PERUMIN 37 CONVENCION MINERA | INSTITUTO DE INGENIEROS DE MINAS DEL PERÚ

FORO DE TECNOLOGÍA INNOVACIÓN Y SOSTENIBILIDAD

MINING 4.0 - A Journey

Professor Laeeque Khan Daneshmend, PhD, DIC

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The Robert M. Buchan Department of Mining

Queen's University, Canada

JUNTOS POR MÁS OPORTUNIDADES Y BIENESTAR PARA TODOS

Overview

- My journey: where my perspective comes from
- Technology’s journey: Industry 4.0
  - and the long road to Industry 3.0
- Mining’s journey: Digital Transformation and Mining 4.0
  - where are we? (current status)
  - where can we get to? (feasible goals)
  - how can we get there? (strategy)
  - challenges and mitigations?

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- **My journey: where my perspective comes from**
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  - and the long road to Industry 3.0
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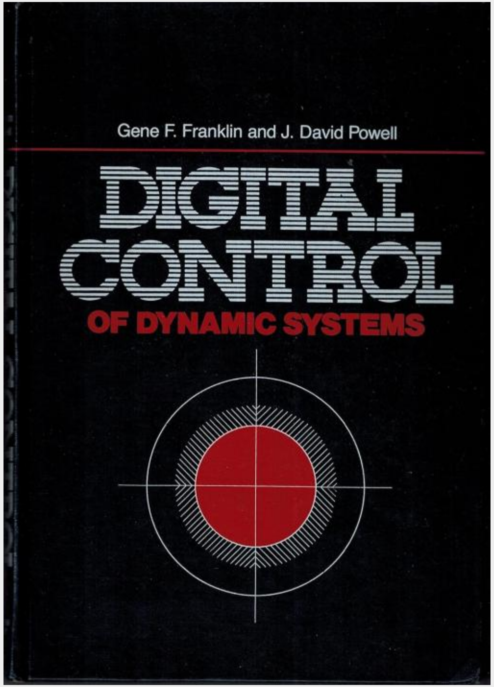
  - challenges and mitigations?

University of Southampton

Bachelors Degree, 1981

- Electronic Engineering



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FORO DE TECNOLOGÍA
INNOVACIÓN Y SOSTENIBILIDAD

Imperial College London

Graduate Studies – PhD 1985

- Mechanical Engineering
- Manufacturing Automation

SCIENTIA

SCIENTIA IMPERII DECUS ET TUTAMEN

ADAPTIVE CONTROL AND MONITORING

OF A C.N.C. LATHE

USING FEED-FORCE AND MACHINE-VISION

By

Laeeque Khan DANESHMEND, B.Sc.

January 1985

THESIS SUBMITTED FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN THE FACULTY OF ENGINEERING

UNIVERSITY OF LONDON

AND

FOR THE DIPLOMA OF MEMBERSHIP OF

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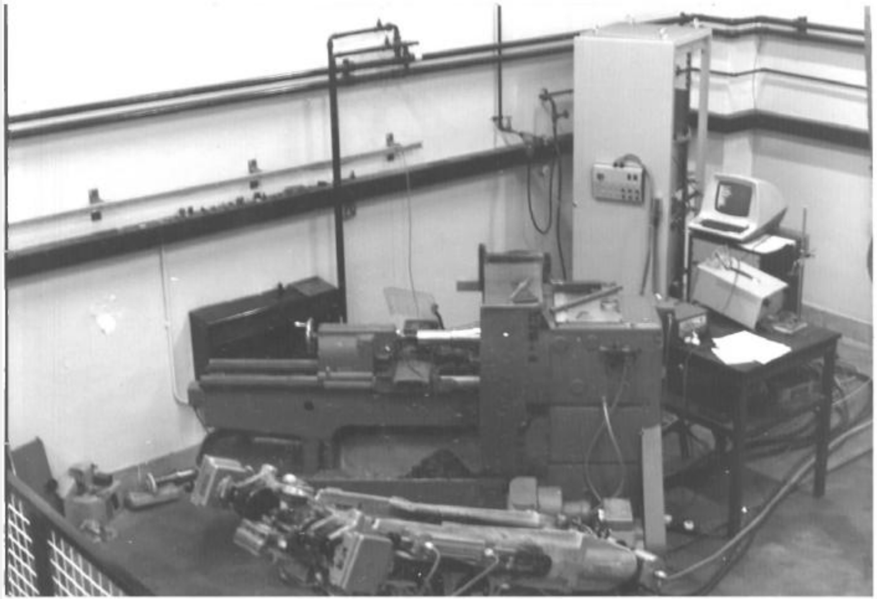

Figure 2.5: Overall view of the lathe and control cabinet, located in the Imperial College Robotics Laboratory

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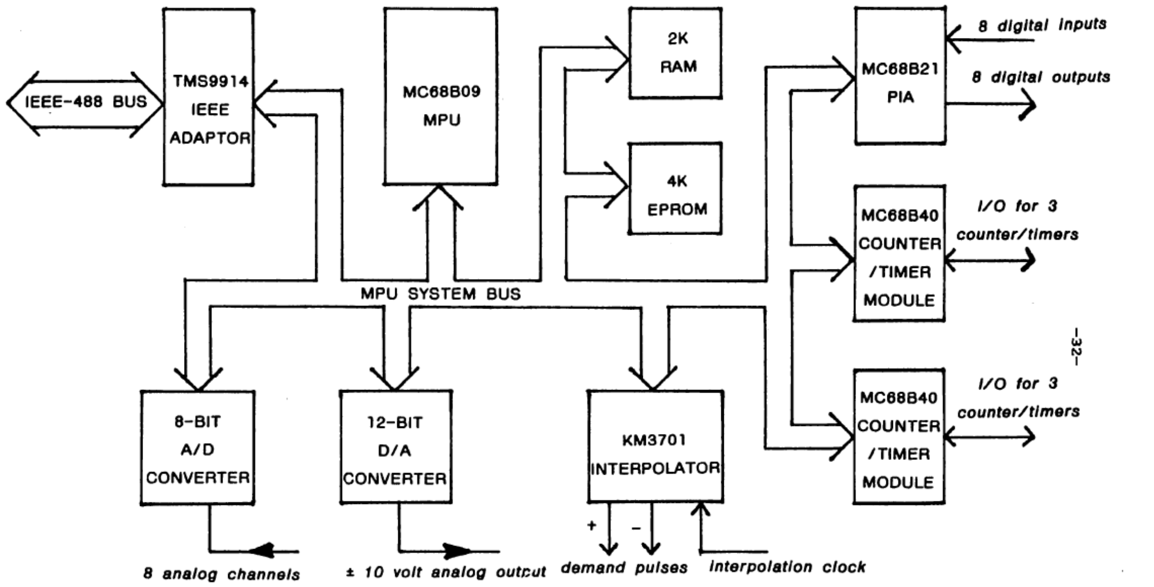
Real-Time

- ➢ Software
- ➢ Hardware
- ➢ Sensors
- ➢ Machine Control



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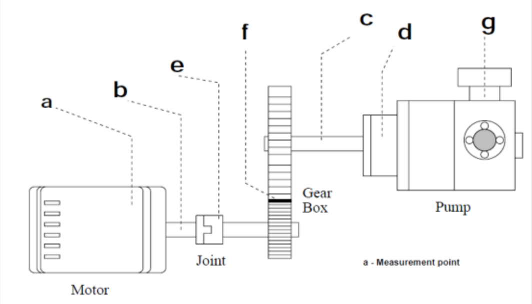
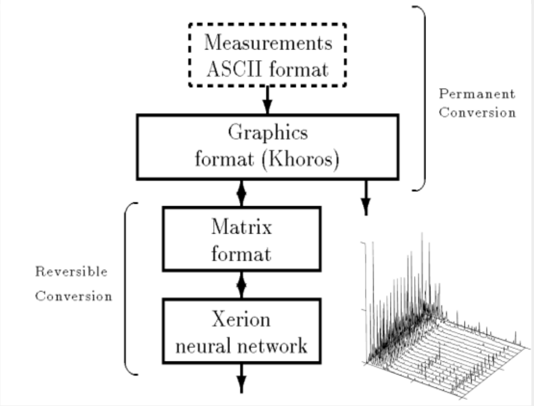




McGill

Mid 1980's / Early 1990's

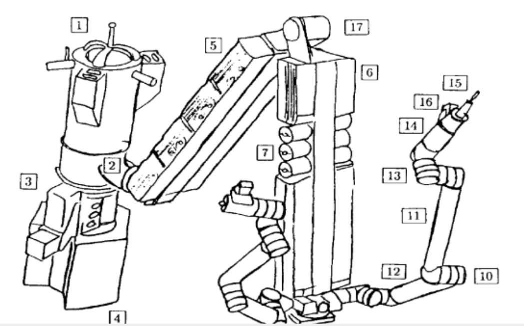
Early academic career

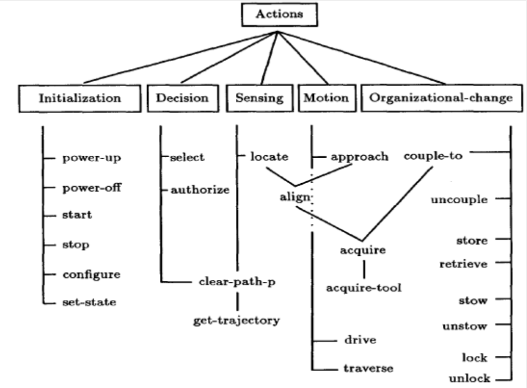
Robotics

- Field Robotics
- Space Robotics

Artificial Intelligence

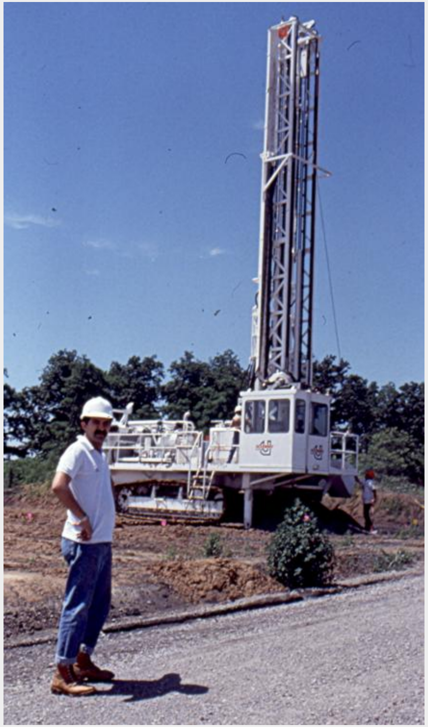
- Neural Networks
- Symbolic Reasoning





A CATALYST
(1989)

Jon Peck



McGill

Late 1980's / Early 1990's
Initial introduction to Mining

Surface Blast-Hole Drills
- Control
- Monitoring-While-Drilling

Electric Rope-Shovels
- Diggability Monitoring

Underground
- LHD Monitoring
- Diamond-Drill Automation
- Reliability & Maintenance

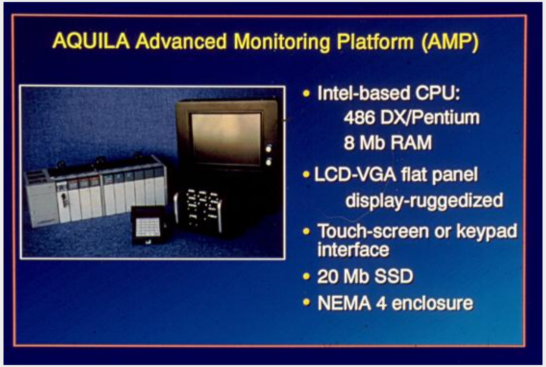
AQUILA
mining systems ltd.

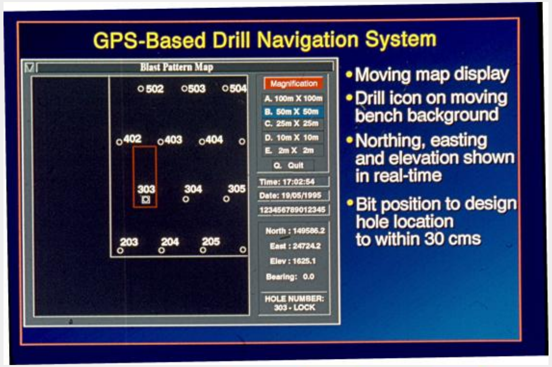
Mid-to-Late 1990's
Entrepreneurial Phase

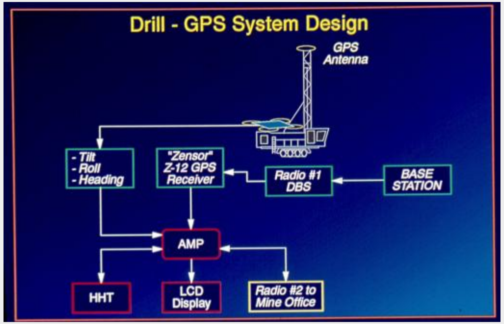
First-To-Market
Commercial Products

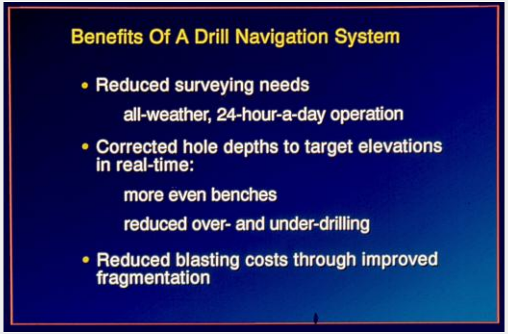
Surface Blast-Hole Drills
- GPS
- Control
- MWD

Electric Rope-Shovels
- GPS
- Diggability Monitoring
- Fault Detection









Mid-to-Late 1990's
Entrepreneurial Phase

First-To-Market
Commercial Products

Surface Blast-Hole Drills
- GPS
- Control
- MWD

Electric Rope-Shovels
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- Diggability Monitoring
- Fault Detection


Trimble
MINING AND CONSTRUCTION PRODUCT

TMS-Shovel
Cable Shovel Guidance and Monitoring System

Rugged GPS Systems for Machine Guidance

The key to increasing profitability is better information, information that allows your operator to work more productively and that lowers equipment operating costs. The TMS-Shovel™ system delivers productivity improvements by ensuring that your operator stays on grade or knows where to dig, day or night, in all weather—without the need for survey stakes. The modular system can optionally provide detailed information on machine performance, diggability, and production statistics. This information allows you to optimize short range mine planning by more effective use of shovels under varied production and geological conditions.

The TMS-Shovel system combines the field-proven GPS and communications technology from Trimble with the advanced shovel monitoring technology from Aquila Mining Systems Ltd. This system is compatible with TMS-Drill™ and GPS surveying systems, allowing mines to use a common reference station and data communications system. The TMS-Shovel system also supports an interface to the leading mine information and dispatch facilities and on-board PLCs.

The TMS-Shovel system is comprised of the Aquila Advanced Monitoring Platform (AMP), a Trimble 7400MSi GPS receiver and a radio modem, packaged in environmentally sealed, shock-isolated housings.

The Trimble 7400 MSi GPS receiver provides low latency, accurate, all weather, position control.

The Aquila AMP supports up to 10 serial ports and 50 channels of analog and digital input, allowing it to readily interface to a variety of sensors and on-board systems.

The display unit is a clear, daylight-readable LCD VGA panel, mounted in a rugged and sealed housing, designed for convenient installation and viewing in the shovel cab.

The on-board guidance software is Aquila's SM-5 basic grade control module. This software module enables the measured offset from the tracks, above or below a target grade, to be numerically displayed to the operator. The SM-5 moving map display (MMD) module is offered as an option. This software provides real-time, graphical viewing in plan of the shovel bucket relative to the locations of target digging zones. Optional software modules and hardware enable real-time production or maintenance monitoring and diggability calculation.

The antenna unit is comprised of a rugged L1/L2 GPS antenna on a shock mounting and protected by an environmental cone. The environmental cone protects the antenna from any buildup of snow, coal dust, or iron ore dust that may degrade the antenna performance.

The TMS systems are supported worldwide by Trimble's network of factory-trained service and support personnel.

My Experience in Mining Technology over the past 35+ years

Technology hasn't been a Panacea…

Lots more Data

+

Lots more Computing Power

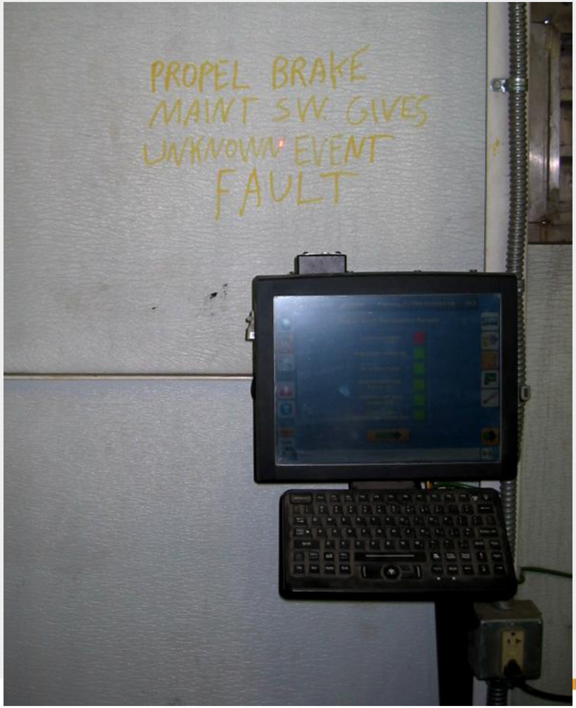
…

But often the results are

NOT USEFUL

or

NOT USED



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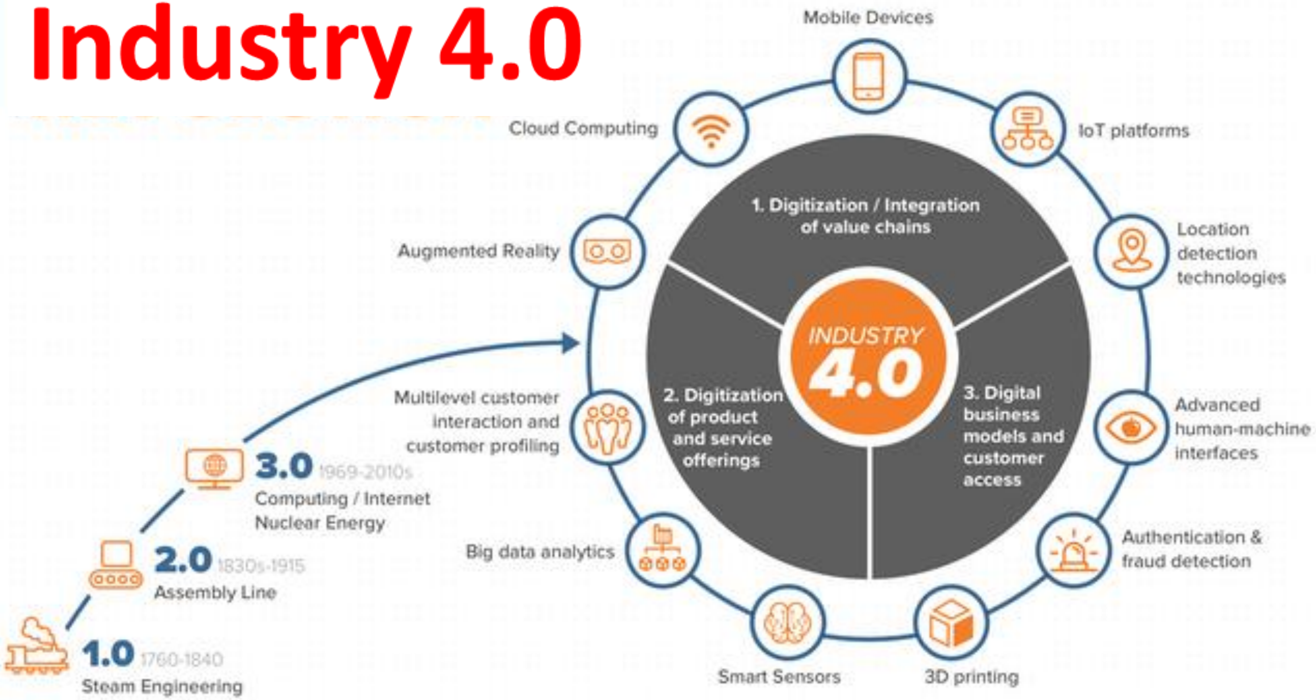
Industry 4.0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IoT platforms
Location detection technologies
Advanced human-machine interfaces
Authentication & fraud detection
3D printing
Smart Sensors
Big data analytics
Multilevel customer interaction and customer profiling
Augmented Reality
Cloud Computing
1. Digitization / Integration of value chains
2. Digitization of product and service offerings
3. Digital business models and customer access
INDUSTRY 4.0
3.0 1969-2010s
Computing / Internet
Nuclear Energy
2.0 1830s-1915
Assembly Line
1.0 1760-1840
Steam Engineering

Industry 4.0

The advent of Industry 4.0 is commonly placed in the early 2010s onward, characterized by accelerating trends toward

- **pervasive computing**
- **affordable data storage**
- **robust connectivity**
- **inexpensive sensor technologies**

Taken together, these have resulted in

- "co-engineered interacting networks of physical and computational components" — otherwise known as cyber-physical systems (CPS), smart systems, or embedded systems.

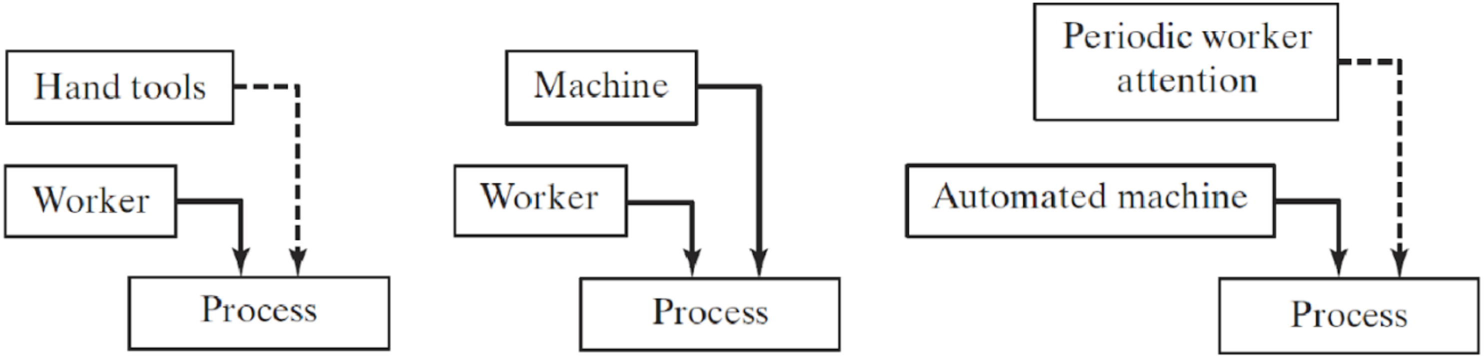
The power and potential of CPS has in turn been magnified via ever increasing connectivity to yield the **Industrial Internet of Things (IIoT)** leveraged via **cloud computing** to enable more **widespread industrial application of recent advances in machine learning and artificial intelligence technologies**.

Industry 3.0 Mindset (Legacy Approach)	**Industry 4.0 Mindset (Modern Approach)**
Efficiency & stability focused	Future-focused
Process-first	Digital-first
Experience-driven decision making	AI & data-driven decision making
Standardized & repeatable	Smart & adaptive
Historical & descriptive analytics	Predictive & prescriptive analytics
Just-in-time operations	End-to-end agility
Transactional engagement (one-time, one-size)	Personalized engagement (continuous, tailored)
Capital Expenditure (CapEx)-driven	Continuous funding & improvement

Industry 1.0

Industry 2.0

Industry 3.0



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Industry 3.0

- Made possible by **availability of more widely accessible digital computing** from the late 1940s onwards.
- Leading to fundamental changes to fundamental aspects of manufacturing in the 1950s through **development of computer numerical control (CNC) for machine tools commonly used in manufacturing**, such as lathes and milling machines.
- Advent of **computer-aided design (CAD) and computer-aided manufacturing (CAM)** in the 1960s onward.
- Resulting in **ability to rapidly reprogram CNC machine tools, and transformation of manufacturing processes**—now known as **computer integrated manufacturing (CIM).**
- The development and widespread deployment of **the programmable logic controller (PLC)** from the 1970s onward, **enabled cost-effective and flexible automation of industrial processes and systems beyond manufacturing**.
- PLC capabilities have continued to evolve in tandem with the decreasing cost of computing power, and they are still widely used for monitoring and control purposes in most industrial sectors.

Industry 3.0

Initial Drivers – *Aerospace* Manufacturing

→ → → Computer Aided Design
& Computer Aided Manufacturing (CAD/CAM)

Cold War

- Extremely high demand for production of aerospace parts with
  - Challenging Part Design
    - Complex Shapes
    - Extremely Tight Tolerances
  - Materials
    - High Cost of Scrapping parts
- Shortage of Skilled Machinists

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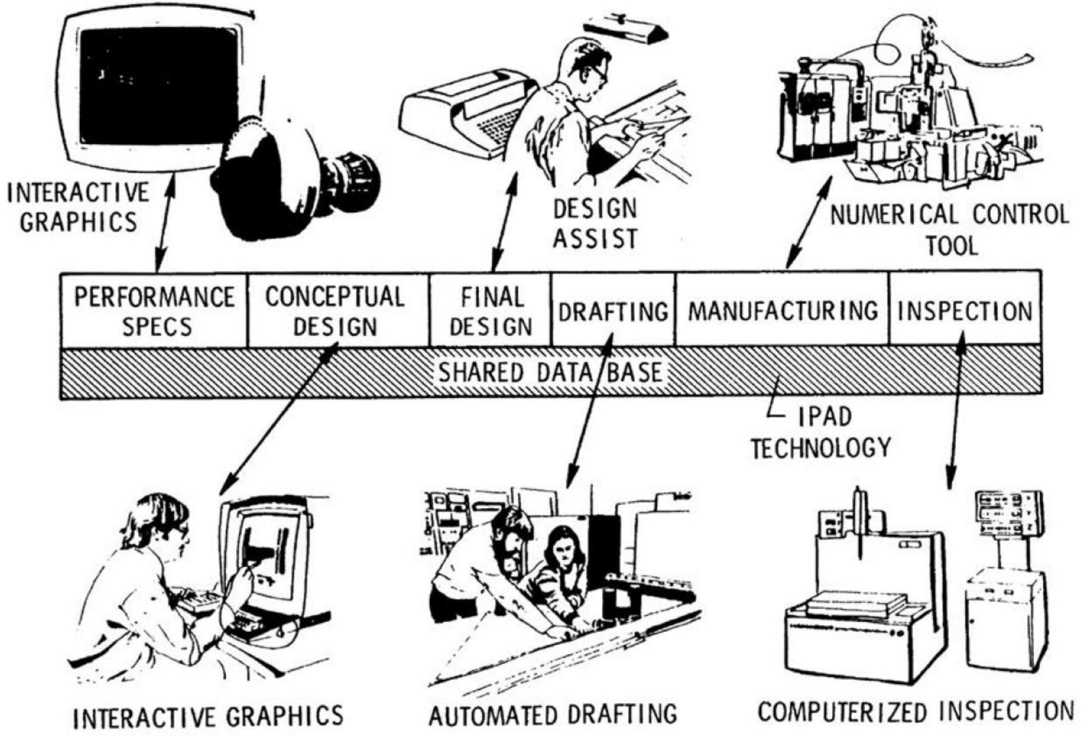
Industry 3.0 to get to CAD/CAM

~ 25 years

Government Funding ($$$$$$$$)

Standardization

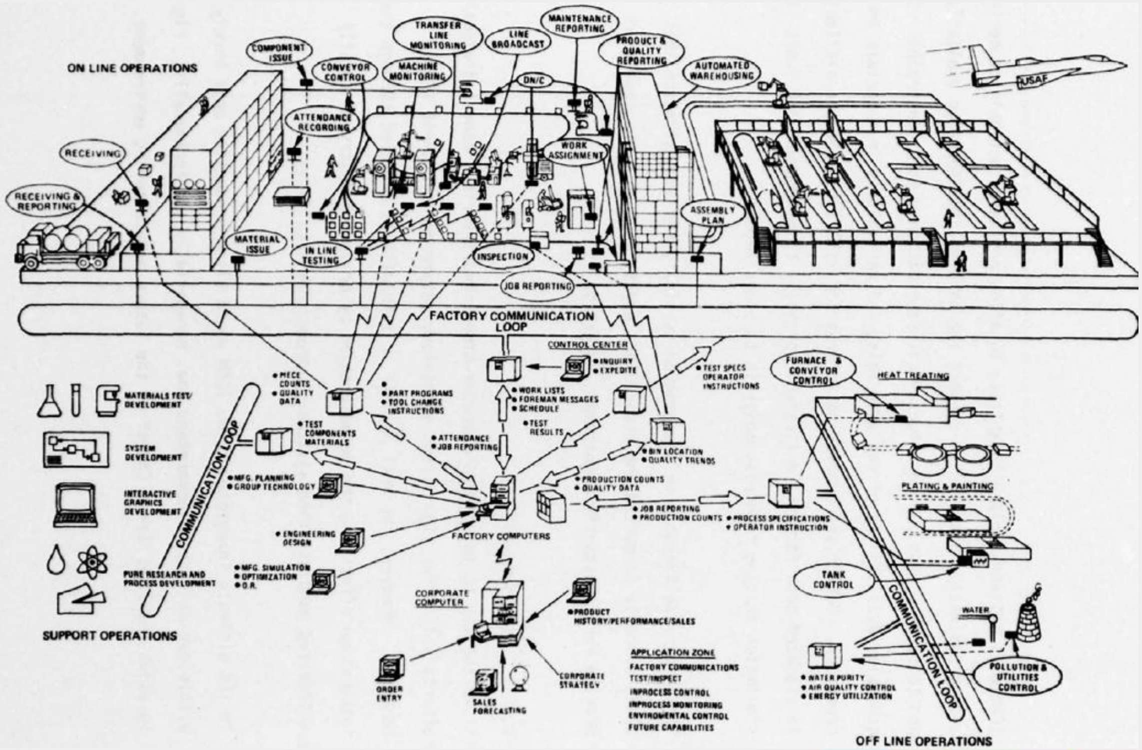


Industry 3.0 to get to CIM

~ 25 +10 years

Government Funding ($$$$$$$$)

Standardization



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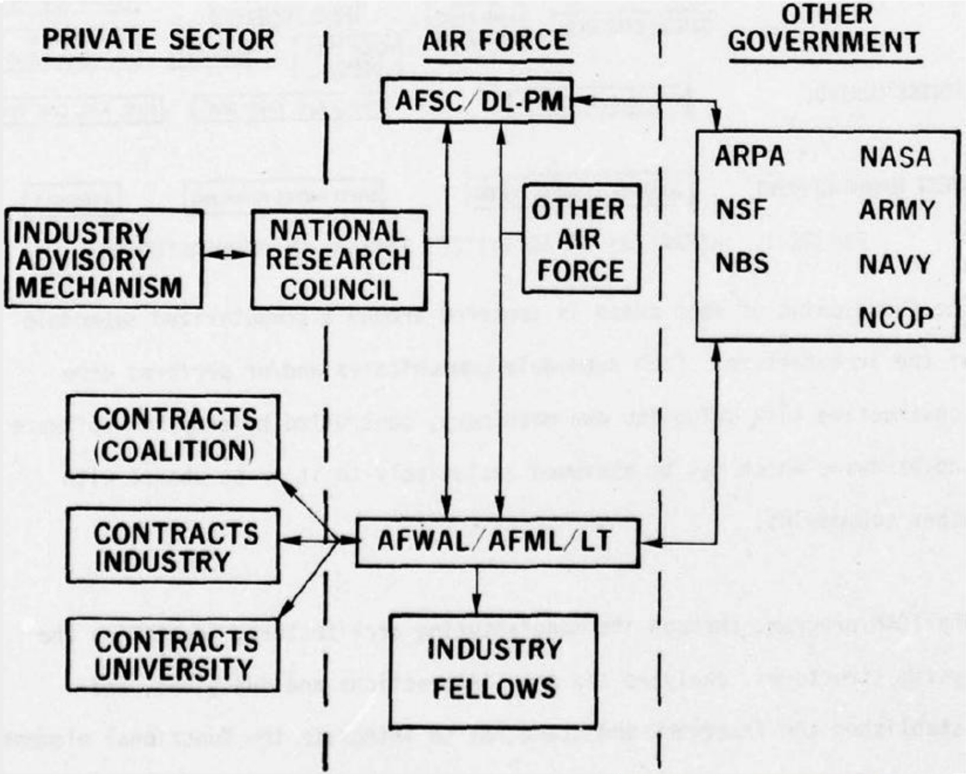
Industry 3.0 to get to CIM

~ 25 +10 years

Government Funding ($$$$$$$$)

Standardization

Involvement of broad spectrum of stakeholders



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    - **Micro-Level (Equipment)**
  - where can we get to? (feasible goals)
  - how can we get there? (strategy)
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Digital Transformation

Digital transformation is about change at the macro level. The business is digitally transformed, enabling the strategic modification of business processes. Some other common terms used regarding digital transformation are:

- **Digitization:** the processes and technologies which enable the digital representation of information and its digital processing.
- **Digitalization:** the processes and technologies which enable physical systems to capture their own state and operating context and share that information as required. (Digitization and digitalization are about digital technology; that is, information is digitized, processes are digitalized.)
- **Industry 4.0:** the technological paradigm shift within which digital transformation has become possible.

Mining 4.0 (my personal definition… debatable!)

The appropriate (better?) information

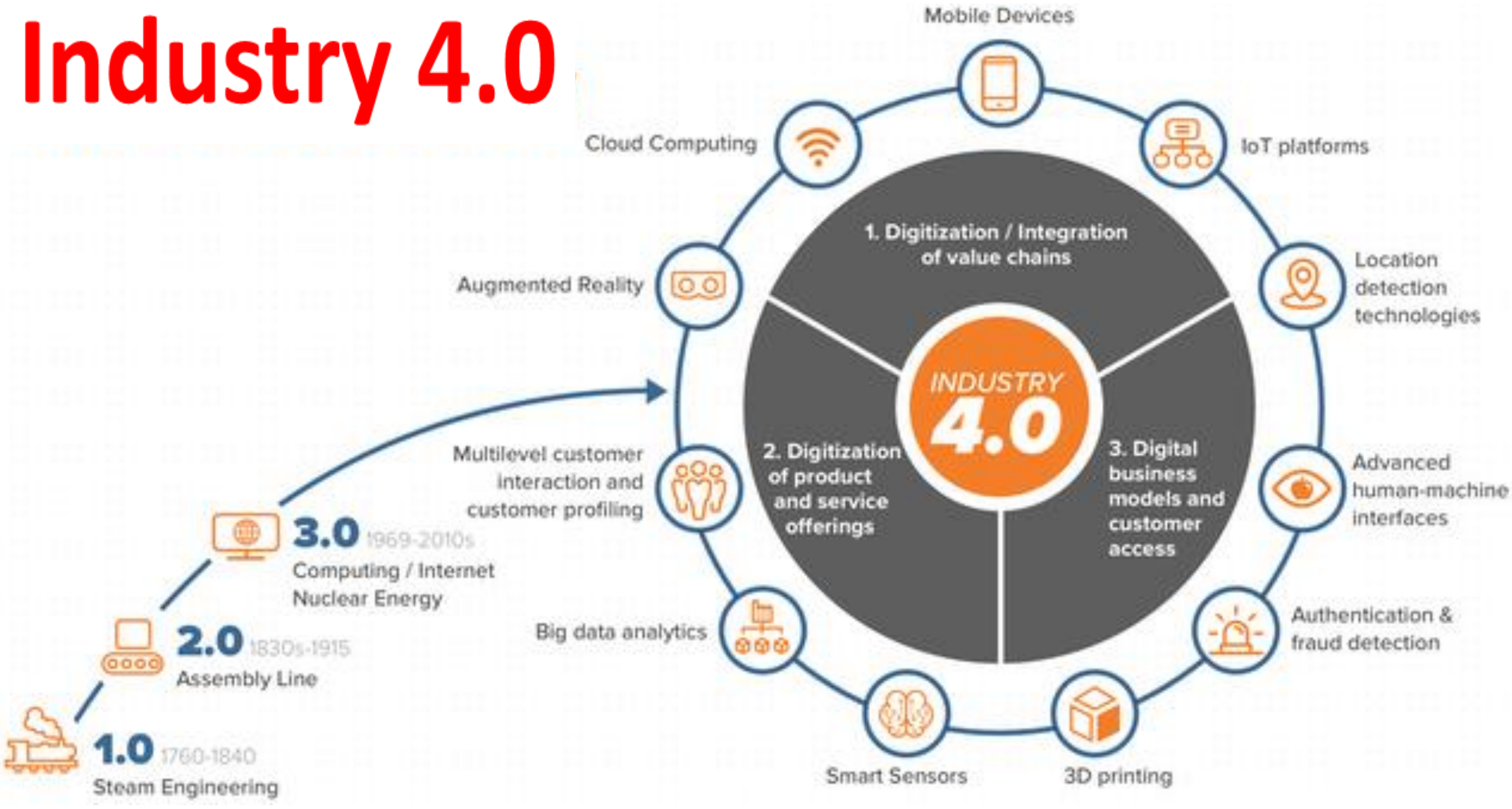
To the relevant people/systems

At the right time

To make better decisions

Leading to better outcomes
(safety, economic, environmental, social, …)

Industry 4.0



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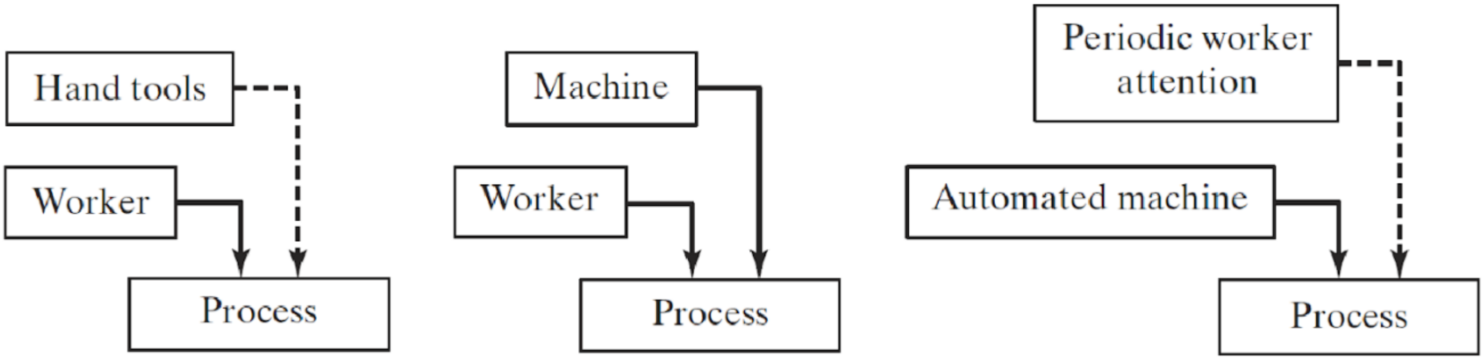
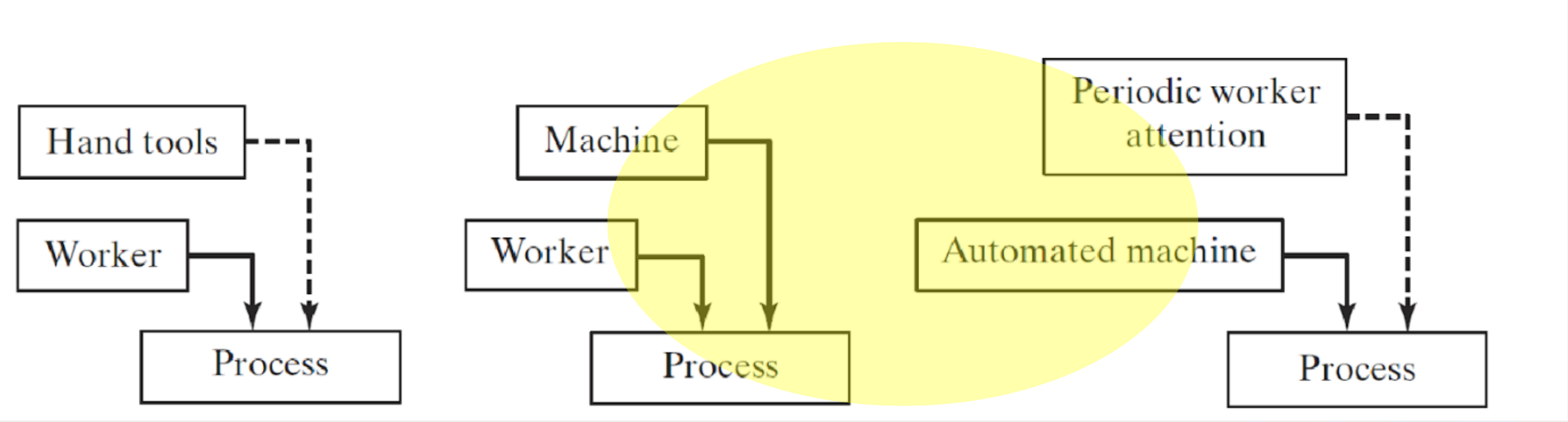
WHERE ARE WE TODAY IN THE MINING INDUSTRY?
(At the Equipment Level)

Industry 1.0 **Industry 2.0** **Industry 3.0**



WHERE ARE WE TODAY IN THE MINING INDUSTRY?
(At the Equipment Level)

Industry 1.0 **Industry 2.5???**

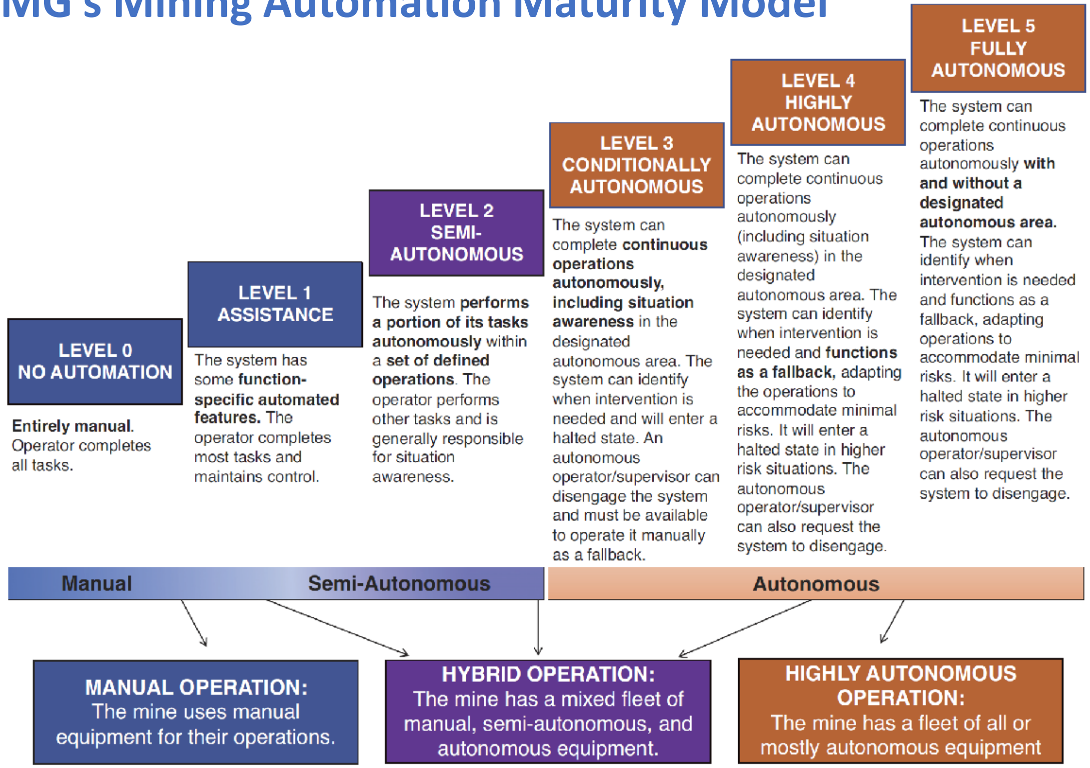


SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	**You <u>are</u> driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You <u>are not</u> driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

For a more complete description, please download a free copy of SAE J3016: https://www.sae.org/standards/content/J3016_201806/

GMG's Mining Automation Maturity Model



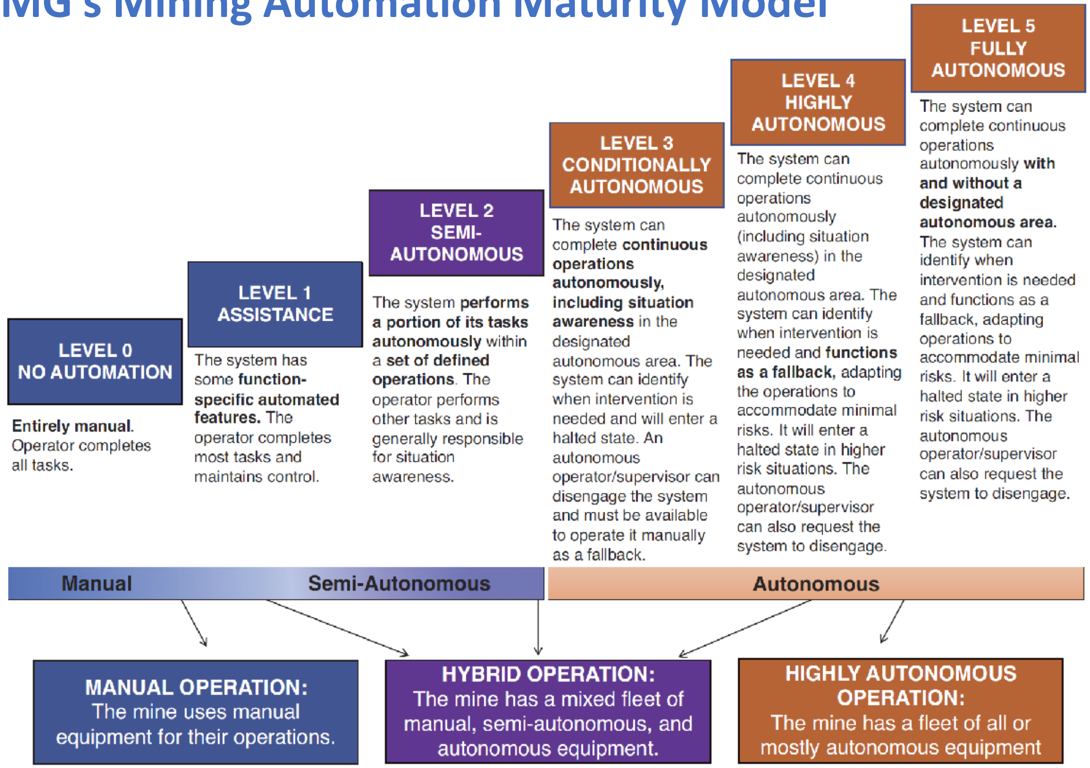
GMG’s Mining Automation Maturity Model - Examples

- Level 0: an old-fashioned “dumb” Load-Haul-Dump (LHD) with little or no sensing or computing capabilities built into it.
- Level 1: an LHD with a rudimentary level of sensing and computing capabilities – e.g. measuring the weight of the load of material in the LHD bucket and displaying it to the operator, potentially also initiating alarms for excessive load and even possibly disabling hauling until the bucket load was reduced.
- Level 2: an LHD that can perform the “haul” **portion of its function without human operator intervention** under certain conditions (e.g., a well-maintained haulage route, with no falls of rock or other obstacles).
- Level 3: an LHD that **can perform all three aspects of its function (load, haul, and dump) without intervention of a human operator under specified operational condition, in a specific area designated for autonomous operations—and determine when to request human intervention** - e.g. if the fragmentation of the rock in the muck pile is beyond the bounds of specified operation conditions, such that the autonomous loading function would fail to load the bucket.

GMG’s Mining Automation Maturity Model - Examples

- Level 4: an LHD that could perform all three aspects of its function (load, haul, and dump) without intervention of a human operator under a broad range of operating conditions, **in a specific area designated for autonomous operation**, and adapt how it functions in response to operating conditions (e.g., adjusting its loading algorithm in response to variations in rock fragmentation).
- Level 5: an LHD that could perform all three aspects of its function (load, haul, and dump) without intervention of a human operator under a broad range of operating conditions, **in any area**, and adapt how it functions in response to operating conditions (e.g., adjusting its loading control algorithm in response to variations in rock fragmentation).

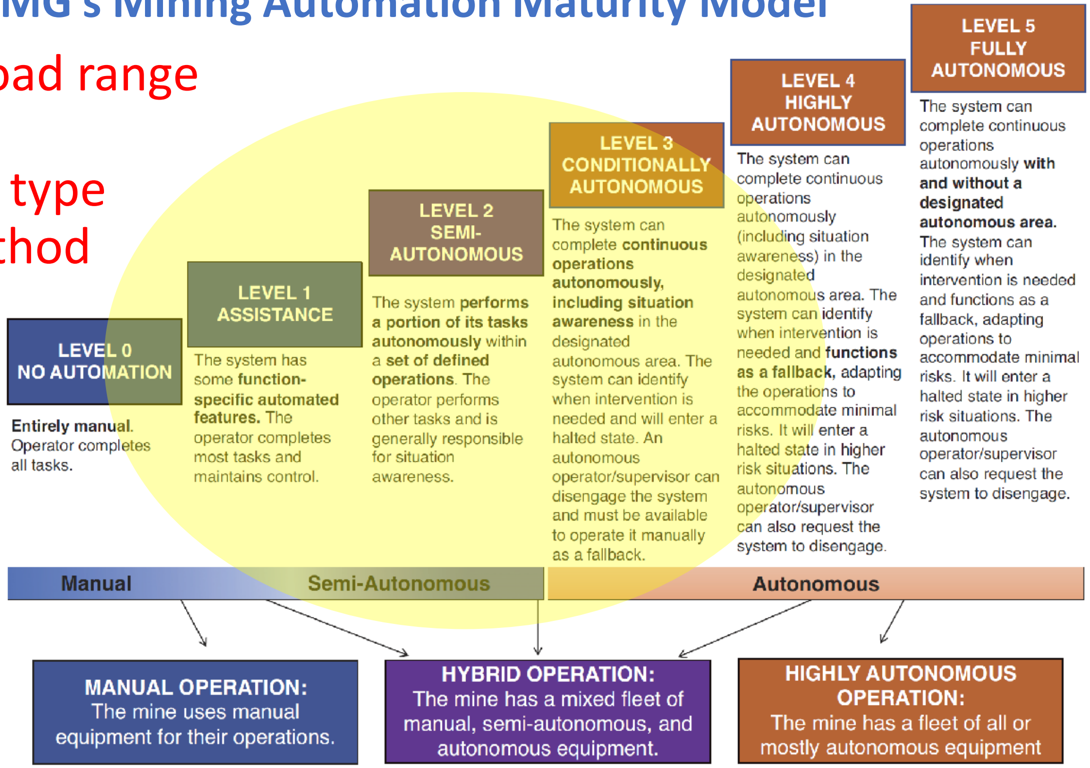
WHERE ARE WE TODAY IN THE MINING INDUSTRY?
(At the Equipment Technology Level)
GMG's Mining Automation Maturity Model



WHERE ARE WE TODAY IN THE MINING INDUSTRY?
(At the Equipment Technology Level)

GMG's Mining Automation Maturity Model

Spanning a broad range depending on
- equipment type
- mining method



WHERE ARE WE TODAY IN THE MINING INDUSTRY?
(At the Equipment Technology Level)

Lack of integration between

- technology vendors and OEMs

Lack of integration within OEM

FOUR screens
3 from OEM
1 from 3rd Party

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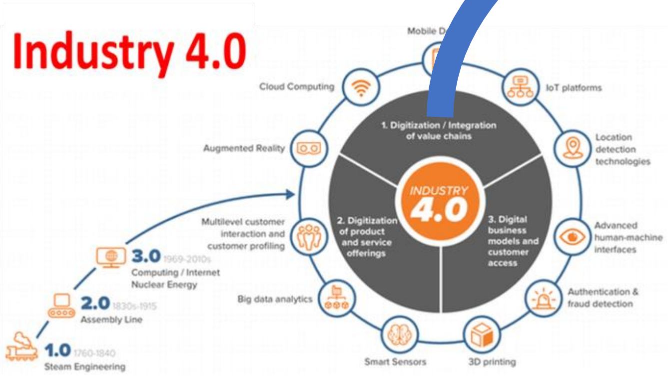
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1. Digitization / Integration of value chains

WHERE ARE WE TODAY IN THE MINING INDUSTRY?
(Macro-Level – Value-Chain)

Conventional Drill-To-Mill Vision
- focused on Equipment / Physical Assets

Drill & Blast

- Drills
- Explosives Trucks

Load & Haul

- Loading Eqpt
- Trucks
- Ancillary Eqpt

Stockpiles, Comminution, Processing

- Conveyors, Stackers
- Reclaimers, Dozers
- Crushers, Mills
- Site-Specific Processing Plant and Control Systems

WHERE ARE WE TODAY IN THE MINING INDUSTRY? (Macro-Level – Value-Chain)

Conventional Drill-To-Mill Vision - *Local Optimization, at best*
- focused on Equipment / Physical Assets

Drill & Blast

- Drills
- Explosives Trucks

Load & Haul

- Loading Eqpt
- Trucks
- Ancillary Eqpt

Stockpiles, Comminution, Processing

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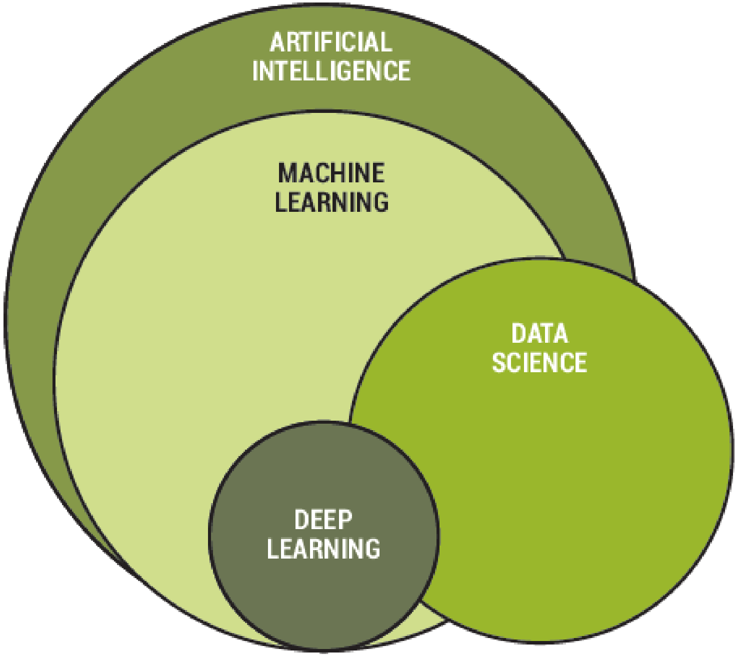
AI/ML TERMINOLOGY

from:
FOUNDATIONS OF AI
A FRAMEWORK FOR AI IN MINING, GMG
Whitepaper



MATURITY LEVELS – AI-Enabled Mine

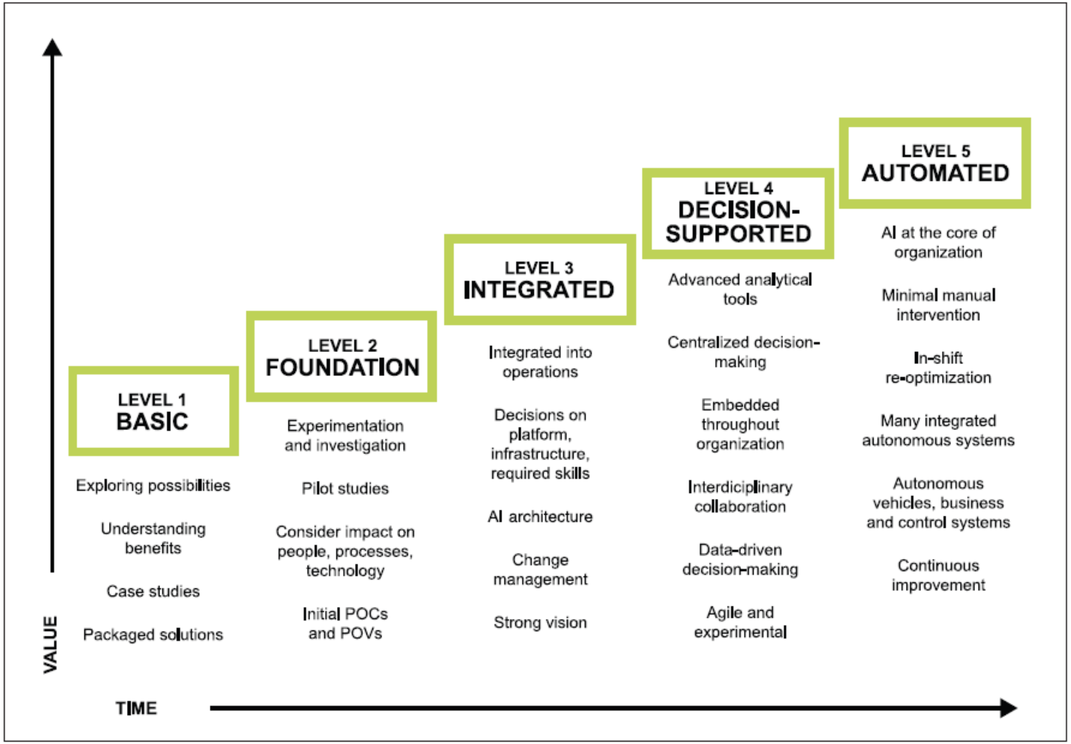
from: FOUNDATIONS OF AI A FRAMEWORK FOR AI IN MINING, GMG Whitepaper

Level 1	BASIC ▶	Exploration of what AI is, what it does, and what the benefits are.
Level 2	FOUNDATION ▶	Laying the foundations of the AI strategy, often through experimentation and investigation.
Level 3	INTEGRATED ▶	Integrating AI into business operations.
Level 4	DECISION SUPPORTED ▶	Leveraging analytical tools to provide centralized decision-making capabilities.
Level 5	AUTOMATED ▶	AI is at the core of the organization and most systems and processes are either fully automated or require minimal manual intervention.

MATURITY LEVELS
– AI-Enabled Mine

from: FOUNDATIONS OF AI A FRAMEWORK FOR AI IN MINING, GMG Whitepaper

Abbreviations:
proof of concept (POC), proof of value (POV)



MATURITY LEVELS
– AI-Enabled Mine

from: FOUNDATIONS OF AI A FRAMEWORK FOR AI IN MINING, GMG Whitepaper

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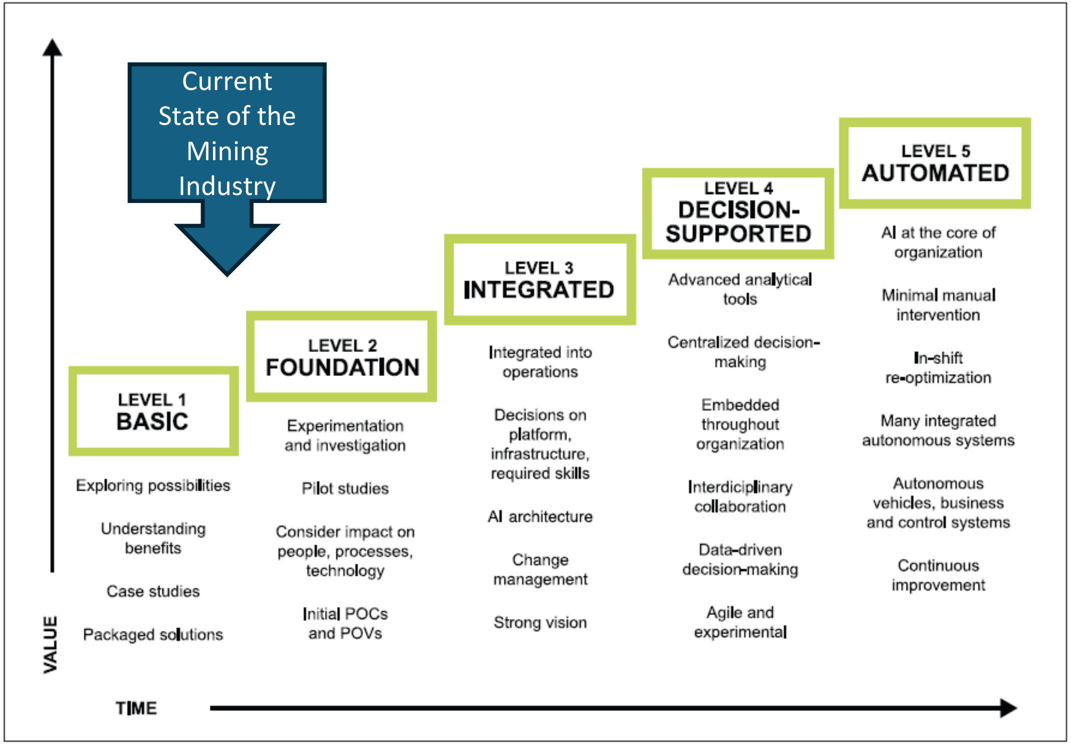

Overview

- My journey: where my perspective comes from
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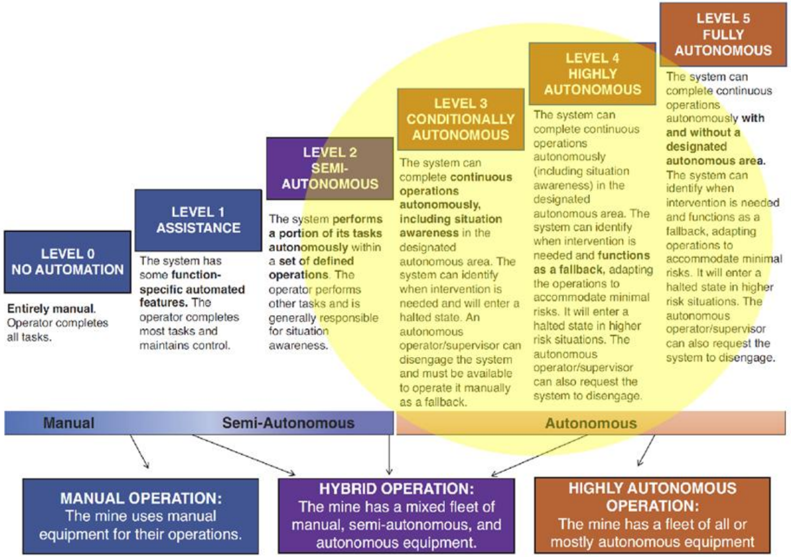
WHERE CAN WE GET TO IN THE MEDIUM TERM?
(At the Equipment Technology Level)

Shift the balance towards Industry 3.0
- Automation of more types of equipment

Coupled with innovations in
- mining methods
- equipment designs

GMG's Mining Automation Maturity Model



WHERE CAN WE GET TO IN THE MEDIUM TERM?
(At the Equipment Technology Level)

Innovations in equipment designs

- Some concepts developed by OEMs

Need more

- radical thinking
- early adopters
- risk taking

This was showcased 9 years ago!!!

WHERE CAN WE GET TO IN THE MEDIUM TERM?
(At the Equipment Technology Level)

Innovations in mining methods can
- drive equipment design innovations
- radically transform value-chain

Needs tight coupling between
- equipment designers
- mine designers
- mine operators

e.g. slot-borer coupled with reef-coring mining method (Epiroc + Anglo-American)

WHERE CAN WE GET TO IN THE MEDIUM TERM?
(At the Equipment Technology Level)

Lack of integration between
- technology vendors and OEMs

Lack of integration within OEM

FOUR screens
3 from OEM
1 from 3rd Party

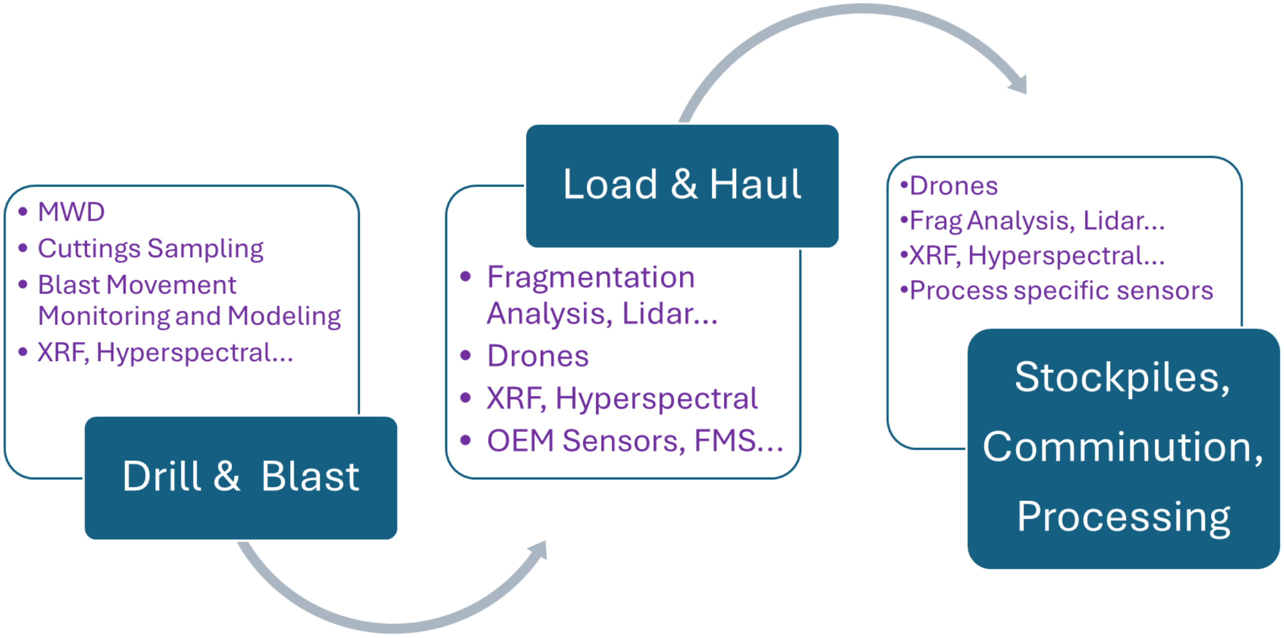
GOAL
- Interoperability
- Standardization

Has to be DEMANDED by end-users
(Money talks!)

WHERE CAN WE GET TO IN THE MEDIUM TERM? (Macro-Level – Value-Chain)

Data-Driven Drill-To-Mill Vision

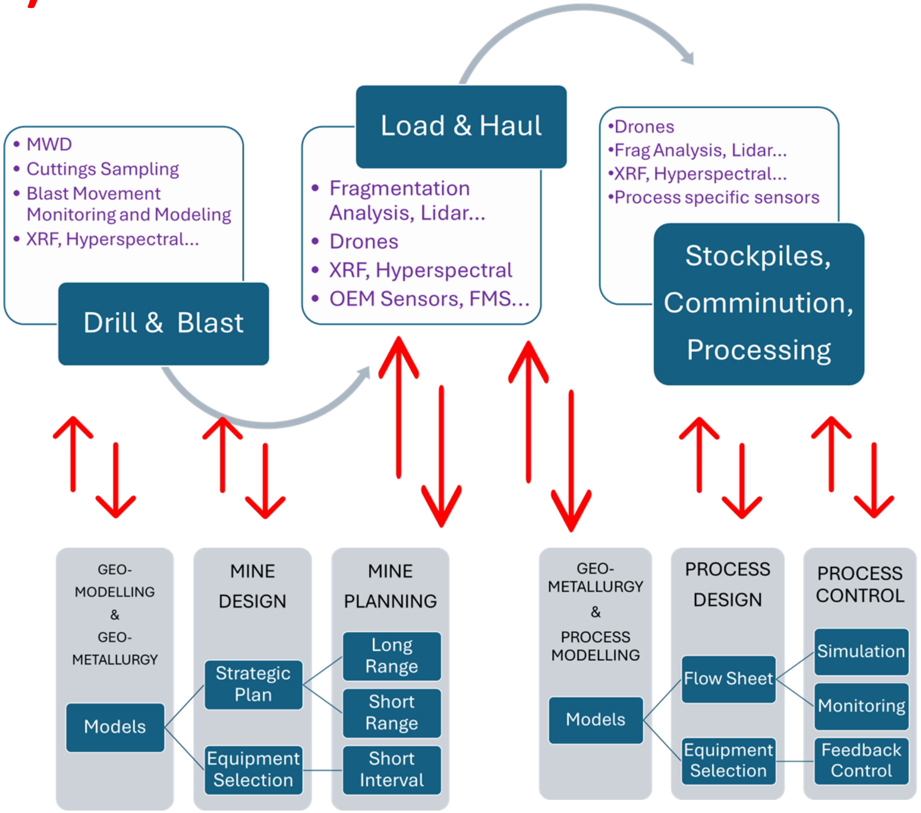
- focused on Sensing & Information - *Global Optimization*



WHERE CAN WE GET TO IN THE MEDIUM TERM?
(Macro-Level – Value-Chain)

Data-Driven
Drill-To-Mill Vision

Bridging the Gaps



Mining 4.0 (my personal definition…)

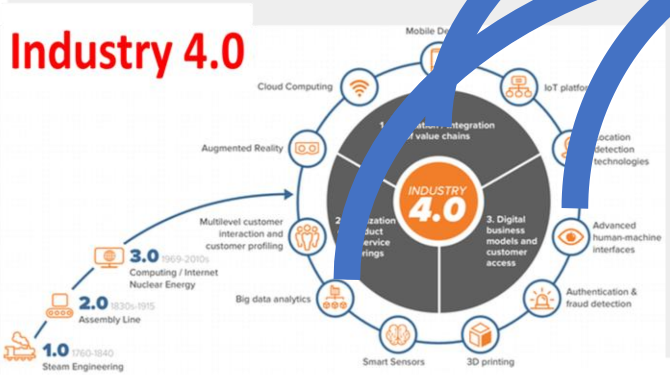
The appropriate (better?) information

To the relevant people/systems

At the right time

To make better decisions

Leading to better outcomes
(economic, safety, environmental, social, …)



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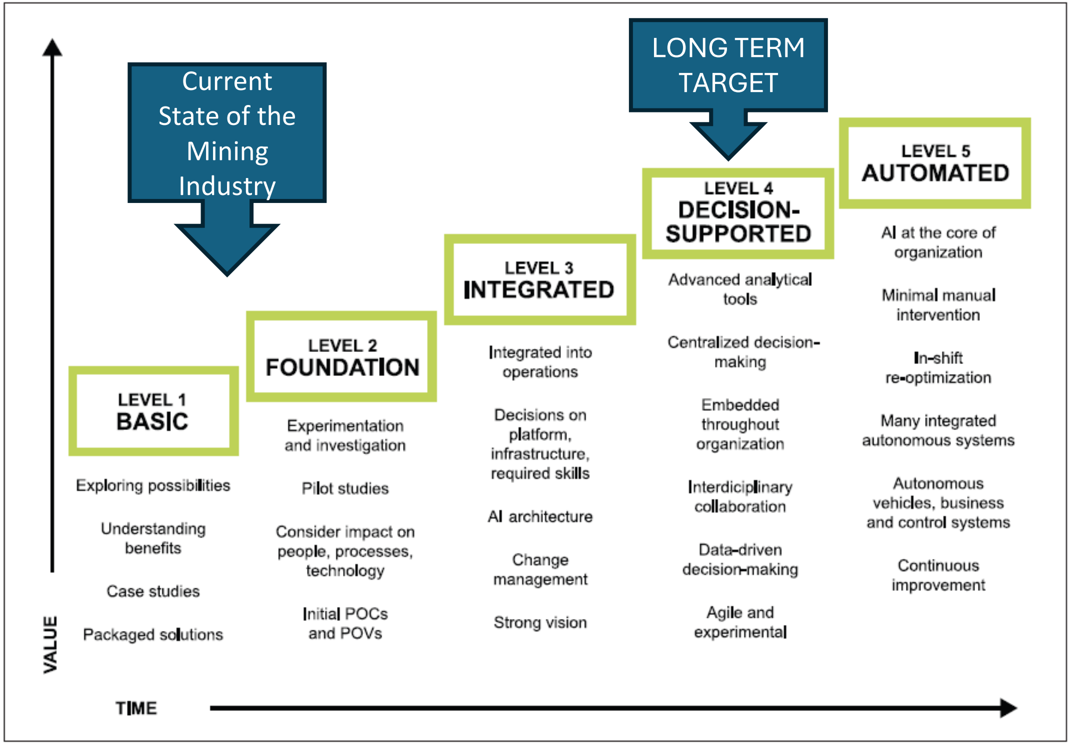

LONG TERM TARGET

LEVEL 4: DECISION SUPPORTED MINING

from: FOUNDATIONS OF AI A FRAMEWORK FOR AI IN MINING, GMG Whitepaper

Level 4 organizations leverage advanced analytical tools in order to provide centralized decision-making capabilities and further improve the operation. At this level, AI is embedded throughout the organization, and it is likely already using a variety of AI technologies. The new technology will significantly affect many business processes and it will be important to ensure that good governance is in place. The following three changes* need to occur in order to embed AI into the organization and to achieve this level of maturity:

1. **"From siloed work to interdisciplinary collaboration."** Interdisciplinary collaboration not only means that domain experts from different areas of operations are working with data scientists and analysts but also that there is collaboration across all areas of operations. For example, predictive maintenance strategies can be rolled out across mine, processing plant, rail, and port operations and the benefits can be fully realized with full collaboration between these entities.
2. **"From experience-based, leader-driven decision making to data-driven decision making at the front line."** In building AI-based systems, operator knowledge is embedded into the system so that when the system makes a recommendation, it should be trusted and not require management approval.
3. **"From rigid and risk-averse to agile, experimental, and adaptable."** The move to agile practices is being widely adopted in the mining industry. To fully embrace these practices, mindsets need to change throughout the entire organization (See Section 1.4).

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The Transformational Opportunity of AI

ADAPTED FROM: AI Transformation in Mining, 2024 Mining Industry White Paper, Microsoft Corporation, March 2024

- Increase the speed and efficiency in decision making
- Enhance the quality and innovation of products and services
- Optimize plans and schedules
- Improve engineering and design
- Solve complex problems and challenges
- Reduce operating costs and risks
- Automate and streamline processes
- Create new and disruptive business models, and
- Transform value propositions and competitive advantages

The Transformational Opportunity of AI

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Empower your workforce

Build an inclusive and collaborative culture that attracts, engages, and retains employees who are empowered to do their best work

- Digital field worker
- Talent management and skills enhancement
- Knowledge management and collaboration
- Productivity and process improvement

Operate for the future

Increase operational profitability and productivity by securely connecting and maximizing existing assets

- Health and safety
- Intelligent supply chain
- Connected assets and operations
- Physics-based models

Generative AI – the Opportunity

ADAPTED FROM: AI Transformation in Mining, 2024 Mining Industry White Paper, Microsoft Corporation, March 2024

Generative AI – the Opportunity

ADAPTED FROM: AI Transformation in Mining, 2024 Mining Industry White Paper, Microsoft Corporation, March 2024

The mining industry faces Herculean challenges with respect to its workforce.

- In general, mining is not perceived as an employer of choice.
- Mine sites are most often located where the talent base is quite small to non-existent, and where educational attainment, literacy, and digital fluency may be lacking. Work at mine sites is usually difficult, dirty, and dangerous compared to other industries.
- as the baby boom generation retires, the talent pool is shrinking. “Fewer people will be working by the end of the decade—and employers need to brace for a ‘forever’ labor shortage.”

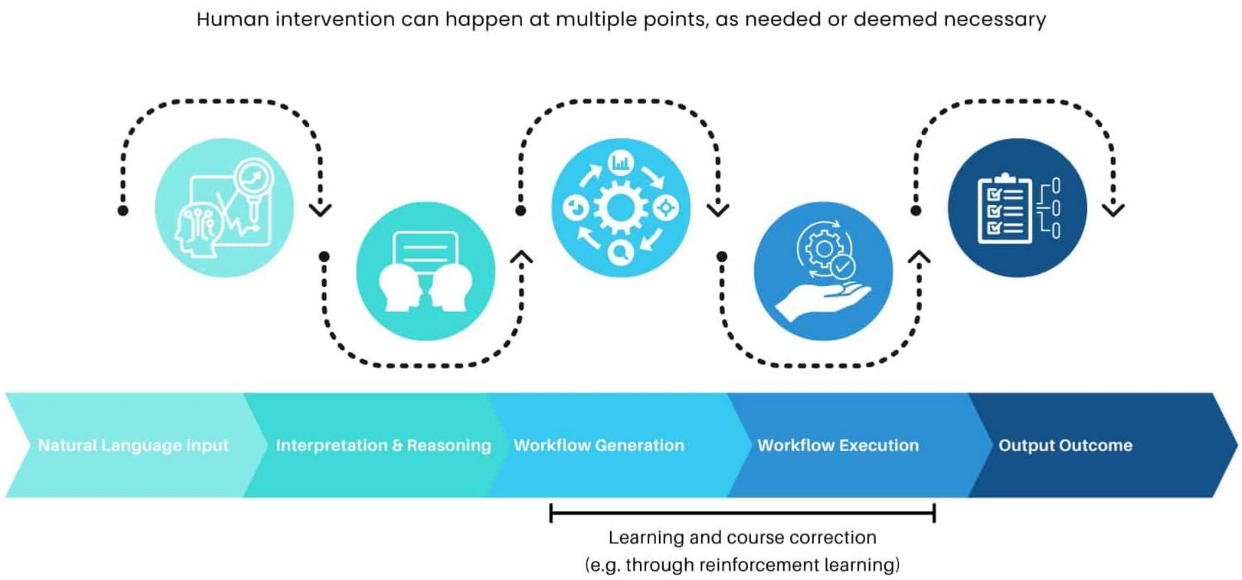
To remain profitable and productive, mining companies and their partners must revolutionize the very nature of work and the workplace.

- ~~They must accomplish more with fewer people while constantly developing and reskilling their employees.~~
- They must accomplish more, in terms of dealing with new data and information streams, while coping with a finite pool of human resources, often with lower skill levels, and limited capacity for constant reskilling their employees.

AI, especially generative AI, can propel this revolution.

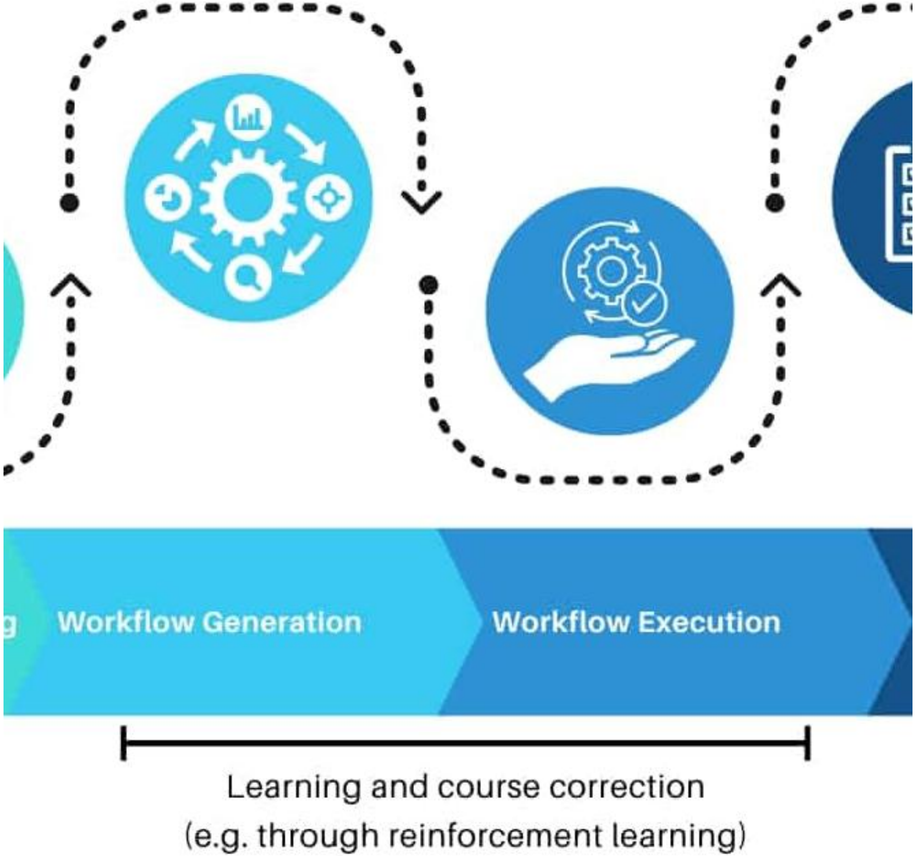
Going to the next level - AGENTIC AI

https://kms-technology.com/emerging-technologies/ai/agentic-ai-the-next-evolution-in-intelligent-automation.html



Going to the next level - AGENTIC AI

Learning & Knowledge Refinement



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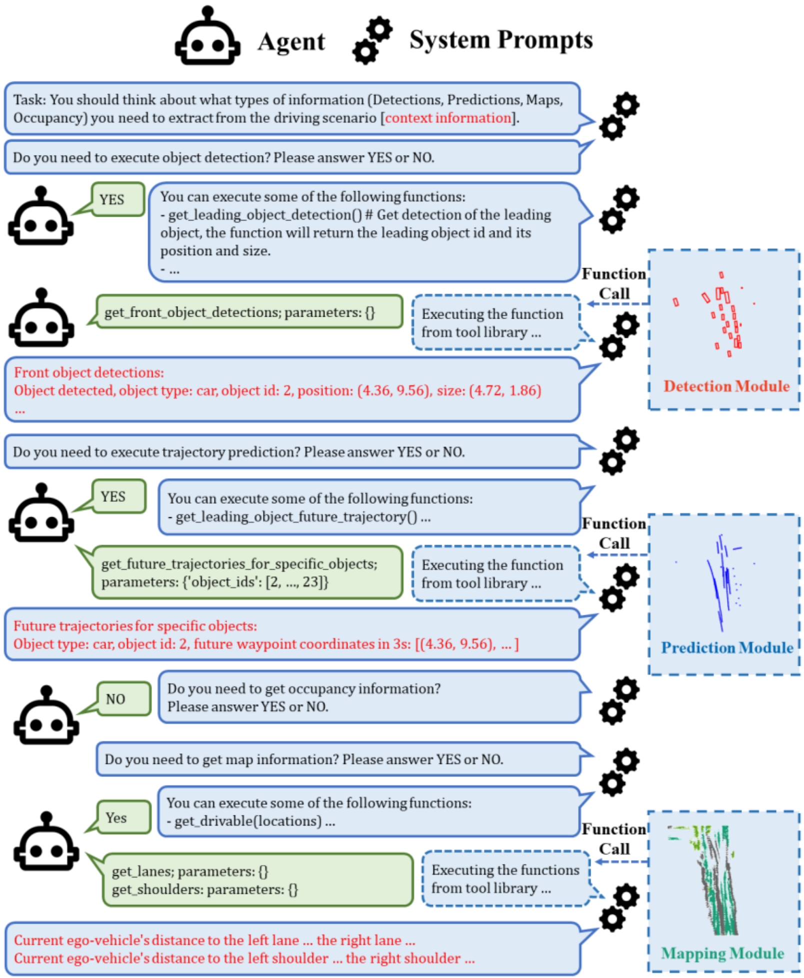
Going to the next level - AGENTIC AI

Learning & Knowledge Refinement

Example:
Nvidia's Agent-Driver

httpshttps://usc-gvl.github.io/Agent-Driver/



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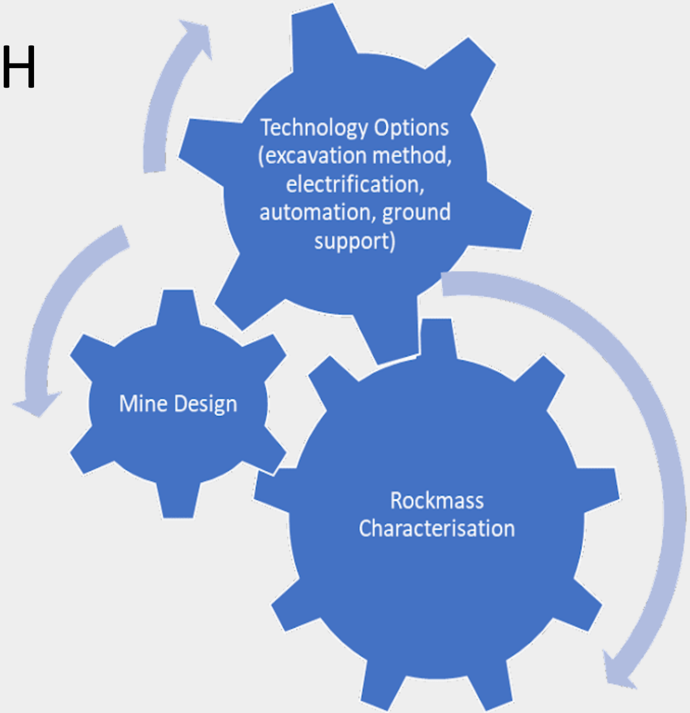
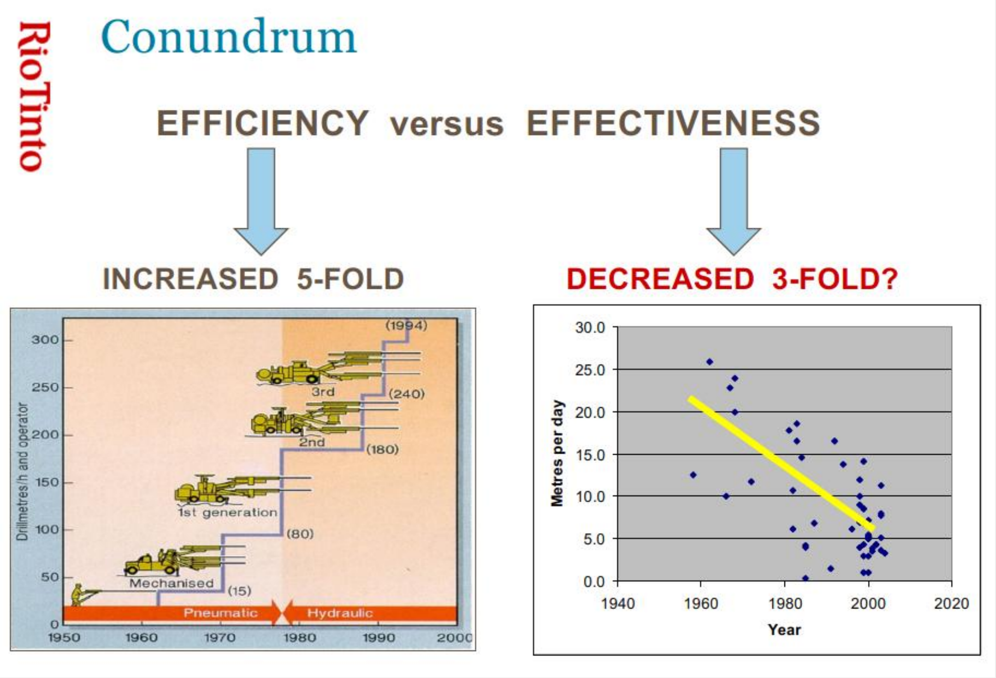
Adopting a HOLISTIC SYSTEMS APPROACH to Technology Development & Deployment is CRITICAL

e.g.
for Underground Hard Rock Mining



Successful TECHNOLOGY DEPLOYMENT does NOT necessarily lead to better outcomes

e.g.
for Underground Development Drilling
- more powerful, efficient, mechanized drills
- yielding to lower advance rates



Successful TECHNOLOGY DEPLOYMENT does NOT necessarily lead to better outcomes

e.g.
for Underground Development Drilling
- more powerful, efficient, mechanized drills
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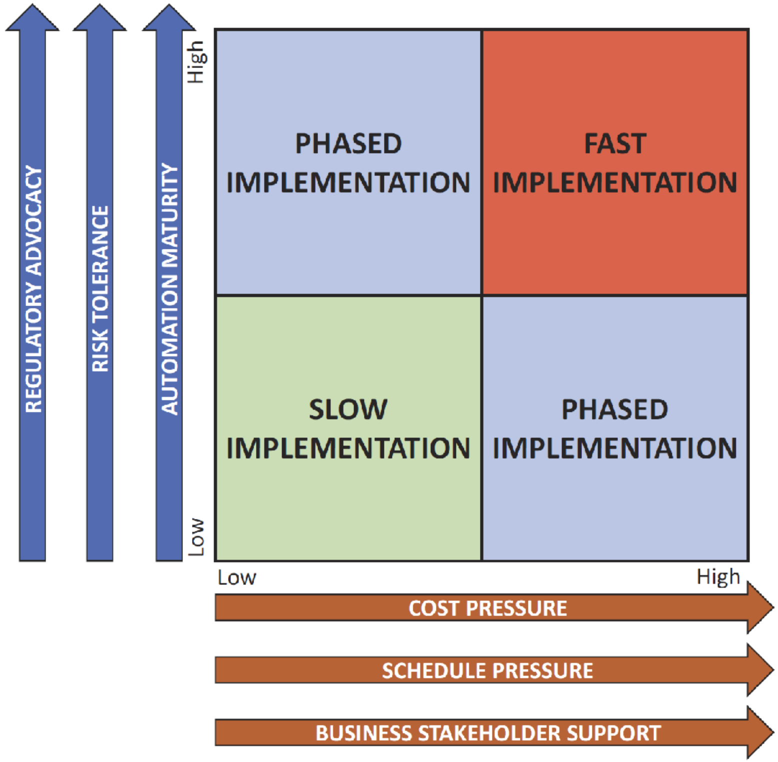
Have to **maintain** (and often enhance) core competencies of work force

- Operators
- Maintainers
- Supervisors
- Planners
- Managers

in order to unlock value…



Choice of Approach for Technology Implementation / Deployment

GMG (Global Mining Guidelines Group). 2019, Guideline for the Implementation of Autonomous Systems in Mining. https://gmggroup.org

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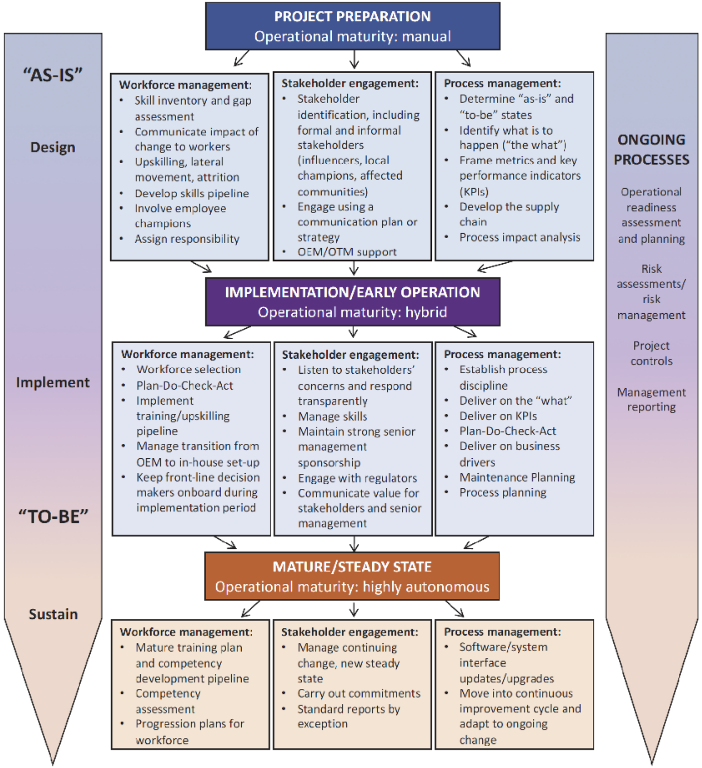
FORO DE TECNOLOGÍA INNOVACIÓN Y SOSTENIBILIDAD



Change Management!

GMG (Global Mining Guidelines Group). 2019, Guideline for the Implementation of Autonomous Systems in Mining. https://gmggroup.org

QUESTIONS?