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# Knowing what you don't know. Lessons learned from managing the logistics of mine closure

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## Abstract

*Lessons learned from managing the logistics of mine closure. The process of mine closure is complex and requires extensive analysis, planning and management to ensure efficient and safe completion that meets the needs of stakeholders. The mine asset will have played a key role in the establishment of crucial infrastructure and supply chains, which local communities may rely on as a source of major revenue and jobs. Decommissioning and rehabilitation of a physical mine site is challenging, and our experience suggests there are many inhibitors to success. Mines are often located in geographically challenging locations, creating unique logistics issues, a mixed regulatory environment and reduced pool of available contractors capable of delivering the decommissioning and reclamation requirements. Years of ongoing upgrades and modification in addition to expansion at the mine means a single source of accurate mine asset information may simply not exist. This creates challenges for mine closure teams resulting in expensive and time-consuming asset mapping to provide a single version of the truth. This paper presents a critical review of the planning and delivery of logistics management during mine closure. It will explore the challenges, potential risks and provide lessons learned based on our experience of mine closure logistics and materials management. The operation of mine closure can be improved through initiatives such as the implementation of new technologies that capture, store, retrieve and distribute important physical records to support those making decisions about disposal. This digitization initiative plays a critical role in ensuring compliance with legal and regulatory requirements, as well as maintaining efficiency and safety as the mine closes. Given the complex and high-risk nature of the mining industry, it is essential to have efficient processes in place to ensure that all relevant stakeholders have access to relevant documents such as permits, licenses, contracts alongside the ability to sign off decisions. The paper will support mining companies to improve resilience in mine closure and to remove excess risk associated with logistics project management and execution.*

**Keywords:** *Mine closure logistics, logistics, digitization*

# 1 Introduction

Logistics is the detailed organisation and implementation of a complex operation. Mine closure is a complex multidisciplinary undertaking, requiring several years of planning and a coordinated effort from government and industry stakeholders (Brock & Stevens 2021). The logistics of mine closure involves the planning and carrying out of decommissioning and demolition of mine operation facilities, as well as the movement and disposal of material, which can often include hazardous waste. The logistics of mine closure can be challenging due to remote locations, adverse weather conditions, unclear scope, and long and complex supply chains. Through a literature review and case study example, this paper aims to provide insight into the challenges, risks, and lessons learned from managing the logistics of mine closure and recommends supporting technologies to increase the success of mine closure logistics. It highlights the need for integrated planning and the use of technology to support stakeholder engagement, decision-making, ensure compliance with legal and regulatory requirements, and maintain efficiency and safety as the mine closes.

# 2 Challenges and risks to effective closure logistics

Mining companies face a range of challenges, including volatile commodity prices, fluctuating demand, and changing regulations which can impact their profitability and sustainability. The industry operates in a complex environment, involving exploration, extraction, and processing of mineral resources that are essential for economic development (Natural Resources Canada 2023). To add to the complexity is the process of decommissioning and rehabilitation of the mine site which requires extensive planning and management to ensure a safe and efficient completion that meets the needs of stakeholders (IGF 2023). The closure of a mine can have significant impacts on local communities, the environment, and the economy, making it essential to manage the process effectively (Stratos 2021). An often-underrepresented part of closure planning is the logistics required to decommission, decontaminate, demolish, and dispose of the various components.

## 2.1 Geographical location

Depending on the mine's location, logistics can require considerable effort and planning. Even for those mines that are near transportation networks, the sheer volume of people and materials requires detailed planning and resources. Although the people and materials required for closure differ from operations, the need for logistics planning remains important. The challenges become greater if the mine is in a remote location such as northern Canada, eastern Siberia, or the Andes. Although numerous experiences of long-duration remote sites in the Arctic are documented, a comprehensive dynamic logistics system for short-durations is lacking (Hulsey 1993). Understanding the constraints of the site location and executing a detailed logistics plan will provide a better rate of success.

## 2.2 Regulations

According to Brock & Stevens (2021), "Further challenges common to both industry and government include the inadequate or uncertain policy and regulatory landscape, obscuring the responsibilities and expectations of both industry and regulators. For example, the pathway or process to relinquish a closed mine site is often uncertain even in some of the world's leading mining jurisdictions". As an example of multiple jurisdictions, Canada uses a federal system where mining responsibility lies with the provinces. However, the federal legislature has instituted several initiatives which provide procedural and enforcement mechanisms in support of mine closure planning, implementation, and subsequent outcomes across all provinces (Kabir et al. 2015). The closure planning team must have a clear understanding of the regulations and requirements, especially if crossing various jurisdictions.

## 2.3 Planning

It is estimated that around three-quarters of mines close suddenly with little to no planning (Syahrir et al. 2021). This can lead to a lack of understanding of constraints and environmental impacts when planning mine closure (Smith, 2007). Factors to be considered when planning the logistics of mine closure include stakeholder relationships, available resources, size and scale of mining operation, terrain and associated risks and challenges, which require to be reviewed and actively managed. It will be essential to map the capacity and capability of the supply chain including contractors and available disposal options suitable to support the mine closure. Mine closure planning is a critical part of operating a mine and the logistics involved during closure are key to success, although the latter is rarely mentioned in available texts.

## 2.4 Scope

Due to modifications made during the mine site's operation, the lack of a single source of accurate mine asset information can result in expensive and time-consuming asset mapping to enable adequate understanding of scope for decommissioning. Scope definition is the greatest challenge faced in developing closure plans and cost estimates (Watson 2006). An insufficient understanding of the physical and chemical characteristics and volumes of waste material is another critical fault of closure processes (McCullough 2016). This can lead to delays in the mine closure process, increased costs, and compliance risks.

## 2.5 Stakeholders

The stakeholders involved in managing mine closure include mining company executives, mine closure teams, regulatory agencies, local communities, and environmental groups. Although completion of a successful closure project is important and of interest to all stakeholders, not all will have the capacity to be involved in the details and onsite delivery of the project. McCullough (2016) continues by stating "Failure to engage stakeholders in a documented process is a prime failing still identified in recent industry events that continue to plague more companies in the planning process."

Challenges include a diverse range of stakeholders, from company executives to local community members, making management and engagement with all stakeholders difficult. Failure to manage local community stakeholders correctly can lead to the loss of local support, access and visibility of local supply chains and trust from key community members.

## 2.6 Resources

As the mine moves into closure, site resources (people, equipment, and capabilities) are lost. The combined knowledge that long-term employees have of the site, communities, and challenges would be invaluable during the closure process, but are often moved to other operations or simply laid off. "Employees, often long serving, have to find other jobs and other places to live. Some of the best and brightest managers leave to pursue careers elsewhere, often in newly opened mines where they can 'make their mark'" (Laurence 2006). In addition, the mining company may re-prioritize resources to active operations where income is being realized, including vendors, suppliers, contractors, and consultants. The loss of knowledgeable staff can significantly increase the risk of developing a workable closure and logistics plan.

# 3 Case study on closure logistics at a remote site

## 3.1 Introduction

The author was the logistics manager during a recent mine closure project, involving the construction of a winter road - an ice road is a winter road that runs mostly on frozen water expanses (Barrette 2015) and the management of the movement of over 800 truckloads of equipment and material. This case study provides evidence of real-life challenges faced by the logistics team and lessons learned during the planning and execution phases.

The logistics team were employed to manage the planning and execution of all logistic functions associated with the removal of assets and material from the site, while liaising with the project team conducting ongoing remediation works. The tactical planning, physical asset tracking, preparation, transportation, and disposal of assets were carried out by several contractors, adding a layer of complexity to the management. In addition, a winter road was required to be constructed to provide a line of communication between the mine site and the logistics staging area, as this was the only transport route available, other than air transport. The winter road was constructed and maintained by local contractors and was operational for approximately six weeks, although several periods of closure occurred during this time due to weather or operational safety.

## 3.2 Logistics planning phase

The logistics planning phase lasted approximately five months, although daily refinements and updates continued through the execution phase. The management of multiple contractors, creation and testing of standard operating procedures, identifying the logistics challenge, and managing stakeholder expectations were key activities.

Planning included creating several artifacts to track the usage and location of assets that required preparation and movement to the staging location. These artifacts were 'living documents' updated daily, providing critical planning information to the logistics team and trucking contractors for the planning of loads and scheduling. Key planning artifacts included:

- **Asset Register**. Used for tracking all mobile assets, such as vehicles and heavy plant and shipping containers.
- **Hazardous waste tracker**. Documented all hazardous waste onsite, with relevant transport hazard information.
- **Loading List**. Contained details of all assets located on site. Showed those assets identified for removal daily load plans with number of transports and assets assigned, equipment operating constraints to ensure loading and offloading viability and provided a clear view of the transport challenge.
- **Executive Dashboard**. Provided relevant information to inform corporate executives of logistics progress.
- **Disposal Matrix**. Tracked disposal information for assets.

The artifacts were critical to the planning and execution of the programme, and were created on Microsoft products, shared with relevant shareholders through SharePoint and Teams IT systems. This provided accessibility and shared working with those that required access to the information.

## 3.3 Logistics execution phase

The logistics execution phase culminated on the closure of the winter road and was approximately three months in duration. This phase immediately followed the planning phase, and the planning documents and records were used to manage the execution of the programme. The logistics team mobilised to site on a rotational basis, providing management oversite of the process and reviewing the actual situation on site. The winter road remained operational for approximately six weeks within this phase and was used by trucking contractors to transport equipment to and from site on a 24 hours' a day basis, every day that the road was available for use. The logistics team managed the contractors responsible for providing the logistics outputs, while prioritising equipment and ensuring that best use was being made of available assets.

## 3.4 Key challenges

The following are keys challenges identified during the programme:

- **Location.** The remote location of the site caused the greatest challenge, as it could only be accessed by air or winter road when operational.
- **Time.** Due to the unnegotiable duration of the winter road operational period, time was a key constraint.
- **Weather.** The mine site was in an area of extremely low temperatures and unpredictable weather during winter months. This was essential for the construction and maintenance of the winter road, but made trucking operations and associated outdoor activities, such as loading, hazardous and more time consuming than in a more weather benign location.
- **Resources.** The remote location and low population in the mine site area made contracting suitable resources challenging, particularly the necessary trucking, drivers, and heavy support equipment, such as cranes. It was mandated that trucking was resourced from an indigenous complaint company, in this case sub-contracted through the general contractor. This visibility of trucking assets and drivers was poor, resulting in inaccurate planning. Lower numbers of transport assets were available to execute the programme than planned, reducing the overall load count.
- **Communication.** The multitude of contractors and sub-contractors involved in the delivery of logistics outputs made communication difficult and slowed the flow of information. This impacted critical information such as trucking capacity, equipment availability and personnel resources being seen by the logistics team. The difficulty in communication was felt especially with the local community members, as many did not use the same communication methods as the project team and worked in locations with no means of contact.

## 3.5 Key lessons

The following are keys risks identified during the programme:

- **Planning.** Early and integrated planning is key to success. Planning is at the core of project controls and project management, and dedicated resource and commitment is required to manage the sequence and timing of mine closure logistical activities.
- **Resources.** Mine closure benefits from the addition of professional logisticians located on site, with project systems in place to implement logistics management best practices. This provides an accurate and truthful picture of site conditions to be established and critical decisions to be made in a timely manner.
- **Analysis.** A full understanding of the mine environment, including transportation and regulatory restrictions is required. This is conducted prior to planning and includes analysis of the wider remediation plan, asset mapping and the strategic intent of the senior, decision-making stakeholders.
- **Stakeholder Management.** A full understanding and commitment from stakeholders of the strategic, logistical needs of the mine closure. Stakeholders must be aligned with the goals of the project and what is to be achieved to consider the project a success. Where possible, reduced communication levels and close interaction with the local supply chain.

# 4 Recommendations for a new approach

## 4.1 Planning

While there is an extensive body of knowledge available to support mine closure planning, little is offered by way of mine closure logistics. For example, The ICMM's Integrate Mine Closure Good Practice Guide 2nd Edition does not mention the requirement for logistic planning (ICMM 2019). This contrasts with other industries such as defence, which dedicates substantial effort to logistic planning, and understanding the

effects this can have on a successful operation. For example, there is NATO doctrine dedicated to logistics (AJP 4 2018) and the Joint Doctrine Publication 4-00 (Ministry of Defence 2015). The Military planning doctrine provides a framework and suggested artifacts to support independent, but integrated logistics planning. The Joint Doctrine Publication 4-00 dictates that a full and detailed understanding of the logistics picture, including risks, constraints, restraints, and assumptions is captured and used to inform the logistics plan.

A logistics plan must be detailed, yet flexible enough to allow for reasonable scope changes and additions. It must be created in unison with the main closure plan and outcomes integrated to ensure efficient use of resources and greatest chance of success. Typical mine closure scope change that will impact the logistics plan may include:

- **Volume of waste material.** The original volume or classification of waste material may change as unknown areas of contamination are discovered and require rehabilitation. This could increase transport requirements, alter regulatory requirements and planned disposal.
- **Schedule.** The overrun of the construction schedule may impact the availability of construction equipment for dismantling and transportation. This will test the flexibility of the load plan and could impact the disposal of the asset.
- **Regulatory environment.** Changes in the regulatory environment could impact onsite disposal, transport of hazardous material and further transport and disposal plans.
- **Owner's decision.** A significant change in the project scope by the owner would likely impact the logistics plan, particularly if the change involved a pause in construction operations, a change to the final purpose of the site requiring different construction machinery, or a change in delivery strategy.

Given that mine closure is a complex operation involving multiple stakeholders, complex infrastructure, and often hazardous waste, it is recommended the discipline of logistics management be incorporated within the planning process to support the operational requirements necessary to guarantee assured, effective, and efficient mine closure requirements. This will require coordination with all stakeholders as well as knowledge of the capacity and capabilities of the local supply chain.

## 4.2 Technology—scanning equipment

The application of "Drone-based geophysical methods can be used to assess post-mining areas to facilitate remediation planning, and to monitor them as part of long-term institutional control in the post-closure phase" (Preugschat 2022). Drone and laser-based methods used to survey and collect data to develop a digital twin of the mine asset provides opportunity for technical benefits, efficiencies, and savings. The use of autonomous, fixed, or wearable LiDAR devices enables efficient and accurate capturing of information at a rate of up to 600,000 points of data per second (Carmicheal, 2023). Once converted to a 3D point cloud, this can be used to update the mine asset's digital twin to form an accurate assessment of the scope for the mine closure contractor and project management team alike. This information can be used to inform logistics planning and execution, identifying volumes of waste, lengths and conditions of internal mine roads, areas for storage and regular monitoring can help build trends in demolition material.

## 4.3 Technology—asset visibility and tracking

Logistics should be underpinned by robust logistic information services (Ministry of Defence 2015) and these systems must contain accurate and up to date information. AngloAmerican (2019) identified the need for a detailed asset register to be created in the 10-15 years prior to the planned mine closure. This highlights the importance of this information to inform further planning and guide execution. This register would be a living document and require regular updating to ensure accuracy when required.

Both asset visibility and asset tracking are critical to a logistics plan, as they support the provision of accurate and timely information for both planning and execution. The visibility and tracking of assets are different but both can be achieved manually, however it is likely simpler and more efficient to employ a suitable information system. Several commercially available systems exist, each suited to a different use or environment. Some of the types and functions of which are:

- **Asset Visibility**. Provided by: Radio Frequency Identification, Quick Response coding or barcode technology. Asset visibility is critical to the logistics plan, providing a real time view of the logistics challenge. If the data is not already in existence at the beginning of the planning phase, this will need to be determined during the early stages of logistics planning. The technology can provide asset information including weights and dimensions, maintenance periods, hours run and other information which may impact the disposal decision. This can then be immediately available to the user to make informed decisions regarding asset use, movement, and disposal.
- **Asset Tracking**. Provided by: GPS. Providing tracking information of sensitive loads, those hazardous to the environment and high value assets. This provides a high level of governance, which is very attractive to executives and members of the project team, as it provides confidence in an item's location and handover status. Of particular use is the ability to track loads for regulatory compliance purposes, as it will show when loads were moved and signed over to third parties.

Accurate asset visibility is essential to the logistics planner, as this will provide the baseline of data to identify the logistics challenge. It is recommended a detailed asset register and 3D model of the mine operation be created prior to the planned mine closure to support the planning and carrying out of decommissioning and demolition of mine operation facilities, as well as the movement and disposal of materials.

## 4.4 Technology—digitization

Digitising manual and paper-based processes using technology, including cloud-based platforms and mobile devices, can increase efficiencies providing a more streamlined approach to managing logistics and materials management during mine closure, allowing staff to quickly review planning documentation and orders. Digitization enables efficient processes that ensure all relevant stakeholders have access to necessary documents such as permits, licenses, contracts, and the ability to sign off decisions.

A key element of this approach includes the use of mobile devices, cloud-based platforms, and digital workflows to capture, store, and distribute data. This approach ensures that accurate asset information is available remotely, compliance is maintained, and logistics can be efficiently managed during the mine closure process.

An example of a digitized process would be a disposal matrix, which could be created and automated to collect relevant information and decisions quickly and with necessary governance, ensuring the right equipment is disposed of in the correct way. This removes the need for sending emails, repeating, or losing critical information, as it is transferred between the decision-making parties. This type of digitized model can be loaded with the asset information and the remaining steps become automated, and transparent. Figure 1 shows the proposed information flow and associated decision makers that could be digitized.

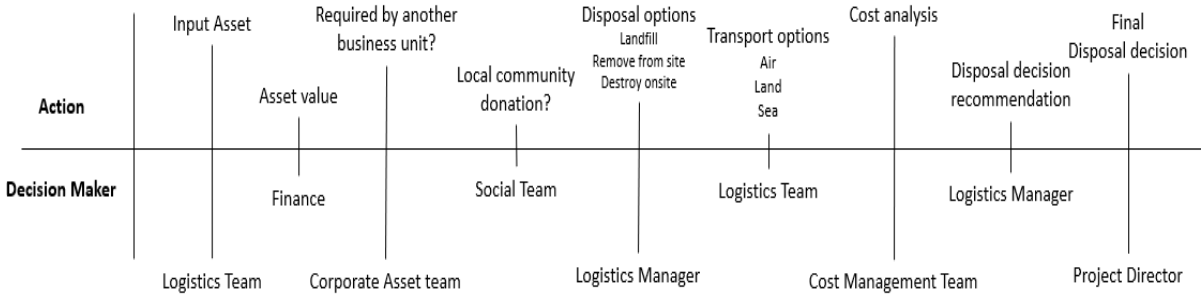


**Figure 1 Disposal matrix example**

Digitized processes providing visibility of information to relevant stakeholders will speed up the passage of information and inform accurate decision making. It is recommended that a suitable and necessary systems are introduced to provide the logistics planning and executions teams the most relevant and timely information.

## 4.5 Transportation

It will be necessary to assess the required capacity and type of transportation required to deliver the mine closure. This assessment will need to incorporate all relevant health and safety regulations, permitting, and training requirements for all stakeholders across the supply chain. It will also be required to take into consideration the unique features of the mine operation, which depending on location and existing infrastructure, will have a significant impact on transportation requirements. Emerging technologies to support transport needs such as the Hybrid Air Vehicles proposed Airlander 50 (hybridairvehicles.com) will enable the efficient movement of heavy and awkward freight with reduced impact on the environment and little reliance on site infrastructure for support.

Transportation will be a key aspect in the logistics of decommissioning and demolition of mine operation facilities, as well as the movement and disposal of material, which can often include hazardous waste. It is recommended all modes of transportation be considered including the use of innovative technologies, to support the reduction in reliance on large, costly, and short-term infrastructure options.

## 4.6 Local community stakeholders

Obtaining Free, Prior and Informed Consent (FPIC) from those mining sites impacting indigenous communities "allows for the highest form of participation of local stakeholders in development projects" (FAO 2016). However, indigenous communities must not be treated as mere stakeholders, as this can lead to distrust and ultimately disruption to the project. (IHRB 2022). Indigenous communities must be part of the decision-making process and included at the highest levels of decision making during all phases of the project, including preparation for and execution of the mine closure.

Failure to address FPIC has resulted in commercial projects facing court cases, advocacy campaigns and reputational damage (Campbell 2012). This can be financially damaging to the corporation, cause delays to the project and alienate the local supply chain.

FPIC cannot be retrospectively sought and only applies to those sites impacting indigenous communities, but it is crucial to liaise with all local communities who desire to be regularly informed on the decisions made on the closure process with the option to provide feedback. They are interested in ensuring that the closure process is transparent and inclusive, and that the site is rehabilitated to a standard that meets their expectations, the lack of engagement can lead to disillusioned and angry community members (Strambo & Aung 2019).

It is our recommendation that stakeholders and affected communities participate fully in planning for mine closure to understand local supply chain constraints, cultural challenges that could impact logistics and

available support from the community. Having a logistics management plan dedicated to mine closure can support improvement in stakeholder engagement and prevent misunderstandings by providing better access to information and facilitating collaboration. This can help build trust and support from local communities, regulators, and other stakeholders.

# 5 Conclusion

In conclusion, managing the logistics of mine closure is a complex process that requires extensive analysis, planning, and management to ensure efficient and safe completion that meets the needs of stakeholders. Lessons learned from adopting a formal logistics management approach during mine closure identified the following benefits and recommendations. These include:

- **Increased efficiency and reduced costs:** Deploying dedicated expertise in logistics project management supports improved scheduling, resource allocation, risk management, and communication. Additionally, deploying technology to support logistics and materials management will enable better and more efficient mine closure planning, management, and execution. This can lead to cost savings by reducing errors, improving productivity, and minimizing rework.
- **Enhanced compliance and risk management:** Deploying a logistics led approach with supporting technology will support compliance with legal and regulatory requirements, reducing the risk of penalties and reputational damage. It can also improve risk management by enabling better tracking, reporting, and decision-making.
- **Improved stakeholder engagement:** Incorporating logistics into mine closure planning can support improved stakeholder engagement by providing better access to information and facilitating collaboration between stakeholders. This can help build trust and support from local communities, regulators, and other stakeholders.

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