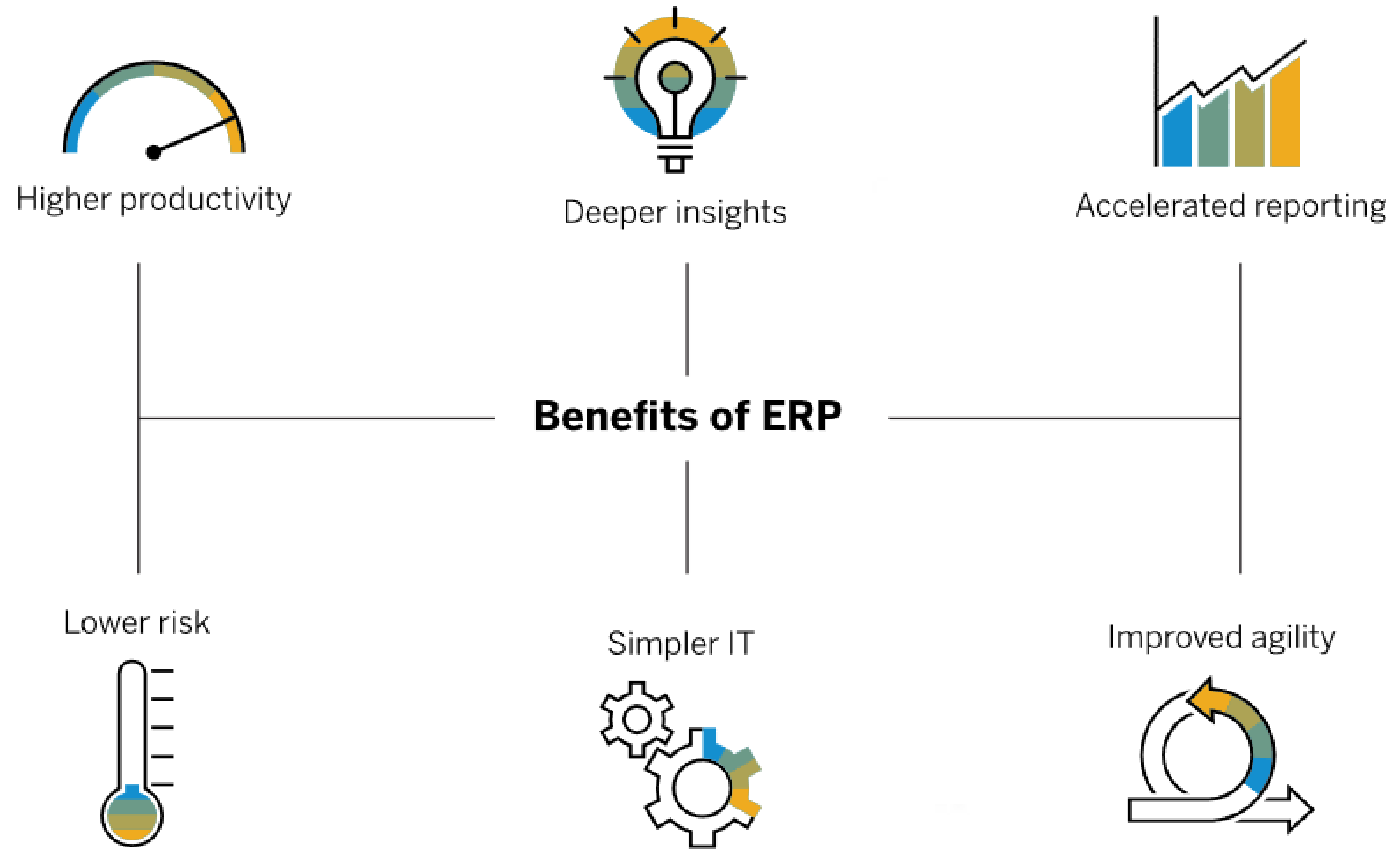
CMMS

Often operates as a standalone system, although it may integrate with other software solutions like ERP for data exchange.

ERP

Designed to be an integrated solution where various modules share a common database, providing real-time data visibility across different departments.

Six key benefits of ERP



Higher productivity

Streamline and automate your core business processes to help everyone in your organization do more with fewer resources.

Deeper insights

Eliminate information silos, gain a single source of truth, and get fast answers to mission-critical business questions.

Accelerated reporting

Fast-track business and financial reporting and easily share results. Act on insights and improve performance in real-time.

Lower risk

Maximize business visibility and control, ensure compliance with regulatory requirements, and predict and prevent risk.

Simpler IT

By using integrated ERP applications that share a database, you can simplify IT and give everyone an easier way to work.

Improved agility

With efficient operations and ready access to real-time data, you can quickly identify and react to new opportunities.

Types of ERP deployment

Cloud ERP

With cloud ERP, the software is hosted in the cloud and delivered over the Internet as a service that you subscribe to. The software provider generally takes care of regular maintenance, updates, and security on your behalf. Today, cloud ERP is the most popular deployment method for many reasons – including lower upfront costs, greater scalability and agility, easier integration, and much more.

Question-1

Why is cloud ERP considered a popular deployment method?

a) It requires high upfront costs

b) It lacks scalability and agility

c) It is challenging to integrate with other systems

d) Lower upfront costs, greater scalability, and agility

e) It involves complex installation procedures

Answer: d) Lower upfront costs, greater scalability, and agility

On-Premise ERP

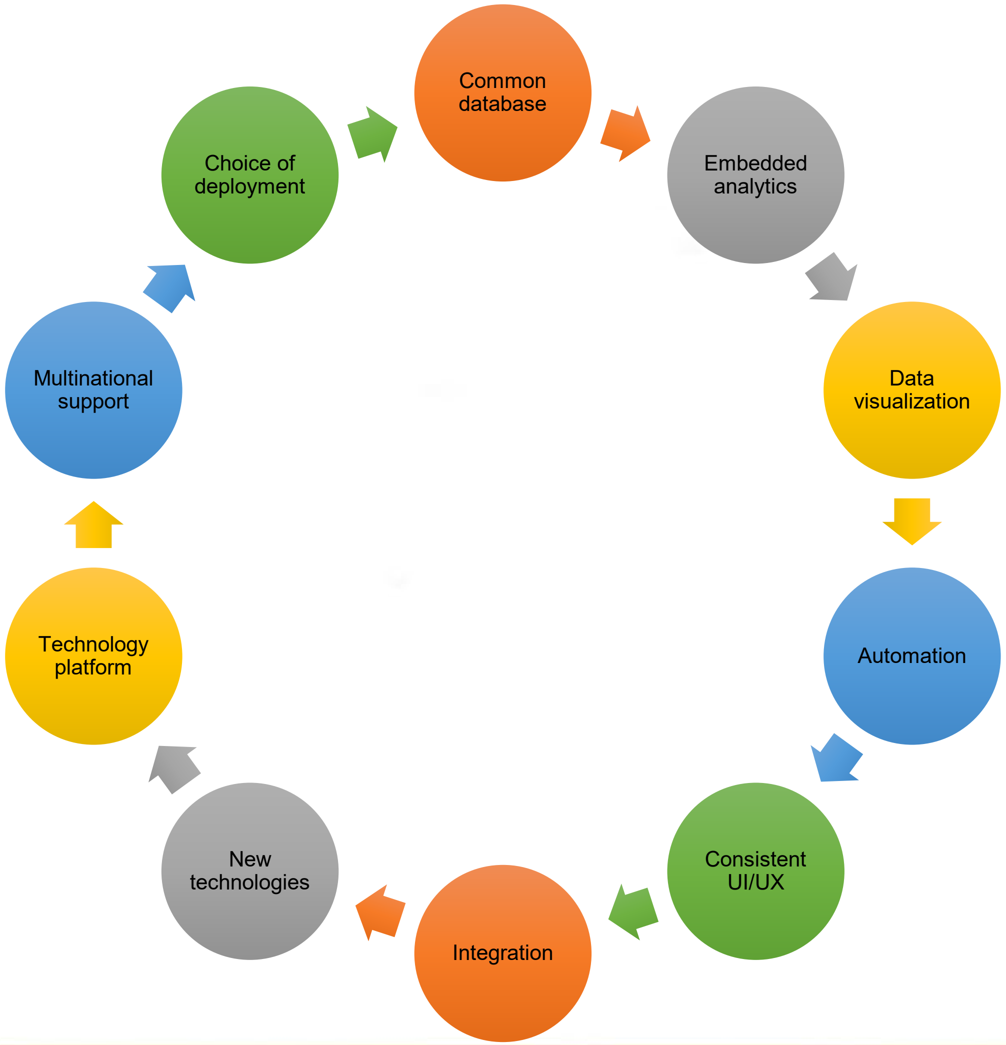
This is the traditional model for deploying software where you control everything. The ERP software is typically installed in your data center at the locations of your choice. The installation and maintenance of the hardware and software is your staff's responsibility.

Many companies are modernizing and upgrading their on-premise ERP systems to cloud deployments. This requires careful planning of your ERP upgrade as well as a thoughtful process of evaluating ERP software and deployment options.

Hybrid ERP

For companies that want a mixture of both to meet their business requirements, there is the hybrid cloud ERP model. This is where some of your ERP applications and data will be in the cloud and some on premise. Sometimes this is referred to as two-tier ERP.

Fundamental features of enterprise resource management systems



Common database

Centralized information and single version of the truth – providing consistent, shared data and a cross-functional view of the company.

Embedded analytics

Built-in analytics, self-service BI, reporting, and compliance tools that can deliver intelligent insight for any area of the business.

Data visualization

Visual presentation of key information with dashboards, KPIs, and point-and-click analytics to assist in quick and informed decision-making.

Automation

Automation of repetitive tasks as well as advanced (robotic process automation) RPA powered by AI and machine learning.

Consistent UI/UX:

The same look and feel across modules as well as easy-to-use configuration and personalization tools for processes, users (including customers and suppliers), business units, locations, and product lines.

Integration

Seamless integration of business processes and workflows as well as open and easy integration with other software solutions and data sources, including from third parties.

New technologies

Support for AI and machine learning, digital assistants, the IoT, RPA, security and privacy, and mobile.

Technology platform

A fast, proven, and stable technology stack for this long-term investment – including a low-code/no-code platform, integration platform-as-a-service (iPaaS), data management, and more.

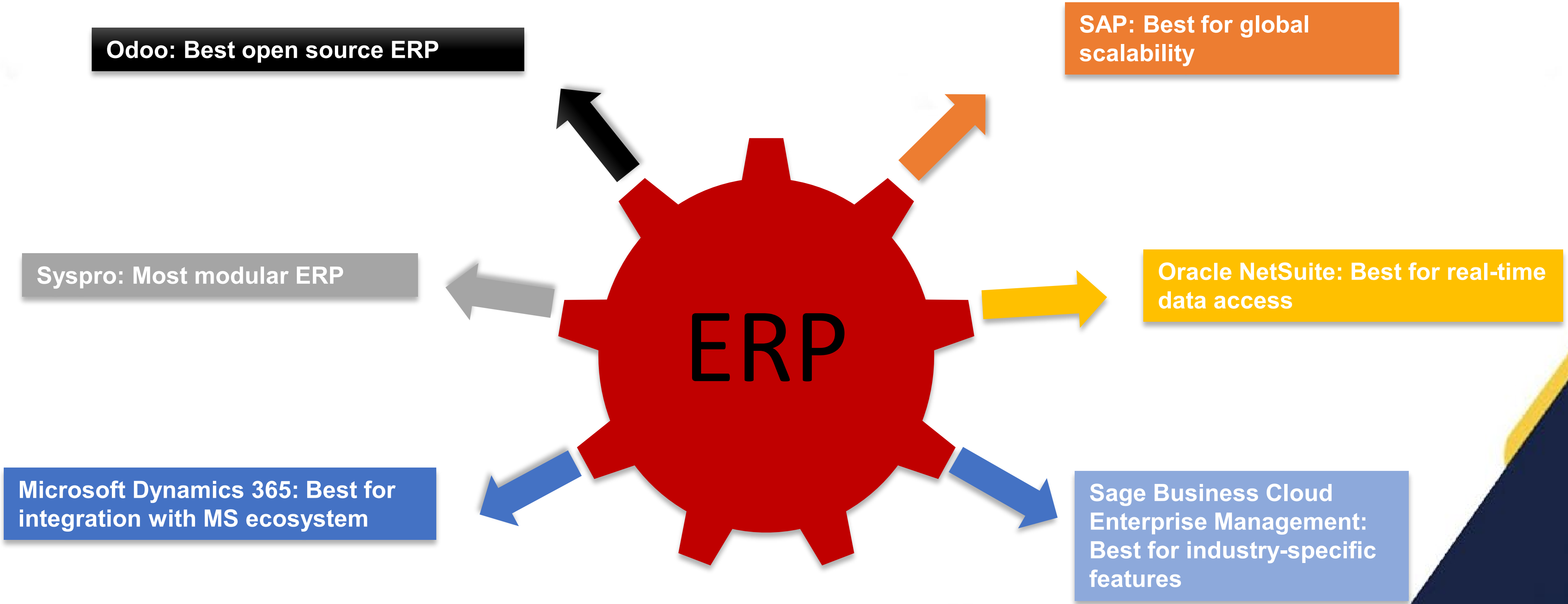
Multinational support

Including languages, currencies, and local business practices and regulations – as well as technical support for cloud services, training, help desk, and implementation.

Choice of deployment

Cloud, on-premise, or hybrid

ERP software's



ERP integration

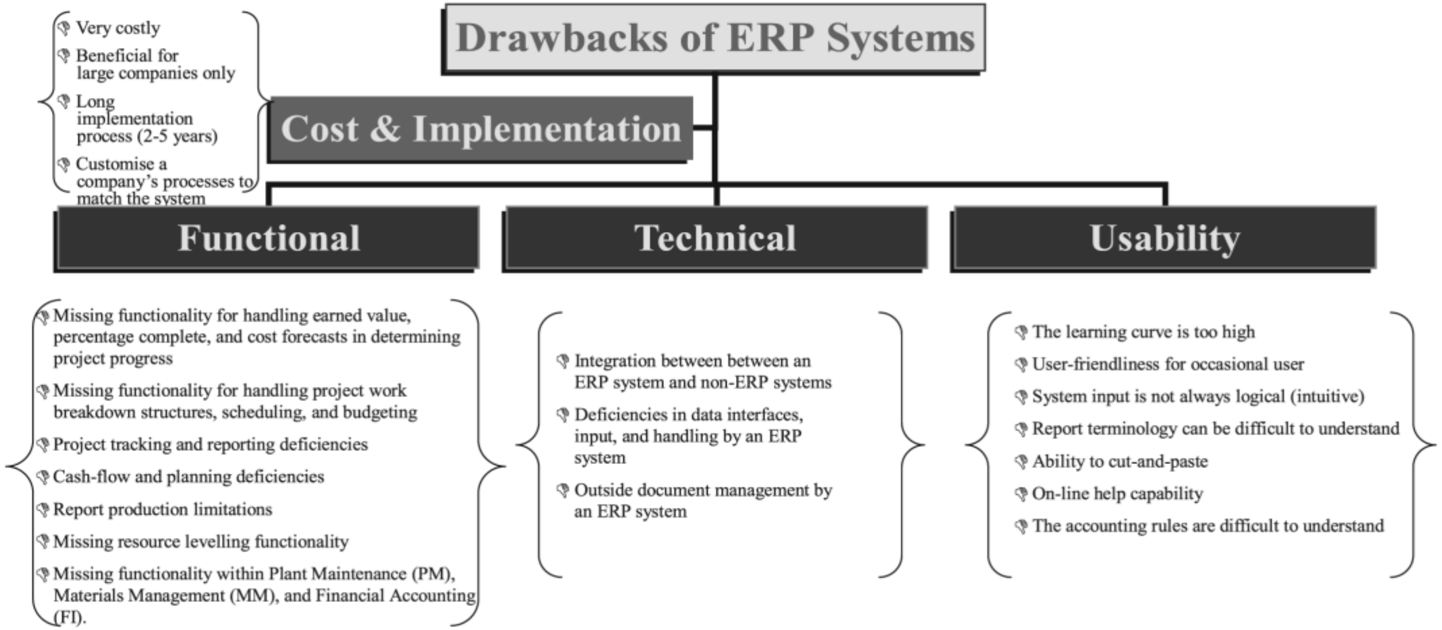
- Modern ERP systems are open and flexible – and can easily integrate with a wide range of software products using connectors or customized adaptors, such as application programming interfaces (APIs).
- Other methods for ERP integration include ESB (enterprise service bus) and iPaaS (integration platform-as-a-service). iPaaS, which offers a cloud-based approach, is a very popular option for modern businesses.

ERP integration

- iPaaS platforms can rapidly sync on-premise or cloud-based ERP with SaaS applications from the same vendor or third-parties. They typically require little-to-no coding, they’re flexible and relatively inexpensive, and they offer a whole host of other uses – such as automatic API generation, machine learning data integration, Internet of Things (IoT) network integration, prebuilt content, and more.

Drawbacks of the ERP systems

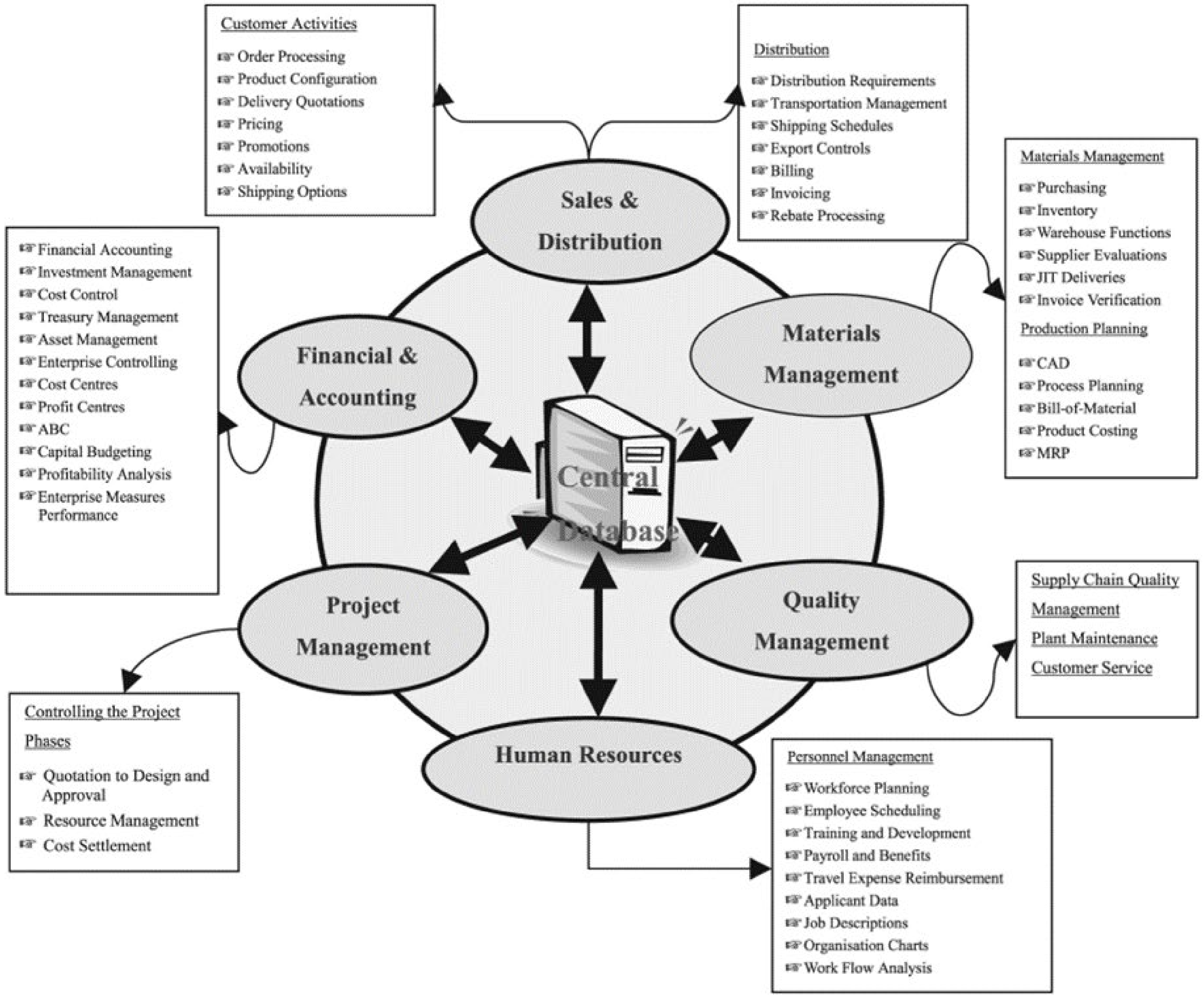
Although ERP systems have certain advantages such as low operating cost and improving customer service, they have some disadvantages due to the tight integration of application modules and data. Huge storage needs, networking requirements and training overheads are frequently mentioned ERP problems.



Modules of ERP

The various modules of ERP include

- Engineering data control (bill of materials, process plan and work centre data)
- Sales, purchase, and inventory (sales and distribution, inventory and purchase)
- Material requirement planning (MRP)
- Resource flow management (production scheduling, finance, and human resources management)
- Works documentation (work order, shop order release, material issue release and route cards for parts and assemblies)
- Shopfloor control and management and others like costing, maintenance management, logistics management, and MIS.


Customer Activities
Order Processing
Product Configuration
Delivery Quotations
Pricing
Promotions
Availability
Shipping Options
Distribution
Distribution Requirements
Transportation Management
Shipping Schedules
Export Controls
Billing
Invoicing
Rebate Processing
Materials Management
Purchasing
Inventory
Warehouse Functions
Supplier Evaluations
JIT Deliveries
Invoice Verification
Production Planning
CAD
Process Planning
Bill-of-Material
Product Costing
MRP
Financial Accounting
Investment Management
Cost Control
Treasury Management
Asset Management
Enterprise Controlling
Cost Centres
Profit Centres
ABC
Capital Budgeting
Profitability Analysis
Enterprise Measures Performance
Sales & Distribution
Financial & Accounting
Materials Management
Central Database
Project Management
Quality Management
Human Resources
Supply Chain Quality Management
Plant Maintenance
Customer Service
Controlling the Project Phases
Quotation to Design and Approval
Resource Management
Cost Settlement
Personnel Management
Workforce Planning
Employee Scheduling
Training and Development
Payroll and Benefits
Travel Expense Reimbursement
Applicant Data
Job Descriptions
Organisation Charts
Work Flow Analysis

Also, the model of ERP includes areas such as

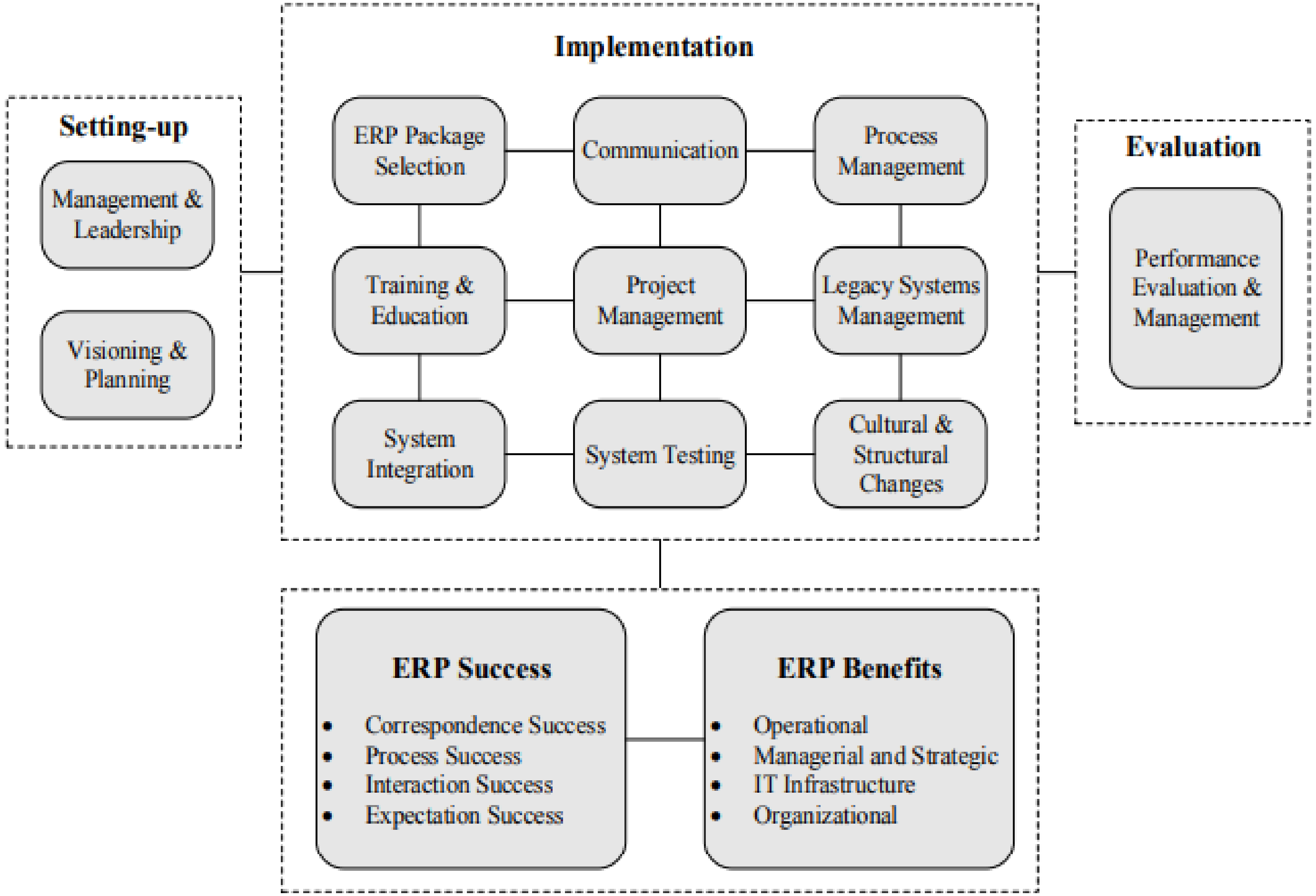
Finance - Financial accounting, treasury management, enterprise control and asset management.

logistics - Production planning, materials management, plant maintenance, quality management, project systems, sales, and distribution.

human resources - Personnel management, training and development, and skills inventory.

workflow - Integrates the entire enterprise with flexible assignment of tasks and responsibilities to locations, positions, jobs, groups, or individuals.

ERP operations

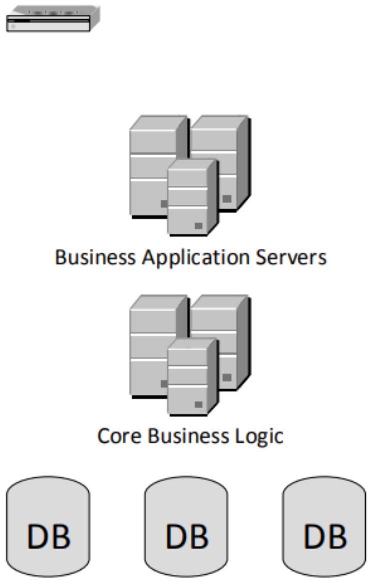


Effect of the Industry 4.0 on ERP Systems

- ERP systems have a complex software environment which includes different layers. ERP software includes a database design and a database layer in order to keep different numbers of data from the system.
- The database can only be accessed by core business logic such as security applications, and firewalls that are provided at the server level.

Effect of the Industry 4.0 on ERP Systems

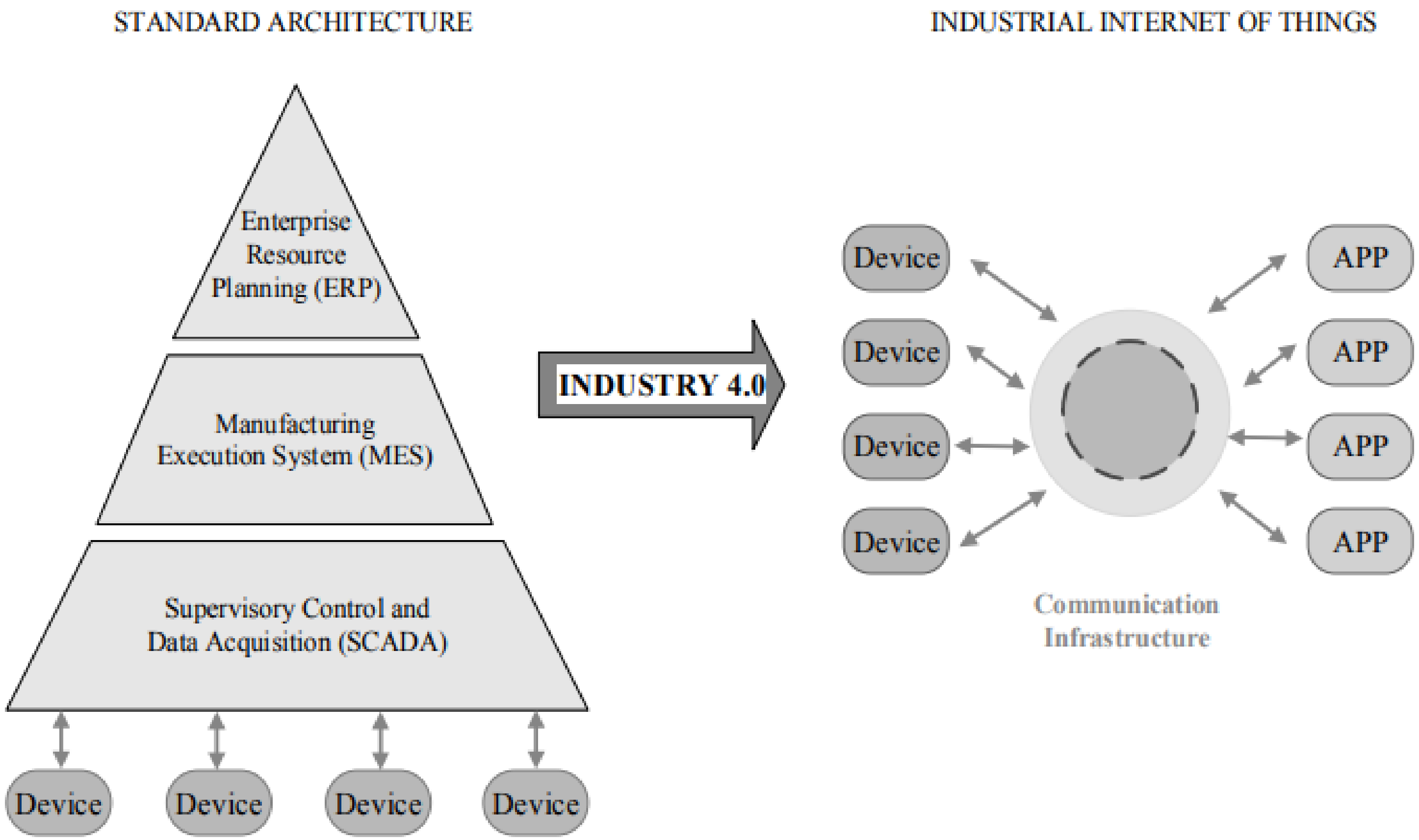
- The business functions such as finance, marketing, production, etc. are modeled as applications at the business applications layer.
- Finally, end-users are accessed to the system by using user interfaces at the end-user layer.



Effect of the Industry 4.0 on ERP Systems

- In the classical approach the corporate data are stored in the SCADA system which is used as data acquisition systems. The data are analyzed in order to achieve manufacturing tracing or better decision-making systems. Finally, at the knowledge level, ERP systems are implemented to increase integration between processes and data. The figure below shows the relationship between classical systems and Industry 4.0 technologies.

Effect of the Industry 4.0 on ERP Systems



What is ERP for the Mining Industry?

- For mining organizations in search of ERP software, maximizing investment benefits is critical. The volatility and risk associated with fluctuating prices of natural resources means expenditures must provide deep positive impact on operations. Investing in Mining Enterprise Resource Planning (ERP) software provides payback through streamlining operations and increasing control of critical processes. Selection of a proven mining management ERP solution — even at the exploration stage- therefore becomes key to driving mining success.

What is ERP for the Mining Industry?

- ERP for Mining Industry is sophisticated business management software that streamlines essential processes involved in the mining industry and facilitates seamless coordination between the human workforce, organizational assets, and resources.
- It encompasses diverse modules for managing mining operations and provides tools and functionalities specifically tailored to mining businesses.

Features of ERP for Mining Industry

Integration

ERP solution for mining industry integrates data from all business aspects. It saves employees from the hassle of entering the same data over and over, eliminating duplicate records and errors. Decision-makers can access key business data to get a better understanding of business operations and find areas for improvement. The best business management software brings operational efficiency and improves various aspects of the mining business, such as project management, asset management, supply chain management, financial management, and compliance.

Features of ERP for Mining Industry

Data Analysis

Data analysis involves collecting, storing, and analyzing data to find historical trends and patterns and accurately forecast future sales, revenues, and expenditures. Mining ERP software has Business Intelligence (BI) Tools and data analytical capabilities that provide useful insights into business data and make actionable decisions that reduce risks, minimize costs, improve profitability, and benefit the business in the long run.

Question 2

What is the primary purpose of an ERP solution in the mining industry?

a) Mining resource extraction

b) Generating geological surveys

c) Integrating data from all business aspects

d) Managing equipment maintenance

e) Conducting environmental impact assessments

Answer: c) Integrating data from all business aspects

Features of ERP for Mining Industry

Reporting and Dashboards

The best ERP for the mining industry provides Business Intelligence tools, also called BI tools. These tools play a vital role in data consolidation and analysis to identify trends and patterns. They use various Key Performance Indicators (KPIs) to make visual representations of the data and predict future events more accurately.

Benefits of Using ERP for Mining Industry

Optimal Resource Allocation

Resource allocation and utilization are some of the critical aspects of mining firms, much like other firms. The asset management module in Mining ERP software enables the company to effectively manage organizational assets, assign human resources, capital resources, machinery, and materials to appropriate work sites, and track them for their performance, efficiency, and defects. ERP implementation provides a deep understanding of how resources are used and helps flag underutilized resources to take timely corrective measures.

Benefits of Using ERP for Mining Industry

Enhanced Supply Chain Management

In order for a mining firm to become profitable, it needs to efficiently handle supply chain management and have an equally efficient inventory management system. One of the benefits of ERP systems is their ability to do route planning, cargo capacity management, transport reservations, driver management, and maintenance scheduling. The supply chain management tools help reduce transportation and operating costs, minimize waste, and improve efficiency in mining operations.

Benefits of Using ERP for Mining Industry

Improved Compliance

Mining companies have to strictly adhere to several environmental, health and safety, labor, and financial regulations set by the Government. Mining ERP software brings end-to-end traceability into business operations and allows it to track emissions and waste, accurately generate financial reports, and reduce human errors. Ultimately, the company can avoid fines, penalties, litigation, and damage to its reputation.

REFERENCES

- https://www.emerald.com/insight/content/doi/10.1108/14637150410548056/full/pdf?title=enterprise-resource-planning-an-integrative-review
- Akyurt, İ. Z., Kuvvetli, Y., & Deveci, M. (2020). Enterprise resource planning in the age of industry 4.0: A general overview. Logistics 4.0, 178-185.
- https://technologyadvice.com/erp/
- https://www.sap.com/india/products/erp/what-is-erp.html
- https://www.sagesoftware.co.in/blogs/erp-for-mining-industry/
- https://www.psainc.ca/industries/mining-erp-software/

CONCLUSION

- Provided an overview of Enterprise Resource Planning (ERP) systems.
- Explored the significance of ERP in streamlining business processes.
- Discussed the comparison between CMMS and ERP
- Examined the advantages, including enhanced efficiency and resource management.
- Classified ERP deployment options for businesses.
- Explored key features essential to Enterprise Resource Management Systems.
- Discussed the software applications facilitating ERP implementation.

CONCLUSION

- Highlighted the importance of seamless integration within ERP systems for optimal functionality.
- Examined the limitations and challenges associated with ERP implementation.
- Explored the diverse functional modules within ERP systems, illustrating their role in comprehensive business management.
- Explored the functioning and processes involved in Enterprise Resource Planning (ERP) systems.

CONCLUSION

- Examined the influence of Industry 4.0 on the evolution and capabilities of ERP systems.
- Defined ERP in the context of the mining industry, emphasizing its relevance.
- Explored specific features tailored for ERP systems in the mining sector.
- Examined the advantages of implementing ERP systems in mining operations for enhanced efficiency and management.


THANK YOU

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MINE AUTOMATION AND DATA ANALYTICS

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Module 03:
Mine Robotics

Lecture 07 (A):
Remote operation and control center

CONCEPTS COVERED

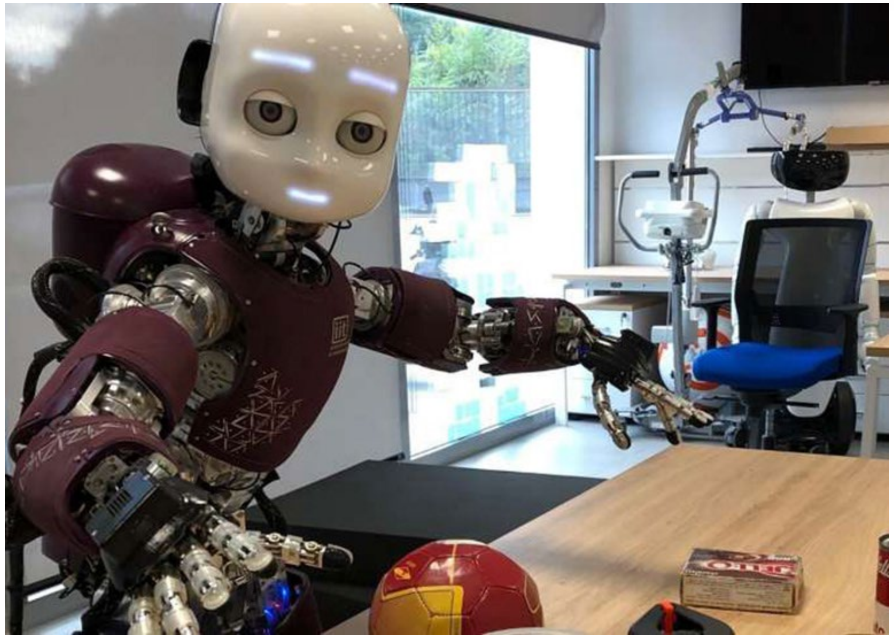
- Basics of Robotics
- Industrial Robots Principal Components
- Role of Robotics in the Mining Industry
- Introduction to Remote operation
- Modes in remote operation
- Remote Operations Centers
- Remote Operations Center Implementation

CONCEPTS COVERED

- Integrated Remote Operations Centers (IROC) and central control rooms in mining
- Office Tele-Remote
- Bench Remote
- Case study on remote operation

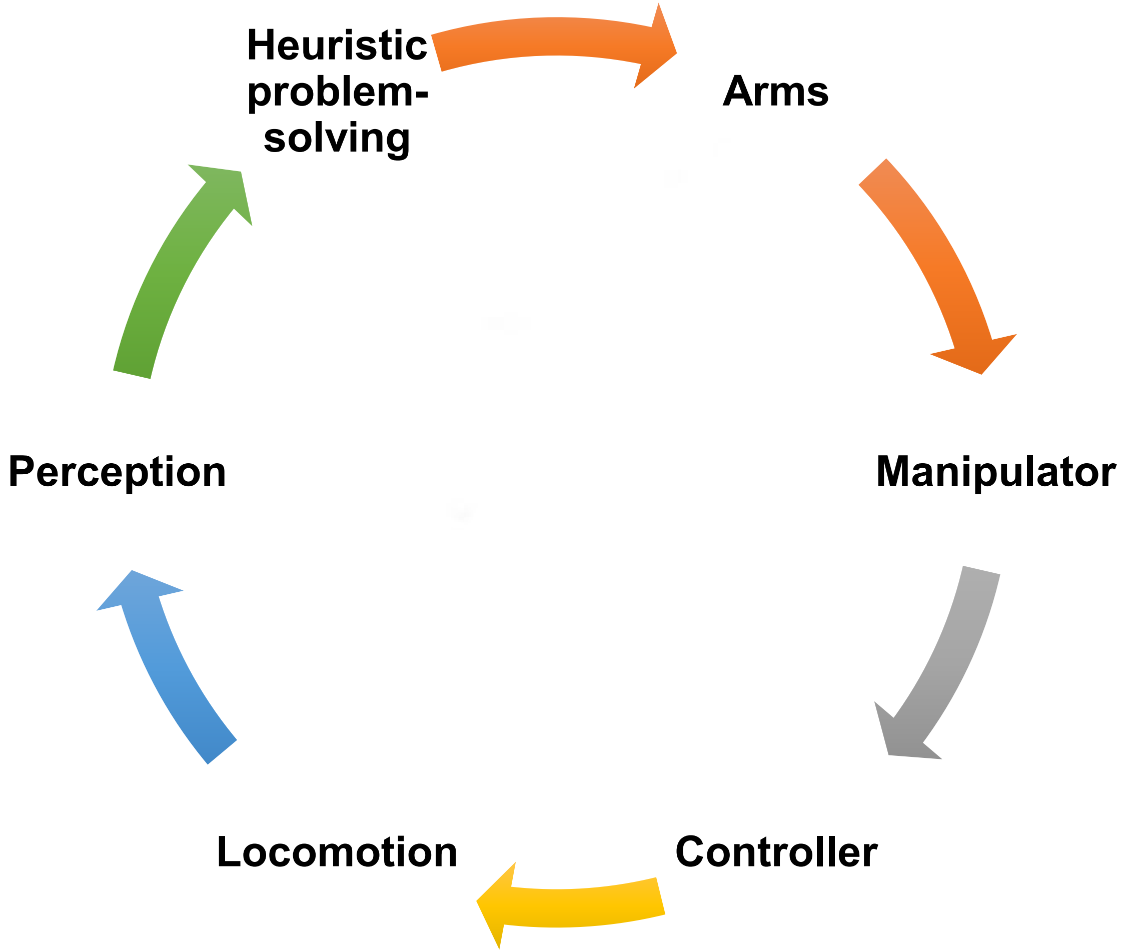
Basics of Robotics

A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialised devices through variable programmed motions for various tasks.



The term robotics describes the field of study focused on developing robots and automation.

Industrial Robots Principal Components



Industrial Robots Principal Components

- **Arm: One or more arms, usually on a fixed base, can move in several directions.**
- **Manipulator: the business end of the robot is the "hand" that holds the tool or the part to be worked.**
- **Controller: that gives detailed movement instructions.**
- **Locomotion: some means of moving around in a specified environment;**
- **Perception: the ability to sense by sight, touch, or some other means, its environment, and to understand it in terms of a task, e.g., the ability to recognise an obstruction or find a designated object in an arbitrary location; and**
- **Heuristic problem-solving: the ability to plan and direct actions to achieve higher-order goals.**

Role of Robotics in the Mining Industry

Robotics plays a significant role in the mining industry, increasing efficiency, safety, and productivity. Deploying robots in mining operations can address various challenges and enhance overall performance. Here are some key aspects of the role of robotics in the mining industry.

Autonomous Vehicles:

Drilling and Blasting: Autonomous drilling and blasting systems can improve precision, reduce waste, and enhance safety by minimising human exposure to hazardous environments.

Haul Trucks: Autonomous haul trucks can transport materials within the mining site, optimising logistics and reducing the risk of accidents.

Question 1

What is the primary characteristic of a robot?

a) Fixed functionality

b) Single-purpose manipulator

c) Reprogrammable and multifunctional

d) Limited range of motion

e) Lack of tool compatibility

Answer: c) Reprogrammable and multifunctional

Remote Operation and Monitoring

Teleoperation

- Operators can control mining equipment remotely, allowing them to manage machinery in safer environments away from potential hazards.

Surveillance and Inspection

- Robots can be used for remote monitoring and inspection of mining sites, ensuring compliance with safety regulations and identifying potential issues.

Automated Exploration

Drone Technology

Unmanned aerial vehicles (UAVs) equipped with sensors and cameras are used for aerial surveys, geological mapping, and exploration activities, providing valuable data for decision-making.

Material Handling and Sorting

Robotic Sorting Systems

Robots equipped with computer vision systems efficiently sort and process mined materials, improving the overall quality of extracted resources.

Data Analytics and Predictive Maintenance

Sensors and IoT Devices

Integration of sensors and Internet of Things (IoT) devices on mining equipment allows for real-time data collection, enabling predictive maintenance strategies and reducing downtime.

Safety Improvements

Robotic Rescue Systems

In emergencies, robots can be deployed for search and rescue operations, minimising risks to human rescuers.

Introduction to Remote operation

- Remote operations involve the physical separation of the driver or operator from the vehicle.
- Vehicles can be operated from remote stations located in a Remote Operation Center (ROC).
- Remote operations are more established in aviation and maritime. In aviation and maritime, remote operations may involve tasks beyond monitoring, with operators often playing a managing role.

- The expansion of remote operations is beneficial as it is likely that human involvement will be needed even in fully autonomous vehicles.
- In ground-based traffic and road freight, remote operations are a relatively new concept. Operators primarily monitor and support the Dynamic Driving Task (DDT) when necessary, in these domains.
- Example of remote operation is remote Air Traffic Control Towers (ATC-Ts) where control officers manage air traffic within designated airport areas from a geographically separate location.

Modes in remote operation

- The driver performs tasks that require different cognitive resources as they differ in nature. This applies to remote operations as well.
- Driving has three levels of abstraction

Strategic level

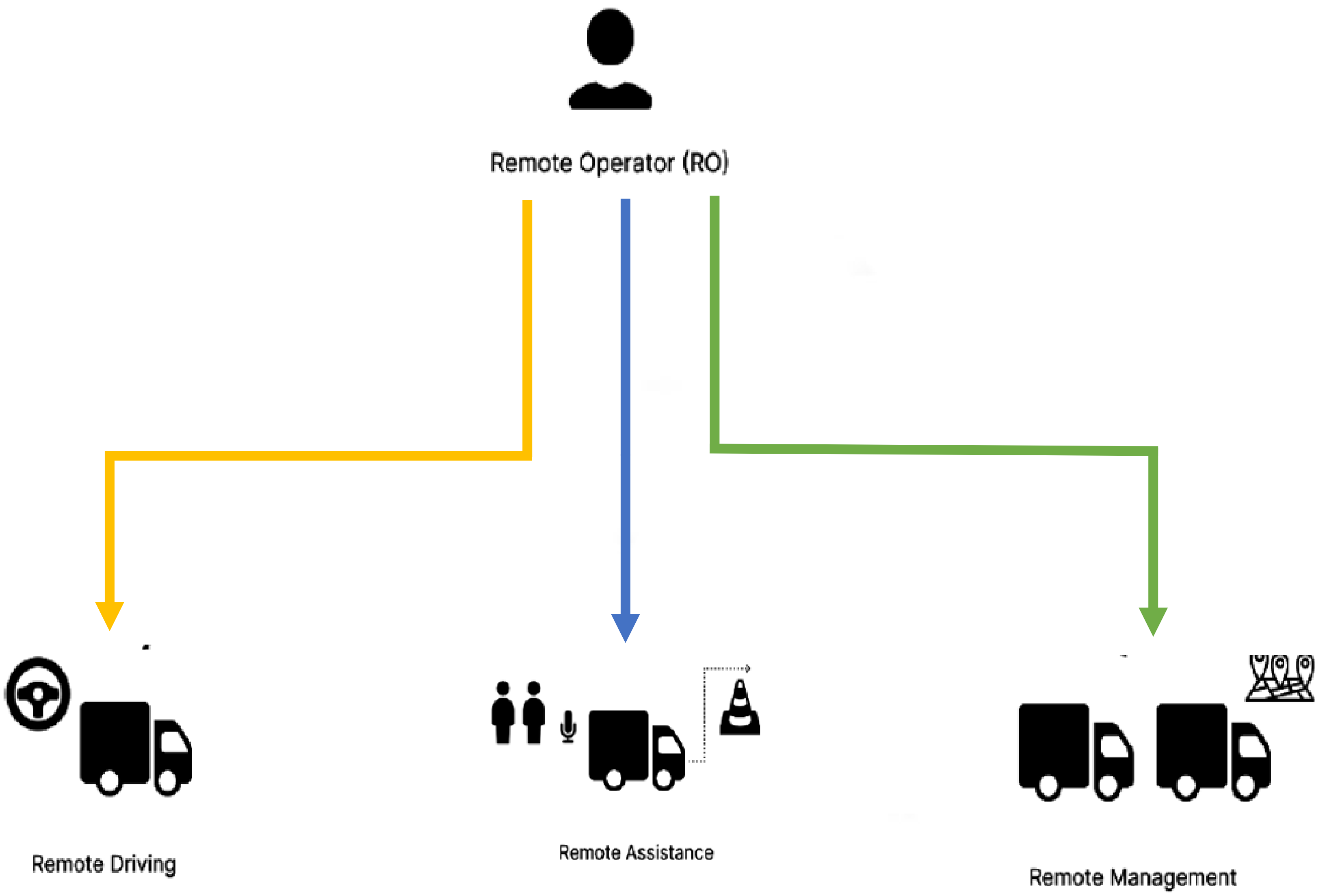
The strategic level involves route planning as well as cost and risk considerations.

Tactical level

The tactical level is conscious and intentional and includes the driver’s decisions, such as when to overtake another vehicle.

Operational level

The operational level implements the decisions made at the tactical level and, therefore, includes simpler operations such as steering, accelerating, or braking.


Remote Operator (RO)
Remote Driving
Remote Assistance
Remote Management

Remote driving

Remote driving, sometimes remote control, is when the entire or parts of the Dynamic Driving Task (DDT), as well as fallbacks, are performed by the RO. The RO thus controls the motions of the vehicle and whilst that is ongoing, it cannot be considered autonomous driving. Remote driving is thus related to tactical and operational levels of abstraction.

Remote driving

Example – Autonomous haul trucks

Autonomous haul trucks are equipped with advanced remote driving systems. The Remote Operator (RO) takes control of the haul truck from a centralised control centre located on-site or miles from the mining operation. The RO utilises a combination of real-time video feeds, sensor data, and communication systems to control the haul truck's motions remotely.

Remote assistance

Remote assistance does not imply that the RO performs the Dynamic Driving Task (DDT) or any fallback. Instead, consider goals and tasks that the Automated Driving System (ADS) should accomplish and facilitate trip contribution in situations where the ADS needs additional input, for example, by putting out waypoints to aid decision-making when overtaking an obstruction. These tasks are related to the tactical and some extinct strategic levels of abstraction.

Remote Operations Centers

A remote operations centre (ROC) enables supervision, control, analysis, and data acquisition from afar. In simplest terms, an ROC can be regarded as a platform for enabling process automation and business integration

A ROC enables

- Enhanced occupational health and safety by removing operators and maintainers from risk exposure;
- Reduced labour costs by relocating high-cost, knowledge-intensive labour away from mine sites to urban centres

Remote Operations Centers

Increased productivity through

- Identification of inefficiencies at operating interfaces,
- Collaborative planning between functions (operations, maintenance, and procurement),
- Sharing of experience and knowledge across mine sites,
- Process visibility along the process chain; and
- Potential to lock in benefits through knowledge capture and reuse

Remote Operations Centers (ROC) Implementation

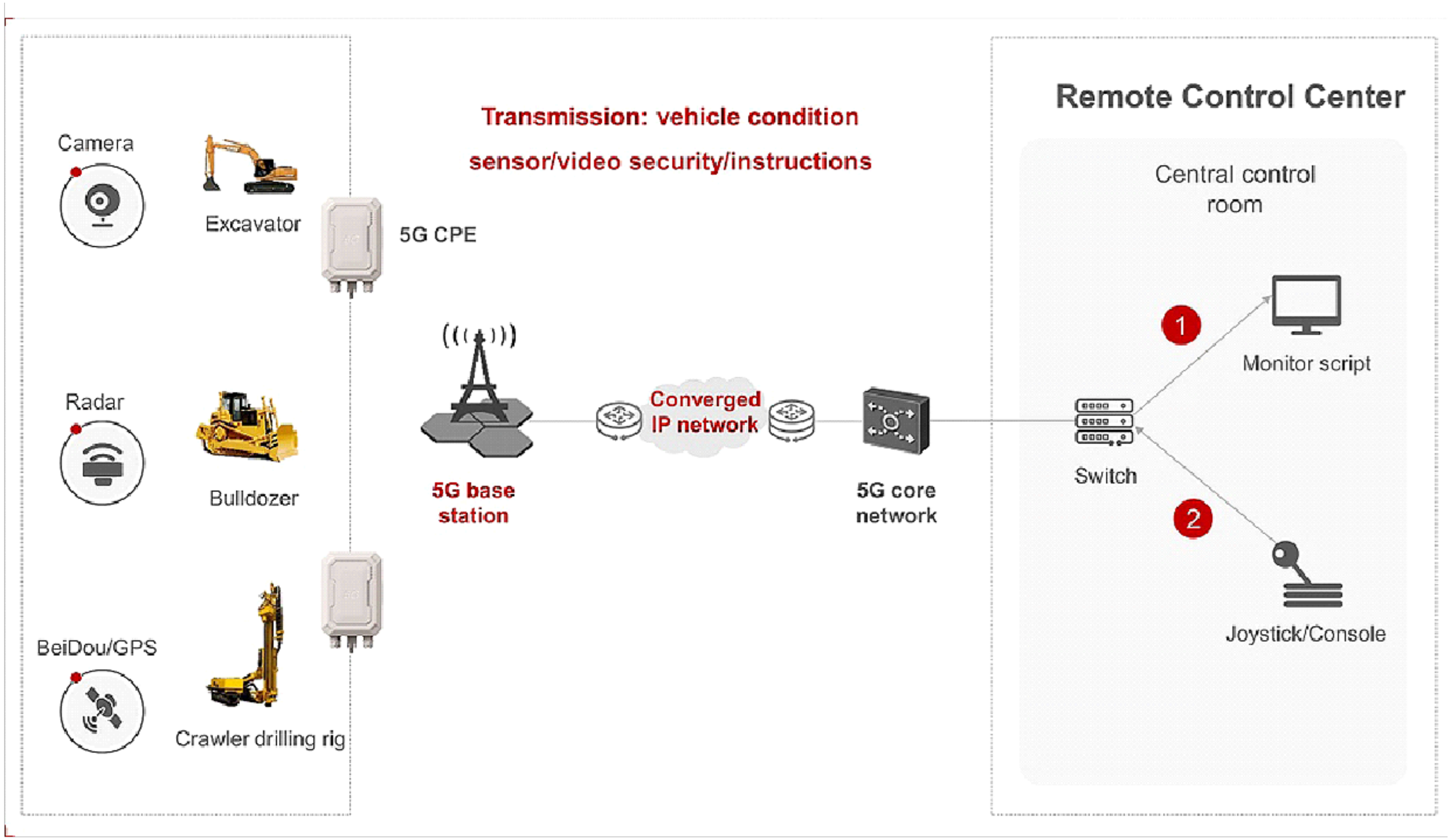
Implementing an ROC provides an essential catalyst for change within an organisation.

Current workflow patterns must be evaluated and modified or adapted.

Implementing ROCs, therefore, provides a necessary stimulus for changing work practices and driving an organisation to achieve higher labour productivity.

Interest in applying ROCs is growing within the mining industry.

Remote Operations Centers (ROC) Implementation



Integrated Remote Operations Centers (IROC) and central control rooms in mining

- By establishing a centralised control room, the seamless monitoring and control of various essential equipment across multiple mines, mills, smelters, and power plants become possible.
- This centralised approach facilitates the recording and analysis of substantial volumes of processing variables. These variables are transmitted from locations kilometres away, enabling effective remote monitoring.

- Moreover, integrating advanced predictive and prescriptive analytics enhances the overall operational efficiency and decision-making processes within the mining, milling, smelting, and power generation facilities.
- Control rooms allow you to monitor, operate, and control existing equipment and auxiliary facilities. Data, verbal information, radio signals, video images, and satellite messages will be transmitted and centrally collected.
- This information can also be fed into the customer's operating network or provided to other users. Mine operators have a complete overview of the mining sites at all times, and they can determine who else can receive the information.

Design of control room

The control room operator's actions directly impact up-time, production output, quality, and safety. A poorly planned and designed control room can lead to costly mistakes that can be related directly to human error.

Question 2

What functions are performed in control rooms according to the description?

a) Limited to data monitoring

b) Solely data collection

c) Monitoring, operating, and controlling equipment and auxiliary facilities

d) Transmitting verbal information only

e) Controlling new equipment installations

Answer: c) Monitoring, operating, and controlling equipment and auxiliary facilities

Functions of control room

- The application of a multi-functional open system is an essential element in the design of a control room. All installed devices are compatible with the Ethernet and TCP/IP protocol.
- The system separates process control from the management level, guaranteeing a stable and safe function. Figures can be displayed on either a full-screen or a diminished window, or they can be transferred to a large screen monitor.

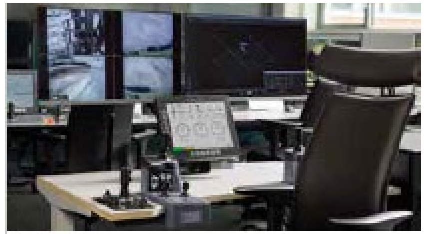
Installing a central control station can cut costs by

- Optimize workforce - the control centre only requires two people so that you can allocate workers in other areas
- Reducing maintenance - problems are recognised early before they can cause severe damage
- Reducing administration support.

Epiroc Office Tele REMOTE

Office Tele REMOTE removes the operator completely from the potentially dangerous mine environment. SmartROC rigs are controlled safely and efficiently from an office on the same local area network (WLAN) as the quarry or mine. This dramatically improves the working conditions for the operator, boosts safety and ramps up efficiency.

Main benefits



Enhanced safety

Mines and quarries can be dangerous places. The Office Tele REMOTE removes the operator from the work site, drastically increasing safety.

Improved working conditions for operators

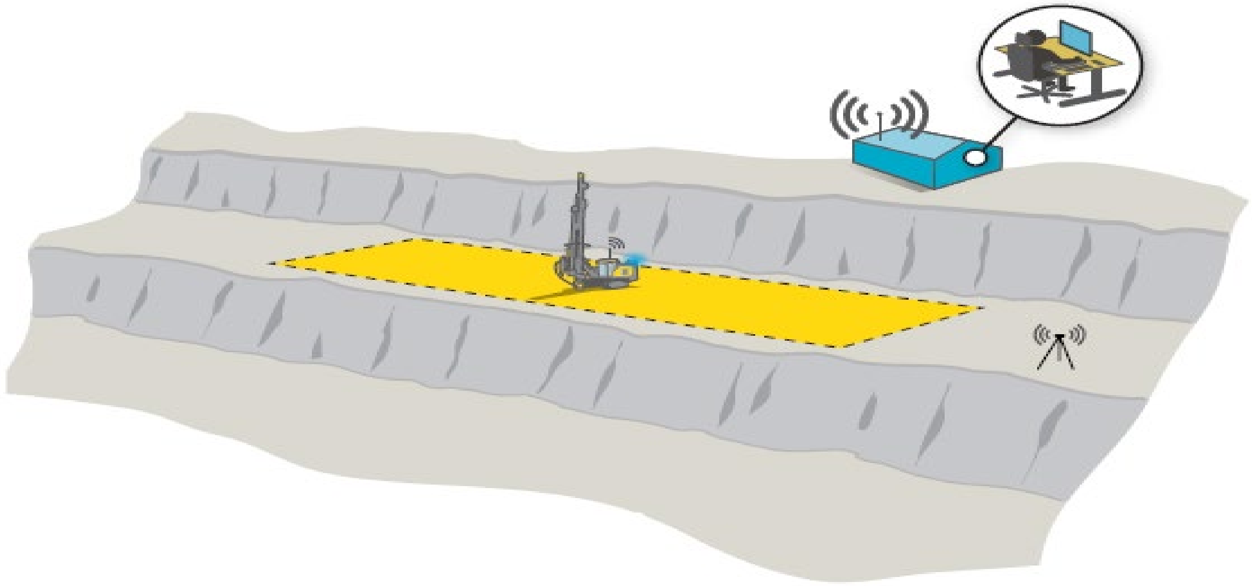
SmartROC rig operators can sit together in the office control centre away from Noise, danger, and dust.

Increased utilisation, productivity, and efficiency

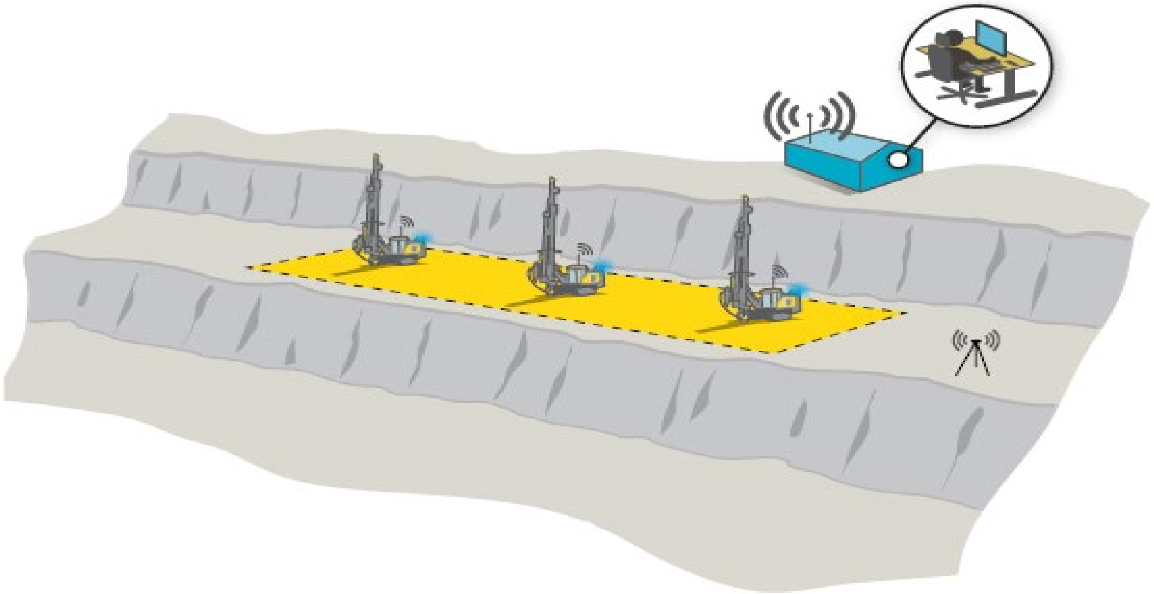
Each Office Tele REMOTE controls a single SmartROC rig as standard, with an option of extending to nine machines using the same server rack. This represents a massive increase in equipment utilisation and return on investment for each rig.

Office Tele REMOTE operation

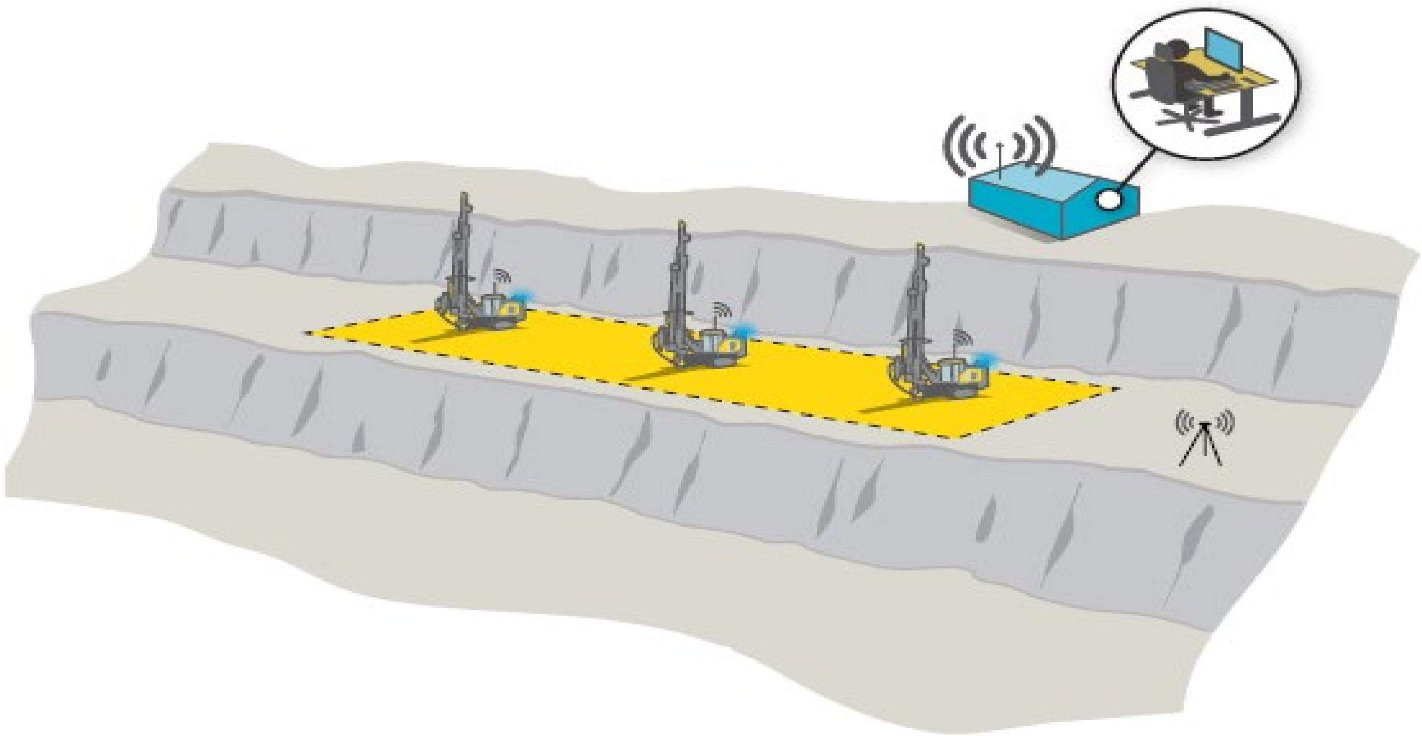
- The Office Tele REMOTE enables the operator to perform drilling operations without entering any hazardous area. This system increases the working distance and moves operators' workspace from a bench to an office environment. It also optimises work time by eliminating the need to transport personnel between the bench and the office.



- The Office Tele REMOTE system comes with built-in scalability. In its standard form, one operator runs a single SmartROC rig. However, this capability can be extended up to nine machines. Also, being a part of the same infrastructure makes network management more accessible and helps overcome network congestion when operating drill rigs with other equipment in the exact location.



- If a site is already operating a Bench REMOTE, an upgrade is available to move it into the office control centre. It can work side-by-side with an Office Tele REMOTE.



Atlas Copco BENCH REMOTE

Bench remote is a unique remote operator station for all SmartROC d65 rigs that enables operators to do their jobs from a safe distance. Bench remote can handle one rig and up to three rigs in parallel. This takes productivity to a new level.

MAIN BENEFITS

Productivity

Increase operator efficiency with multi-task capability. You can operate up to three Atlas Copco SmartROC D65 rigs from one operator station.

Safety

Get away from unstable and hazardous benches. Drill close to the wall without having to enter the drilling area.

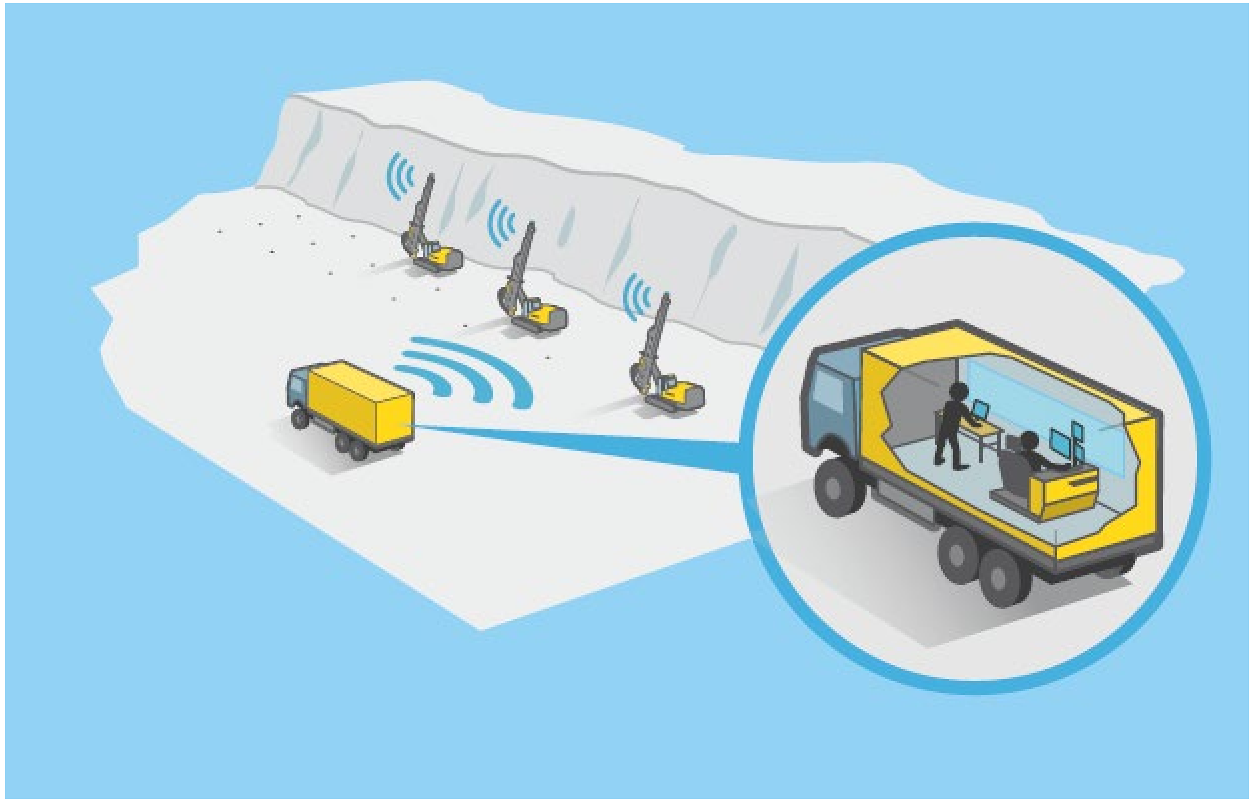
Working conditions

With reduced noise and dust levels, Bench REMOTE makes surface mining operations a safe pleasure. Working together with other rig operators also makes the work more enjoyable.

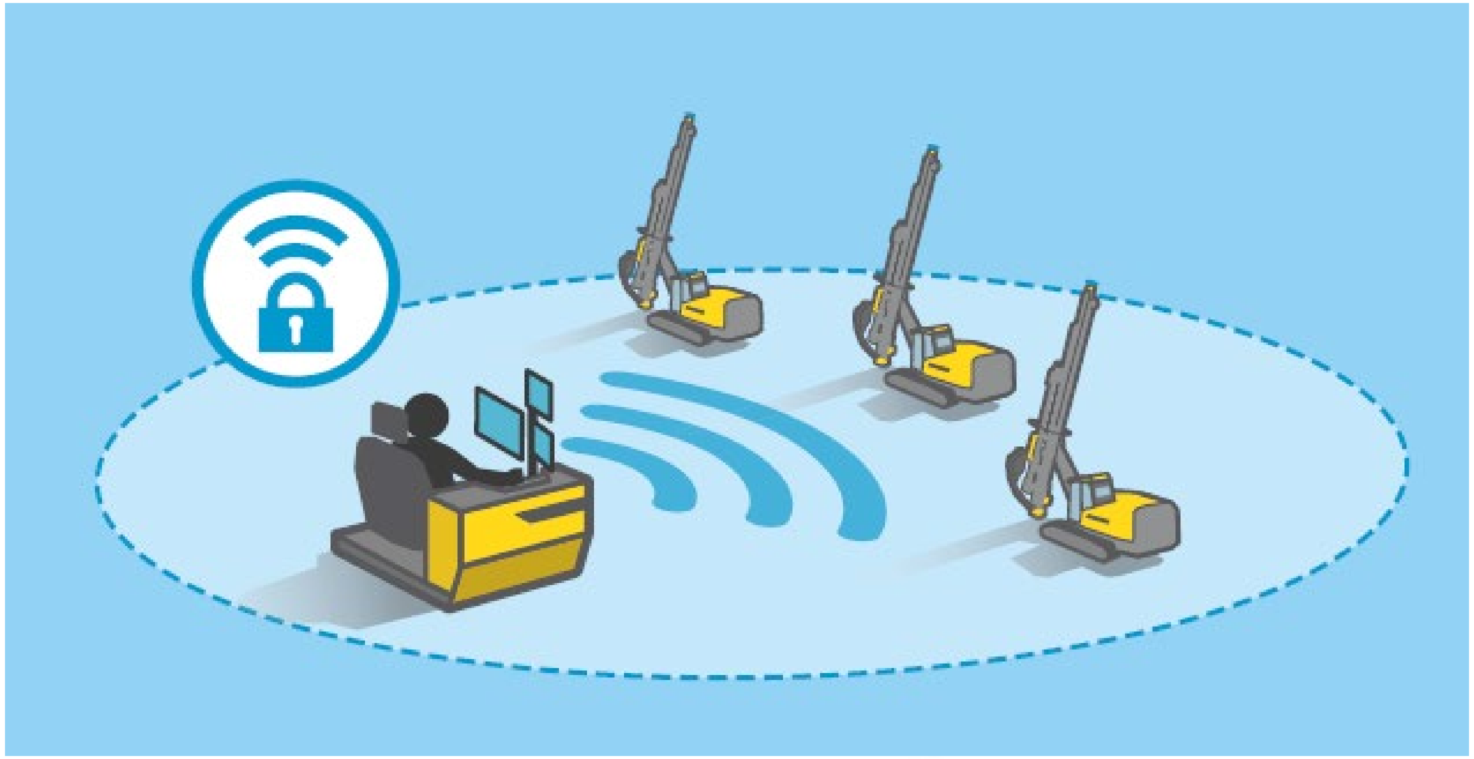
BENCH REMOTE operation

- **Bench REMOTE can be used up to 100 meters from the drill rigs and 30 meters above the rigs, which means that you can be productive without having to enter a hazardous area**

- The operator station can be installed in a vehicle, trailer, or container, and all controls and screens are the same as in the actual rig cabin.



- This provides a secured wireless network communication between the operator station and drill rigs



Case study - 1

Robot Mission (UX-1):

- UX-1 is a robot prepared for a unique mission in the Idrija mercury mine in western Slovenia.
- The mission involves navigating narrow, water-filled passages in a closed mine.
- UX-1's primary function is to autonomously explore the dark, murky waters and employ its multispectral camera to identify various minerals.

Field Test:

- The Idrija mission serves as UX-1's second field test.
- The objective is to evaluate the robot's capability to navigate challenging underwater conditions and effectively use its multispectral camera.

REFERENCES

- https://www.princeton.edu/~ota/disk3/1982/8209/820904.PDF
- https://liu.diva-portal.org/smash/get/diva2:1775619/FULLTEXT01.pdf
- https://new.abb.com/mining/open-pit-mining/central-control-room
- https://www.therobotreport.com/intel-labs-research-helps-robots-learn-new-objects-after-deployment/
- https://eos.org/features/underground-robots-how-robotics-is-changing-the-mining-industry
- Office Tele-remote and Bench Remote details taken from Epiroc and Atlas Copco websites

CONCLUSION

- Introduced fundamental concepts related to robotics.
- Explored vital components that constitute industrial robots.
- Examined the applications and significance of robotics in the mining sector.
- Defined remote operation and its relevance in industrial settings
- Explored different operational modes in remote settings.
- Introduced the concept of remote operation centres.

CONCLUSION

- Explored the process and considerations involved in establishing remote operations centres.
- Examined centralised control setups for remote operations in mining.
- Discussed specific remote operation of Epiroc office Tele-Remote and Atlas Copco Bench Remote.
- Examined a real-world case study illustrating the implementation and outcomes of remote operations


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS

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SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 03:
Mine Robotics

Lecture 07 (B) :
Remote operation and control center

CONCEPTS COVERED

- Role of communication systems for remote operation
- Concept of parallel mines
- Framework of IoT-based Parallel Mines
- IoT-based Parallel Mining System Elements
- Parallel management and control centre
- Autonomous Transportation Platform
- Semiautonomous Mining/Shoveling Platform
- Remote Take Over Platform
- Key Technologies of IoT-based Parallel Mines

Role of communication systems for remote operation

- Communication is essential in the mining process as it aids in the coordination of methods and also in monitoring activities.
- Technological contributions in the communication aspects of mines have resulted in process optimisation as they facilitate and coordinate activities at underground mines' various sites and levels.
- Technology has also facilitated short- and long-range communication at high rates to minimise delays.

Role of communication systems for remote operation

- **Wireless communication systems are areas where technology is gradually improving in the mining sector, more so for underground mines. For instance, the Multi-hop Protocol technology provides wireless communication in underground mines since they have portable relay nodes.**
- **Modern mining involves the use of high technology in communication, and wireless communication networks help in the transportation of data, video, voice, and other applications that facilitate the efficiency of mining operations.**

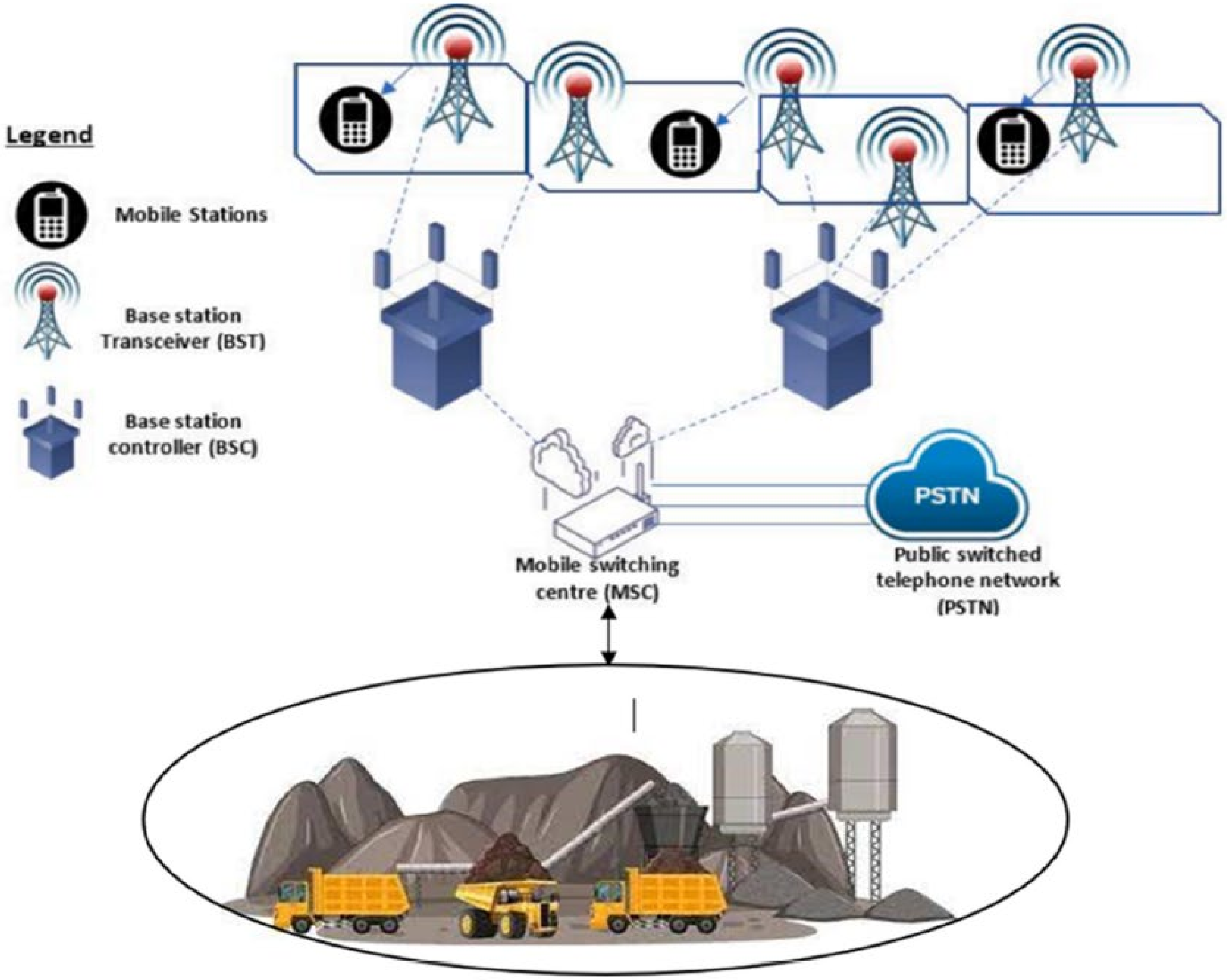
Role of communication systems for remote operation

- **Broadband speed is an essential factor in mining wireless communication networks, and the communication network should also support other applications to ensure cost-effectiveness. One of the newest communication technologies is ZigBee, which provides wide-ranging control applications.**
- **A mining communication network supports real-time video feeds for activities, fleet management, mobile field communication, video surveillance, accessing drill and blast data, safety system monitoring, and real-time monitoring of mobile equipment telemetry.**

Role of communication systems for remote operation

- The essential communication component is the transfer of data from sender to receiver, who may be in a group or from one worker to another. The amount and pace of data travelling across the transmitting medium are the subjects of transmission.
- In addition to 4G technology above the ground, the improvement in wired and wireless communication networks such as ZigBee and Radio Frequency Identification (RFID) appears to be relatively straightforward because massive amounts of data can be transferred at extremely high data rates through bases stations and sufficient switching centres as illustrated in next slide.

Role of communication systems for remote operation



Role of communication systems for remote operation

- This communication system occurs over easily placed cables or optical fibres, where noise can be reduced without requiring unique processes.
- Giant communication companies can be encouraged to site Public Switched telephone network (PSTN) and mobile base stations closer to mines and mineral resources sites to provide solid signals and expand digital technology facilities in mines with robust wireless communication systems.

Concept of parallel mines

The parallel mines inspired by a similar theory and the ACP (in which A refers to artificial society, C refers to computational experiments, and P refers to parallel execution) approach are highly networked intelligent systems in the scope of IoT. IoT-based similar mining also relates to humans, excavators, off-road dump trucks, high-speed heavy trucks, and other devices connected to the mining environment.

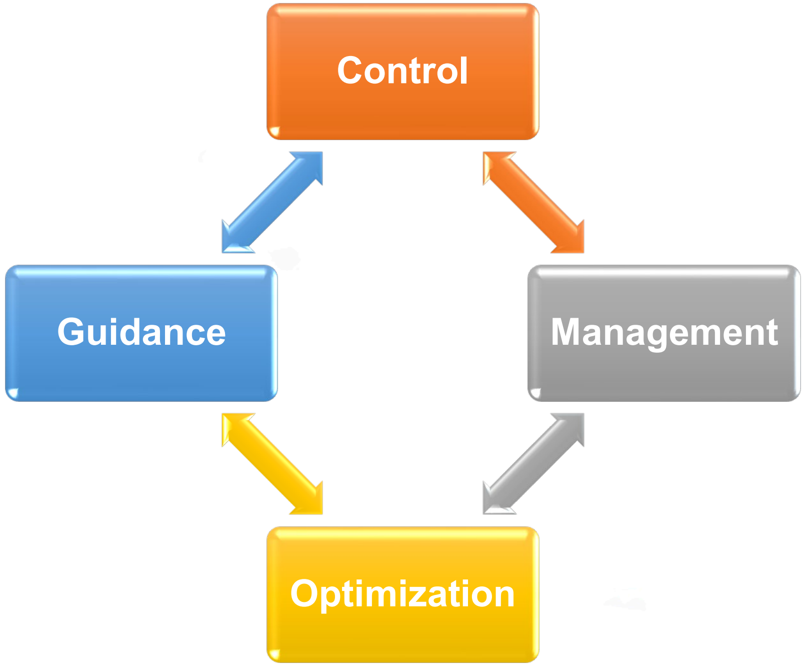
- By using IoT technology, the real-time data of critical systems in mining are collected and transmitted to the management Center, where a dynamic artificial system corresponding to the natural system is constructed.
- This artificial system is proposed to simulate the natural complex system dynamically online and in real-time.
- By studying the evolution and prediction of artificial systems, the prediction and management of natural mining systems are realised.

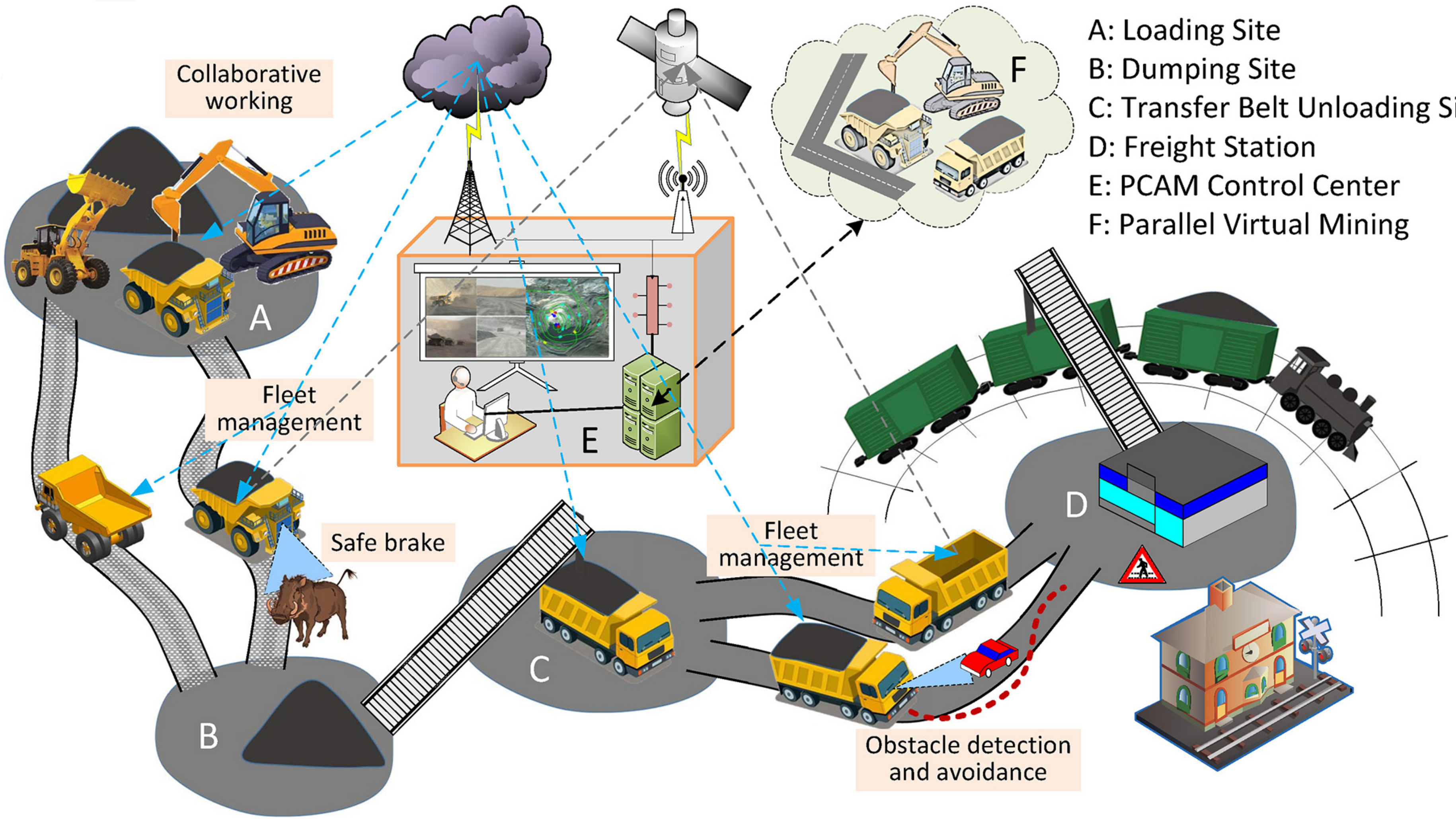
- Overall, it has been possible to realise autonomous driving on single-mining equipment, whether in an above-ground or underground mine.
- To realise end-to-end autonomous mining operations, Komatsu launched the independent haulage system (AHS) to operate and manage fleets of self-driving mining trucks with capacities between 200 and 400 tons.

- Caterpillar released the Cat MineStar system to optimise productivity, enhance security, and improve machine utilisation.
- Sandvik developed autonomous loaders and trucks which operate underground.
- Volvo tested its self-driving tipper inside the earth at a depth of 1320 m and even with artificial lighting.

Framework of Iot-based Parallel Mines

- The concept of parallel systems focuses on complex systems' control, management, optimisation, and guidance by constructing the virtual-real interactive artificial system and accurate system model.

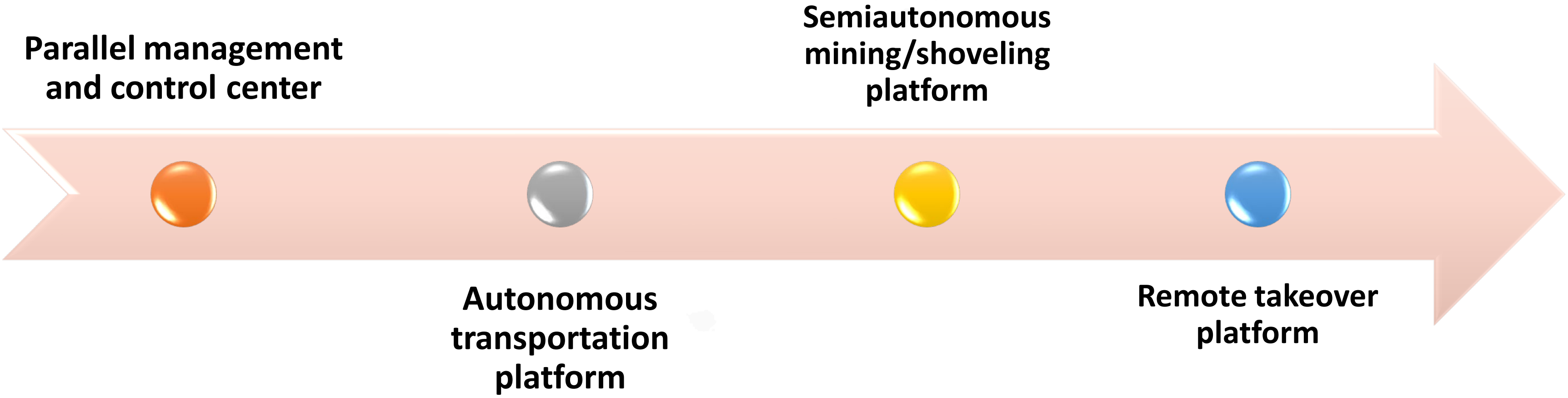




A: Loading Site
B: Dumping Site
C: Transfer Belt Unloading Site
D: Freight Station
E: PCAM Control Center
F: Parallel Virtual Mining

- The framework of IoT-based parallel mining is shown in Figure. It is a true embodiment of a similar system in the field of mining.
- The parallel mines have five critical locations: the loading site A, the dumping site B, the transfer belt unloading site C, the freight station D, and the parallel management and control Center E.
- Among them, A, B, C, and D are natural systems, while E and F can be considered virtual systems.

IoT-based Parallel Mining System Elements



Question 1

What does the concept of a parallel system primarily involve?

A) Simulating only the virtual-real interactive artificial system.

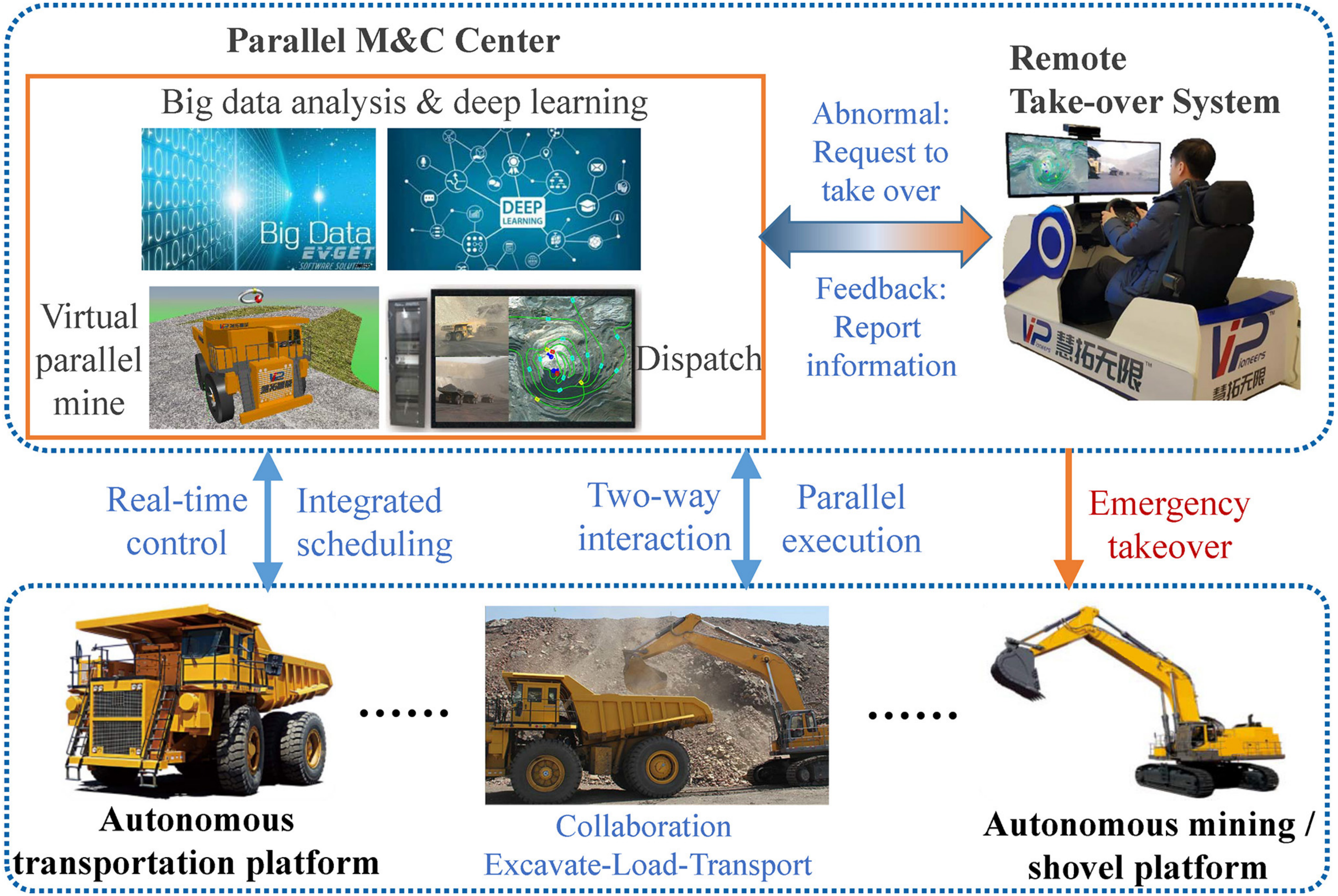
B) Focusing solely on the optimization of complex systems.

C) Managing real system models without virtual components.

D) Constructing both virtual-real interactive artificial systems and real system models.

E) Ignoring the guidance aspect in complex systems.

Answer: D) Constructing both virtual-real interactive artificial systems and real system models

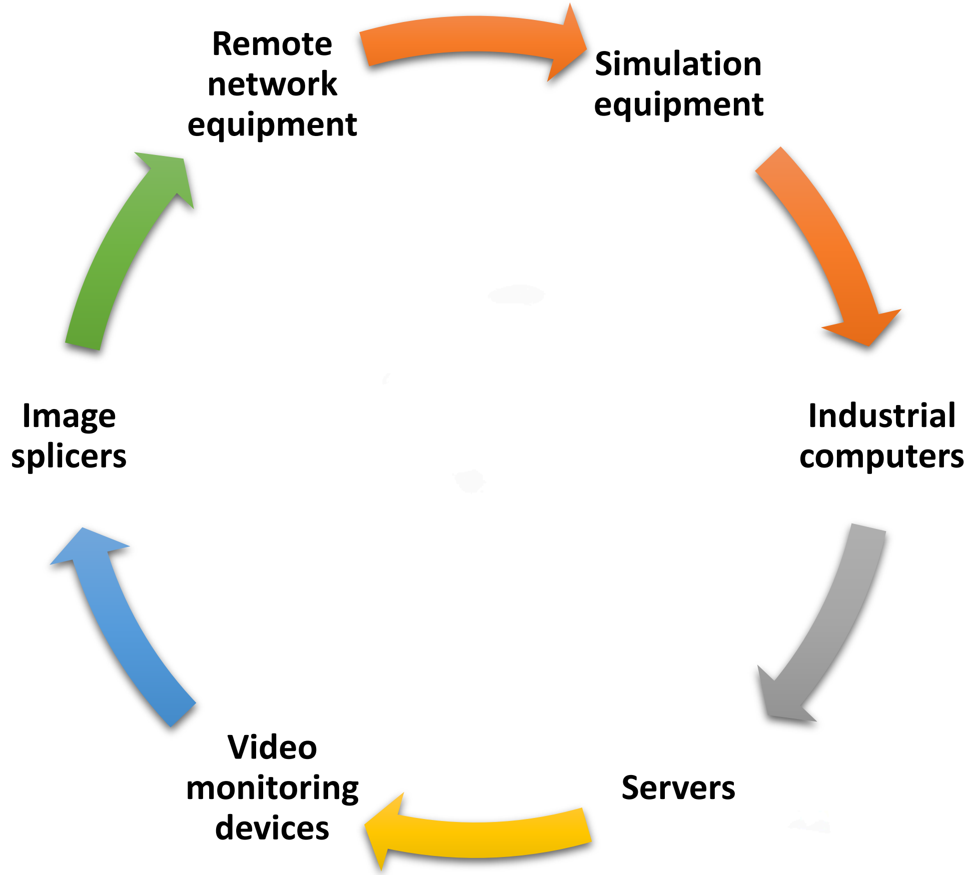

Parallel M&C Center
Big data analysis & deep learning
Big Data
EVGET
DEEP LEARNING
Virtual parallel mine
Dispatch
Abnormal: Request to take over
Feedback: Report information
Remote Take-over System
Real-time control
Integrated scheduling
Two-way interaction
Parallel execution
Emergency takeover
......
......
Autonomous transportation platform
Collaboration Excavate-Load-Transport
Autonomous mining / shovel platform

Parallel management and control center

- The parallel M&C centre consists of a description system defined by the virtual parallel mining system, a prediction system determined by extensive data analysis and the deep learning centre, and a guidance system defined by the dispatch centre.
- Various data generated during mining production and operation are transmitted to the information processing centre, where each subsystem parallel to the actual mining operation is constructed through data fusion, data mining, and visualisation processing.

- Virtual data are built using actual data to complete parallel, online, and real-time simulations of all aspects of mining production operations.
- On the other hand, natural systems' prediction, evaluation, and optimisation are completed through the evolution of parallel systems and collaborative interaction with biological systems, thereby achieving the management and control of the unmanned mining system.

Hardware in parallel M&C center

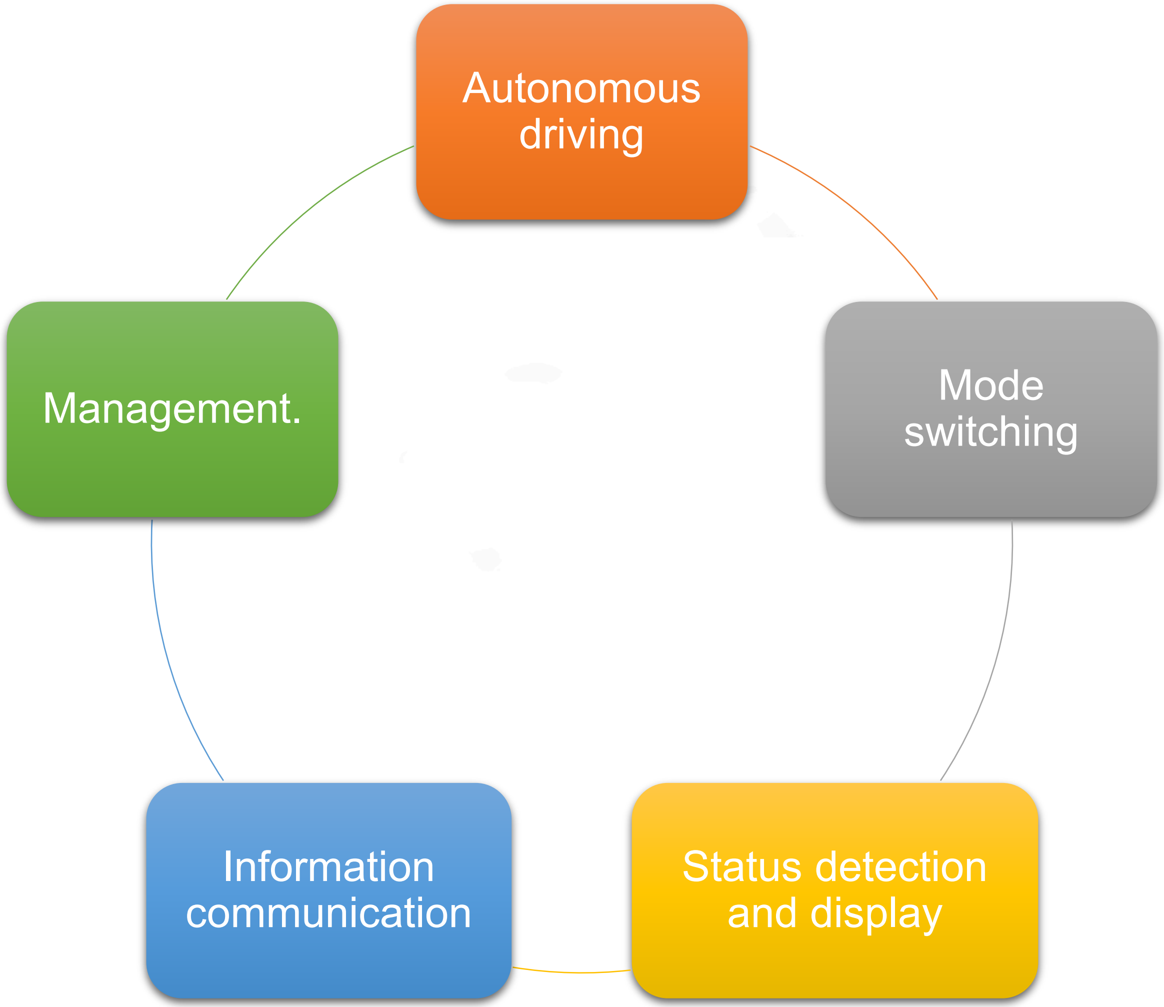


Autonomous Transportation Platform

- The autonomous transportation platform mainly includes off-road dump trucks and high-speed heavy trucks used for short and long-distance transportation, respectively.

- The parallel M&C centre assigns the transportation route of autonomous trucks. The car runs automatically at a suitable speed in the loading, transportation, and unloading cycle according to the target route, its position, and the surrounding environment.

Autonomous transportation platform functions includes



- The mining environment information perceived through lidar, radar, and camera, as well as the positioning information provided by the inertial navigation system, are provided to the decision-making and control subsystem for the decision, planning, and control.

- The communication subsystem is responsible for the wireless communication between the unmanned equipment, the M&C centre, and the remote takeover platform, thus providing support for the remote monitoring and control and the cooperation between excavators and mining trucks.

Semi-autonomous Mining/Shoveling Platform

- The semi-autonomous mining/shovelling platform has sensors, such as displacement, pressure, lidars, an inertial navigation system, cameras, radars, etc. The excavators or loaders cooperate with the autonomous truck through semiautonomous mining or shovelling at mining sites.

- In the collaboration between excavators and mining trucks, the truck's path is planned based on the excavator's position. Using sensor data, the excavator guides the car for loading and performs automatic excavation and unloading into the truck's container.

- A human operator in the control centre monitors the process and intervenes manually when needed, ensuring smooth operations. This cooperative approach improves efficiency and creates a better working environment for the driver.

Remote Take Over Platform

- For heightened safety in unmanned mining, a remote takeover platform ensures secure manual control for autonomous trucks and excavators during emergencies.

- It employs diverse processing strategies and a multilevel security policy, enhancing overall operational quality and productivity while ensuring safety for human drivers and equipment.

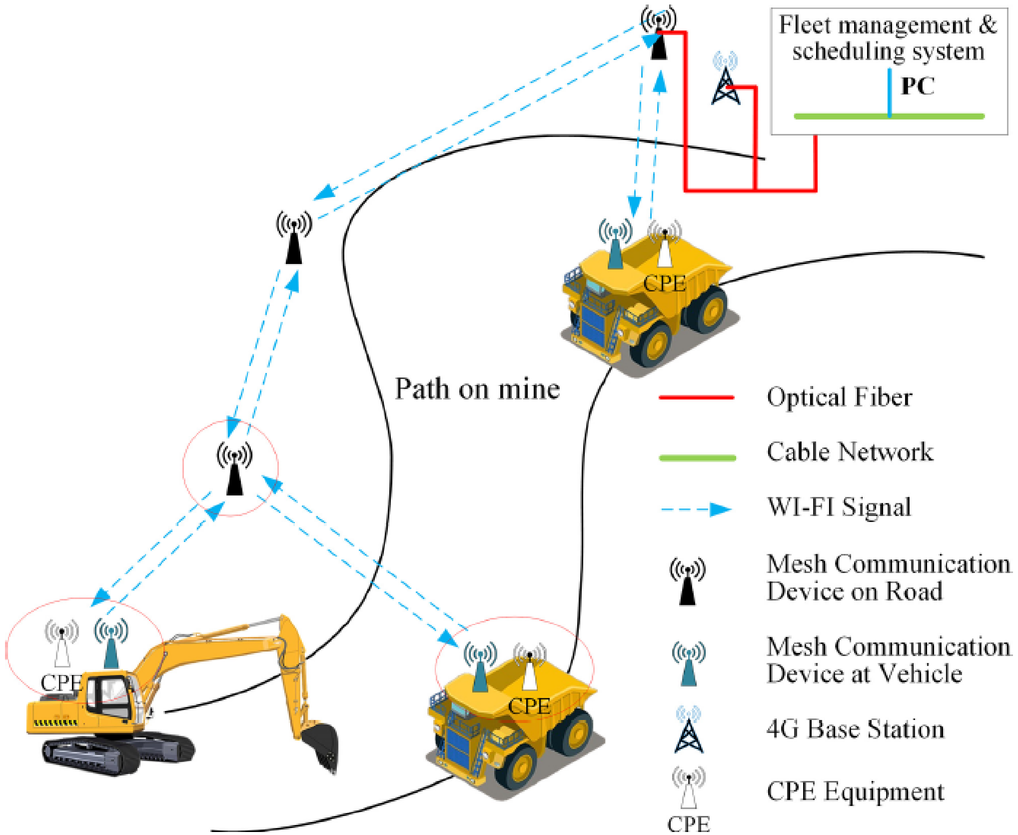
Key Technologies of Iot-based Parallel Mines

Mining Network Communication

- To ensure the reliability and stability of network communication, use a combined network scheme of WIFI-mesh in parallel mining network communication.
- The principle of network communication in parallel mining is shown in the next slide, divided into the remote communication between equipment and centre and the terminal management communication between different equipment connected with the 4G base station to realise the V2Server communication.

Key Technologies of Iot-based Parallel Mines

Mining Network Communication



Key Technologies of Iot-based Parallel Mines

Mining Network Communication

- In the cooperative communication between the mining truck and excavator, the WIFI-mesh communication equipment is installed on the roadside, enabling the excavator and mining truck to realise Vehicle-to-vehicle (V2V) communication.
- The customer premises equipment (CPE), which is communication equipment, is installed on excavators and mining trucks and connected with the 4G base station to realise the V2Server communication.

Key Technologies of Iot-based Parallel Mines

Virtual Parallel Mining Construction

- The autonomous truck simulation platform in virtual parallel mining covers the module of vehicle dynamic model, virtual reality model, virtual sensor and environment perception, deviation calculation, planning and decision making, control, etc. The output data include camera videos from each viewpoint, radar data, 3-D coordinates of vehicles, heading angle, speed, steering wheel angle, throttle/brake pedal's position, tire forces, and so on.

Key Technologies of Iot-based Parallel Mines

Virtual Parallel Mining Construction

Key Technologies of Iot-based Parallel Mines

Virtual Parallel Mining Construction

- The platform takes in relevant data from the actual truck, including current position, vehicle speed, steering commands, and pedal instructions.
- Collected data is imported into the artificial system in real time.
- The autonomous truck in virtual parallel mining is synchronised with the actual truck.
- The platform allows accurate simulation of truck performance and prediction of potential issues.

Key Technologies of Iot-based Parallel Mines

Virtual Parallel Mining Construction

- It enables quick verification of the effectiveness of autonomous driving algorithms in planning, decision-making, and control, especially in extreme conditions.
- Ultimately, prediction, control, and management strategies are applied to the mining system.

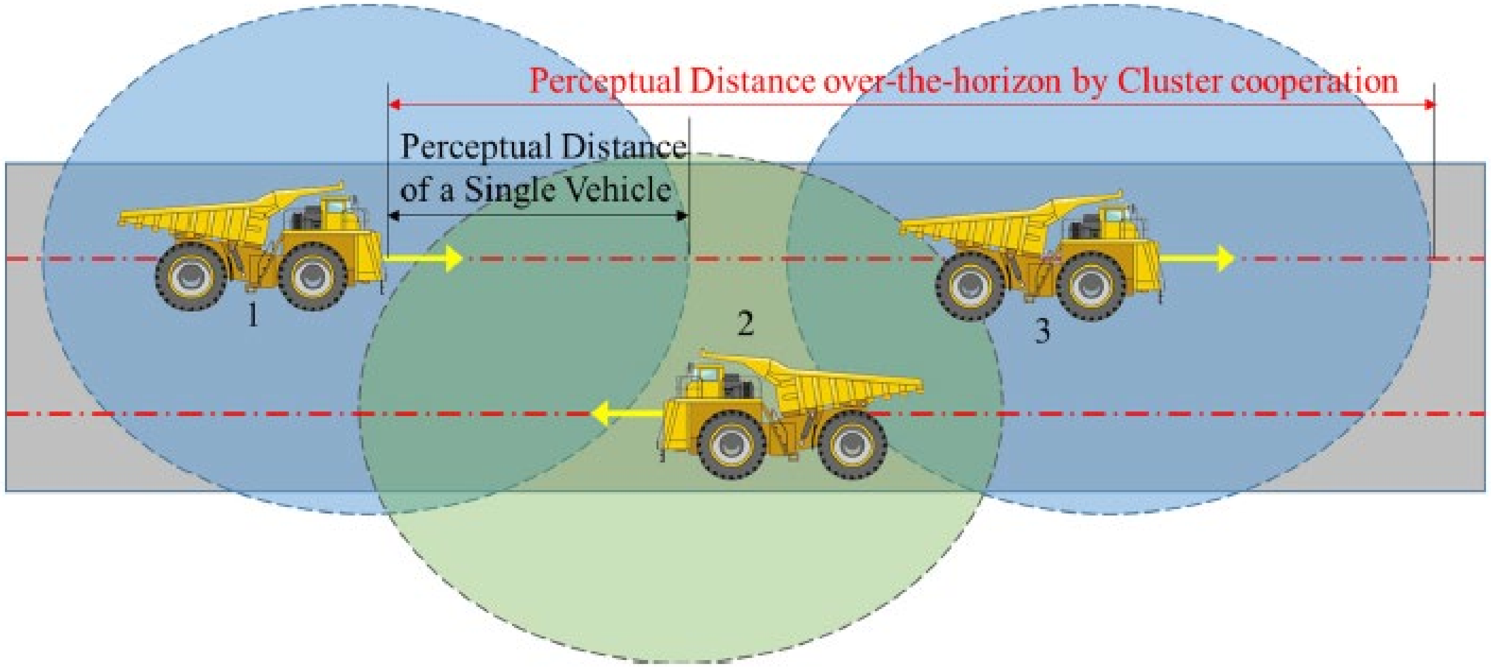
Key Technologies of Iot-based Parallel Mines

Perception Over-the-Horizon in Mining Environment

- **Each mining truck's environment perception system utilises various sensors like lidar, millimetre-wave radar, camera, ultrasonic wave sensor, and infrared sensor.**
- **Multisensor fusion technology is employed during mining machine operations to monitor the driving area, detect and track obstacles, and identify specific targets for collision avoidance.**

Key Technologies of Iot-based Parallel Mines

Perception Over-the-Horizon in Mining Environment



REFERENCES

- Gao, Y., Ai, Y., Tian, B., Chen, L., Wang, J., Cao, D., & Wang, F. Y. (2019). Parallel end-to-end autonomous mining: An IoT-oriented approach. IEEE Internet of Things Journal, 7(2), 1011-1023, https://doi.org/10.1109/JIOT.2019.2948470
- Onifade, M., Adebisi, J. A., Shivute, A. P., & Genc, B. (2023). Challenges and applications of digital technology in the mineral industry. Resources Policy, 85, 103978, https://doi.org/10.1016/j.resourpol.2023.103978

CONCLUSION

- Explored the significance of communication systems in facilitating remote operations.
- Introduced the concept of parallel mines, emphasising simultaneous and integrated mining operations.
- Examined the structure and components of mining systems based on the Internet of Things (IoT).
- Explored the fundamental elements constituting IoT-based parallel mining systems.
- Discussed centralised centres managing and controlling parallel mining operations.

CONCLUSION

- Introduced platforms utilising autonomy for transportation within parallel mining systems.
- Discussed platforms enabling remote takeover for specific mining functions.
- Examined the essential technologies for the functionality of IoT-based parallel mining systems.


THANK YOU

MINE AUTOMATION AND DATA ANALYTICS