

## INVENTORY MANAGEMENT IN GOLD MINING INDUSTRY: OPPORTUNITIES AND CHALLENGES

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**Abstract:** *Inventory management in gold mining represents a strategic and complex function that influences equipment availability, maintenance cost efficiency, and overall operational continuity. Gold mining enterprises rely on extensive inventories supporting a large, diverse set of machinery and equipment required for extraction, haulage, processing, and maintenance. Long-operating mines often accumulate more than 100,000 stock-keeping units (SKUs), driven by continuous technological renewal, changes in machinery suppliers, and evolving operational demands. These factors create significant challenges in forecasting, procurement, and stock optimization. This article examines the key inventory management challenges specific to gold mining enterprises and integrates insights from research articles in spare-parts inventory, supply chain management, and mining logistics. Particular emphasis is placed on intermittent demand, rotables management, long and uncertain lead times, supplier constraints, equipment obsolescence, and the increasing need for digital solutions based on condition monitoring and predictive maintenance. The study provides a structured overview of the problem space and highlights emerging approaches that combine data analytics, risk-based classification, and integrated maintenance–inventory planning.*

**Keywords:** *Inventory management, Gold mining logistics, Inventory optimization, Spare parts, Intermittent demand.*

### 1. INTRODUCTION

Inventory management within the mining industry represents a strategic function that extends beyond the mere tracking of components. It serves as a fundamental driver of operational efficiency, cost optimization, and operational continuity. Effective inventory management systems enable firms to maintain equipment reliability, minimize downtime, and ensure uninterrupted production processes.

Inventory management plays a central role in the operational continuity of gold mining enterprises, where machinery reliability directly affects production outcomes. Given that mining operations are frequently dispersed across geographically remote regions, the timely procurement and distribution of materials, spare parts, and rotables pose significant logistical challenges. Mining operations depend on fleets of excavators, haul trucks, auxiliary heavy-duty equipment, ore processing, gold extraction machinery, and infrastructure that require continuous maintenance supported by thousands of spare parts. Over long operational horizons, especially beyond two decades, stock catalogues may exceed 100,000 SKUs, creating a scale and complexity not typically present in other industrial sectors [4].

This expansion arises due to frequent technological updates, equipment obsolescence, regulatory requirements, and changes in supplier portfolios. For inventory controllers, this environment creates constant pressure to balance availability against cost and optimal stock balance, maintain accurate ERP records, manage supplier transitions, and ensure compliance with logistics and customs constraints. As reported in the literature, unplanned equipment stoppages are among the largest contributors to operating cost variance in gold mining [1].

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Gold mining supply systems are structurally different from traditional manufacturing supply chains in several key dimensions:

- Intermittent and failure-driven demand for spare parts
- Extremely large SKU portfolios (often exceeding 50,000–100,000 stock items) due to long equipment life cycles
- Long and uncertain lead times, especially for OEM components sourced internationally
- Criticality-driven stocking decisions, since failure of a single part can halt production
- Intensive use of rotables, such as engines, final drives, pumps, and gearboxes
- Challenges of obsolescence due to equipment aging and manufacturer portfolio changes

These characteristics necessitate specialized inventory approaches that differ substantially from standard EOQ-based models. Numerous studies emphasize the unique behaviour of spare-parts demand, which is typically intermittent, lumpy, and highly skewed [2, 3]. As Kennedy et al. demonstrated, traditional methods perform poorly for slow-moving mining components, requiring tailored forecasting and classification approaches [4].

To address these constraints, mining companies increasingly rely on data-driven systems that integrate reliability modelling, predictive maintenance, and multi-echelon inventory optimization. However, empirical surveys show that many mining enterprises still face difficulties in maintaining accurate part master data, consistent lead-time records, and reliable demand histories, limiting the effectiveness of advanced optimization tools [5].

This study examines these challenges and investigates the potential of modern digital technologies to improve inventory management efficiency in gold mining.

## **2. INVENTORY MANAGEMENT CHALLENGES**

Although gold-mining enterprises differ in scale and technology, the following systemic challenges are common across global operations.

### **3.1. Challenge 1: Intermittent demand and forecast inaccuracy**

Mining spare parts exhibit extreme demand variability. Studies demonstrate that forecast errors for slow-moving items may exceed 60% when traditional methods are applied [8]. In gold mining, demand is driven by breakdowns, meaning that:

- forecasting accuracy is generally low,
- safety stock must compensate for uncertainty,
- excessive stock leads to capital immobilization.

### **3.2. Challenge 2: Long lead times and Supply-Chain vulnerability**

Supply-chain disruptions – customs delays, transport bottlenecks, supplier constraints – cause frequent deviations from planned lead times. Critical-component delays might be a key cause of production loss for gold mines [9].

### **3.3. Challenge 3: High cost and limited availability of rotables**

Rotables require specialized repair shops and long refurbishment cycles. According to spare-part optimization studies, insufficient rotatable pools increase unscheduled equipment downtime, while excessive pools create unnecessary capital costs [7].

### **3.4. Challenge 4: Obsolescence and Catalogue Growth**

Catalogue growth in gold mining can reach 3–7% per year due to:

- new equipment deployment,
- design updates,
- new supplier introductions,
- regulatory or environmental changes.

Large catalogs complicate ERP maintenance and reduce data quality, affecting all downstream optimization processes.

### **3.5. Challenge 5: Low integration of maintenance and inventory planning**

Scientific literature strongly recommends integrated models that jointly optimize maintenance scheduling, purchasing, and stock management. However, mining enterprises often rely on siloed processes where maintenance teams operate independently from procurement and warehousing, leading to misalignment between planned work and stock levels. Even though logistics scientists prioritize the detailed elaboration of digital technology applications and the examination of their practical implementation possibilities in various industrial environments [15].

Another challenge to be discussed in more detail is the geographical isolation of gold mining sites from the essential infrastructure required to sustain continuous operations. This limiting factor significantly affects the organization and maintenance of the company's logistics activities.

## **3. CASE STUDY OF GOLD MINING INDUSTRY IN KYRGYZ REPUBLIC**

In this section, the logistics challenges faced by gold mining companies operating in the Kyrgyz Republic are examined through the analysis of major gold mines in the country. According to the Ministry of Natural Resources, Ecology and Technical Supervision of the Kyrgyz Republic reserves of gold equal 973 tonnes as of 1 January 2025. [14] The largest deposits include Kumtor area followed by Jeruy, Taldybulak Levoberezhnyi, Chaarat and Makmal.

The gold mining sector is dominated by Kumtor Gold Company which has produced 428 tonnes of gold from the start of commercial production in May 1997 to December 31, 2024 [11]. Kumtor Gold Company is one of the largest gold mining enterprises in Central Asia, employing more than 3,400 employees, generating USD 989 million in annual revenue, and holding USD 1,902 million of total assets as of December 31, 2024 [10].

As shown in Fig. 1, the Kumtor mine has been in continuous operation since 1997, and such long-term uninterrupted extraction requires substantial quantities of spare parts, capital equipment, and sustained maintenance investments. The diversity of fixed assets is explained

by the full-cycle gold production implemented at the site – including geological exploration, open-pit mining, underground development, ore processing at a gold-extraction plant, purification facilities, and a wide network of auxiliary, transport, logistics, and energy departments.

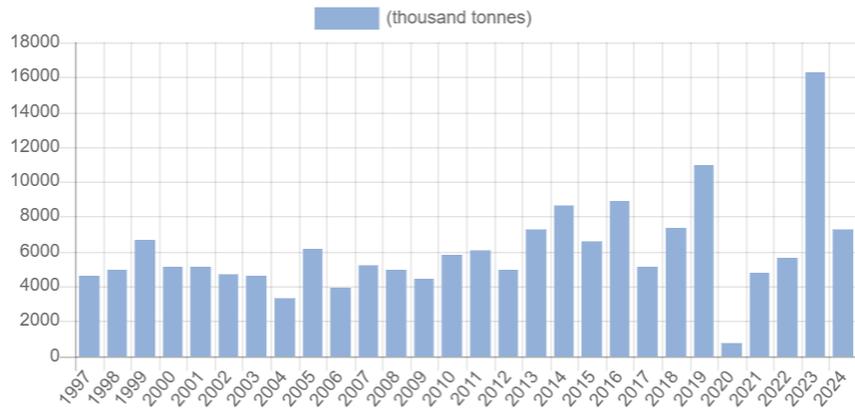


Figure 1. Kumtor Gold Company's lifetime ore tonnes mined [11].

The full autonomy of the operation is necessitated by the mine's extreme location: Kumtor is situated at 4000 meters above sea level in an isolated high-mountain area, with the nearest city located more than 200 kilometres away. This geographic isolation makes inventory management, especially for critical and rotatable spare parts, a strategic priority for operational sustainability.

The configuration of the company's main warehouses is determined by the geographical characteristics of the transport infrastructure in the Kyrgyz Republic. The railway line reaches only the transshipment hub in the city of Balykchy, after which cargo must be transported by road to the village of Barskoon, and then further along a technological access road to the mine site. This challenging route passes through the high-altitude Barskoon Pass at an elevation of 3,800 metres. The company must independently organise deliveries along this route with more than 200 kilometres length. Storage capacity at the mine itself is limited due to its remote mountainous location. Consequently, the enterprise maintains a large transshipment and buffer storage facility in Balykchy to support intermediate cargo handling. This feature makes lead time more longer and adds additional factor to consider in inventory management.

We can assume that in terms of inventory management practices, the company employs several classical models: the Reorder Point (ROP) model with a fixed order quantity, the Min–Max policy, and the Fixed Interval Ordering system. These approaches are among the most widely used methods for managing maintenance, repair, and operations (MRO) inventories in mining enterprises [12].

As of 31 December 2024, the total value of the company's inventories amounted to USD 318 million, according to the official audited reports of Kumtor [10]. It can be assumed that the enterprise operates with at least more than 50,000 SKUs and sources materials from leading global suppliers located across different parts of the world. Spare parts for mobile mining equipment have supplier-specific lead times and therefore require individualised

Min–Max levels. Geological exploration equipment is used only during the summer season, which creates its own specificity in terms of ordering periods. Equipment for the gold processing plant, which under standard conditions must operate continuously without stoppages and can be shut down only a minimal number of times per year for refurbishment and maintenance, requires strictly defined delivery windows for spare parts and equipment replacement. Requiring wide set of spare parts to be at the warehouse right before the planned shutdown of the factory. This may imply that the company uses also Fixed Interval Ordering system and Reorder Point (ROP) model with a fixed order quantity.

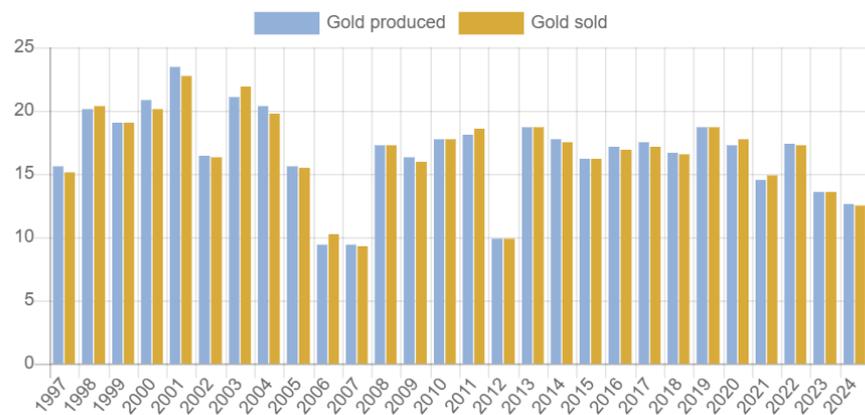


Figure 2. Kumtor Gold Company's lifetime gold produced / sold (in tonnes) [11].

Assuming that out of 50,000 SKUs, 50% correspond to ten categories of mobile equipment used in mining, haulage, and auxiliary operations, 30% represent spare parts for the gold-processing plant, and the remaining 20% consist of various consumable materials. Using a modelling-based approach, these items can be systematically classified into relevant categories, allowing us to construct a comprehensive simulation of the inventory controller's operational environment.

The simulation incorporates standard process times reported in industrial studies on inventory management workloads and material-requirements processing. For the purposes of this analysis, each SKU is assumed to require some form of daily monitoring, although the depth of review varies according to its criticality. Items associated with mobile mining equipment typically involve longer supplier lead times due to globalized procurement channels and therefore require more frequent status verification. In the model, these items are assigned an average handling time of 45 seconds per SKU per day, which corresponds to the time typically needed to confirm stock status, validate consumption rates, and assess proximity to Min–Max thresholds.

Items related to the gold-processing plant are handled differently. Processing plants operate continuously and allow only minimal scheduled downtime, which means their spare parts must be tightly coordinated with planned maintenance windows. As a result, plant components are assumed to require a more involved review process involving coordination with maintenance planners, verification of upcoming shutdown dates, and checks for

potential supply-chain risks. These operations increase the average processing time to approximately 60 seconds per SKU per day.

The category of consumables, while large in quantity, follows more standardized and predictable consumption profiles. Consequently, their daily review time is estimated at 20 seconds per SKU, reflecting automated checks, simple reorder-point triggers, and lower technical complexity.

Under these assumptions, the total daily workload is determined by multiplying the number of SKU in each category by the estimated per-unit processing time and consolidating the results into labor hours required for one inventory controller. The model produces the following daily time requirements: approximately 312.5 labor hours for mobile-equipment parts, 250 labor hours for processing-plant components, and 55.6 labor hours for consumables. The combined workload of 618 labor hours per day makes it evident that no individual specialist - or even a small team - could manually process such a volume without digital decision-support tools.

We can see similar results in Peter Veres's article "Optimizing procurement and inventory strategies with Solver" demonstrate using special software to optimize warehouse inventory management can increase productivity [12].

Although we can be sure that Kumtor inventory controllers use a contemporary ERP that effectively helps to manage their stock, we can assume that implementing simulation modelling and VR technologies will affect more efficient decision-making, consideration of human factors, faster problem identification and resolution [16].

In addition to organizing the inventory catalogue and maintaining appropriate reorder levels to ensure sufficient stock availability, Kumtor must also account for supplier lead times and implement a fair and competitive vendor-selection process. Other gold-mining companies in the Kyrgyz Republic encounter similar challenges, many of which mirror those identified in the Kumtor Gold Company case study.

#### 4. CONCLUSION

Gold prices have been steadily increasing in recent years, reaching a price of USD 3,772 on September 24, 2025. Goldman Sachs has issued a forecast projecting price to rise further to USD 4,000 per troy ounce by the middle of 2026 [13]. This positive trend and favourable market outlook significantly influence operating gold mines, encouraging greater investment in exploration, expansion of mining volumes, and the adoption of new technologies. Consequently, the volume and diversity of inventory stored at mine-site warehouses continue to grow. Moreover, the elevated gold price enhances the attractiveness of previously unprofitable deposits, leading to the development of new mining sites. As a result, mining companies face emerging challenges in logistics, inventory management, and broader supply chain coordination.

The Kumtor case study has proven that widely popularized assumptions about challenges enlisted in Section 2 do exist among gold mining companies. Thus, making special instruments for inventory management crucial for implementation. This study highlights that the challenges identified for Kumtor - intermittent demand, long lead times, rotatable management, obsolescence, catalogue growth, and limited coordination between maintenance and inventory functions - are not unique to a single company. Rather, they reflect systemic characteristics of gold mining in the Kyrgyz Republic and align with patterns documented in global mining research. This suggests that improvements proposed here, such

as enhanced digital integration, simulation modelling, and structured forecasting approaches, have applicability beyond the studied case and could inform inventory-management strategies across other mining enterprises in the region.

Overall, the findings reaffirm that inventory management in gold mining requires specialized, context-sensitive approaches that combine rigorous analytical methods with advanced digital tools. Future research may focus on the development of multi-echelon inventory models tailored to geographically isolated mining operations, the quantification of downtime costs linked to lead-time uncertainty, and the evaluation of digital twin or VR-based systems for improving decision-making in complex mining supply chains.

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