A FRAMEWORK FOR TECHNOLOGY SELECTION IN MINING SYSTEMS:

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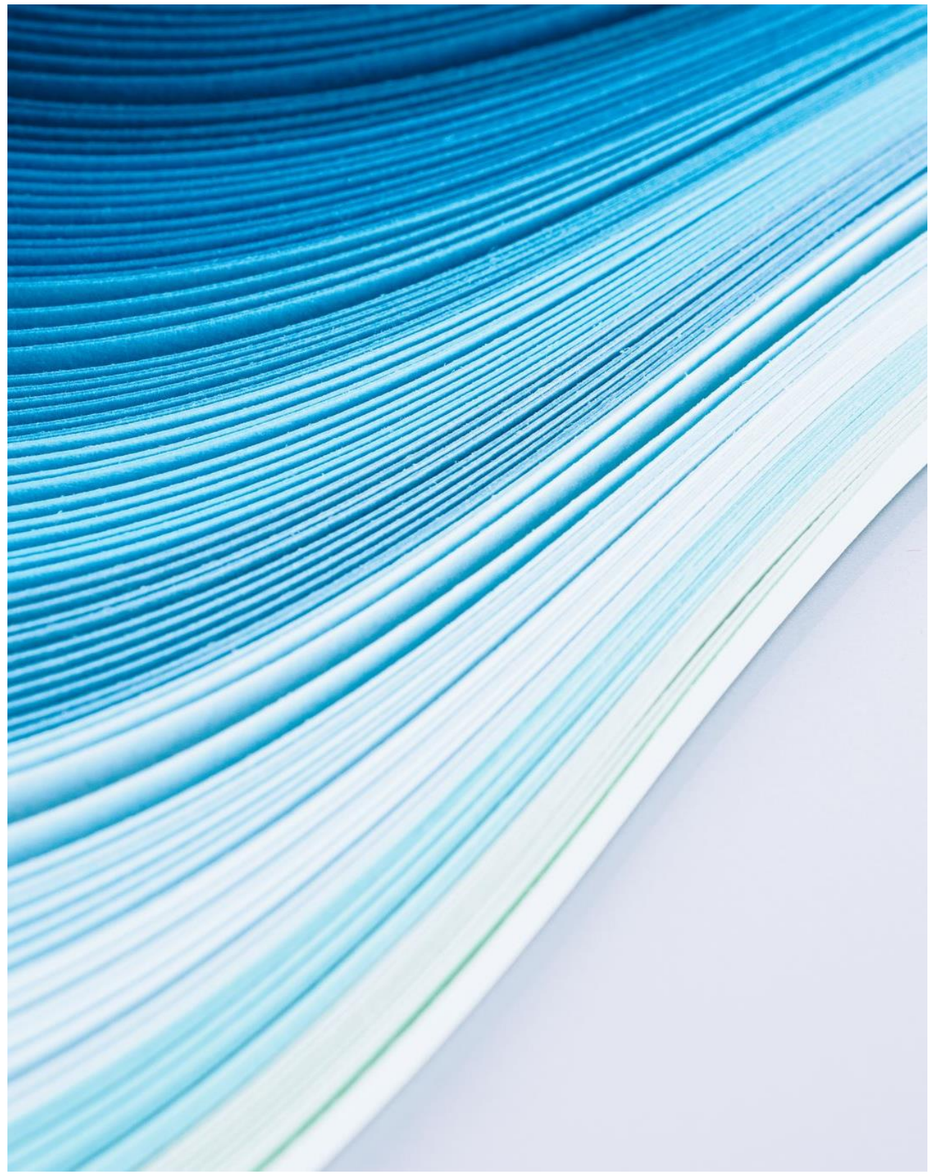
1. Background and Context
2. Research Findings
3. Discussion
4. Simulation
5. Conclusion

Background and Context

TYPE OF RESEARCH



exploratory qualitative research and applying the systems thinking approach (STA)

Abstract

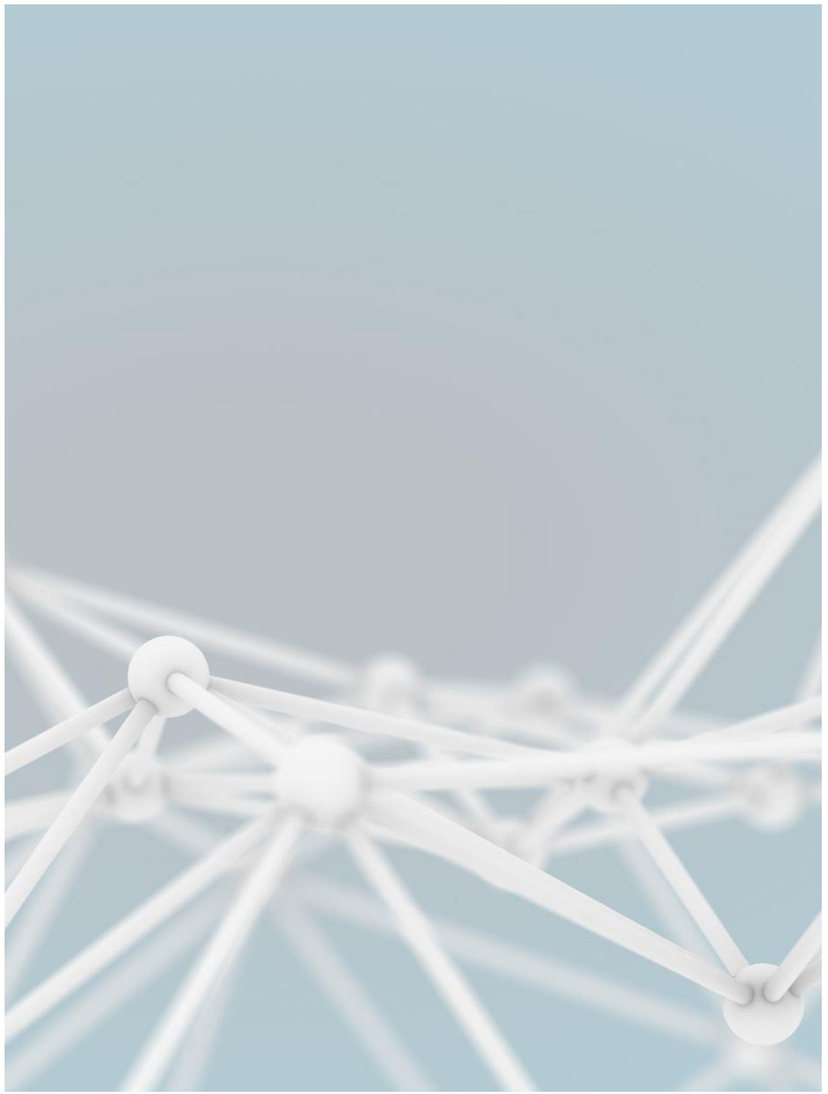
- The report is still a working paper as part of PhD research. The primary objective of this study is to propose a **technology selection framework for designing flexible mining systems**. **Flexibility** is the ability of a system to adapt to predictable and unpredictable changes in future operating conditions. Mining projects are long-term in nature and invariably operate under **conditions of huge uncertainties from multiple internal and external factors**. Literature recommends the inclusion of flexibility options in system design to manage uncertainty. Technology selection during system design phase is one of the approaches which can be used to imbed flexibility in socio-technical systems, as can be learnt from the design of various large-scale systems.

- Using **exploratory qualitative research** and **applying the systems thinking approach**, the study has so far managed to establish some of the key drivers in technology selection for mining and the feedback loops. The paper will thus discuss the finding so far from a Delphi technique round 1 using a set of carefully selected experts in the mining industry.

KEYWORDS

- Flexible mining systems; systems thinking approach; technology selection, uncertainty.

CONTEXT AND MOTIVATION



why is it necessary to do this?

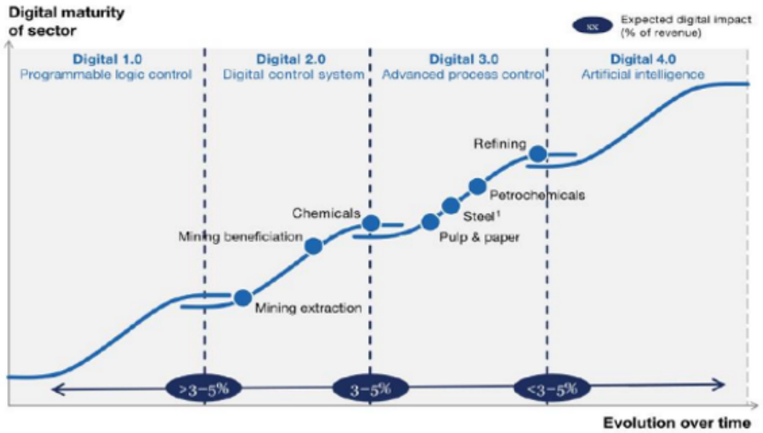
- ❑ Mining is a **complex dynamic techno-social** system
- ❑ Involves interaction of **humans** and **technology**
- ❑ **Multifaceted dimensions (social, legal, geology, technical, etc)**
- ❑ **Large time horizons** in the future (up to 50 or more years)
- ❑ difficulty to model/predict **human behaviour**
- ❑ technology selection in mining **cross disciplinary boundaries**
- ❑ the difficulty to carry **experimental testing** of mining operations

CONTEXT AND MOTIVATION

Views from Literature

❑ MINING IS CLASSIFIED AS :

- One of the **Riskiest Industries.**
- **LAGGING** in the ability to change compared to other industries
- **SLOW TO ADAPT** to uncertainty factors

Author	Description
Ian Runge (2017)	Every mine change throughout its life. It changes because the orebody changes …because the price of the product changes…. because demands of the customers change, and because technology changes. One lesson from the last 8 years (tough) is that (the mining industry) ability to adapt to change has been found wanting.
Ediriweera & Wiewiora (2021)	Mining is often described as an industry where innovation and technological changes are resisted or slowly implemented. The mining sector has long been regarded as having a conservative culture, which is resistant to change, with structural barriers to innovation, such as high capital intensity and geographical dispersion.
Lööw (2021)	The effects of these limitations on the mining industry can be seen in that the level of technological development is lower in mining compared to other industries… Second, where technology does have clear positive effects on the work environment, the rate of technological change is slow in the mining industry, owing to high capital costs, long lifespans and equipment that is expensive to upgrade
Gruenhagen & Parker (2020)	Innovation offers the mining sector the opportunity to address its most pressing challenges. However, the mining sector has long been regarded as having a conservative culture which is resistant to change, while others focus on the structural barriers to innovation such as high capital intensity.
Clausen et al. (2020) Status of the technology adoption in mining compared to other industries	

RESEARCH OBJECTIVES

1 Central Research Question

The Central research question to be answered in this research is:

"How can technology selection be used to imbed flexibility in a mining system design considering the many uncertainty factors inherently present in the mining sector?"

A flexible mining systems is one that should be able adapt to changing situations in the future.

2 The Challenge

- **mining systems are designed before operating situations are fully understood**, and before the impact of future potential operating problems is appreciated
- **how do mine planners and designers select technology** that enables mining systems to be flexible to be able to adapt to any future changes, **considering the long-term nature** of mining and the uncertainty that is invariably present.

Research objectives

a. Understanding the **uncertainties** and **shortcomings** which affect the development of flexible mining systems.
b. Understanding the **technology selection frameworks** in other LSS that operate under high uncertainty conditions such as Energy, Space, Manufacturing and Military sectors.
c. Develop a **technology selection framework for mining systems** using lessons from other LSS.

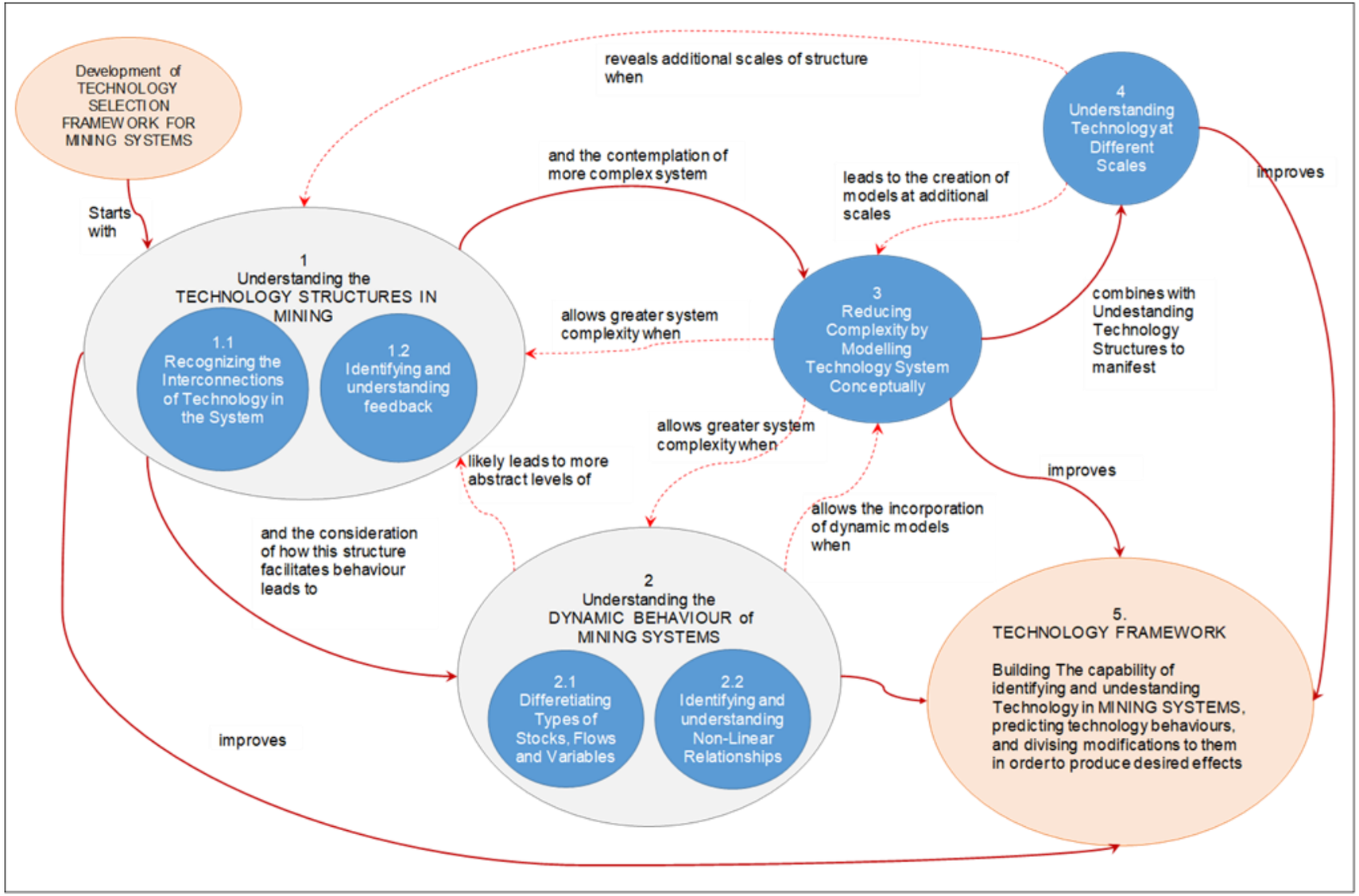
THE RESEARCH APPROACH SYSTEMIGRAM

Applying Systems Thinking Approach (STA)

Approach

1. Understanding mining technology system structures
2. Understanding mining technology dynamic behaviour
3. Reducing mining technology system complexity through modelling
4. Understanding mining technology at different scales
5. Mining Technology Framework

- STA is a holistic perspective
- STA acknowledges relationships
  - among system components,
  - between the components and the environment



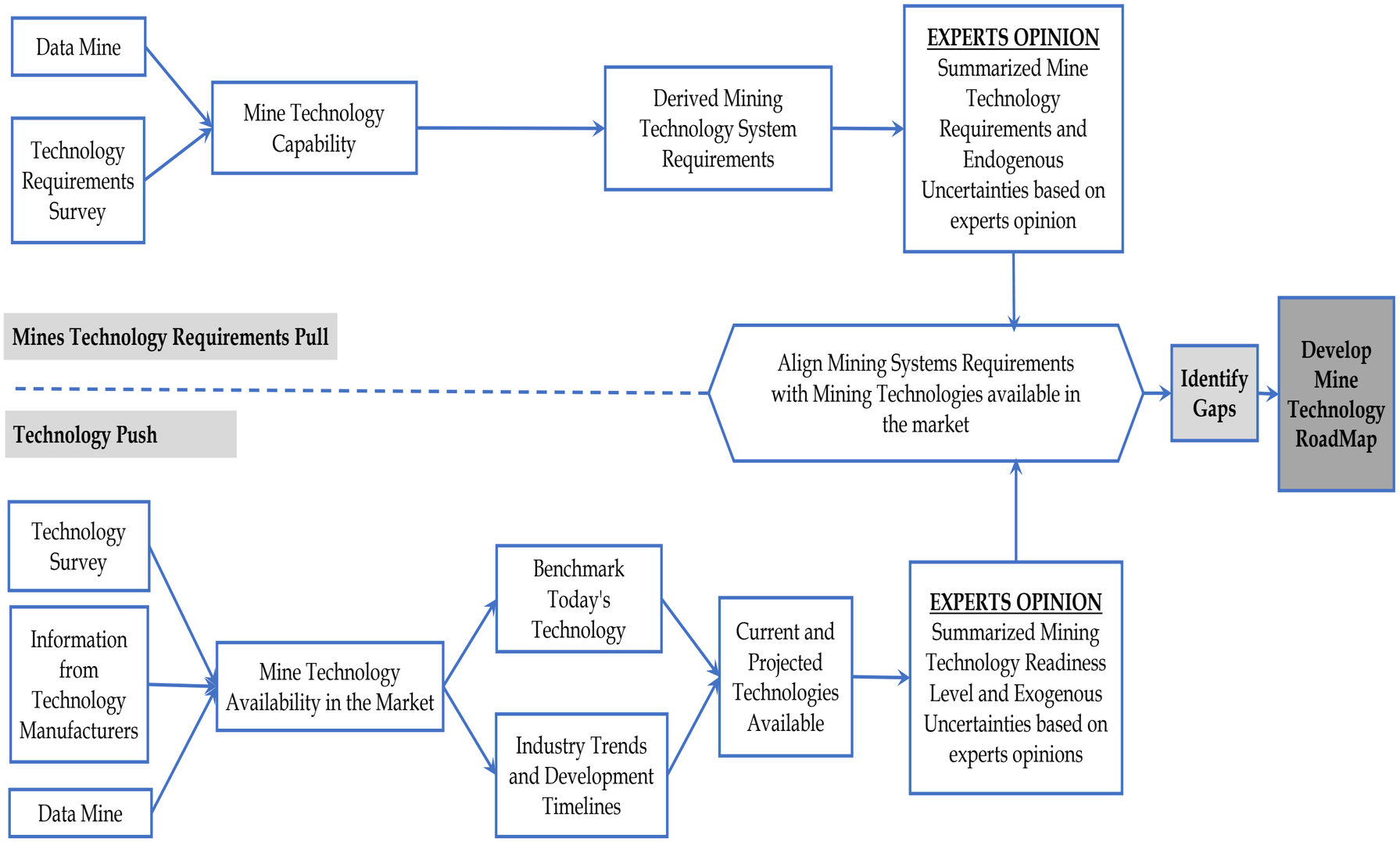
RESEARCH FRAMEWORK

PROCESS MAP

The process will involve both desktop and practical case study surveys of real mines and the interaction with mining technology research institutions.

- **Mine Industry Requirements Pull** - the study will review the mines technology requirements pull factors which drive strategic technology decision.
- **Case Study of a real mine** - Permission has been granted by one large mining entity with 8 operating mines to collect data and create the base case for simulation.
- **Technology push** – most technology development is driven by the **original equipment manufacturers (OEM)**. The balance between what the manufacturers provide in the market and what the industry requires is going to be analysed in detail.
- **Experts Opinions** – opinions from the various Experts using the Delphi Survey Method shall be used to summarize both Endogenous (Internal Factors) and Exogenous (External) factors which have profound impact in technology decisions
- **Simulation** – shall be done using data from the identified Gaps. Technology roadmap shall then be developed using computer simulation techniques.

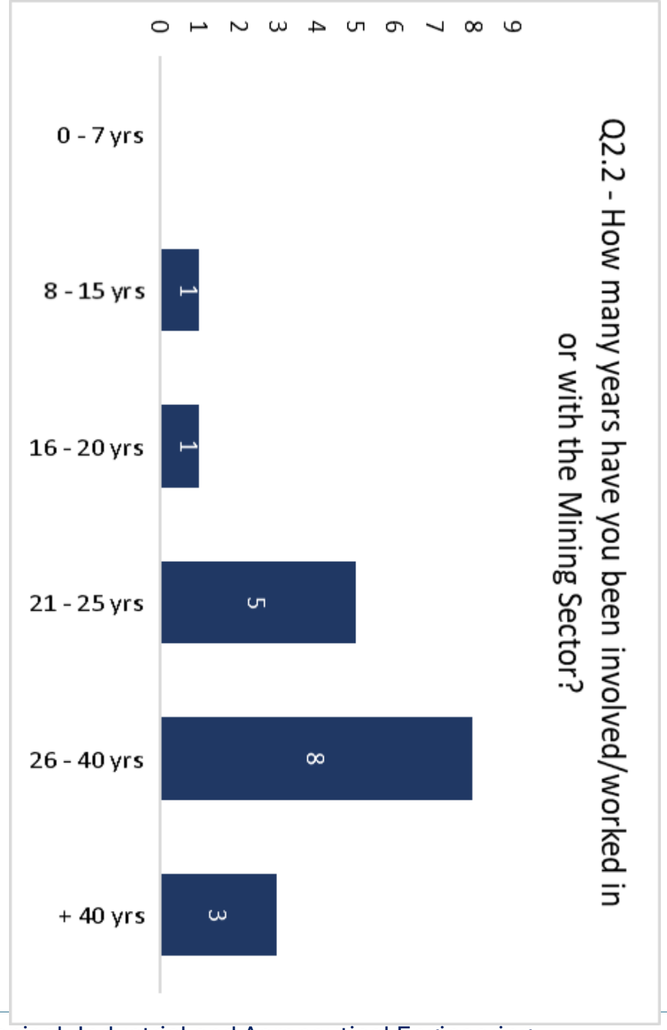
Planned Research Process for developing technology roadmap in mining

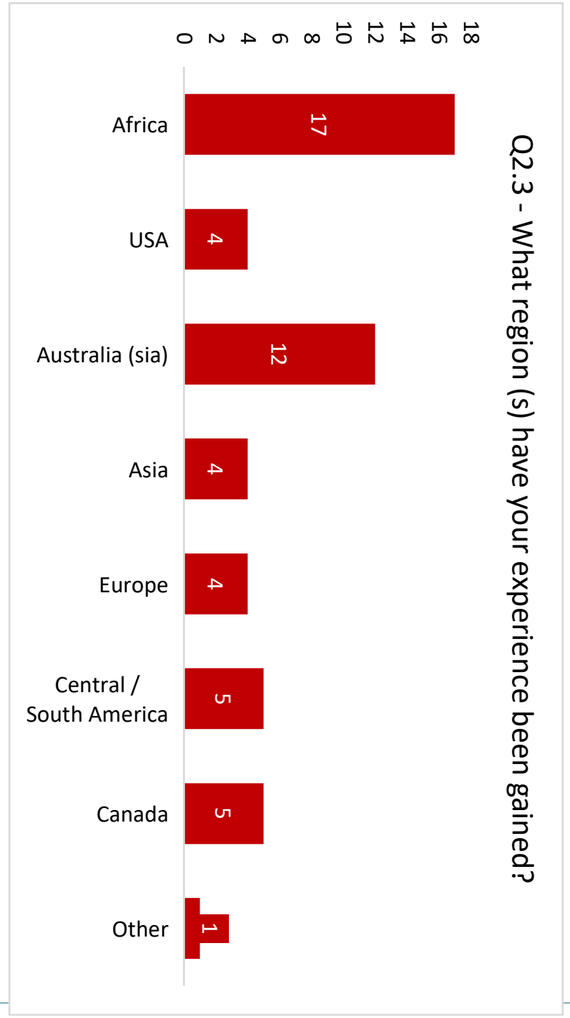


RESEARCH INSTRUMENT – DELPHI METHOD

Delphi method – for eliciting expert opinion in developing the framework

- A 30 questions online survey Questionnaire **sent to 35 experts. 20 responded.**
- List of experts suggested by SAIMM and through referencing.



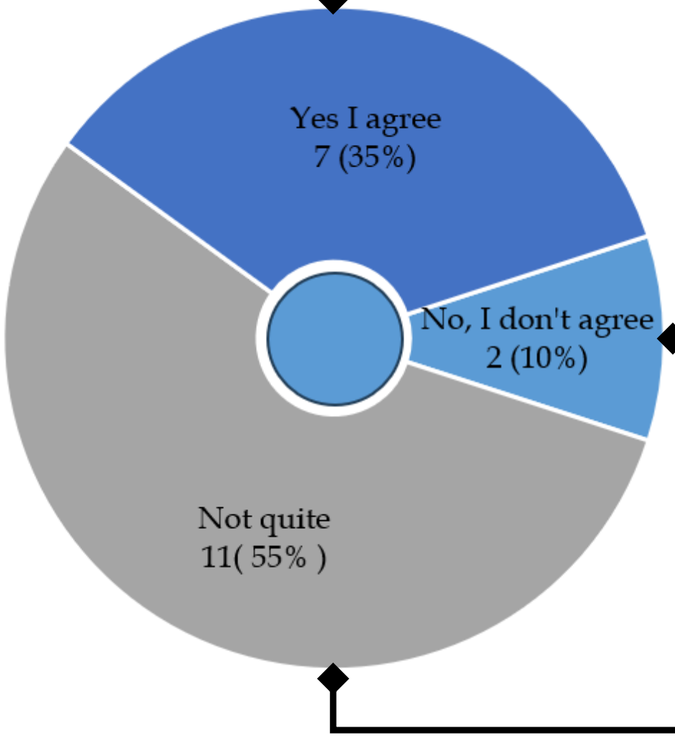


Results and Findings

Findings 1 – *Is mining lagging other industrials*

Q3.4 - A common statement or view found in technology circles is that Mining is lagging in technology compared to other large -scale sectors like manufacturing, oil and gas, automotive, energy, etc. Do you agree with that notion?

The results from the 20 experts who responded showed that
- **35% agreed to the notion,**
- **55% do not quite agree and,**
- **10% don't agree with the notion**



(1) Many of our mining practices haven't changed much in decades besides Technologies being available.
(2) UG mining lagging behind in automation and robotics.
(3) Note that most of these technologies adopted in mining are already in use in other industries.
(4) Mining is complex and not so easy to change over to new technology - mining method is dictated by the ore body.
(5) Mining is slow in adoption of smart systems.
(6) The environment, unpredictability, cost of technology, skill, knowledge and acumen - No support of R & D by mining houses.
(7) Technology is expensive to roll out in underground environment. Capital intensive initiatives.

(1) We have some of the only commercial scale autonomous vehicles in the world.
(2) Mines are quick to adopt technologies that work and are proven. Mines cannot risk unproven tech

(1) We may be slow to change but we adopt technologies that make mining sense and not just other environments
(2) Oil and gas development projects and operations are very large scale and therefore the technology is more advanced.
(3) Technological advances are driven by a need.
(4) The mining value chain - from target identification to mine closure - contains an extensive amount of moving parts. collectively across entire chain, is not necessarily behind.
(5) Technology exists in the mining space and the adoption of the sytems is lagging, due to lack of trust resistance to change or cost
(6) Mining is quite different to most technologies. Is a small industry so rewards are not as great as for other (LSS) industries
(7) Mining companies are increasingly embracing digital solutions, automation, and data analytics to optimize operations, reduce costs, enhance safety, sustainable practices, eco-friendly extraction, waste management, and renewable energy integration.
(8) Mining is an old practice, and at times cannot keep up with innovation / changes due to the nature of activities.
(9) There are some R&D activities but not sufficient for an industry such as mining.
(10) I partially agree, mining is quite pragmatic in what it implements. There needs to be a strong value case.
(11) The physical nature of the mineral resource (eg rock strength, geo metalurgy, orebody geometry, in situ stress, geo structural setting etc) cretaing the basic physical requirements for extraction to which technology must be developed to enable exraction.

Findings 2 – *the Word "TECHNOLOGY" in mining*

Q3.1 - How do you define the Word "TECHNOLOGY" in the context of mining systems?

Full DEFINITION

Mining technology is the application of both **scientific and human knowledge** in the

development of various
[systems, tools, techniques, equipment, solutions, methods, automation, hardware and software]

across the whole **mining value chain** using **planning processes** to plan the
[mining processes, operations, systems, methods and extraction systems]

in order to **improve or increase** the
[efficiency, performance, productivity, safety, sustainability and cost- performance]

of the whole mining business.

Responder	Definition of Technology	Themes	Count of Themes
	COUNT OF KEY THEMES IDENTITIED		5
1	New piece of equipment to improve a mining process and increasing productivity - safety assumed	New, Equipment, Mining Processes, Improve; Increase, Productivity, Safety	7
2	Advances in equipment and systems to improve efficiency and performance in mines	Advances, Equipment, Systems, Improve, efficiency, performance	6
3	Anything controlled by a computer. Any mining method or extraction system.	Computer controlled, Mining method, Extraction system	3
4	Automation systems	Automation systems	1
5	The application of science to make the mining operations safer, more efficient and more cost effective	Application, Science	2
6	Any system, process or equipment that is used to extract the metal or mineral along the value chain	System, process, equipment, value chain, extract	5
7	Any specific way of undertaking a mining process, including planning processes	Way, Planning process	2
8	It refers to the application of scientific knowledge, including automation and data analysis to enhance the efficiency, safety, and sustainability of mining operations.	Scientific knowledge, Data analysis, automation, mining operations, efficiency, sustainability, safety	5
9	Application of science to change and improve mining systems	Change, application, science, improve	
10	Software and hardware to extend the productivity of equipment	Extend, software, hardware, productivity	4
11	Currently proven or adequately researched approaches and systems to obtain an appropriately acceptable output or solution.	Currently, proven, researched, systems, output solutions	5
12	The process, method, equipment, and system that is knowledge based and can facilitate or improve mining operations	Knowledge, equipment, system, process, mining operations	5
13	I refer to technology as any system that uses some type of digital solution from computing to communications to data or control system	Data, systems, computing, communication, digital solution, control system	6
14	Application of scientific knowledge through leveraging the use of software and/or hardware	Application, scientific, knowledge, software, hardware	5
15	Any advancement towards mine automation	Advances, Mine automation	2
16	The tools, techniques (skills), knowledge applied in extraction of metals and minerals	Applied, knowledge, tools, techniques, extraction	5
17	Technology in mining systems span across all the different aspects that are related to mining. In some areas old technology is still in use and in other areas the latest technology is used. It depends on the need to upgrade old technology and also the availability and affordability of new technology. Mining systems could still perform well by using older technology and in other cases it could be that legacy systems are due to be replaced by the latest technology that is available in the market.	New, Old, Legacy, mining systems	4
18	Application of human knowledge that manifests in artifacts applied to productive use	Application, human, knowledge, artifacts, productive	5
19	Any system, product equipment or material that is used in the process of mining to enhance: safety, efficiency and cost of production.	Equipment, System, Product, Material, mining process, enhance, efficiency, cost, safety	9
20	Modern methodologies that make the mining function more efficient and effective.	Modern, methodologies, efficiency, effective	4

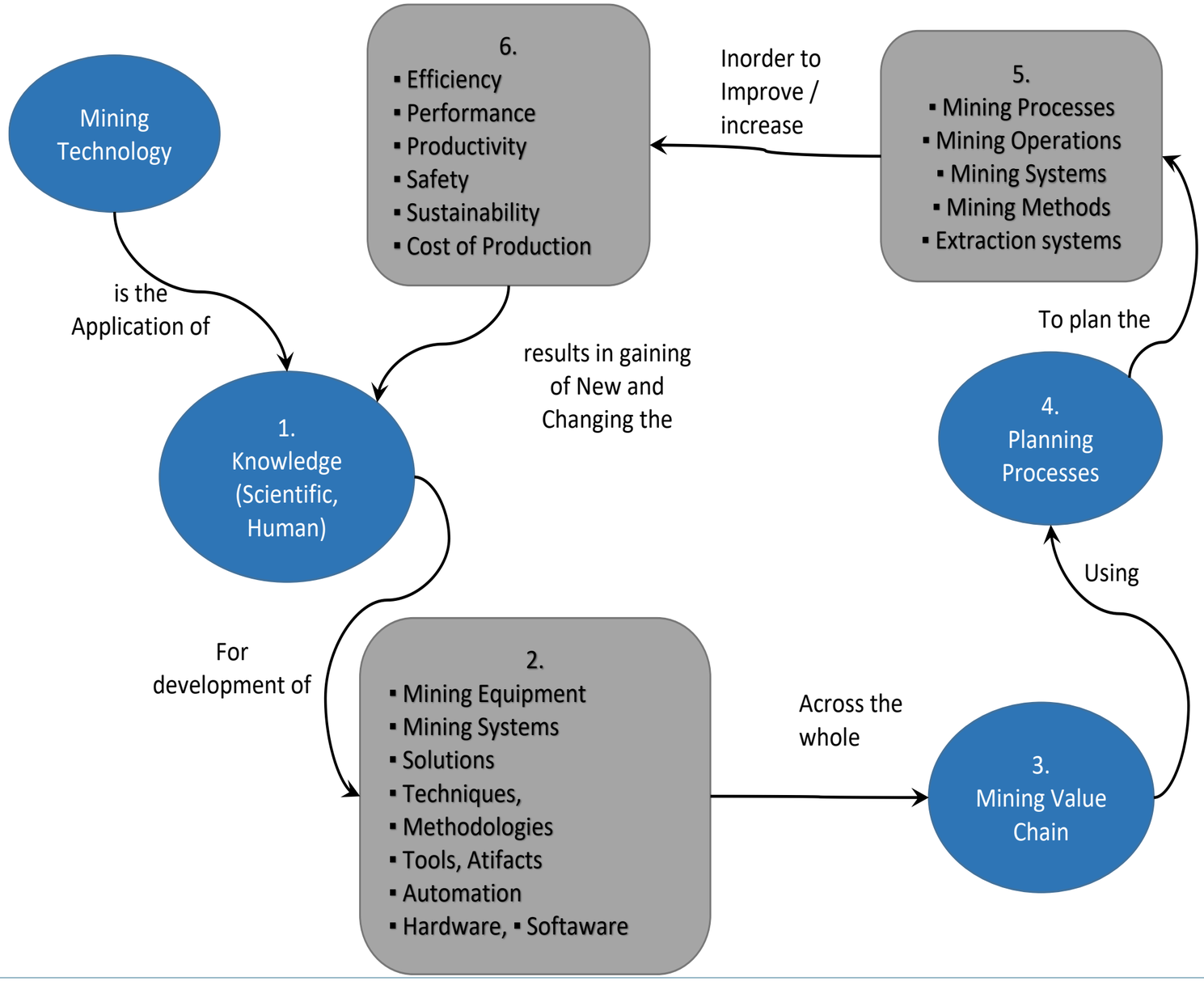
Findings 2 (*cont'd*)– *the Word "TECHNOLOGY" in mining*

What is Technology Question

Definition System Map

Key aspects of the definition

- Application of knowledge, in
- development of Solutions, tools, techniques, equipment, software, hardware
- across the whole mining Value Chain
- using Planning Processes
- To plan the mining Processes, Systems, Operations,
- In order to improve efficiency, performance, productivity, safety, sustainability, cost of production



Findings 3 – *Ontology/classification of mining technologies*

Q3.2. In your experience, what are the main technologies you find in most hard-rock mining system (underground/open pit - excluding the processing plants)

Another important aspect of understanding the structure of mining technology

- **How technology systems are classified in the mining sector**
- **What are the types of technology.**

Findings from the survey and the analysis of this from 20 responses:

❑ **16 Classes of Mining Technologies**

Rock breaking technologies	Rock handling / Ore Extraction	Ground Support Technologies	Materials Handling	Equipment Monitoring Systems	Automation Technologies	Utilities - Energy, Water, Air Technologies	Advanced technologies
- Drill vs Blast - Drill technology - Hydraulic drills - Blasting technology - Rock cutting technology - Rock breaking technology - Blasting monitoring - Sequential blasting	- Mining equipment - Trackless machinery u/g - Ore moving technology - Movement of waste - Backfill system and Movement of tailings - Haul trucks - High capacity loaders -	- Hydraulic supports systems - Hanging wall support - Excavation stability - Ground support - Ground stability monitoring - Cavity monitoring	- Movement of enabling resources - Transport - Ore clearing systems - Hoisting - Conveyor belts - Sorting technology and selectivity	- Equipment dispatch systems - Fleet management systems - Sensors and monitoring devices for tracking equipment performance - Real time decision making - Defects fault detection	- Process automation - Autonomous operation - Robots - Automation and remote technology - Remote operating systems - Autonomous Haulage Systems (AHS) - Autonomous Drilling - Remote controlled functions (loading & drilling)	- Technologies for water treatment, and conservation are essential, especially in underground mining, to prevent flooding and maintain environmental sustainability. - Energy technologies - ESG related technologies	- Artificial intelligence - Location awareness - Equipment replacing miners in dangerous areas - Use of Drones - Machine Learning & Large Data - Block Chain - 3D Printing - Synthetic Materials

Geological modelling systems and Rock Engineering	Survey and Geographical Positioning Systems	Mine Design and Planning Systems	Communication Systems	Human & Safety Technologies	Ventilation and Air-quality Systems	Process Monitoring & Control Systems	Support Services
- Geological modelling tools/software -Mineral resource evaluation tools - Rock engineering tools - Ground penetrating radar - Sesmic sensors - Rock quality and rock defects monitoring	- Mine surveying software - GIS and mapping of mine sites - Spartial data visualization - Spartial techniques and systems - Laser scanning - Survey tools - Beacons - Drones based surveying techniques	- Mine design and scheduling tools - Mine Planning and production systems - Planning and operational applications - Mine planning & optimization software - Mine dispatch system - Production tracking	- Communications systems - Wifi - Fixed line - Mobile - Satellite - Data processing and Transfer - Networks	- Human safety PPE - Time and attendance systems - Fatigue measurement - Personnel tracking systems - Proximity detection - Collision Avoidance Systems - Safety systems - Lighting - Safety management	- Ventilation Tools - Ventilation technology - Air quality control - Ventilation/Cooling	- Data Collection - Monitoring devices - Decentralized Information - Mobilility information - Sensory & Instrumentation - Control & Instrumentation - Operational reporting tools - Time and Event systems - Tracking systems - Warning/alerts	- Maintenance - Warehouse and Inventory Management Software - ESG analytics tool to track ESG parameters of the mining operations and supply chain - Tools for Economic Analysis

Findings 3 (cont'd) – *Ontology/classification of mining technologies*

Example of a Technology Taxonomy from NASA

NASA has a diverse and extensive technology portfolio. To manage and communicate this extensive and diverse technology portfolio, NASA uses a technology taxonomy. This taxonomy identifies, organizes, and communicates the technology areas that NASA advances in order to achieve future space missions and aeronautics activities.

- NASA classifies technology into 17 groups
- NASA Technology Taxonomy has structure that aligns Technology Areas based on technical disciplines.
- The structure breakdown technology into Level 1 and Level 2 technology areas

The taxonomy is a foundational element of NASA's technology management process. NASA's Mission Directorates (MDs) reference the taxonomy to solicit technology proposals and to inform decisions on NASA's technology policy, prioritization, and strategic investments.

Figure 1. The second-level breakdown of the structure used in the 2020 Technology Taxonomy. This document contains details at the third level, with fourth-level technology examples provided in all cases.

Reference

https://www.nasa.gov/wp-content/uploads/2015/03/2020_nasa_technology_taxonomy_lowres.pdf#:~:text=The%20technology%20Taxonomy%20is%20key%20to

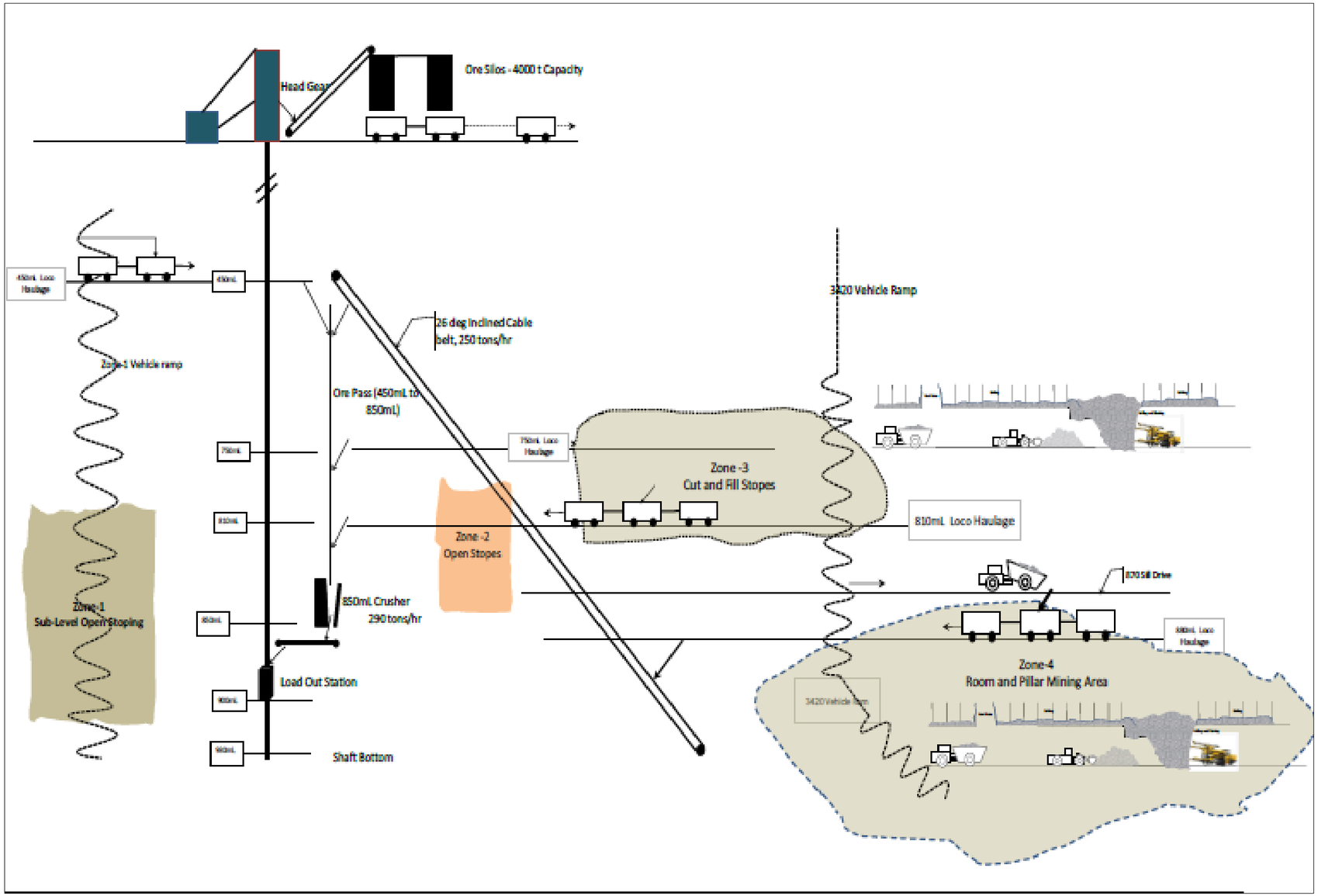
Findings 4 – Typical underground mining technology system layout

Typical technologies in an Underground Mining Systems

VARIOUS TECHNOLOGIES

- Hydraulic Drills
- Load and Haul
- Tipping Points
- Crushers
- Conveyors
- Railing
- Hoisting

- Water Handling
- Communication
- Rock Support
- Compressed Air



Findings 4 – *Uncertainties and long-term nature of mining industry*

- Q3.8 is one of the questions designed to identify some of the main uncertainties and factors that drive decision in mining technology. The results of the responses were analysed and classified into four key themes, namely,
  - Commodity cycles,
  - Technology
  - Social/government/political and,
  - Other factors

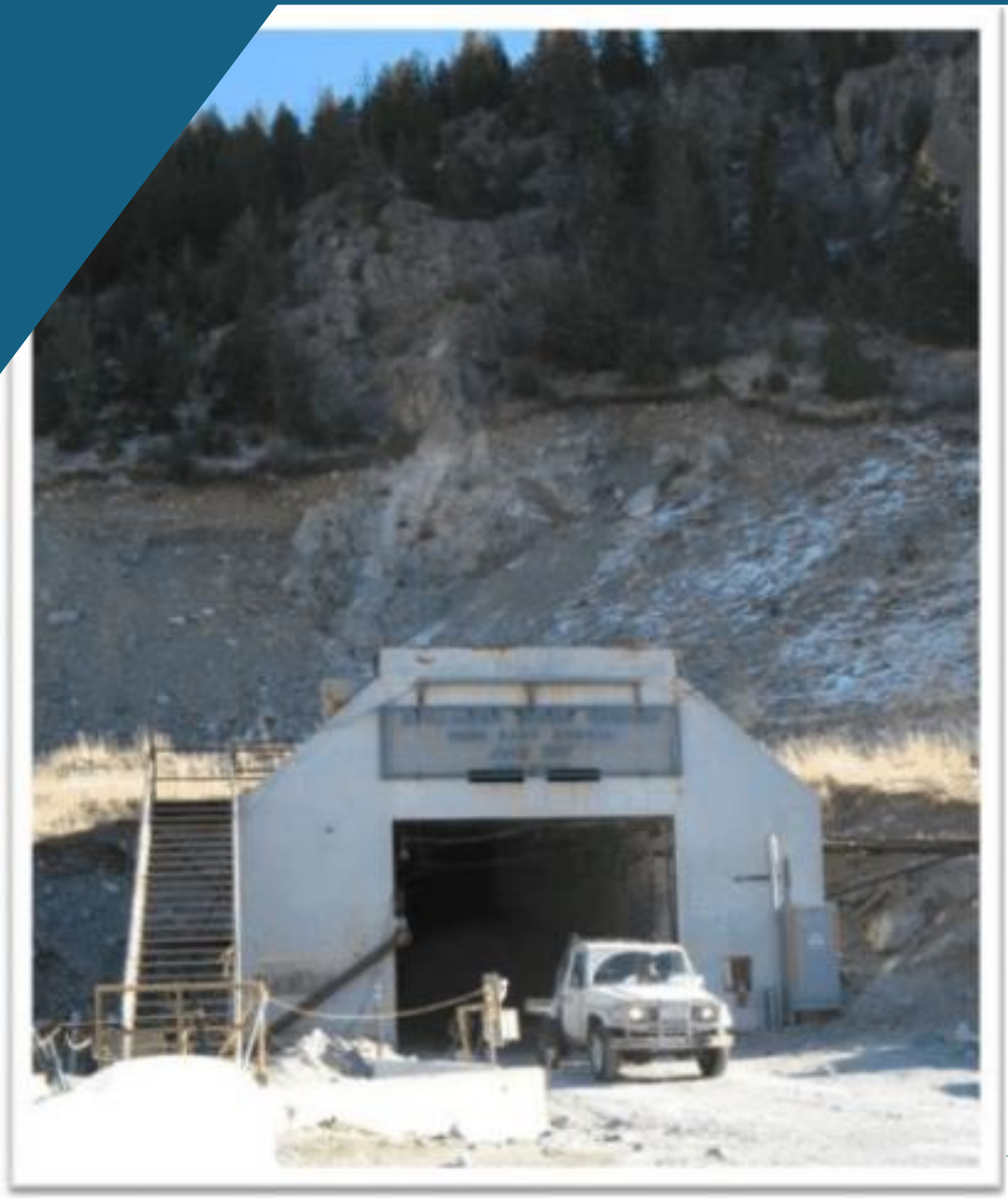
THEMES related to Social/Political/ Environmental	Total on Theme (out of 20)
Government regulatory environment and Legislative certainty	8
Community and Social factors	5
Political/Geo-political influences	5
Environmental regulations and standards	2
Local skills	1
Availability and quality of training	1
Security of tenure	1
Non-governmental organizations (NGOs)	1
Climatic/Weather Events	1
Environmental activism	1
Sovereign Risk	1

THEMES Related to Commodity Cycles	Total on Theme (out of 20)
Commodity Prices	12
Market Condition (supply/demand)	8
Exchange rates	2
Global economic trends	1

THEMES Related to Technology itself	Total on Theme (out of 20)
Availability of Support for the Technology	6
Cost of the Technology and other inputs	4
Technology changes/alternatives	4
Availability (of the technology in the market)	2
Reliability/Durability of the technology	2
Technology readiness	1
Technology Risks (Cyber security/data)	1
(Technology) Brand or reputational	1
Research and development	1

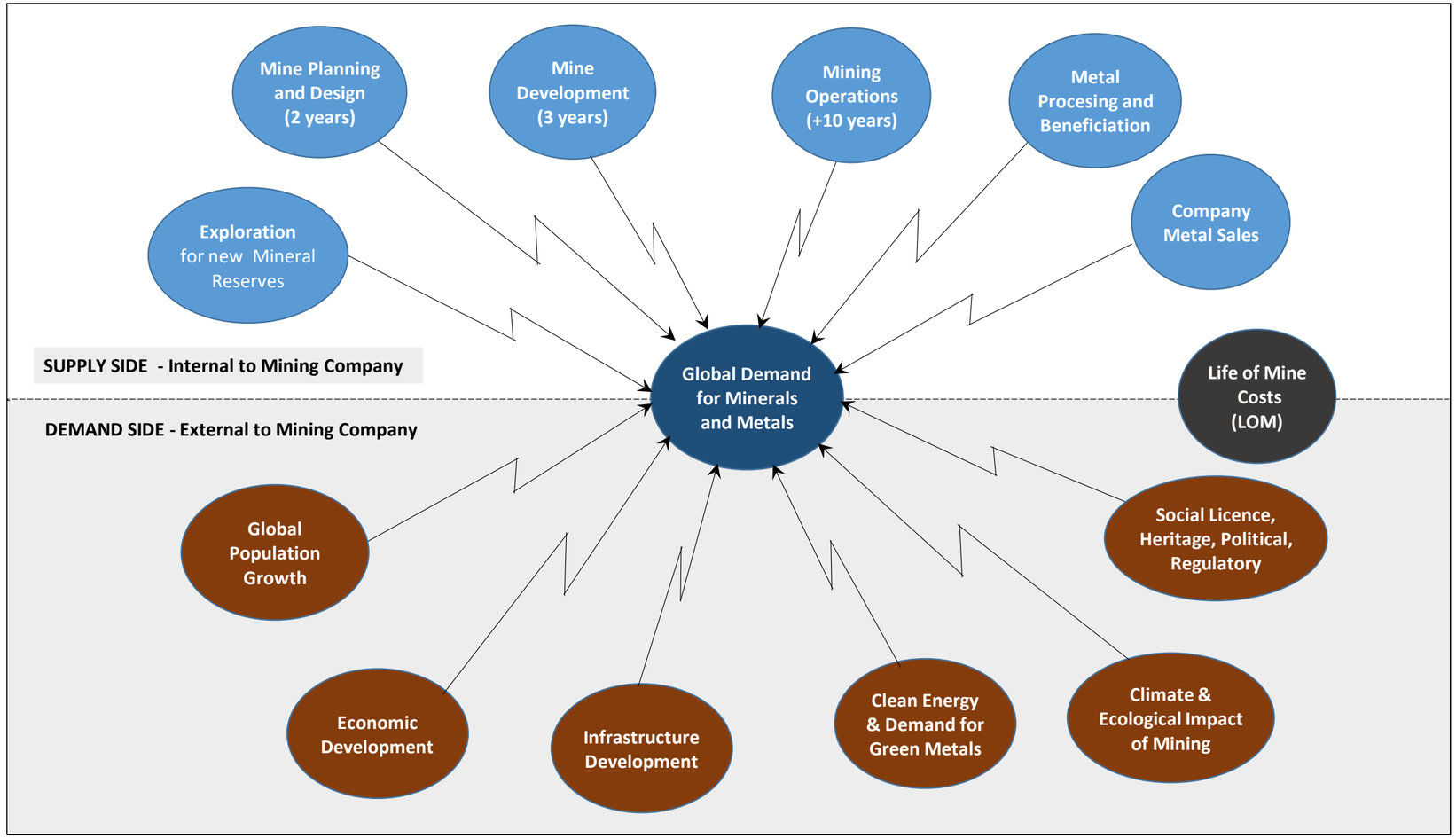
Other THEMES	Total on Theme (out of 20)
Critical Infrastructure challenges	2
Geological Issues/surprises	2
Media coverage	1
Shareholders changes to values or priorities	1
Investment appetite	1

Discussion



Interconnectedness of the Mining System

Mining Value Chain



The mining systems comprise of

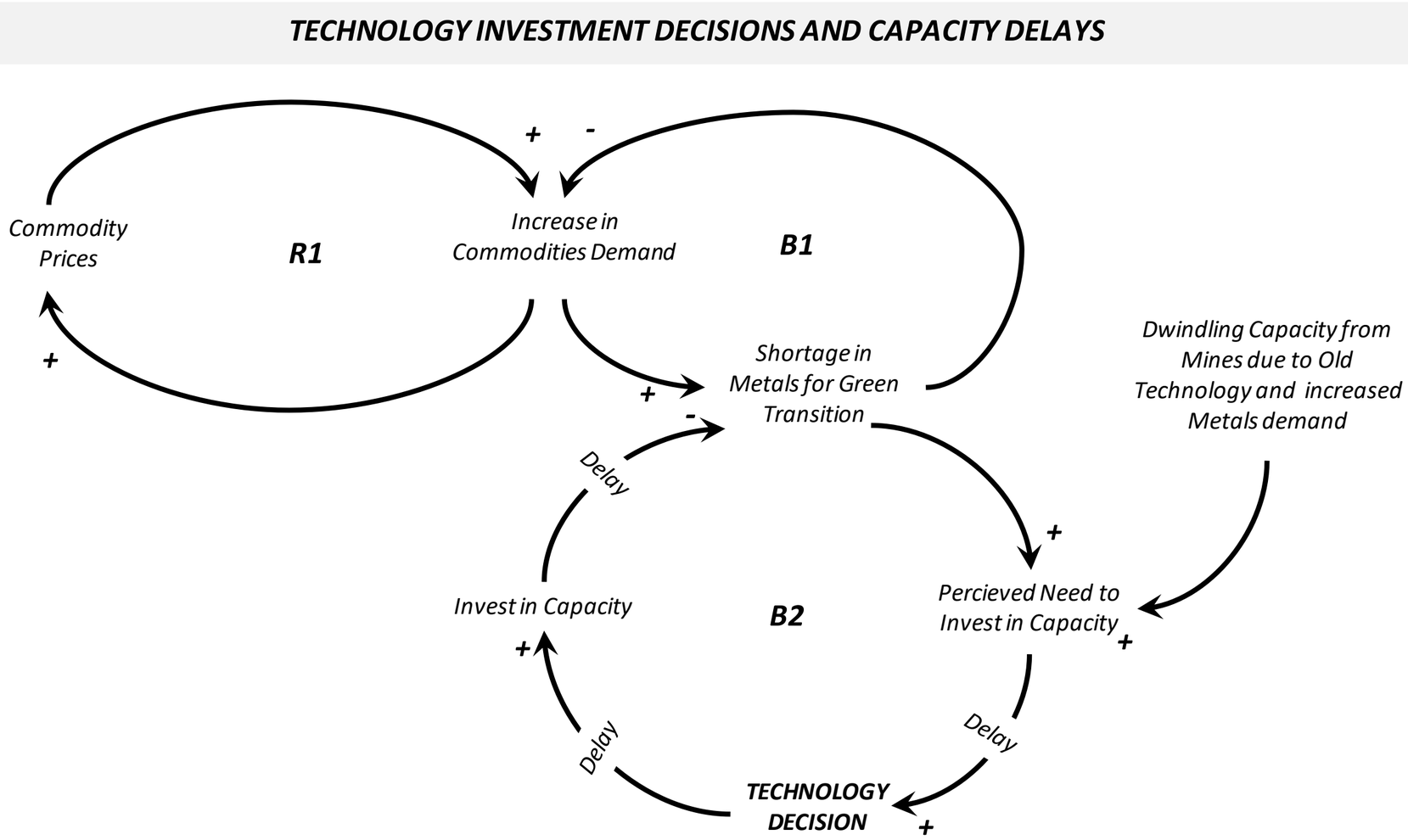
- technical systems which convert material inputs (rocks and chemicals) into the desired metal or mineral outputs by use of various process technologies.
- understanding of various complex issues such as
  - the social and cultural processes, economic issues and markets (supply and demand), technological standards, interoperability, new knowledge, environmental and climatic issues, governance, institutional and legal issues, among others (Sterman, 2002).

EXAMPLE - Causal Loop Diagram for technology decisions in mining:

- R1 – Reinforcing loop – increase in green metals demand -→ Increase Prices
- B1 – Balancing loop – Shortage of Green metals in the market.
- B2 – Balancing loop – Mining businesses making decisions to invest in Capacity.

Commodity cycles influence investment decisions

"Growth and Underinvestment" STA archetype



Understanding the Dynamic Behaviour of the mining system - Policy and structure Diagram

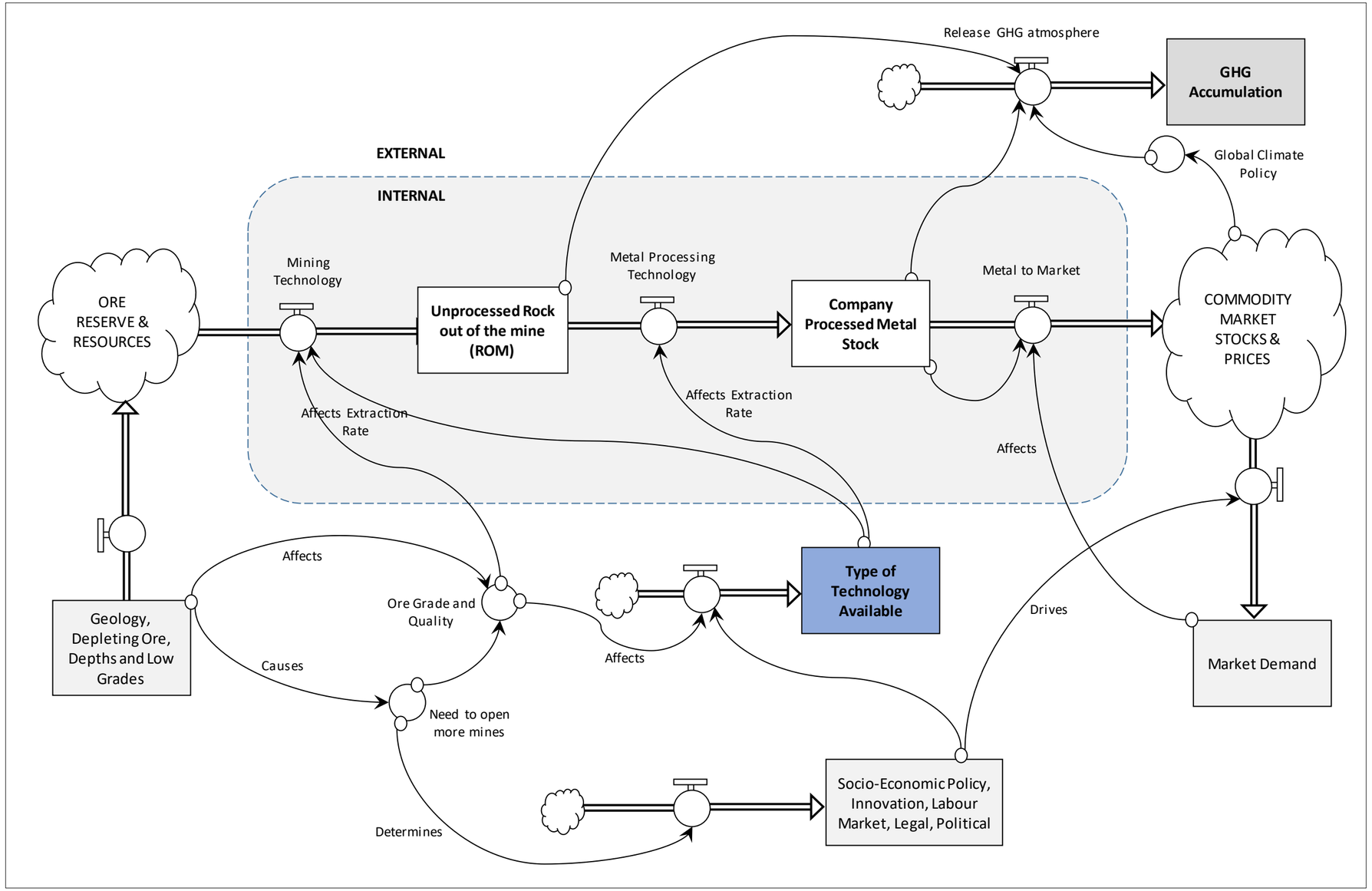
STOCK AND FLOW DIAGRAMS

PURPOSE OF POLICY STRUCTURE DIAGRAM
- Is being used to represents the dynamic relationships in a mining system

INTERNAL MINING STOCKS INCLUDE
- Reserves and Resources
- ROM
- Processed Metal

EXTERNAL MINING STOCKS INCLUDE
- Type of Technology Available in Market
- Commodity in the Market
- Others – GHG emissions, Labour, Skills, etc.

TYPE OF TECHNOLOGY AVAILABLE
- Type of Technology Available in Market
- Commodity in the Market
- Others – GHG emissions, Labour, Skills, etc.



The Mining System Policy and Structure Diagram

- The Policy Structure Diagram shows the **stocks**, **flows** and **variables** which affect a typical mining operation.

- The **MAIN STOCKS** in the mining process are made up of **DRILLED** and **BLASTED ROCKS** in the mine.
  - **Reserves and Resources** – this is the main stock which drives investments as it defines the resources by quality and volumes.
  - **The Blasted Rock** is normally **Primary crushed** in the mine and then **STOCKPILED** out of the mine (**Run-off Mine – ROM**) before it is processed by the metallurgical plants.
  - Other smaller WIP stockpiles might also exist inside the mine – **Muck piles**, **Silos**.

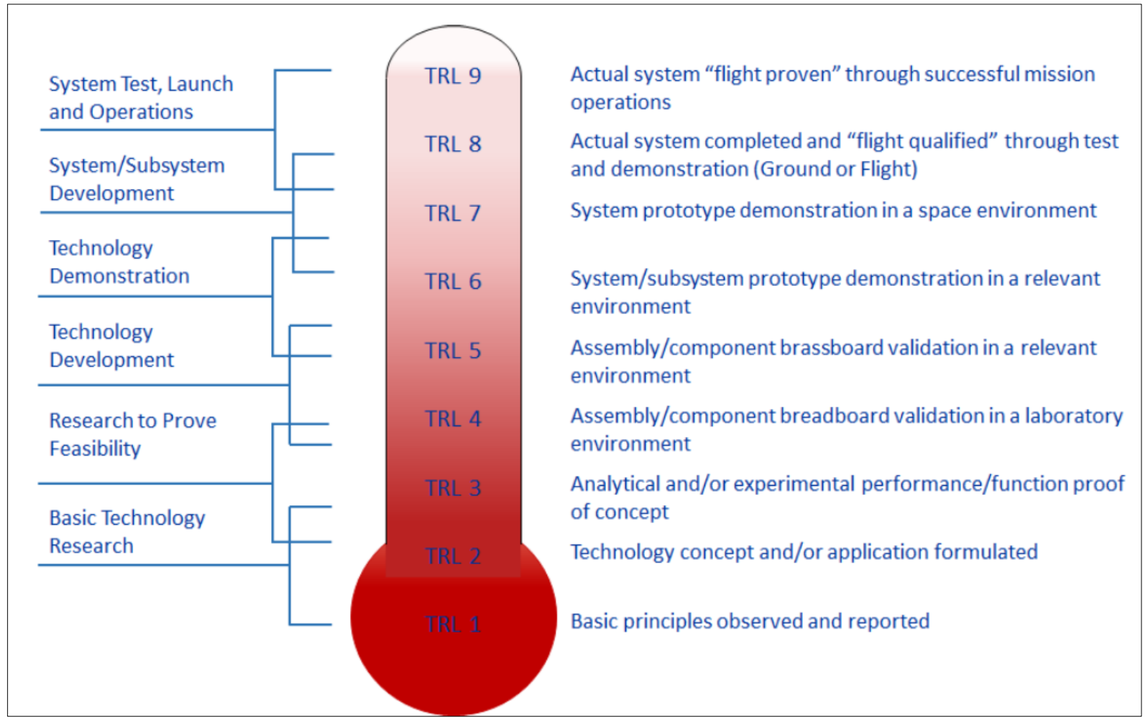
- The **MINE THROUGHPUT (Out-flow)** is mainly dependent on the type of technology used in the rock extraction processes.
  - The most **common technology** used in extracting the rock is the **DRILL and BLAST technology**.
  - Other **new technologies** available like **mechanical rock extraction** are still not well tried in the mining industry.
  - The biggest challenge with the rock extraction technology is their very **Low Turn-Down Ratios** (**range between maximum capacity and minimum capacity**).
  - **Mining Flexibility** - Due to the structure of the technologies used in mining, it is **difficult to change the processing rate** from **what it is designed for** due to various reasons. This affects the flexibility in terms of the mine to be able to respond quickly to changes in demand of the metals, especially if there is increase in demand.

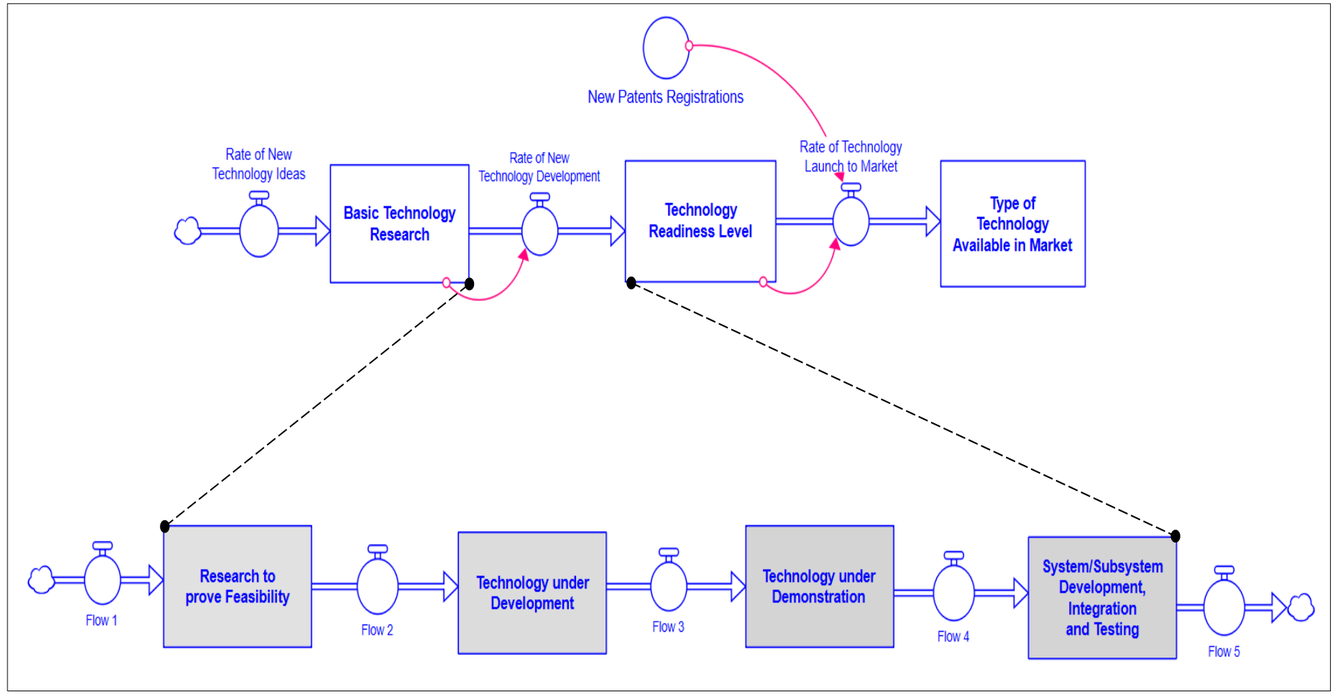
Simulation Process

Focus on technology development process

Technology Maturity Levels – is measured by use of technology readiness levels which start from level 1 to level 9.

- **Levels 1 to 4 -** represents the levels of basic research and up to feasibility levels. After this stage we expect rejection of ideas that are not feasible.
- **Level 5 to 8 –** represents levels of technology development. In this stages these are ideas that have proved to be feasible, and they go for laboratory testing and then after that development of system prototypes.
- **Level 9 –** Is actual "flight proven" through actual operations. Rejection is also expected after prototype testing.



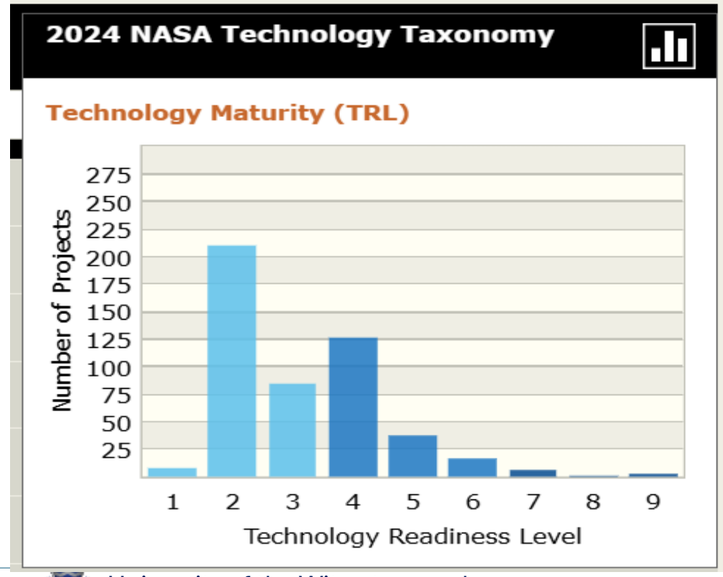


Inputs into the Model– Rate of technology changes and Technology maturity levels

Example - NASA Technology Maturity Levels

NASA has a very intense and deliberate technology development

- Nasa's technology development program is well documented.
- Due to the absence of mining data, this was used as a dummy actual data to test the behaviour of the model.
- The data shows the progression of projects at various technology readiness levels.

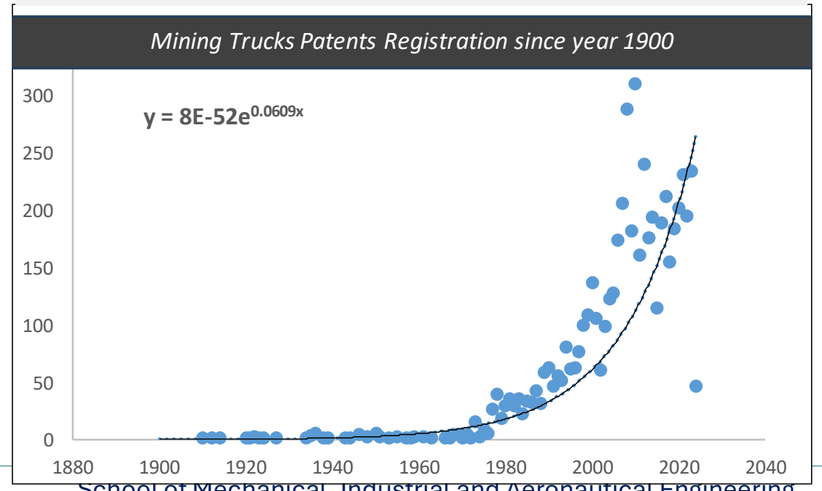


- **Rate of change of technology** ----> Proxy - Rate of registration of new patents for a particular technology class.
- World Intellectual Property Organization (WIPO) website, Mining trucks and Drill Rigs - an exponential growth curve commencing from around 1980. Trigger point - Introduction of mechanized mining systems

Technology Half-life – 10-11 Years (Doubling of patents)

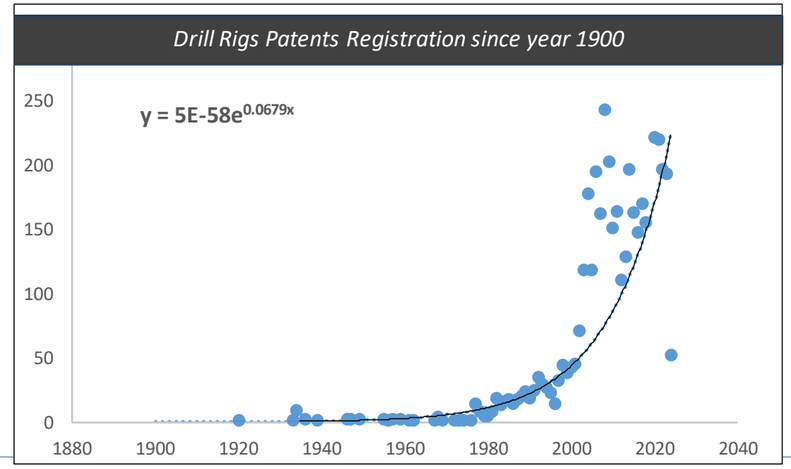
Mining Trucks Patents Registration since year1900

- **Mining Trucks are used in both underground and surface mines to carry mined rocks (ore and waste)**
- Technology half life for the trucks is 0.0609/year. This gives doubling time of 11.5 years for mining trucks



Drill Rigs Patents Registration since year1900

- **Drill rigs are used in both underground and surface mines to break the rock into fragments out of the insitu rock**
- Technology half life for the trucks is 0.0679/year. This gives doubling time of 10.3 years for mining drills

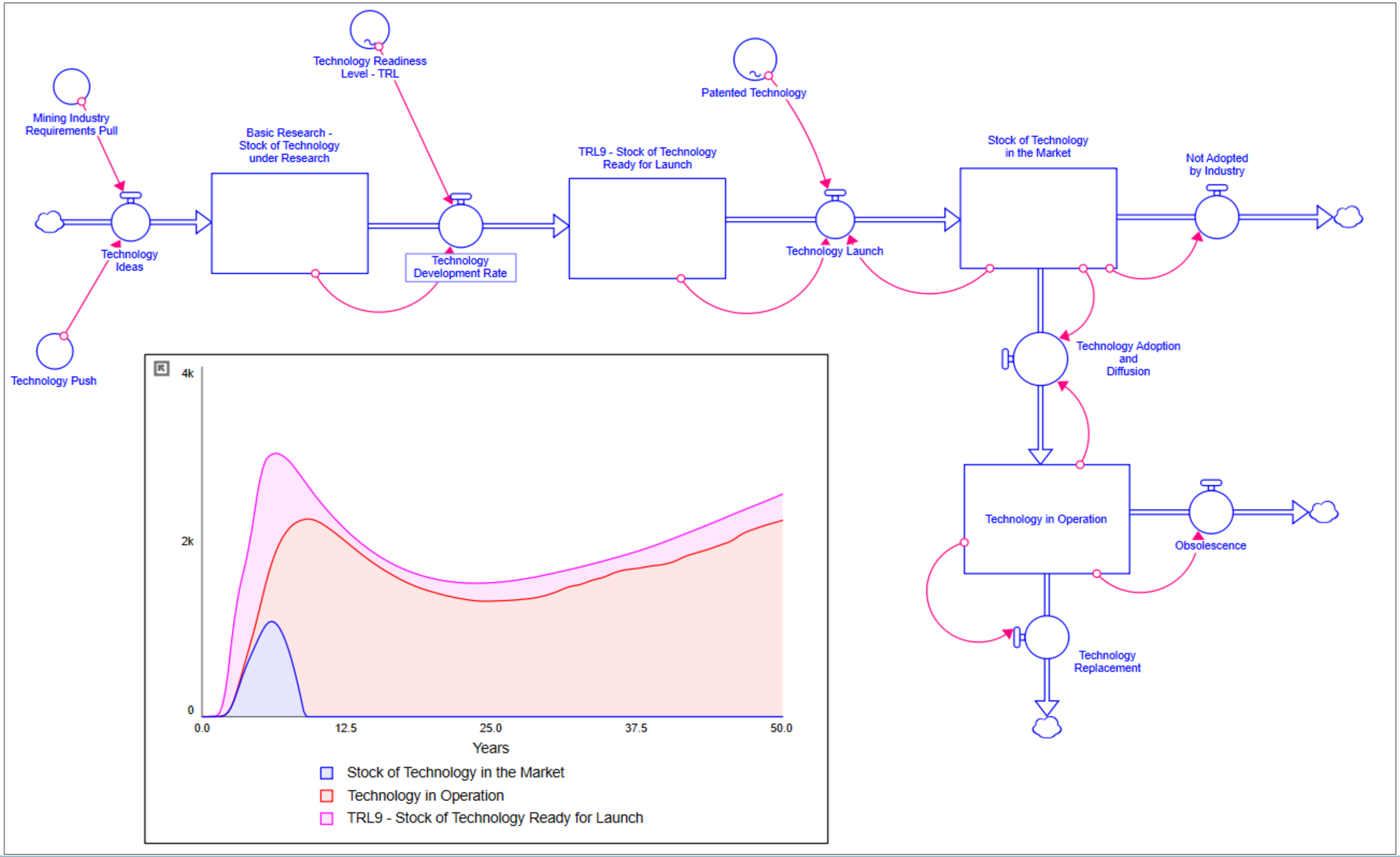


Assuming Bathtub Stock

SIMULATION OF THE TECHNOLOGY READINESS MAP

Behaviour when assuming stocks to be bathtub

- Mining industry requirements pull and Technology push as main sources of technology ideas.
- Stock of Basic technology under research which will influence the technology development rate.
- Technology readiness levels expected to influence the stage of development – used NASA data as dummy.
- Patented technology is a proxy for rate of technology that eventually gets launched.
- Technology in operations and replacement rate/obsolescence



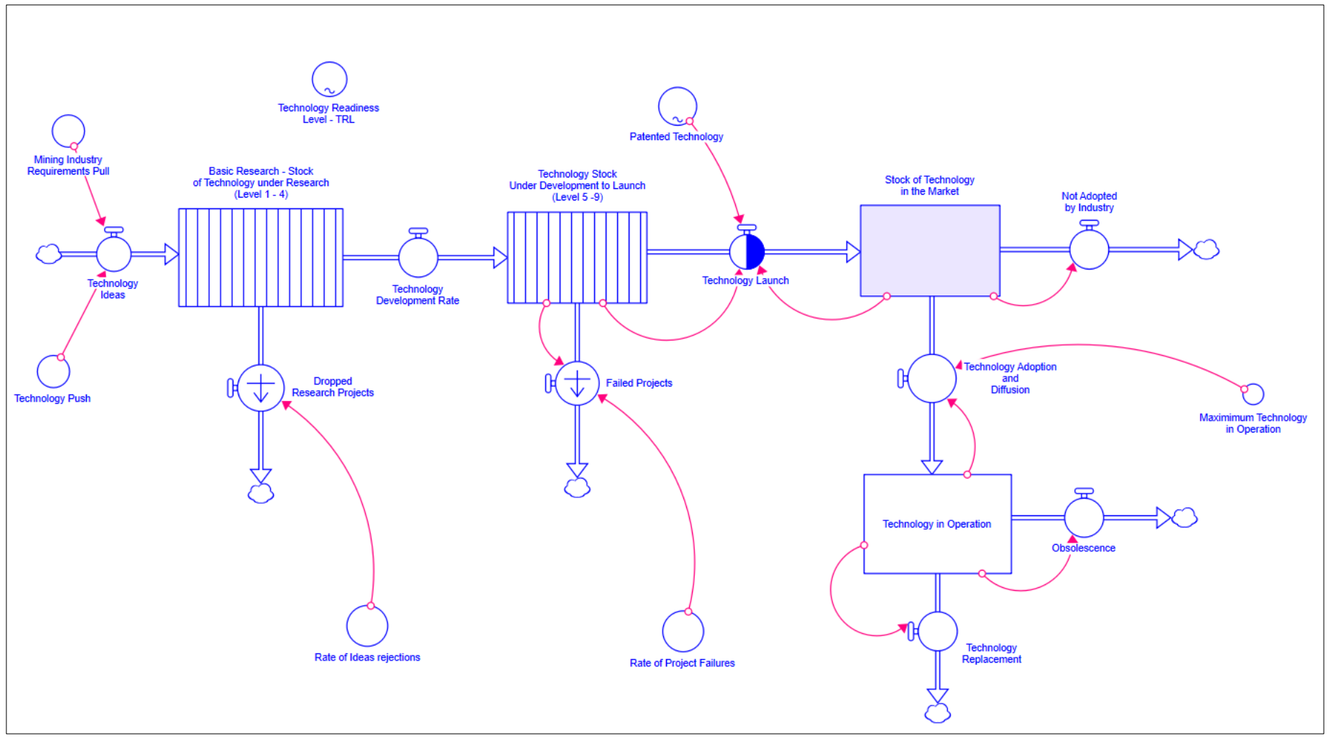
Using Conveyor stock

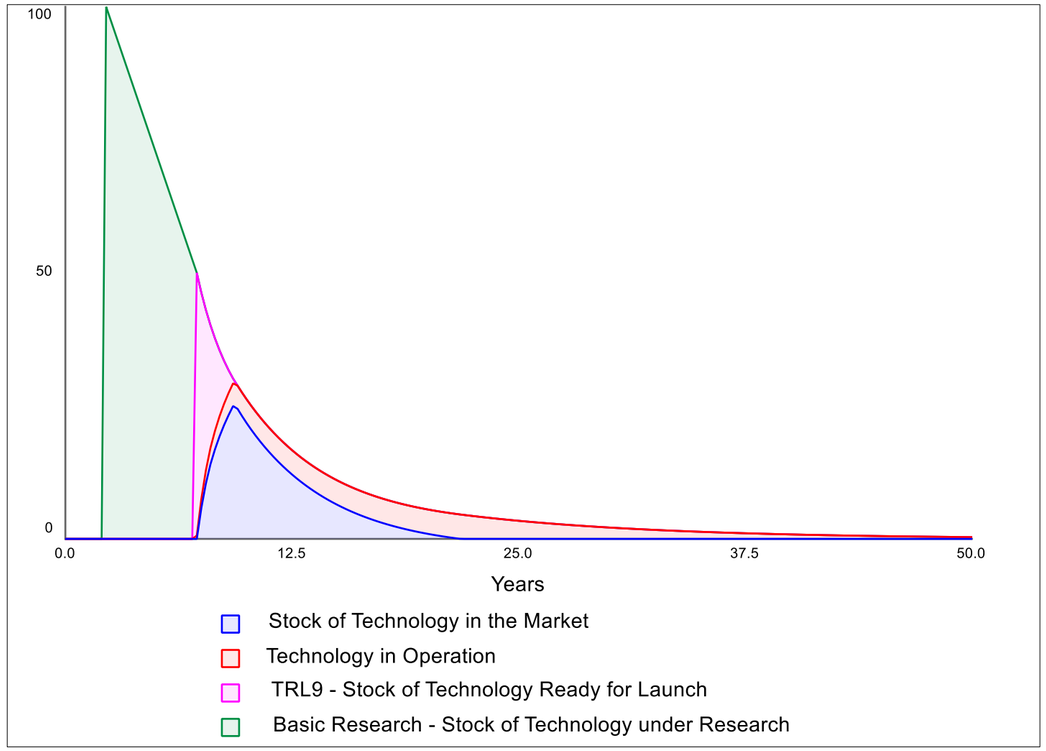
SIMULATION OF THE TECHNOLOGY READINESS USING CONVEYOR

Behaviour when assuming stocks to be conveyor

- The NASA technology readiness figures were used as the dummy
- Transit time taken to be 4 years for the basic research phase and 5 years for Project development stage.
- Rejection rate at both research stage and development stage
- Limiting set for the Maximum technology that will be in operation

MODEL STILL UNDER FURTHER DEVELOPMENT





Conclusion & NEXT STEPS

CONCLUSIONS AND NEXT STEPS

Develop models for the various interacting aspects of the model such as

- Market Dynamics of the metals commodity markets which have influence on investment decision
- Geological aspects such as available reserves and resources, structure of the orebody, hydro-geology all which have impact on technology choices
- Consider the Socio-economic aspects also

Carryout a Case Study on an actual operating mine to develop actual data for validating the model

- Permission has been granted to work with one large mining entity which has 8 operating mines

PROCESS

Carrying out a Technology Gap Analysis for Large Mining Entity

Develop and Propose a Technology Framework

FOCUS ON

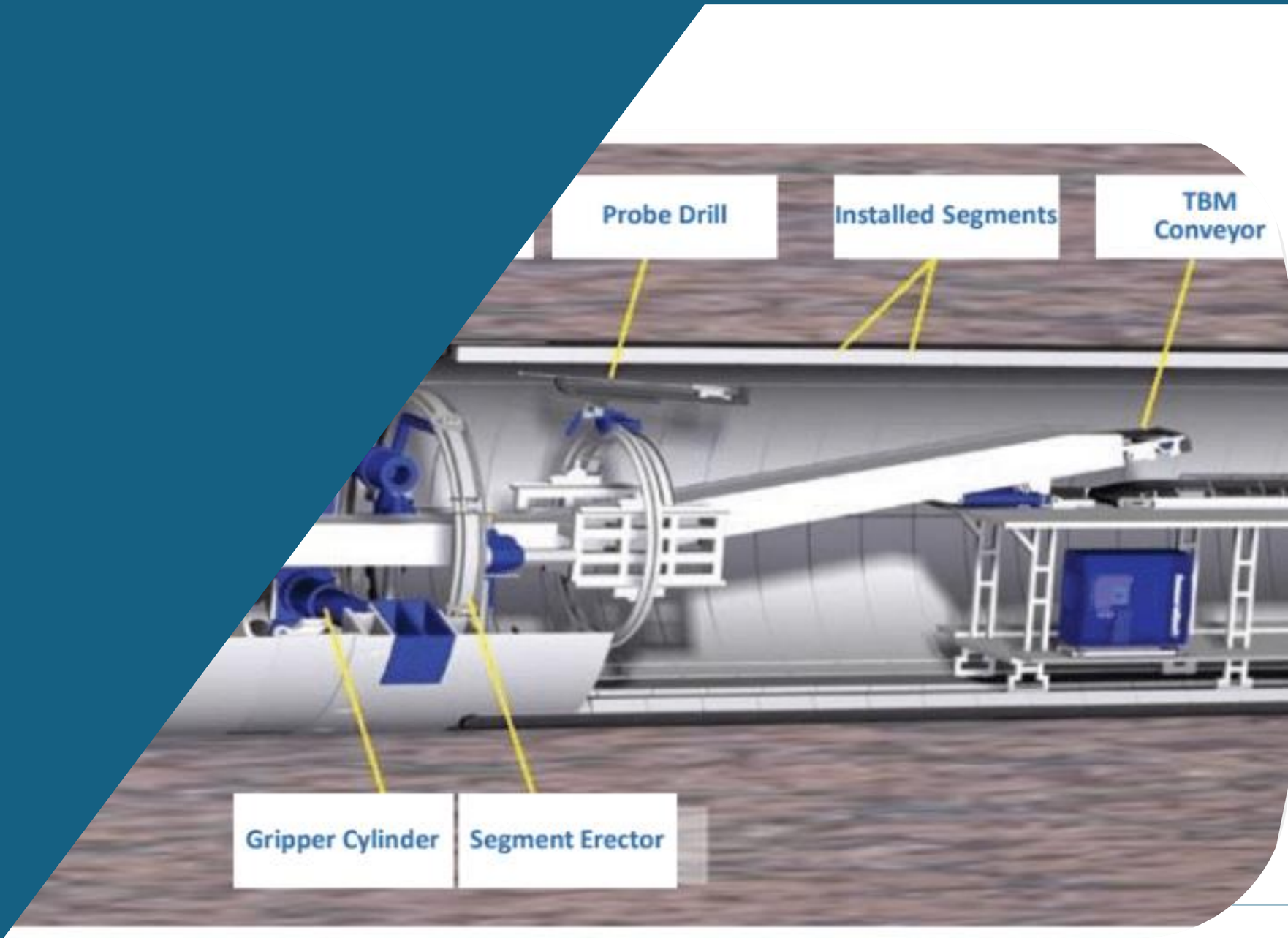
Mining Technologies

Processing Technologies

Energy Technologies for mining operations

Questions and Answers

END


Probe Drill
Installed Segments
TBM Conveyor
Gripper Cylinder
Segment Erector