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SUPPLY CHAIN RESILIENCE: CALCULATION OF MAXIMUM TOLERABLE DOWNTIME (MTD) AND OPTIMUM STOCK LEVEL WITH A RISK-BASED APPROACH

KEKUATAN RANTAI PASOK: PERHITUNGAN WAKTU HENTI MAKSIMUM YANG DAPAT DITOLERIR (MTD) DAN TINGKAT STOK OPTIMAL DENGAN Pendekatan BERBASIS RISIKO

Yoga Wishnu Pradana[1], Nur Budi Mulyono[2],
Program Studi Magister Administrasi Bisnis (Master of Business Administration), Institut Teknologi Bandung[1,2]
yoga_wishnu@sbm-itb.ac.id[1], nurbudi@sbm-itb.ac.id[2]

ABSTRACT
The coal mining sector faces major challenges in maintaining operational continuity due to market fluctuations, logistics disruptions, and external uncertainties. This study evaluates the supply chain resilience of PT XYZ using a risk-based approach. The main objectives are to calculate the Maximum Tolerable Downtime (MTD) and determine the optimum inventory level adjusted to the company's financial risk tolerance limit. Currently, PT XYZ is experiencing an imbalance between production and sales, causing coal stock to approach the maximum capacity limit of 14.7 million tons. The increase in average stock from 2020–2024 has an impact on high storage costs and operational risks. This study integrates operational data, risk assessment models, and quantitative methods to convert financial risk limits into operational limits in tonnage units. The result is a predictive model that functions as an early warning system to help companies maintain operations within safe limits and improve decision making amid uncertainty.
Keywords*: Coal Mining, Supply Chain Resilience, Risk Limit, Maximum Tolerable Downtime (MTD), Optimum Stock Level.*

ABSTRAK
Sektor pertambangan batu bara menghadapi tantangan besar dalam menjaga kesinambungan operasional akibat fluktuasi pasar, gangguan logistik, dan ketidakpastian eksternal. Penelitian ini mengevaluasi *supply chain resilience* PT XYZ dengan pendekatan berbasis risiko. Tujuan utama adalah menghitung *Maximum Tolerable Downtime (MTD)* serta menentukan tingkat persediaan optimum yang disesuaikan dengan batas toleransi risiko keuangan perusahaan. Saat ini, PT XYZ mengalami ketidakseimbangan antara produksi dan penjualan, menyebabkan stok batu bara mendekati batas kapasitas maksimum sebesar 14,7 juta ton. Peningkatan rata-rata stok dari tahun 2020–2024 berdampak pada tingginya biaya penyimpanan dan risiko operasional. Studi ini mengintegrasikan data operasional, model penilaian risiko, dan metode kuantitatif untuk mengubah batas risiko finansial menjadi batas operasional dalam satuan tonase. Hasilnya adalah model prediktif yang berfungsi sebagai sistem peringatan dini untuk membantu perusahaan menjaga operasi dalam batas aman dan meningkatkan pengambilan keputusan di tengah ketidakpastian.
Kata Kunci : Pertambangan Batubara, Ketahanan Rantai Pasok, Batas Risiko, Maximum Tolerable Downtime (MTD), Tingkat Stok Optimum.

INTRODUCTION

The coal mining industry plays a vital role in supplying energy to power plants and industries but faces challenges such as demand fluctuations and supply chain disruptions. Supply chain resilience is essential, involving readiness of production equipment, effective inventory management, adaptive marketing strategies, robust logistics infrastructure, accurate demand forecasting, risk mitigation, and strong collaboration with partners (Sinaga et al., 2024; Gartner, 2020). PT XYZ, a major coal company in Indonesia, must optimize its inventory management to ensure operational continuity and cost efficiency in a highly volatile market environment.

Among the various factors affecting supply chain resilience, risk management and inventory management are key elements that support decision-making and stable operations amid uncertainty and market volatility. This study aims to enhance supply chain resilience at PT XYZ by integrating optimal stock level strategies with risk management and mitigation, enabling the company to better handle demand fluctuations and operational disruptions. Through a thorough analytical approach, PT XYZ is expected to build a resilient, competitive, and efficient supply chain capable of adapting to dynamic market conditions.

Company Profile Summary

PT XYZ is one of Indonesia's largest coal mining companies, established in 1981 to support the government's mission of managing coal resources more efficiently and sustainably. Strategically positioned as a key energy supplier for both domestic and international markets, PT XYZ operates primarily in South Sumatra and has developed an extensive production and distribution network across Asia and Europe. In addition to mining and coal distribution, the company has invested in robust logistics infrastructure to ensure efficient global delivery.

Historical Background

Coal exploration in South Sumatra dates back to the Dutch colonial period in 1860. Systematic mining development began in 1919 with the construction of mining and transportation infrastructure. Commercial production using underground mining methods started around 1938 and continued until operations were disrupted by World War II.

Business Process

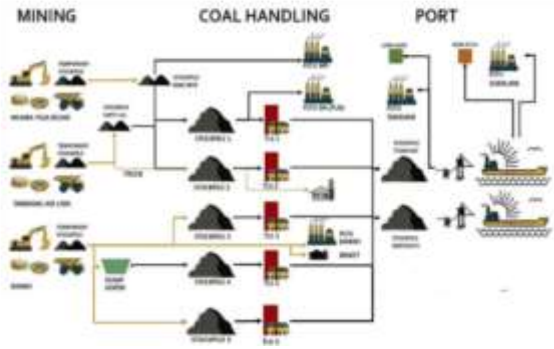

Figure 1. Business Process of PT XYZ
(Source: Internal Document, 2024)

PT XYZ's business process consists of three main stages: Mining, Coal Handling, and Distribution via Ports. Mining is conducted in three key areas, where coal is temporarily stored in stockpiles before being processed and transferred. The Coal Handling stage involves storing mined coal in five main stockpiles, each connected to a Train Loading Station (TLS) for distribution to power plants or ports. Coal is transported from mines such as Muara Tiga Besar, Air Laya, and Banko Barat to major consumers like PLTU and industrial clients.

The Distribution stage is supported by two main ports: Tarahan Port (for exports to countries like India, China, Japan, and South Korea) and Kertapati Port (for domestic markets in Java and Sumatra). A dedicated railway network enables efficient, low-cost coal transport from the South Sumatra mining sites to both ports, supporting PT XYZ's strategic supply chain operations.

Business Issue

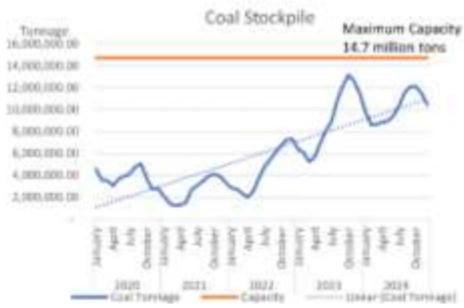

Figure 1. Historical Stock Volume Graph (2020-2024)

(Source: Internal Document, 2025)

The historical coal stock data from January 2020 to December 2024 shows significant fluctuations and a rising trend nearing the maximum storage capacity of 14.7 million tons. This indicates an imbalance where production exceeds sales, causing coal to accumulate in stockpiles and potentially impacting the company's ability to respond to market changes and distribution challenges.

Figure 2. Graph of Coal Volume and Inventory Costs

(Source: Internal Document, 2025)

To address operational challenges in the mining sector, it is crucial for the company to maintain a well-balanced coordination between production, distribution, and storage capacities to develop a resilient and agile supply chain. Any imbalance among these factors may lead to inefficiencies, escalating costs, and diminished capability to handle external disruptions. This issue is evident in the recent trends of coal stock fluctuations, as illustrated by the historical coal inventory data from January 2020 to December 2024 in Table 1

Table 1. Average Stock Volume

Year	Average Volume (ton)
2020	3,788,905.68
2021	2,692,518.28
2022	4,483,894.79
2023	8,974,628.20
2024	10,203,404.52

The coal volume graph shows a steady increase in inventory costs alongside rising stock levels since 2022, reflecting higher storage expenses and logistical inefficiencies. This situation increases risks such as financial loss, operational decline, and failure to meet market demands. To address this, PT XYZ needs an early warning system to monitor stock volume in real-time, keeping inventory within optimal limits based on the company's risk tolerance.

This study focuses on managing supply chain resilience at PT XYZ by determining the Maximum Tolerable Downtime) MTD and developing a formula for the optimum annual coal stock level based on the company's risk limits. It uses a quantitative approach analyzing historical coal stock data from 2020 to 2024 and integrates risk management into supply chain planning. Limitations include data restricted to 2020–2029, focus solely on coal commodities, and use of PT XYZ's risk limits rather than traditional safety stock parameters. The study is organized into five chapters covering introduction, literature review, methodology, analysis, and conclusions with recommendations.

1. Literature Review

Supply Chain and the Challenges Faced

Supply chains are complex networks involving suppliers, manufacturers, distributors, and consumers working together to deliver products efficiently. Resilience and vulnerability are key concepts in managing risks, where resilience is the ability to adapt and recover, and vulnerability is the susceptibility to disruptions (Elleuch et al., 2016). Globalization has increased supply chain complexity, with major challenges including:

- Supply Fluctuations: Caused by production uncertainties, logistics disruptions, and strategic risks like natural disasters and conflicts. Resilience strategies such as facility strengthening, emergency inventory, and route diversification are essential (Zeng et al., 2023).

- Demand Fluctuations: Driven by economic, seasonal, and market changes, leading to risks of stockouts or overstocks. Predictive tools like data analytics help manage these uncertainties (Chopra & Meindl, 2019).
- Price Fluctuations: Influenced by global market dynamics, regulations, and geopolitical events, impacting profitability. Fixed-price contracts and market diversification are effective mitigation strategies (Ogura & Tsuda, 2020).

Supply Chain Resilience

Supply chain resilience (SCR) is the capability of a supply chain to respond, adapt, and recover from disruptions while maintaining operations. Its key components are flexibility (quickly adjusting resources or strategies), visibility (real-time risk monitoring), and collaboration (strong stakeholder cooperation). Research by Sheffi and Rice (2005) shows that companies with high SCR handle crises better. Technology, like blockchain, enhances transparency and reduces risks such as fraud and delays.

Gartner (2020) outlines six key strategies to enhance supply chain resilience: multisourcing to reduce supplier risk; nearshoring to shorten lead times; harmonizing platforms, products, or plants for flexibility; fostering ecosystem partnerships for better disruption response; maintaining inventory and capacity buffers; and diversifying manufacturing networks geographically. Similarly, Zeng et al. (2023) highlight five resilience strategies including facility fortification, emergency inventory reserves, direct-to-port delivery, reliable distribution centers, and multiple transportation routes.

Figure 3. Six Strategies for Supply Chain Resilience (Source: Gartner, 2020)

Inventory Management

Inventory management is a strategic process focused on planning, controlling, and optimizing stock to meet operational needs efficiently while controlling costs, often supported by technologies like IoT and machine learning for real-time monitoring. In the coal industry, effective inventory management ensures order fulfillment despite disruptions, with predictive analytics helping forecast demand. Safety stock acts as a buffer against demand and supply uncertainties, considering factors such as demand variability, supply lead time, and holding costs. Proactive safety stock management reduces stockout risks and improves customer service (Tang, 2007).

Supply Chain Risk

According to Elleuch et al. (2016), supply chain resilience needs to be analyzed simultaneously with its vulnerability, because effective mitigation strategies can only be achieved by understanding both aspects. Supply chain performance is greatly influenced by the combination of resilience and the ability to identify vulnerable points.

Tang and Tomlin (2008) and Sheffi and Rice (2005) classify risks in the supply chain as follows:

- Process Risk: Logistics disruptions, delivery delays, or operational system failures that cause instability in distribution activities.
- Demand Risk: Uncertainty in the volume, variety, or timing of customer demand. Inaccurate demand projections can lead to excess or shortages.
- Supply Risk: Limited raw materials, dependence on a single supplier, or distribution disruptions. Including cost risk (price uncontrollability) and commitment risk (long-term, inflexible contracts).
- External Risk: Natural disasters, geopolitical conflicts, and regulatory changes that can disrupt operational continuity.

Risk Management Strategy

Risk management strategy is a key part of a company's management system aimed at ensuring business continuity, resilience, and achieving strategic goals.

According to ISO 22301:2019, organizations must systematically identify risks, perform Business Impact Analysis (BIA), and develop continuity plans with appropriate risk controls. For state-owned enterprises (BUMN), regulation PER-2/MBU/03/2023 mandates integrating risk management into good corporate governance (GCG). PT XYZ, as part of a holding group, aligns its risk profile and strategy with its parent holding company.

Risks must be managed thoroughly through identification, measurement, mitigation, monitoring, and reporting. Risk management supports the preparation of the Long-Term Plan (RJP) and the Work and Budget Plan (RKAP) to anticipate strategic risks that may hinder goals. According to Ministerial Regulation PER-2/MBU/03/2023 Article 67, Risk Management Policy must include: integrated risk strategy across subsidiaries and parent SOE, definitions of risk appetite, tolerance, and limits considering risk capacity, risk taxonomy, measurement methods and information systems, and contingency plans for worst-case scenarios.

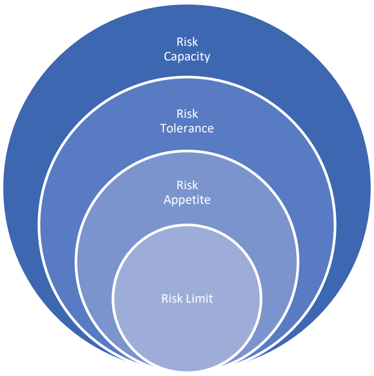

Figure 4. Risk Hierarchcy Diagram

(Source: Internal Document, 2025)

The government's technical guideline SK-6/DKU.MBU/10/2023 explains key concepts:

- Risk Capacity: The company's maximum ability to absorb risk impacts based on financial resources, guiding risk appetite and tolerance limits.
- Risk Tolerance: The maximum risk level tolerated before corrective action, operationalized with Key Risk Indicators.
- Risk Appetite: The overall risk the company is willing to accept to achieve strategic goals, reflecting management's risk attitude.
- Risk Limit: Specific quantitative or qualitative thresholds at unit/activity level derived from risk tolerance to keep operations within strategy, with breaches prompting escalation and mitigation.

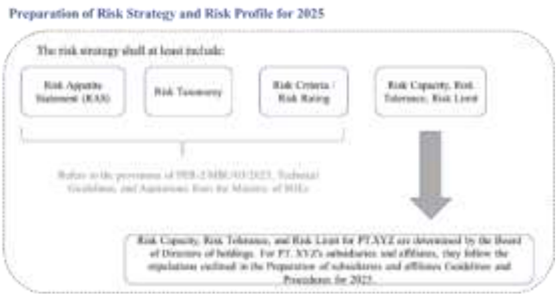

Figure 5. Framework for Risk Strategy
(Source: Internal Document, 2025)

Maximum Tolerable Downtime (MTD)

Maximum Tolerable Downtime (MTD) is an important indicator in disaster recovery planning and business continuity management. MTD is defined as the maximum time limit a business process can be disrupted before causing an unacceptable impact on the continuity of organizational operations.

According to Swanson et al. (2010), MTD reflects the maximum duration of disruption that can still be tolerated, considering all risks and impacts. Determining a clear MTD helps companies choose the right recovery method and develop appropriate recovery procedures, both in terms of scope and technical depth.

Determining the MTD value is recommended through the Business Impact Analysis (BIA) approach, which is a systematic method for identifying critical business functions and analyzing the impact of operational disruptions. Other terms that are often used synonymously with MTD include Maximum Acceptable Outage (MAO) and Maximum Tolerable Period of Disruption (MTPD).

Conceptual Framework

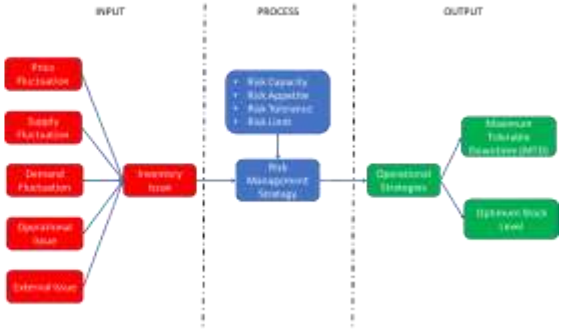

Figure 6 Conceptual Framework

The conceptual framework of this study illustrates how supply chain disruptions, such as fluctuations in demand, price, supply, operational issues, and external factors (e.g. natural disasters or regulations), can threaten the sustainability of coal production and distribution at PT. XYZ.

To anticipate this, the company needs to build a risk strategy consisting of four main elements: risk capacity, risk appetite, risk tolerance, and risk limit. This strategy is the basis for determining the Optimum Stock Level and calculating the Maximum Tolerable Downtime (MTD).

Optimum Stock Level aims to maintain stock availability within safe limits according to the company's risk capacity, while MTD is the maximum tolerance limit for acceptable operational disruption time. These two components are part of a risk-based operational strategy to proactively and adaptively increase supply chain resilience in the face of mining industry uncertainty.

RESEARCH METHODOLOGY

Research Design

This research begins with identifying the actual conditions of the company through direct interviews to understand problems such as stock imbalances and operational disruptions. The main problems are then formulated into research questions.

Data collection was carried out qualitatively (interviews and literature studies) and quantitatively (internal reports, operational data, regulations, and market data). All data was analyzed to find the root of the problem, then continued with quantitative analysis based on PT. XYZ's risk limit approach.

The results of the analysis were used to calculate the optimum stock level and MTD as the tolerance limit for operational disruptions. These findings are the basis for formulating strategic recommendations to improve PT. XYZ's supply chain resilience in facing various potential disruptions.

Data Collection Method

The data collection method in this study was carried out with a mixed method approach. This approach combines qualitative by interview and quantitative methods to obtain more comprehensive and in-depth data. The use of these two approaches allows researchers to see phenomena from various perspectives and increase the validity of research results.

Data Analysis Method

The analysis stage begins by determining the Financial Risk Limit, which is the maximum limit of the loss value (cost or opportunity loss) that the company can still tolerate without disrupting operational continuity. This value is obtained from internal documents such as risk management policies and historical financial reports, and is expressed in currency units.

Next, the Financial Risk Limit is converted into the Tonnage Risk Limit, which is the risk limit in units of coal volume (tons). The conversion is carried out by considering the contribution margin per ton, which is the difference between the selling price and production costs:

$$M = S - P \qquad (1)$$

Which,

M = Margin (per ton)

S = Selling Price (per ton)

P = Production Cost (per ton)

Knowing this margin value, the financial risk limit can be converted into tonnage using the formula:

$$Rt = \frac{Rf}{M} \qquad (2)$$

Which,

$\boldsymbol{Rt}$ = Risk Limit (Tonnage)

$\boldsymbol{Rf}$ = Risk Limit (Financial)

$\boldsymbol{M}$ = Margin (per ton)

The result of this conversion shows the maximum volume of coal that can be disturbed without exceeding the financial risk limit. This Risk Limit (Tonnage) value is the basis for calculating MTD and Risk Limit (Financial) Value for Optimum Stock Level, so that operational decisions remain within the risk capacity that the company can tolerate.

Maximum Tolerable Downtime (MTD)

After obtaining the Risk Limit value in tonnage units, the next step is to calculate the MTD, which is an estimate of the maximum time of disruption that can still be tolerated without exceeding the set risk limit. MTD is calculated in days and is divided into two main components:

- **MTD Production**
  Describes the maximum time limit for production disruption that can be tolerated. Calculated using the formula:

$$MTDp = \frac{Rt}{Pr} \qquad (3)$$

Which,

$\boldsymbol{MTDp}$ = MTD Production

$\boldsymbol{Rt}$ = Risk Limit (Tonnage)

$\boldsymbol{Pr}$ = Daily Production (Tons/day)

- **MTD Delivery**
  Shows the maximum duration of delivery disruption that can still be tolerated. Calculated by the formula:

$$MTDd = \frac{Rt}{d} \quad (4)$$

$\boldsymbol{MTDd}$ = MTD Delivery
$\boldsymbol{Rt}$ = Risk Limit (Tonnage)
$\boldsymbol{d}$ = Delivery Capacity (Tons/day)

Optimum Stock Level

Optimum Stock Level Analysis aims to determine the ideal limit of the amount of coal stock that the company must have so that inventory costs do not exceed the financial risk limit. The calculation is carried out using PTBA's financial risk limit approach, namely the maximum limit of inventory costs that the company can tolerate.

The risk limit value in rupiah is converted into the maximum limit of permitted stock tonnage, using the formula:

$$OSL = \frac{Rf}{IC} \quad (5)$$

$\boldsymbol{OSL}$ **=** Optimum Stock Level
$\boldsymbol{Rf}$ **=** Risk Limit Financial
$\boldsymbol{IC}$ **=** Inventory Cost (per ton)

By keeping the stock level below this limit, PTBA can avoid inventory cost inflation that exceeds the predetermined financial risk limit. The results of this calculation are an important reference in efficient and risk-based stock control.

RESULT AND DISCUSSION

Risk Limit Analysis

According to Bertsimas & Thiele (2006), in the context of supply chain management, robust optimization supports a risk-based approach by converting financial risk tolerances to supply or demand uncertainty into operational constraints that can be used to determine optimal stock levels and adaptive recovery strategies.

As part of the Holding group in the mining industry, PT. XYZ is required to follow the risk management policy that has been centrally determined by the parent company. This is in accordance with the Holding's internal regulations and the provisions of the Ministry of SOEs which require the integration of subsidiary risk profiles into the parent company's risk management framework.

In preparing the 2025 RKAP, PT. XYZ uses the risk limit that has been determined top-down by Holding, as stated in Holding Letter Number 537/E.DIRPPU/XII/2024 dated December 30, 2024. This value is used as a reference in planning and controlling the company's operational and financial risks.

Through financial simulations of current assets and retained earnings, and using the Altman Z-Score model, the total risk capacity of Holding is IDR 7.304 trillion. Based on these results, PT. XYZ's risk tolerance for 2025 is set at IDR 1.272 trillion (17.4% of the total risk capacity of Holding).

The strategic risk appetite range set by Holding is:

- Upper Range (U): IDR 1,144 trillion (90% of risk tolerance), used for very high impact risks, such as major disasters, significant regulatory changes, or systemic disruptions.
- Lower Range (L): IDR 890 billion (70% of risk tolerance), used for high impact risks, which can still be controlled through managerial intervention or strengthening internal processes.

For 2025, PT. XYZ's risk limit is set at IDR 763 billion (60% of risk tolerance) which can still be mitigated through cost control, project rescheduling, or resource reallocation.

This risk limit will then be converted into operational parameters in the form of coal tonnage, which is used in calculating the MTD and Optimum Stock Level, so that every operational decision remains in line with the company's overall risk resilience capacity.

After Holding sets the risk limit value of PT. XYZ for 2025 at IDR 763 billion, the next step is to convert the value from financial units to operational units, namely in the form of coal volume (tons). The purpose of this conversion is so that the financial risk limit can be used as a reference in making operational decisions related to production, distribution, and stock management.

The conversion is done by calculating the contribution margin per ton, which is the difference between the average selling price of coal and the production cost per ton. Based on the 2025 production plan, PT. XYZ targets a production of 50 million tons, consisting of various calorie classes (CV), with a dominant distribution in ICI-3 (5000 kcal/kg) and ICI-4 (4200 kcal/kg).

The average coal price data for 2025 based on the Argus index shows a Weighted Average Selling Price (WASP) of USD 66 per ton, or equivalent to IDR 1,061,257 per ton (exchange rate IDR 16,200). With a production cost of IDR 400,000 per ton, a contribution margin of IDR 661,257 is obtained.

The calculation results show that PT. XYZ has a maximum tolerance limit for production or distribution disruptions of ±1.1 million tons per year. If the volume of disruption exceeds this limit, the financial impacts caused have the potential to exceed the established risk threshold, and can trigger the need for corrective actions both strategically and operationally.

The thing that companies need to pay attention to is that coal prices can be very volatile depending on market conditions and other global influences such as geopolitics and war. Research conducted by Gininda (2023) shows that coal price fluctuations trigger significant spillover effects between companies, both in the short and long term. This finding indicates strong interdependence within the mining sector, which in turn emphasizes the importance of implementing responsive risk management strategies, careful portfolio diversification, and energy policies that support the transition to a sustainable energy system.

Maximum Tolerable Downtime (MTD)

The Maximum Tolerable Downtime (MTD) Production value is calculated by dividing the risk limit value in tonnage units by the average daily production capacity. Based on 2024 data, PT. XYZ's annual production reached 41.9 million tons with 301 effective working days (after deducting rainy days, religious days, and system disruptions), so that the daily production capacity was recorded at 140,000 tons/day.

By using a risk limit value of 1,103,957 tons, the Production MTD value or risk limit that can be tolerated if there is a total production disruption for ±7 days. If the potential disruption lasts longer than that duration, the financial impact is at risk of exceeding the risk limit set by Holding, so strategic intervention is needed to mitigate the risk quickly.

The Maximum Tolerable Downtime (MTD) Delivery value is calculated by dividing the risk limit in tonnage units by the average daily distribution capacity. Based on 2024 data, PT. XYZ's annual delivery was recorded at 35.4 million tons with 361 effective working days, so the company's daily distribution capacity is 98,000 tons/day. With a tonnage risk limit of 1,103,957 tons, the MTD Delivery value or risk tolerance limit if there is a total delivery disruption for ±11 days. If the disruption lasts longer than this duration, the potential loss is at risk of exceeding the financial risk threshold set by

Holding, so strategic mitigation steps are needed to avoid further risk escalation.

According to Swanson et al., (2010) Maximum Tolerable Downtime (MTD) functions as an important indicator in the decision-making process regarding recovery methods and setting business continuity priorities, which ultimately plays a role in minimizing operational risks that can develop into more serious ones.

Optimum Stock Level

The determination of the optimum stock level at PT. XYZ in this study is based on the financial risk limit set by Holding, which is IDR 763 billion. This value is compared with the annual inventory cost per ton to determine the maximum limit of the amount of coal that can be stored without incurring excess cost burdens. Based on operational data in 2024, the total inventory cost of PT. XYZ reached IDR 708.2 billion, with an average annual stock volume of 10,203,405 tons, resulting in an inventory cost of IDR 69,408 per ton. Therefore, the Optimum Stock Level owned by PTBA is 10.99 million tons per year which can be stored by PT. XYZ so that inventory costs do not exceed financial risk.

Table 2. Inventory Plan Volume

Year	Month	Optimum Stock Level (tons)	Inventory Plan Volume (tons)	Deviation (%)
2025	January	10,992,937	7,634,506	69%
	February		6,348,306	58%
	March		5,110,106	46%
	April		5,084,906	46%
	May		5,447,706	50%
	June		6,121,506	56%
	July		7,379,306	67%
	August		8,842,106	80%
	September		10,115,906	92%
	October		10,678,706	97%
	November		10,053,006	91%
	December		8,916,306	81%

Evaluation of the 2025 inventory volume plan shows that in the first semester, the company was still in the low-risk zone, with an average stock below 70% of the optimum limit. However, in the second semester there was a significant increase, where the stock in October reached 97% of the maximum limit, and several other months such as September, November, and December were above 90%. This trend indicates potential financial pressure due to the risk of overstock, which can trigger increased storage costs and decreased coal quality. Therefore, adjustments to the distribution strategy, delivery priorities, and stock monitoring system based on risk indicators need to be implemented to maintain operational efficiency and sustainability.

The integration of the results of this analysis into the operational planning system and monthly evaluation is expected to help PT. XYZ in managing stock adaptively, efficiently, and in accordance with the risk capacity set by the Holding.

Business Solution

As part of the effort to formulate a solution that can be implemented in real terms, this study involved a series of Focus Group Discussions (FGD) with stakeholders from various functions at PT. XYZ, such as the Mine Planning Division, Mining Operations, Coal Handling & Transportation, Laboratory, and Risk Management. Through this FGD process, a mapping of business needs, identification of pain points, and a list of system needs (wishlist) were obtained which became the basis for designing an applicable solution in supporting a comprehensive risk-based inventory management approach. The results of the FGD grouped system needs into four main categories.

First, Data Monitoring, which emphasizes the importance of real-time monitoring of the entire coal supply chain process. This monitoring includes stock (with minimum and maximum alerts), coal flow from upstream to downstream, daily heavy equipment operations, quality recording and measurement, and tracking of shipments and costs.

Second, Risk Monitoring & Early Warning System, which aims to detect and respond to potential disruptions proactively. This system includes early warning of stock shortages, monitoring of quality deviations, notification of changes in shipping schedules, and cost tracking to identify sources of operational disruptions and financial deviations.

The third category is Data Integration, which addresses the challenge of lack of data integration between functions. The FGD highlighted the need for a centralized system capable of consolidating production, delivery, quality, and reporting data into one real-time platform. This also includes digitizing communication and information flows between departments to reduce manual input and improve data accuracy and timeliness.

The fourth category is Data Governance & Reporting, which highlights the importance of a centralized reporting mechanism, integration of multi-level reports (operations, quality, costs, delivery), and strengthening the company's internal data security.

Based on the identification of these needs, it can be concluded that stock management problems at PT. XYZ cannot be solved simply through a risk-based stock calculation model, but require the support of an integrated digital system so that they can be implemented effectively in daily operational processes. For this reason, this study proposes a business solution that integrates a risk-based inventory management approach through three main components, namely Risk Limit, Maximum Tolerable Downtime (MTD), and Optimum Stock Level (OSL). Risk Limit is used to determine the operational risk tolerance limit, including demand fluctuations and delivery times. The MTD component calculates the duration of disruption that is still acceptable without disrupting the continuity of sales contract fulfillment. Meanwhile, OSL is determined based on the allowable financial risk value and the actual cost of stock handling.

Currently, PT. XYZ is developing an Enterprise Resource Planning (ERP) system as part of the company's digital transformation. This ERP system is a strategic initiative to improve business process integration, data standardization, and the provision of accurate and real-time management information. ERP not only functions as an operational administration system, but also becomes the main foundation in cross-functional data-based decision making. With the ongoing development of ERP, the risk-based inventory management solution that has been formulated in this study is expected to be synergistically integrated into the ERP system.

This integration is very important because stock management issues cannot be solved only at the conceptual level, but must be supported by a digital system that is able to run calculation models automatically and responsively to actual operational data. Through an integrated ERP system, Risk Limit, MTD, and OSL calculations can be done automatically, while accelerating the monitoring, evaluation, and adaptive decision-making processes. Thus, the combination of a quantitative risk-based approach and ERP development forms a comprehensive business solution—not only solving technical issues of stock management, but also addressing cross-process, technology, and organizational decision-making challenges to achieve supply chain resilience and long-term operational excellence for PT. XYZ.

Business Implication

Based on the calculation results of Risk Limit, MTD, and Optimum Stock Level, there are a number of strategic implications that can be implemented by PT. XYZ to increase supply chain resilience and strengthen the company's capacity to deal with operational disruptions. This calculation uses historical data on production, distribution, downtime, and stock volume to obtain operational resilience parameters for 2025. This means that the calculation results are valid for use as a reference for operational planning in 2025. However, because this model is dynamic—influenced by variables such as financial risk limits, coal prices, production capacity, and logistics costs—the model input needs to be updated regularly to remain relevant and accurate according to the actual conditions of the company and the market.

First, PT. XYZ is expected to implement a Risk-Based Operational Limit approach by using the results of the conversion of the financial risk limit of IDR 763 billion to ± 1.1 million tons as the main reference in making operational decisions. All strategic decisions that have the potential to cause production or distribution disruptions need to be analyzed for their impact on the risk limit. This requires strong cross-functional coordination as well as the establishment of a risk coordination forum and risk awareness training for all work units.

Second, the company needs to strengthen its real-time downtime monitoring system, considering the relatively tight operational disruption tolerance limit: only ±7 days for production and ±11 days for distribution in a year. All disruptions need to be documented and monitored centrally so that management can immediately take corrective action before the MTD limit is exceeded.

Third, strict control of stock volume is important considering the maximum annual stock tolerance limit is ±10.99 million tons, while the current average stock is approaching 10.2 million tons. Control strategies include evaluating reorder points, adjusting production and distribution strategies, and monitoring stock rotation to remain within safe limits both financially and logistically. Fourth, the integration of all the results of this study will be more optimal if supported by the implementation of an Enterprise Resource Planning (ERP) system. ERP not only functions as an administration system, but needs to be developed as a real-time operational risk control center equipped with risk limit monitoring features, automatic notifications when stock approaches the maximum limit, and scenario simulations to evaluate potential risks before disruptions occur.

With the integration of Risk Limit, MTD, and OSL calculations into the ERP system, PT. XYZ can build a responsive data-driven decision-making center, accelerate cross-functional coordination, and ensure that the company's supply chain management is adaptive, resilient, and aligned with long-term strategy. Therefore, the results of this calculation not only provide an overview of the current year's risk conditions, but can also be developed as a model for risk-based operational decision-making that is sustainable and flexible following the dynamics of the company's future conditions. Elock Son (2018) emphasized that forecast accuracy and demand stability can be affected by information distortion known as the bullwhip effect, which is characterized by increased demand volatility upstream in the supply chain. This effect is also considered to play an important role in the implementation of decision-making coordination mechanisms.

According to Kunduru, (2022) Enterprise Resource Planning (ERP) systems have a number of significant advantages, such as their ability to integrate various business functions into one centralized system, support process automation to increase efficiency, provide real-time data visibility to accelerate decision making, and provide analytical and reporting features that help in monitoring organizational performance; ERP is also modular and scalable so that it can be adjusted to evolving business needs, and when integrated with the Internet of Things (IoT), ERP acts as the main foundation in the company's digital transformation towards an intelligent and data-driven operating system. On the other hand, the use of ERP also faces various challenges, including the limited flexibility of legacy ERP systems in accommodating new technologies such as IoT, the complexity of data architecture and process integration between ERP systems and IoT devices, increasing cybersecurity risks due to the expansion of data access points, and the scarcity of experts who master cross-field competencies in ERP and IoT. In addition, high investment costs and the difficulty of measuring benefits directly, resistance to change within the organization, and lack of collaboration between ERP and IoT vendors also become obstacles to effective implementation.

CONCLUSION

This study was conducted to answer three main questions related to strengthening the supply chain resilience of PT. XYZ, namely: determining the risk limit value as an operational safety limit, calculating the Maximum Tolerable Downtime (MTD) based on risk, and determining the optimum annual stock level using a risk-based approach. The three questions were analyzed through a quantitative approach using the company's actual operational data for 2025, referring to the risk management framework implemented by PT. XYZ. Based on the results of data processing, the financial risk limit value of PT. XYZ for 2025 was set at IDR 763 billion. By considering the contribution margin of IDR 661,227 per ton, this risk limit was converted into a risk limit in the form of a volume of 1,103,957 tons of coal, which is the maximum limit of disruption that can still be tolerated before having a significant impact on the company's financial condition. The calculation of the Maximum Tolerable Downtime (MTD) shows that the company has a tolerance for operational disruption of 7 days for production and 11 days for distribution. This value is an important indicator in the preparation of the company's contingency plan and early warning system. In addition, this study also succeeded in determining the optimum annual stock level of 10,992,937 tons of coal, based on the financial risk limit value and inventory cost of IDR 69,408 per ton. This optimum stock value provides a balance between the need to maintain smooth operations and storage cost efficiency, and helps companies avoid the risk of overstock or stockout that can disrupt the fulfillment of customer contracts.

REFERENCES

Behzadi, G., O'Sullivan, M. J., & Olsen, T. L. (2020). On metrics for supply chain resilience. European Journal of Operational Research, 287(1), 145–158.

https://doi.org/10.1016/j.ejor.2020.04.040

Bertsimas, D., & Thiele, A. (2006). Robust and data-driven optimization: Modern decision-making under uncertainty. European Journal of Operational Research, 173(3), 465–487. https://doi.org/10.1016/j.ejor.2005.07.005

Buttriss, K. (2020). A framework for assessing organisational risk appetite [Doctoral dissertation, University of Portsmouth].

Chopra, S., & Meindl, P. (2016). Supply chain management: Strategy, planning, and operation (6th ed., Global Edition). Pearson Education.

Coviello, K. (2014). Risk appetite in the financial services industry: A requisite for risk management today. Deloitte Development LLC.

Elleuch, H., Dafaoui, E., Elmhamedi, A., & Chabchoub, H. (2016). Resilience and vulnerability in supply chain: Literature review. IFAC-PapersOnLine, 49(12), 1448–1453. https://doi.org/10.1016/j.ifacol.2016.07.775

Elock Son, C. (2018) Supply Chain Risk Management: A Review of Thirteen Years of Research. American Journal of Industrial and Business Management, 8, 2294-2320. https://doi.org/10.4236/ajibm.2018.812154

Fahimnia, B., Tang, C. S., Davarzani, H., & Sarkis, J. (2015). Quantitative models for managing supply chain risks: A review. European Journal of Operational Research, 247(1), 1–15. https://doi.org/10.1016/j.ejor.2015.04.034

Fredendall, L. D., Patterson, J. W., Lenhartz, C., & Mitchell, B. C. (2002). *What Should Be Changed? A comparison of cause and effect diagrams and current reality trees shows which will bring optimum results when making improvements*. *Quality Progress*, January 2002, pp. 50–59**.**

Gartner. (2020). *Six strategies for supply chain resilience* [Infographic]. Gartner. https://www.gartner.com/smarterwithgartner/six-strategies-for-supply-chain-resilience

Gininda, N. B. (2023). *The effect of coal price volatility on the performance of South African coal mining firms* (Master's thesis). University of the Witwatersrand, Johannesburg.

Govindan, K., Fattahi, M., & Keyvanshokooh, E. (2017). Supply chain network design under uncertainty: A comprehensive review and future research directions. Computers & Industrial Engineering, 109, 650–667. https://doi.org/10.1016/j.cie.2017.01.017

International Organization for Standardization. (2019). ISO 22301:2019 Security and resilience – Business continuity management systems – Requirements. https://www.iso.org/standard/75106.html

Ivanov, D., Dolgui, A., & Sokolov, B. (2023a). Adaptation of supply chains to sustainable and resilient paradigms: Methods and frameworks. Computers & Industrial Engineering, 174, 108656. https://doi.org/10.1016/j.cie.2023.108656

Kementerian Badan Usaha Milik Negara Republik Indonesia. (2023). Peraturan Menteri BUMN Nomor PER-2/MBU/03/2023 tentang Pedoman Tata Kelola dan Kegiatan Korporasi Signifikan BUMN [termasuk SK-6/DKU-MBU/10/2023 dan juknis agregasi risiko]. https://peraturan.go.id

Kunduru, A. R. (2022). *IoT futuristic integration with ERP systems: A review*. International Journal on Human Computing Studies, 5(5), 43–49.

National Institute of Standards and Technology. (2010). Contingency planning guide for federal information systems (NIST Special Publication 800-34 Rev. 1). https://csrc.nist.gov/publications/detail/sp/800-34/rev-1/final

Ogura, T., & Tsuda, K. (2020). Fluctuation of commodity price in the EC market and its factor analysis. Procedia Computer Science, 176, 1577–1585. https://doi.org/10.1016/j.procs.2020.09.169

Peng, X., Song, W., Li, X., & Xu, Q. (2023). Analysis of factors influencing the volatility of coal industry development under the double carbon policy. *Journal of Innovation and Development, 2*(3), 152–154.

Rajagopal, V., & Thakur, S. (2016). A decision-support model for dynamic inventory management under demand uncertainty. Journal of the Operational Research Society, 67(7), 910–924. https://doi.org/10.1057/jors.2016.7

Sheffi, Y., & Rice, J. B. Jr. (2005). A supply chain view of the resilient enterprise. MIT Sloan Management Review, 47(1), 41–48. https://www.researchgate.net/publication/255599289

Sinaga, P. T., Simanjuntak, M., & Arafah, W. (2024). Enhancing supply chain resilience in coal mining. Journal of Business and Economic Review, 8(4), 1–12.

Swanson, M., Bowen, P., Phillips, A. W., Gallup, D., & Lynes, D. (2010). *Contingency planning guide for federal information systems* (NIST Special Publication 800-34 Rev. 1). National Institute of Standards and Technology. https://csrc.nist.gov/publications/detail/sp/800-34/rev-1/final

Tang, C. S. (2006). Robust strategies for mitigating supply chain disruptions. International Journal of Logistics Research and Applications, 9(1), 33–45. https://doi.org/10.1080/13675560500405584

Tang, C. S. (2006). Perspectives in supply chain risk management. International Journal of Production Economics, 103(2), 451–488. https://doi.org/10.1016/j.ijpe.2005.12.006

Tang, C. S., & Tomlin, B. (2008). The power of flexibility for mitigating supply chain risks. International Journal of Production Economics, 116(1), 12–27. https://doi.org/10.1016/j.ijpe.2008.07.008

Tang, O., & Nurmaya Musa, S. (2011). Identifying risk issues and research advancements in supply chain risk management. International Journal of Production Economics, 133(1), 25–34. https://doi.org/10.1016/j.ijpe.2010.06.013

Wijaya, M. E., & Limmeechokchai, B. (n.d.). Impacts of coal price on Indonesian electricity planning:

The oil price perspective and CO_2 emissions. https://www.researchgate.net/publication/228419458

Zeng, L., Liu, S. Q., Kozan, E., Burdett, R., Masoud, M., & Chung, S.-H. (2023). Designing a resilient and green coal supply chain network under facility disruption and demand volatility. Computers & Industrial Engineering, 183, 109476. https://doi.org/10.1016/j.cie.2023.109476

Zhu, S., Chi, Y., Gao, K., Chen, Y., & Peng, R. (2022). Analysis of influencing factors of thermal coal price. *Energies*, *15*(5652). https://doi.org/10.3390/en15155652

Zhou, G., & Benton, W. C. (2007). Supply chain practice and information sharing. Journal of Operations Management, 25(6), 1348–1365. https://doi.org/10.1016/j.jom.2007.01.009