COSTING: Journal of Economic, Business and Accounting
Volume 8 Nomor 2, Tahun 2025
e-ISSN : 2597-5234

OPERATIONAL OPTIMIZATION OF COAL HANDLING FACILITY USING THEORY OF CONSTRAINT (TOC) AND STOCK AND FLOW MODELS

OPTIMASI OPERASIONAL FASILITAS PENANGANAN BATUBARA DENGAN MENGGUNAKAN THEORY OF CONSTRAINT (TOC) DAN MODEL STOCK AND FLOW

Azizul Amri[1], Nur Budi Mulyono[2]
Program Magister Administrasi Bisnis, Institut Teknologi Bandung[1,2]
azizul_amri@sbm-itb.ac.id[1], nurbudi@sbm-itb.ac.id[2]

ABSTRACT
Coal remains one of the most cost-effective energy sources, playing a crucial role in Indonesia's national energy mix and making a significant contribution to national revenue. PT XYZ, a leading coal producer, recorded a total production of 41.94 million tons in 2023, with coal transportation reaching 32.42 million tons. For 2026, PT XYZ has set an ambitious target of producing and delivering 60 million tons. This projected increase in annual shipment volume is expected to place considerable pressure on PT XYZ's existing heavy equipment, particularly the Load Out system at the Coal Handling Facility (CHF). The current Load Out system at CHF 3, with a nominal capacity of 1,500 tons per hour (TpH) for each conveyor, is already operating near its maximum capacity. However, this capacity is projected to be insufficient to meet the 2026 target of 10 million tons, especially as demand continues to rise towards 2030 and beyond. As coal production and transportation demands increase, it is essential to assess whether the existing infrastructure can sustain this load without compromising operational efficiency or reliability. This study employs a supply chain capability analysis method, focusing on coal transportation logistics at Train Loading Station 3 (TLS103). The key findings highlight the need for strategic enhancements to the Loading system at CHF 3, particularly in increasing conveyor capacity and optimizing the operational configuration of TLS103. Through the calculation of the required tonnage per hour (TpH) needed to achieve the 2026 production target, this study identifies significant gaps in the current system that could hinder PT XYZ's ability to meet its goals. The results of this research will serve as recommendations for decision-making regarding capital investments and operational improvements.
Keywords: *Coal Load Out, Coal Handling Facility (CHF), Train Loading Station (TLS), Coal Handling, TLS Bunker, Theory of Constraints (TOC), Rail System, Stock and Flow*.

ABSTRAK
Batubara masih menjadi salah satu sumber energi yang paling hemat biaya, memainkan peran penting dalam bauran energi nasional Indonesia dan memberikan kontribusi yang signifikan terhadap pendapatan nasional. PT XYZ, salah satu produsen batu bara terkemuka, mencatat total produksi 41,94 juta ton pada tahun 2023, dengan pengangkutan batu bara mencapai 32,42 juta ton. Untuk tahun 2026, PT XYZ telah menetapkan target ambisius untuk memproduksi dan mengirimkan 60 juta ton. Proyeksi peningkatan volume pengiriman tahunan ini diperkirakan akan memberikan tekanan yang cukup besar pada alat berat yang ada di PT XYZ, khususnya sistem Load Out di Coal Handling Facility (CHF). Sistem Load Out di CHF 3 saat ini, dengan kapasitas nominal 1.500 ton per jam (TpH) untuk setiap konveyor, sudah beroperasi mendekati kapasitas maksimumnya. Namun demikian, kapasitas ini diproyeksikan tidak akan mencukupi untuk memenuhi target 2026 sebesar 10 juta ton, terutama karena permintaan terus meningkat hingga tahun 2030 dan seterusnya. Seiring dengan meningkatnya produksi dan permintaan transportasi batu bara, penting untuk menilai apakah infrastruktur yang ada dapat menopang beban tersebut tanpa mengorbankan efisiensi atau keandalan operasional. Studi ini menggunakan metode analisis kapabilitas rantai pasokan, dengan fokus pada logistik transportasi batu bara di Stasiun Pemuatan Kereta Api 3 (TLS103). Temuan utama menyoroti perlunya peningkatan strategis pada sistem pemuatan di CHF 3, terutama dalam meningkatkan kapasitas konveyor dan mengoptimalkan konfigurasi operasional TLS103. Melalui perhitungan tonase per jam (TpH) yang dibutuhkan untuk mencapai target produksi 2026, penelitian ini mengidentifikasi kesenjangan yang signifikan dalam sistem saat ini yang dapat menghambat kemampuan PT XYZ untuk mencapai target. Hasil dari penelitian ini akan menjadi rekomendasi untuk pengambilan keputusan terkait investasi modal dan perbaikan operasional.
Kata Kunci: Coal Load Out, Coal Handling Facility (CHF), Train Loading Station (TLS), Penanganan Batubara, Bunker TLS, Theory of Constraints (TOC), Sistem Rel, Stock and Flow.

INTRODUCTION

The global energy landscape is undergoing a transformative shift, with coal remaining a critical component of the energy mix, particularly in developing countries. In Indonesia, coal plays a vital role in the nation's economy, primarily catering to domestic energy needs rather than export. PT. XYZ, a leading coal mining company, significantly contributes to Indonesia's coal production to fulfill the national power requirements.

The clear trend toward a significant reduction in coal usage, along with the Paris Agreement's goal of achieving net-zero emissions by 2050 and global financial regulations pushing financial institutions to decrease their fossil fuel portfolios, indicates that coal will no longer be a primary energy source.

Kategori/*Category*	Penjelasan/*Explanation*
Hijau *(do no significant harm, apply minimum safeguard, provide positive Impact to the environment and align with the environmental objective of the taxonomy).* Green *(do no significant harm apply minimum safeguard, provide positive Impact to the Environment and align with the environmental objective of the taxonomy).*	Kegiatan usaha yang melindungi, memperbaiki, dan meningkatkan kualitas atas perlindungan dan pengelolaan lingkungan hidup, serta mitigasi dan adaptasi perubahan iklim serta mematuhi standar tata kelola yang ditetapkan pemerintah dan menerapkan praktik terbaik di tingkat nasional ataupun tingkat internasional. *Business activities that protect, restore, and improve the quality of environmental protection and management, as well as climate change mitigation and adaptation, and comply with the governance standards by government, and apply best practices at both the national and international level.*
Kuning *(do no significant harm).* Yellow *(do no significant harm).*	Kegiatan usaha yang memenuhi beberapa kriteria/ambang batas hijau. Penentuan manfaat kegiatan usaha ini terhadap perlindungan dan pengelolaan lingkungan masih harus ditetapkan melalui pengukuran serta dukungan praktik terbaik lainnya. *Determination of business benefits for environmental protection and management must still be conducted through measurement and support of other best practices.*
Merah *(Harmful activities).* Red *(Harmful activities).*	Kegiatan usaha tidak memenuhi kriteria/ambang batas kuning dan/atau hijau. *The business activities do not meet the yellow and/or green criteria/ threshold.*

Figure I.1 World's Coal Based Power Generation & Paris Agreement Benchmark until 2050

(Source: Coal Generation vs Paris Agreement : https://350jp.org/jpbank/jpbank3/coal_generation_vs_paris_agreement/ , Accessed October, 2024)

In Indonesia, financial institutions, including banks, are required to comply with regulations aimed at reducing carbon portfolios and promoting sustainable finance. The key regulation is the Financial Services Authority (Otoritas Jasa Keuangan or OJK) Regulation No. 51/POJK.03/2017 on implementing Sustainable Finance for Financial Services Institutions, Issuers, and Public Companies. This regulation mandates that financial institutions integrate environmental, social, and governance (ESG) principles into their operations and decision-making processes, including reducing carbon portfolios (OJK, 2017). According to the table, which outlines the easiness classification for financing:

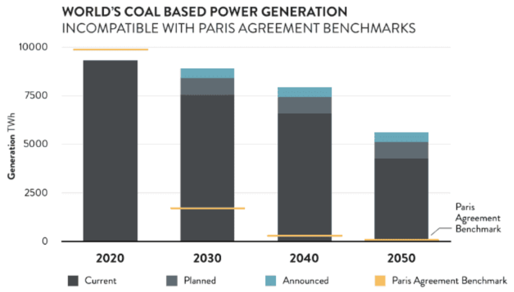


Figure I.2 Indonesia Green Taxonomy Category

(Source: Taksonomi Hijau Indonesia, 2021)

Indonesia's Green Taxonomy is a vital tool that directs financial institutions towards sustainable practices by classifying economic activities based on their environmental impact. Developed under the guidance of the Financial Services Authority (OJK), the taxonomy emphasizes environmental protection, climate change mitigation, and adaptation, aligning with national and international standards.

The taxonomy involved extensive collaboration, including 43 directorates-general from 8 ministries, and categorizes approximately 2,700 sectors and subsectors. It serves as a reference for transparency in the financial services sector, aiding in developing sustainable financial products and services. This system supports classifying activities into green, yellow, or red for financing ease, with green representing the highest environmental standards. Coal mining does not meet the criteria for green classification (Indonesia Green Taxonomy, 2022), making it challenging for the industry to secure financing from financial institutions. Unless the coal industry significantly improves its environmental impact and aligns with the green standards, it will face increasing financial financing difficulties.

This scenario exerts additional pressure on the coal mining industry to innovate and enhance their cost leadership to remain viable. Despite the controversy, coal remains globally necessary because current alternative technologies have not yet achieved the economic scale or efficiency of conventional fossil fuels.

However, in 2024, the Ministry of Energy and Mineral Resources received 883 requests for coal mining work plans and budgets (RKAB). Out of these, 587 RKAB applications were approved. Based on these 587 RKAB applications, the approved coal production tonnage will reach 922.14 million tons in 2024. For 2025, the approved production target will be 917.16 million tons, and for 2026, it will be 902.97 million tons.


UPDATE PROSES RKAB BATUBARA TAHUN 2024

Status	Jumlah
Permohonan	883
Disetujui	587
Ditolak	121
Dikembalikan (revisi 1-4)	100
Saldo (evaluasi 1-5)	75

Status 18 Maret 2024

Total tonase dari RKAB yang disetujui:
2024 : 922.14 juta ton
2025 : 917.16 juta ton
2026 : 902.97 juta ton

PENOLAKAN RKAB BATUBARA TAHUN 2024

Alasan Penolakan	Jumlah
SK IUP Habis	8
PNBP	75
FS dan AMDAL	4
MODI/Dirkom	13
Keuangan	8
PPM	11
Lainnya (Teknis, IPPKH, dll)	2
TOTAL	121

Figure I.1 Rkab Coal Minning 2024
(Source: Document of Meeting Commission VII DPR RI, 2024)

In the same period, PT. XYZ is targeting a production of 42.5 million tons in 2024, and 53.2 million tons in 2025, and maintaining this level at 53.2 million tons in 2026 (Internal Data of PT. XYZ Operational Director, accessed in April 2024). In the Rapat Umum Pemegang Saham Tahunan (RUPST), the CEO mentioned that For 2024, the company's approved coal production is 41 million tons. Meanwhile, in 2025 it will reach 50 million tons. Then, in 2026 coal production is approved at around 60 million tons (May 2024). Despite the ministry's overall production targets decreasing annually from 2024 onwards, PT. XYZ's production targets show a rising trend until 2025, with a stabilization in 2026. This indicates that PT. XYZ continuously optimizes its production capabilities, aiming for higher outputs even as national targets decline.

As production scales up, the corresponding volume of coal requiring transportation (rehandling) will naturally increase. PT. XYZ has set ambitious targets for coal transport volumes, aiming for 35.87 million tons in 2024 and 42 million tons in 2025, a significant rise from the 32.42 million tons transported in the previous year. This anticipated growth in rehandling demand necessitates a proportional enhancement in the capacity of coal transportation equipment. Without such upgrades, the existing infrastructure risks becoming a bottleneck, potentially impeding the efficiency of coal transport operations.

To address this challenge, the writer proposes a strategic solution: upgrading the capacity of the existing coal transportation systems. This enhancement will ensure that the infrastructure is adequately equipped to handle the future demand, thereby preventing potential inefficiencies and ensuring seamless operations as production continues to expand.

PT XYZ is a subsidiary of Indonesia's Mining Industry. PT. XYZ, established in 1950, is a key player in Indonesia’s energy sector, specializing in coal mining and power generation.

Operating primarily in Sumatra, the company manages extensive coal reserves and has integrated its operations to include energy production, leveraging its resources for domestic electricity supply.

Beyond its core business, PT. XYZ is gradually diversifying into renewable energy, exploring options like solar power. The company emphasizes sustainability, focusing on land reclamation and emissions reduction while also engaging in community development initiatives.

Though its primary focus remains within Indonesia, PT XYZ is cautiously expanding its reach, aiming to adapt to global energy shifts and strengthen its position in the international market. The company's approach is methodical, balancing its traditional operations with a gradual shift towards more sustainable energy solutions.

The core process of coal mining involves several critical stages that ensure the efficient and effective extraction, processing, and delivery of coal. Here is an elaborated narrative of the core processes:

a. Exploration and Feasibility Studies
   The coal mining in PT. XYZ process begins with comprehensive geological surveys to identify and evaluate coal deposits. Geologists use advanced techniques such as seismic surveys, core drilling, and geospatial mapping to determine the size, quality, and accessibility of coal seams. Following this, feasibility studies are conducted to assess the economic viability of the mining project. These studies consider factors such as coal quality, market demand, production costs, and potential environmental impacts. Environmental Impact Assessments (EIA) are performed to ensure that the mining activities comply with environmental regulations and obtain the necessary permits and approvals from relevant authorities.
b. Planning and Development
   Once the feasibility of the coal deposit is confirmed, detailed mine planning is undertaken. This involves designing the mine layout, selecting appropriate mining methods, and planning the sequence of operations. The development phase also includes building the necessary infrastructure to support mining operations, such as access roads, power supply systems, water management facilities, and worker accommodations. During this phase, mining equipment is procured and logistical arrangements are made for its delivery and maintenance.
c. Mining Operations
   Mining operations begin with the removal of overburden, which is the soil and rock covering the coal seams. In PT. XYZ, we do open pit mining, this is done using large machinery such as excavators, shovels, and bulldozers. From 1984 to the early 2000s, we used the Bucket Wheel Excavator (BWE) system for overburden (OB) removal. The extracted OB soil was spread by a Spreader, a larger and more mobile machine that dispersed the overburdened soil to predetermined locations via a conveyor. However, currently, our Spreader has been put on standby since the current coal seam is not suitable for continuous mining. As a result, the BWE is now only used for rehandling, taking coal from the stockpile to be transferred to the Train Loading Station (TLS) through a series of conveyors. Once the overburden is removed, the coal seams are exposed and can be extracted using various methods. techniques such as open-pit or strip mining are employed, where large

volumes of coal are removed using excavators and trucks.

Figure I.2 Bucket Wheel Excavator At Pt. Xyz

d. Coal Handling and Processing

Figure I. 3 Train Loading Station 3 At Pt. Xyz

After extraction, the coal is transported to processing facilities where it is crushed. Crushing reduces the coal to a manageable size. This improves the coal's quality and prepares it for market. The processed coal is then stockpiled in designated areas, ensuring that it is readily available for transportation. Proper handling and processing are crucial for maintaining coal quality and meeting market specifications. In PT. XYZ, the lump size is usually at 200 mm. When it reaches the docks, downstream of the business, the 200 mm coal lump will be adjusted by a crusher. The size will vary between 50 mm to 200 mm.

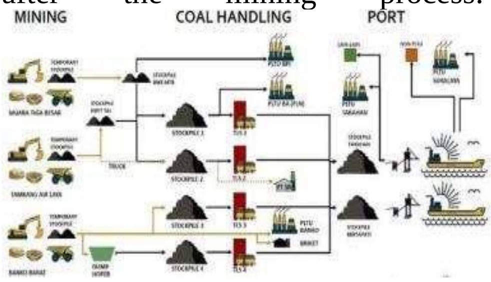
e. Transportation and Logistics

The final stage of the core process involves transporting the processed coal to its end users. Coal is loaded onto trains for rail transportation to ports or power plants. In PT. XYZ cases, barges are used to transport coal via sea, especially when the destination is on the other island. Trucks are also used for short-distance transportation to local consumers or transfer points. Efficient logistics and transportation systems are essential for minimizing costs and ensuring timely delivery of coal to customers.

f. Reclamation and Conserving Habitats

This process begins with land contouring to reshape the terrain to its natural or intended topography, followed by soil replacement to provide a foundation for future vegetation. Revegetation is then undertaken, where grasses, trees, and other plants are introduced to stabilize the soil and restore the habitat. Effective water management systems are implemented to control runoff, prevent erosion, and protect water quality. Additionally, waste management practices ensure that any remaining waste or hazardous materials are properly dealt with. At PT. XYZ, reclamation post-mining is a key focus area in achieving our ESG targets. These practices have contributed to PT. XYZ receiving multiple PROPER HIJAU and EMAS awards for high environmental standards and sustainable practices.

All these activities are consistently related to the challenge of achieving production per unit (Ton/Hour or TpH) by considering the equipment's capacity or capability and the performance efficiency of the operators. Excavation at PT. XYZ employs a PC 3000 and an Excavator. For rehandling, PT. XYZ uses a Bucket Wheel Excavator (BWE) system, which includes a Belt Wagon (BW), Cable Reel Car (CRC), and Hopper Car (HC). Alternative methods include using a Reclaim Feeder (RF) or trucking. All these tools utilize a conveyor line, except for the trucking method. After that, the coal is transported to Port Kertapati and Port Tarahan via a rail system and then shipped using barges. Finally, our business process includes reshaping the land, replacing soil, and conducting extensive revegetation to restore and stabilize the environment after the mining process.



Business Issue

PT. XYZ, an important player in the coal industry, is experiencing an increasing level of apprehension regarding its operational capabilities. The current infrastructure is at a significant risk of being unable to maintain pace with the increasing production targets year after year. The Coal Handling Facility 3 (CHF 3), situated in Banko Barat, is essential for the coordination of the coal movement from mining operations to downstream consumers. Train Loading Station 3 (TLS103) is essential in CHF 3, as it facilitates the transportation of coal to docks for shipment to customers such as power facilities, cement manufacturers, and fertilizer producers.

Currently, TLS103 is functioning at practically its maximum capacity. It is probable that the station will not have sufficient capacity to accommodate the heightened coal volume if production continues to expand as anticipated. This could result in delays, congestion, and disruptions in the supply chain, which could impede PT. XYZ's ability to fulfill its customer obligations. The issue is not solely about maintaining the current state of affairs; it also pertains to the system's capacity to accommodate the forthcoming changes in the future years.In order to resolve this issue, PT. XYZ must conduct a thorough examination of the prospect of expanding or optimizing its coal handling and transportation systems. It is imperative to prioritize the prevention of capacity constraints before they escalate into significant issues, while simultaneously guaranteeing consistent delivery to downstream consumers. Operational slowdowns may affect PT. XYZ's market competitiveness if these issues are not resolved.

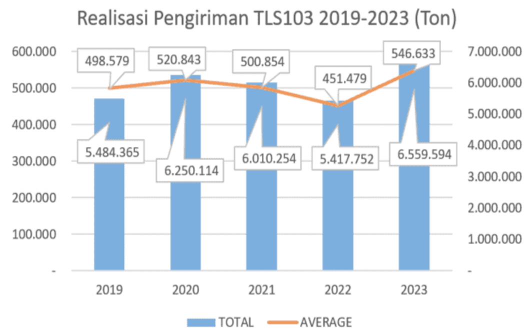
Current State of Load Out System

CHF 3’s Load Out system is designed to rehandle coal from the stockpile to TLS103. The system comprises three main conveyors: CV04, CV05, and CV06, each with a specific capacity that supports the overall material handling process. Specifically:

- **CV04** has a length of 400 meters and a capacity of 1,500 TpH.
- **CV05** spans 2,062 meters with a capacity of 1,500 TpH.
- **CV06** is 1,097 meters long and also has a capacity of 1,500 TpH.

These conveyors work in conjunction with three vibrating feeders (VF1, VF2, VF3). Each VF has capacity of 1,500 TpH and arranged serially on CV04, each with a capacity designed to ensure consistent material flow into the downstream conveyors. Despite these specifications, while currently functional, the Load Out system at CHF 3 is projected to be insufficient for future operational needs. In 2022, the Load Out system successfully rehandled 5.4

million tonnes of coal, and this figure rose to 6.5 million tonnes in 2023. However, even with this improvement, the system's output is expected to fall short of PT. XYZ's future annual rehandling target of 8.4 million tonnes in 2024 until 2026.



Operational Challenges

Several operational challenges have been identified as the primary obstacles to achieving the desired performance of the Load Out system:

a. The existing conveyors (CV04, CV05, and CV06) are currently operating at their maximum capacity of 1,500 tonnes per hour (TpH). However, as PT. XYZ's production volume increases, and these conveyors might no longer sufficient to handle the projected future demand. In 2026 alone, the target production will be at 60 million tonnes, and by that, TLS103 need to supply at least 10 million Tonnes in 2026.

b. The current train configuration limits the TLS103 directly impact PT. XYZ's ability to meet its rehandling targets. With a rehandling target of 8.4 million tonnes per year in 2024 and 2025, the existing system, with its average monthly capacity of 546.633 Tonnes, and throughput flow rate at 1,561 TpH (average 2023), falls short of the required future output.

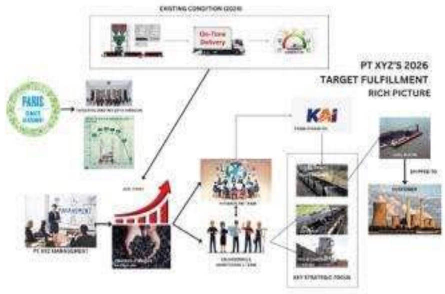


Figure I.4 Project Rich Picture

LITERATURE REVIEW

This Chapter Lays The Theoretical Foundation For The Study By Reviewing The Key Concepts, Frameworks, And Previous Research That Support The Analysis Of Load Out Chf 3 Within The Context Of Pt. Xyz's Ambitious Production Goals. Given The Company's Unique Position As The Only Organization Utilizing Train Loading Stations In This Industry, This Chapter Focuses On Internal Evaluations Of Throughput, Capacity, And Logistics, Alongside Strategic Decision-Making Approaches To Optimize Coal Handling And Transport.

The key areas covered in this chapter include the The Principle of Load Out CHF 3 Movement, starts from Input through Vibrating Feeders, Conveyor System, and finally to TLS, then it flows out the coal to the train containers.

Theoretical Foundation

In this section, the theoretical foundation will define all terms related to research, from theories, concepts, literature, best practices, and journal papers in terms of the research topics.

Coal Infrastructure and Railway System Supply Chain

The coal supply chain's efficiency relies significantly on infrastructure, particularly in load-out and railway systems, to ensure seamless transportation from mines to end-users. Our research on Load-Out CHF 3, a crucial logistical hub within the CHF network, provides a focal point for analyzing these dynamics. The following sections integrate insights from existing literature with specific considerations for optimizing Load-Out CHF 3 operations.

The Role of Infrastructure in the Coal Supply Chain

Load-out facilities, such as CHF 3, represent critical junctions in the coal supply chain where mined coal is loaded onto railways for transport. Affleck (2005) identified that bottlenecks in load-out and rail infrastructure are a major challenge, particularly when handling export-grade coal in regions like Queensland and the Hunter Valley. These constraints can result in delays that cascade throughout the supply chain, affecting overall system throughput.

At Load-Out CHF 3, such challenges may manifest as inefficiencies in synchronization between incoming coal from the mine and outbound rail transport schedules. Masoud, M., et al (2016) address that integrating coal shipment, stockpiles, and railing operations into a single decision support system can optimize the entire coal transport process. This system helps in better decision-making regarding resource allocation and infrastructure upgrades, thereby improving capacity utilization.

Infrastructure Considerations for Load-Out CHF 3

Investments in load-out infrastructure, such as automation and real-time monitoring, have been highlighted as key enablers for enhancing supply chain efficiency. Mathu (2014) applied the Theory of Constraints (TOC) to identify that prioritizing load-out infrastructure optimization, particularly at critical nodes like CHF 3, can significantly alleviate rail congestion and improve throughput.

Chen, H et al. (2024) further emphasized the scheduling integration on the infrastructure of the logistics transportation. Their research showed that by bridging the gap between operation control and scheduling, dynamic systems enable better information exchange and co-optimization, leading to more resilient and efficient high-speed railway operations, a finding highly relevant to improving CHF 3 performance.

Flow Principles of Load Out CHF 3

The principles of flow in material handling systems provide a basis for understanding the movement of materials across various stages of processing, transportation, and storage. In industrial contexts, such as coal handling, flow management is essential to maintaining steady operations and avoiding disruptions that may affect the throughput system. Continuity of flow in coal supply chains is critical for ensuring consistent supply and operational efficiency. It is influenced by factors such as efficient logistics, information sharing, and the ability to mitigate disruptions caused by environmental, economic, or geopolitical challenges. Yu, Z., et al (2023) further emphasize that advanced methodologies, such as optimization models and resilience planning, are often employed to manage these factors effectively and sustain coal flow across the supply chain.

The configuration of PT. XYZ's Load Out CHF 3 consists of three main conveyor segments: CV-04, CV-05, and CV-06, each with a throughput capacity of 1,500 tonnes per hour (tph). The conveyors transport coal from the stockpile to the loading station (TLS

103) and the bunker. The system includes:

1. **Vibrating Feeders (VF01, VF02, and VF03) (1.500 TpH/VF)**: A vibrating feeder is a machine unit that functions to regulate the flow of coal originating from the Belt Plough so that it can flow to the conveyor (in this case the CV04 conveyor). According to Chandravan, M. L., & Mukhopadhyay, A. K. (2017), this flow arrangement uses a vibration system to deliver coal according to the capacity of the conveyor. The Vibrating Feeder in CHF 3 is designed according to the throughput capacity of a series of CHF 3 conveyors, namely 1500 TpH. 3 machines that become the coal input, to feed the conveyor **CV04.** Work independently to regulate the feed rate from the stockpile onto the conveyors. PT. XYZ, has 3 Vibrating Feeders set in series at CHF 3, allowing the combination of these three VFs to work, capable of producing a total of up to 4500 TpH. However, because the use of one VF is sufficient to meet the target of 1500 TpH, the other two VFs will become spare if at any time a breakdown occurs in one of the VFs.
2. **CV04 (400 meters/1.500 TpH)**: Transfers coal from the stockpile via Vibrating Feeders **(VF1, VF2 and VF3)**
3. **CV05 (2.062 meters/1.500 TpH)**: Extends the flow towards the subsequent stages.
4. **CV06 (1.097 meters/1.500 TpH)**: Delivers the material to the loading and storage facilities.
5. **TLS103**: Zonailo, G. W. (2013) explained that TLS is an abbreviation for Train Loading Station, which is the last station where coal stops and is then transported using a coal train. TLS103 is one of the TLS available at PT. XYZ and plays an important role in coal delivery. TLS103 have 1000 Ton Bunker of capacity (we usually call it 'Surge Bin') and can flow out up to **2.053 TpH** to the train containers (December's average, 2023). But, the normal throughput based on the Standard Operational Procedure (SOP) is **1.830 TpH.**

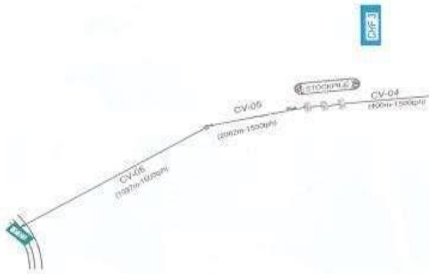


Figure II.1 Load Out Chf 3 Layout

(Source: Internal Company Document: Layout Conveyor Transportation CHF PTE, 2023)

Principles Governing Flow in the System

1. Continuity of Flow:

The principle of continuity implies that the flow of material should remain uninterrupted from the point of origin (the stockpile) to the final destination (TLS 103 and the bunker). Any disruption in the flow such as mechanical failures, inconsistent feeder operation, or capacity constraints, can result in bottlenecks that reduce throughput and increase downtime.

2. Capacity Matching:

The flow capacity of each segment must be appropriately matched to avoid overloading or underutilization. In this system, the conveyors (CV04, CV05, CV06) all share the same capacity of 1,500 tph, which simplifies flow regulation and reduces the risk of bottlenecking at individual conveyor segments. Proper coordination is required to ensure that the feeders deliver coal at a rate that matches the conveyors' capacity, thus preventing the accumulation of excess stock on the belts.

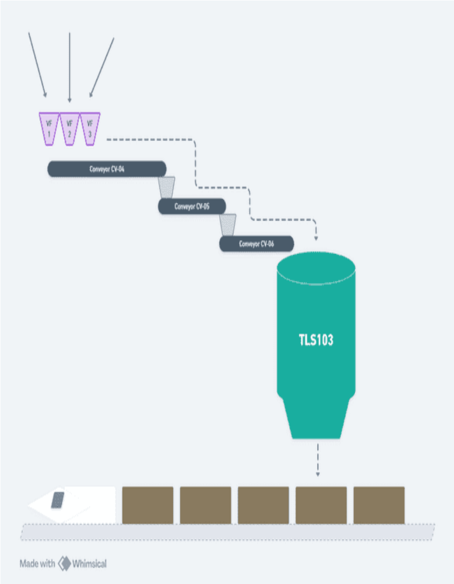


Figure II.2 Flow Of Material Of Load Out Chf 3

3. Balancing and Synchronization: Balancing the flow of coal is essential for maintaining a consistent supply to the TLS 103 and avoiding interruptions in the loading process. The initial coal flow requires approximately 15 minutes to travel from the vibrating feeders through conveyors CV04, CV05, and CV06, operating at a rate of 1.500 TpH. The 1.000-tonne surge bin at TLS 103 functions as a buffer to manage variations in the flow.

The standard operational procedure indicates that loading 61 railcars (Tarahan dock) takes **100 minutes**, corresponding to an average throughput of 1.525 TpH. The system must align the inflow rate from the conveyors with this loading rate to prevent discrepancies that could cause either overfilling or depletion of the surge bin.

The presence of a **20-minute buffer time before and after** the loading process, as outlined in the standard procedure, provides additional flexibility for managing the surge bin's coal level. This buffer period allows for adjustments to the coal flow and preparation of the surge bin, ensuring that the coal volume remains stable and sufficient for continuous loading operations. Proper use of this buffer time can help maintain synchronization between the inflow and the throughput requirements of TLS 103.

Theory of Constraints (TOC)

The Theory of Constraints (TOC) was originally developed by Eliyahu M. Goldratt in the 1980s and introduced in his book "*The Goal*." TOC has been compared with other management philosophies, particularly in its treatment of measurement, behavior, and goals in enterprises. Lewandowska-Ciszek, A. (2018) emphasize the potential to transform industries, such as UK manufacturing, depends on whether a paradigmatic or pragmatic mode of change is adopted. TOC is predicated on the idea that in any complex system, whether in manufacturing, logistics, or service industries, there is always at least one constraint or bottleneck that determines the overall performance of the system. TOC identifies this constraint and works to improve its performance, leading to overall system improvements. Over the past 25 years, TOC has evolved from a niche scheduling software to a widely accepted management philosophy. Despite its growth, there are still challenges in achieving broader acceptance, particularly in transitioning from niche to mainstream applications (Watson et al., 2007).

The TOC philosophy emphasizes that optimizing everything in a system equally is often counterproductive. Instead, by focusing on the system's most significant limitation (or "constraint"), the greatest improvements can be made with the least effort and cost. TOC is particularly useful for industries like coal handling, where logistical and operational efficiency are critical for meeting production goals.

Constraints - The Chain Analogy

A chain is only as strong as its weakest link, and likewise, every system has a constraint that limits its performance. This is evident because no system can produce infinite results; for instance, no company can achieve limitless sales or profits.

Figure II.3 Weakest Link

In a chain, there is always a single weakest link, and strengthening the other links won't improve the overall strength, as they aren't the limiting factor. In fact, reinforcing a link that isn't the weakest could potentially reduce the chain's overall strength, as it would add extra weight without addressing the true limitation.

Figure II.4 Miss-Addressing The Weakest Link

In a similar way, efforts to optimize individual processes and functions often overlook the system's constraint, leading to various unforeseen issues that can diminish the organization's overall performance and effectiveness.

What if we focused on making the most of the weakest link? We could exploit its potential by minimizing idle time, ensuring the chain is continuously in use, or by adjusting other elements to avoid sudden stress when the weakest link is under full load. Once we learn to utilize the chain effectively, we can then look for ways to reinforce the weakest link itself. Even a small improvement in its strength could significantly enhance the overall strength of the entire chain.

Every system is inherently limited by a constraint, whether recognized or not. When correctly identified and effectively managed, constraints offer the most rapid path to substantial improvement and serve as the foundation for ongoing development. Conversely, when overlooked, constraints can remain underutilized, leading to wasted system capacity. If left uncontrolled, a constraint can also disrupt delivery schedules and cause unexpected delays. Thus, it is essential for managers to optimize the utilization of constraints and develop strategies for their effective management.

Key Theoretical Components of TOC

1. The Five Focusing Steps
   TOC is structured around a cyclical process called the Five Focusing Steps, which are applied to continuously identify and resolve system constraints. These steps ensure that the entire process is aligned with the constraint and that system efficiency is optimized:

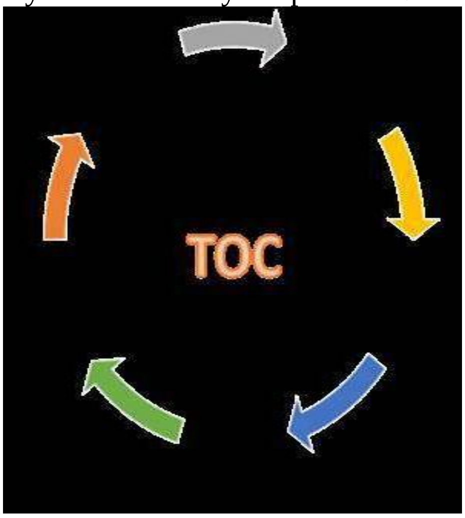


Figure II.5 Theory Of Constraint 5 Focusing Step

(Source: TOC Van Goldratt – Management Platform, https://managementplatform.nl/theory-of-constraints-van-goldratt/08/04/2023)

2. Identify the Constraint

   The first step is to identify the most significant limiting factor or bottleneck in the system that restricts throughput. In PT. XYZ's case, this could be a specific component of the Load Out CHF 3 system, such as conveyor capacities, the performance of the Train Loading Stations, or the alignment between the coal handling equipment and transportation schedules.

   In coal handling, constraints may arise from equipment limitations, transportation delays, maintenance downtime, or even external factors such as weather-related disruptions. Constraints in coal supply chains often stem from equipment limitations, transportation delays, maintenance downtime, or weather disruptions. Addressing these issues, as highlighted by Sarkar, B. D., & Shankar, R. (2021) involves resolving logistical inefficiencies and optimizing interconnected activities like transportation schedules, storage allocation, and terminal operations.

3. Exploit the Constraint

   Once identified, the constraint should be maximized to improve system performance. This involves ensuring that the constraint is always active and not idle. Non-constraint resources should not be utilized at 100% capacity if it does not contribute to the overall system output (Aryanezhad et al., 2010). This step involves tweaking the existing resources and processes to make the best use of the constraint. In PT. XYZ, exploiting the constraint could involve optimizing coal flow to TLS, ensuring regular maintenance schedules to reduce downtime, or improving operational planning to avoid overloading.

   Key Actions:

   - Reducing downtime and maximizing utilization
   - Implementing preventive maintenance
   - Increasing shift efficiency and worker coordination

4. Subordinate Everything Else to the Constraint

   In this step, the entire system is realigned so that all processes operate in a way that supports the identified constraint. Woeppel, M. (2000) said that subordinating everything else to the constraint is not just a step; it is a commitment to align the entire organization's operations, ensuring that every resource works in harmony with the system's most limiting factor to maximize throughput. This may involve adjusting the flow of coal through Load Out CHF 3, modifying train schedules at TLS103, or aligning the transportation chain so that it works seamlessly with the bottleneck. In practice, this might involve rescheduling coal deliveries to align with TLS's maximum handling capacity, so that no system components are over- or under-loaded.

5. Elevate the Constraint

   If the constraint remains unresolved after exploiting and subordinating, the next step is to make structural changes or upgrades. For PT. XYZ, this could mean increasing the capacity of conveyors, upgrading loading equipment, or improving the automation of the Load Out system.

   Elevating the constraint may require investments, such as upgrading equipment, implementing new technology, or increasing labor resources.

Key Methods for Elevating the Constraint:

1. Increasing Equipment Capacity: For PT. XYZ's Load Out CHF 3, this could involve upgrading the current conveyor system from 1,500 tonnes per hour (TpH) to a higher capacity, which would better align with future production goals.
2. Enhancing Automation: Automating key parts of the Load Out system may help improve throughput by reducing reliance on manual operations, increasing precision, and decreasing errors in coal loading and handling.
3. Improving Train Loading Stations (TLS): PT. XYZ's Train Loading Stations (TLS103) could be upgraded to handle a higher throughput, better aligning with production targets and minimizing downtime or delays.
4. Increasing Transportation Infrastructure: For example, if the constraint is related to limited rail capacity or train schedules, expanding rail availability or adding more frequent transportation cycles can significantly boost output.
5. Repeat the Process
   TOC is an ongoing process. After a constraint is resolved, the next step is to continuously monitor the system for the emergence of new constraints. As PT. XYZ reaches its capacity goals for Load Out CHF 3, new bottlenecks might arise elsewhere in the coal handling process or transportation logistics.

Identifying Key Strategic and Key Decision Addressing Bottlenecks

Mathu (2014) qualitatively analyzed the South African coal supply chain and identified bottlenecks in areas such as rail transport capacity, loading procedures, and handling systems. In this research, we identify key strategic challenges in the cyclic process as the process that tackling us to fulfill the 2026 target, which comes from three parts; the Conveyor System, TLS, and the Train Systems. The key decisions as a recommendations will be found when we are done with the cyclic process. Applying TOC involves pinpointing these constraints and focusing on improvements where they are most needed. For PT. XYZ, this could mean examining rail logistics to see if existing capacity supports the anticipated increase in coal production. It may also require reviewing the scheduling and frequency of trains or considering rail infrastructure adjustments.

The research does not fully address the entire TOC process, particularly the later stages such as "elevating the constraint" or "repeating the process." Also, does not include adequate empirical data to simulate the identified constraints or test proposed solutions. This limits its ability to provide a holistic understanding of TOC implementation in a complete operational cycle and reduces its ability to validate TOC's impact on system throughput or predict the outcomes of suggested improvements.

Optimizing Operational Systems

Li, W et al. (2021) examined how coal terminal handling systems, including train loading stations, can be optimized by identifying and acting on the most significant delays in the system. This involves monitoring real-time data to detect where the coal handling process slows down. For PT. XYZ, the monitoring could focus on whether delays occur at specific equipment points, due to scheduling issues, or because of handling methods.

Once the key constraint is identified, adjustments can be made to improve the flow of operations. If the throughput at the loading station is limited by equipment capacity, additional loading equipment or faster conveyor systems could help increase coal transfer rates.

Practical Steps for PT. XYZ Based on TOC To apply TOC at Load Out CHF 3, PT. XYZ could:

1. Expand rail capacity by scheduling more trains, improving train turnaround times, or increasing the number of tracks.
2. Automate the loading process to reduce manual handling delays. Automatic loaders could be introduced to manage coal transfer based on stockpile levels.
3. Implement monitoring tools and dynamic scheduling to identify operational delays and adjust train arrivals according to the loading station's current capacity.

System Dynamics (Stock and Flow)

Ragni et al., (2011) mentioned humans often struggle with dynamic stock and flow tasks due to the complexity of balancing endogenous and exogenous flows, which can be governed by hidden dynamics and computationally complex functions. Fischer & González (2016) emphasize systematic errors, known as SF failure, occur when individuals focus on specific elements rather than the overall system structure. This local processing approach leads to misunderstandings of the system's behavior. The Stock and Flow theory, a fundamental concept within System Dynamics, was developed by Jay W. Forrester with the publication of his seminal work, "*Industrial Dynamics*" (Forrester, 1961). System Dynamics is a methodology used to understand the behavior of complex systems over time, characterized by interdependencies, feedback loops, time delays, and non-linear relationships. The Stock and Flow framework is essential in modeling how quantities accumulate and change within a system, providing insights into the underlying structure that drives system behavior.

Definition and Key Concepts

1. Stocks

   In System Dynamics, stocks represent the accumulated quantities or levels of resources at any given point in time. They can be thought of as the state variables of the system, which store the history of the system's behavior. Stocks change their levels based on the net balance between inflows and outflows, effectively serving as buffers or accumulators within the system.

   Examples of stocks include physical inventories, such as coal stockpiles in a mining operation, the amount of money in a bank account, or even the number of employees in an organization. In each case, the stock represents a quantity that accumulates or depletes over time depending on the rates of addition (inflows) and subtraction (outflows).

   In the context of PT. XYZ's Load Out CHF 3, stocks would specifically refer to the quantities of coal present in different storage locations or transit points. Managing these stocks effectively is crucial to ensuring that coal handling operations run smoothly without bottlenecks or interruptions.

2. Flows

   Flows determine the rate at which stocks increase or decrease over time. They are activities that either add to the stock (inflows) or subtract from it (outflows). Flows are continuous over time and are measured as rates, such as tons of coal per hour, units of inventory per day, or dollars per month.

In practical terms, flows in a coal handling facility could include the rate at which coal is delivered to the stockpiles (inflow) and the rate at which coal is loaded onto trains or barges for shipment (outflow). The balance between these flows determines whether the stock of coal increases or decreases, impacting the overall system's stability and efficiency.

3. Feedback Loops

A feedback loop occurs when a change in a stock influences the flows feeding into or out of that stock, creating a cycle of cause and effect. Feedback loops can be positive (reinforcing) or negative (balancing):

Positive feedback loops amplify changes in the system, leading to exponential growth or collapse. For instance, in a business context, higher sales (stock) can lead to increased production rates (inflow), further boosting inventory.

Negative feedback loops work to stabilize the system by counteracting changes. An example in a coal handling facility could be a situation where excessive coal stockpile levels (stock) trigger a reduction in the loading rate (outflow) to prevent overcapacity.

4. Delays

Delays are the time lags between changes in flows and their effects on stocks. Delays can significantly affect system behavior, often causing oscillations or instability if not properly managed. In industrial processes, delays may result from factors such as transportation times, equipment maintenance schedules, or processing delays.

At PT. XYZ, delays in the transportation of coal or loading onto trains may cause fluctuations in stock levels, making it difficult to maintain a steady flow of operations. Understanding and accounting for these delays are essential for effective capacity planning.

The Dynamics of Stocks and Flows

Effective system dynamics models combine robust stock and flow structures with rich numerical data. Homer, (2019) highlight this combination enhances the model's credibility and allows for compelling conclusions that can influence decision-making and policy.

Figure II.6 Stock And Flow Diagram

(Source: Thinking in Systems: A Primer. Donella H. Meadows (2008) pg. 18)

The interaction between stocks and flows lies at the heart of System Dynamics modeling. The fundamental relationship is that a stock changes over time according to the difference between its inflows and outflows. Mathematically, this relationship is represented by the equation:

$$Stock_t = Stock_{t-1} + (Inflow_t - Outflow_t) \times \Delta t$$

where:

$Stock_t$ is the level of the stock at time t,

$Stock_{t-1}$ is the previous level of the stock,

$Inflow_t$ is the rate of inflow into the stock,

$Outflow_t$ is the rate of outflow from the stock, and

Δt is the time increment over which the changes occur.

This equation illustrates how changes in inflows and outflows determine the accumulation or depletion of a stock over time. When applied to coal handling at PT. XYZ, such modeling can help predict changes in stock levels based on rehandling rates (inflows) and transportation/loading rates (outflows).

Stock and Flow modeling can:

- Visualize Accumulation and Depletion by representing the flow of coal through various stages (from extraction to storage and transportation). The model can identify where bottlenecks may occur. If inflows (coal production) consistently exceed outflows (loading and transport), stockpile levels may grow excessively, indicating a need for capacity adjustments.
- Assists in capacity planning by identifying the ideal inventory levels and flow rates necessary to achieve future production objectives. The simulation of various scenarios, such as heightened coal production or modifications in loading capacity, management is equipped to make well-informed decisions concerning infrastructure investments and operational modifications.
- Comprehending the effects of time delays in transportation or processing on inventory levels facilitates improved scheduling and resource distribution. For example, if a delay in rail transport is anticipated, proactive steps can be implemented to modify loading schedules or effectively manage stockpile capacities.

Conceptual Framework

The conceSptual framework for this research focuses on addressing the constraints and capacity challenges in Load Out CHF 3 at PT. XYZ to meet the ambitious production target of 10 million tonnes by 2026. This framework integrates the Theory of Constraints (TOC) and Stock and Flow Analysis to identify, exploit, and resolve bottlenecks within the system. By analyzing the throughput of key components such as conveyors, surgebins, and train systems, the framework establishes a systematic process to enhance operational efficiency and align the coal handling system with future demands.

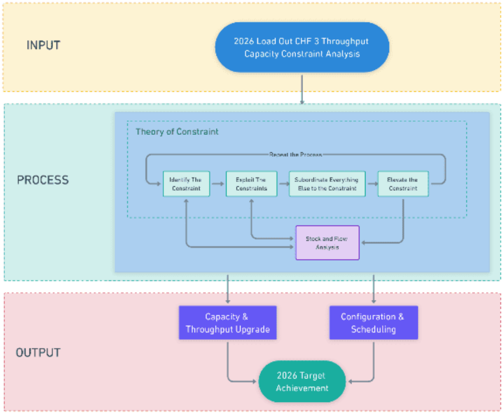


Figure II.7 Conceptual Framework

This framework is divided into three core elements: Input, which involves analyzing the current capacity and constraints of CHF 3; Process, which employs TOC and iterative Stock and Flow Analysis to evaluate and improve system performance; and Output, which translates these findings into actionable strategies such as capacity upgrades and configuration optimizations.

RESEARCH METHODOLOGY

The research design employed in this study is strictly quantitative, focusing on numerical and statistical analysis to draw conclusions about CHF 3's operational efficiency. This desiSgn is structured to investigate the relationship between current system capacity and projected production goals, focusing specifically on the quantitative factors that influence throughput and operational performance.

The quantitative research design consists of several key components:

1. Quantitative Research Approach
   This study employs a quantitative approach. Quantitative research methods are used because the data used is almost entirely operational, in the form of time, duration, throughput and operational procedure data, leveraging numerical data to assess and address operational constraints. The choice of a quantitative design allows for:
   - Objective Evaluation: Measurable performance metrics such as throughput, cycle time, and capacity utilization are analyzed to pinpoint inefficiencies. and avoid subjective opinions and silo mentality from each personnel responsible for each process in the entire supply chain system that we study
   - Data-Driven Decision-Making: This approach supports evidence-based (actual history) recommendations by grounding the analysis in empirical data collected from the facility so that it can reflect actual events in the coal delivery process from Load Out CHF 3 for further analysis.
   - Replicability: Quantitative results provide a repeatable process (cycles) for analyzing constraints, then the values is running can be played back in the next cylce to find another bottleneck.

Sources of Data

Operational Data:

The examination of real-time operational data is crucial for comprehending the daily performance metrics of Load Out CHF 3. The data gathered via the facility's monitoring systems documents essential performance indicators (KPIs). The analysis of these KPIs seeks to pinpoint particular areas within the facility that may contribute to delays or exhibit inefficiencies in operation. This real-time data provides valuable insights into the interactions among various components of the process across different operating conditions, including peak and off-peak hours.

The data analysis method utilizes a structured, quantitative approach, integrating **Excel-based simulation modeling** with the **Theory of Constraints (TOC)** framework and **Stock and Flow Analysis** to address bottlenecks and operational challenges in PT. XYZ's Load Out Coal Handling Facility (CHF) 3. The steps are as follows:

1. **Statistical Analysis**
   - Key performance metrics, such as throughput, cycle time, and capacity utilization, are evaluated using data from Vibrating Feeders, Conveyors (CV04, CV05, CV06), and Train Loading Station (TLS103).
   - Analysis focuses on identifying areas with high capacity utilization or extended cycle times to pinpoint constraints and inefficiencies.

Business Solution

This section provides a detailed and narrative exploration of the critical interventions required to address the key constraints in the Load Out Coal Handling Facility (CHF) 3 at PT. XYZ. The focus is on upgrading the conveyor system and optimizing train scheduling, identified as the two most significant bottlenecks impacting the system's ability to achieve the 2026 throughput target of 10 million tonnes. Guided by the Theory of Constraints (TOC), these solutions are designed to create a seamless and efficient coal handling operation.

1. Conveyor System Upgrade

The conveyor system, comprising CV04, CV05, and CV06, is a crucial component of the Load Out facility, responsible for moving coal from the stockpile to the TLS. Each conveyor operates at a maximum capacity of 1,500 TpH, which is insufficient to meet the future throughput demand of 2,381.24 TpH by 2026. The 37% capacity deficit poses a significant risk to PT. XYZ's ability to meet its production targets, making it imperative to address this bottleneck. To overcome this constraint, a comprehensive upgrade of the conveyor system is proposed. This includes:

1. **Upgrade Drive Systems to Increase Belt Speed:**
   - Existing motors and drive components will be replaced with higher-capacity models to handle increased loads and operational speeds.
   - The current belt speed of 3.76 m/s limits the system to 1,500 TpH. By increasing the belt speed to 5.6 m/s, the conveyor system can achieve a throughput of 2,500 TpH.
   - Energy-efficient motor systems will be incorporated to minimize operational costs and improve sustainability.
2. **Reinforce Structural Components:**
   - Frames, rollers, and bearings will be upgraded to withstand the mechanical strain of higher speeds and increased coal volumes.
   - Wear-resistant materials will be used to enhance the durability of critical components, reducing maintenance frequency and costs.

The upgrading process will be staged to cause least disturbance to present operations. With a 12 to 18 month planned completion time, key benchmarks will be procurement, installation, and testing.

By removing the main throughput barrier, the suggested improvements will let the conveyor system surpass the 2026 production goal. Furthermore, the improved dependability of the system will lower maintenance downtimes, therefore improving general efficiency and reducing costs.

2. Train Scheduling Enhancements

Train scheduling inefficiencies exacerbate operational bottlenecks within the Load Out system. Deviations from standard operating procedures (SOPs), prolonged train queuing, and inconsistent shunting operations contribute to significant delays and disrupt the smooth flow of coal to downstream customers. To address these challenges, the following train scheduling enhancements are proposed:

1. **Dynamic Scheduling and Synchronization**
   - Implement a predictive scheduling system that uses real-time data from TLS103 and train movement systems. This ensures synchronized train arrivals and departures, avoiding congestion and maximizing system flow.
   - Optimize train arrival intervals to align with conveyor output and Weight Bin discharge rates, ensuring continuous coal flow and eliminating idle times.
2. **Improved Train Movement and Loading Operations**
   - Adjust train speeds through TLS103 to match the Weight Bin's rapid discharge capabilities, leveraging the upgraded hydraulic accumulator system for faster gate operations. This supports efficient coal loading and reduces train turnaround times.

- Revise the Standard Operating Procedure (SOP) for Tarahan trains to reflect the increased throughput capacity: 73,2 minutes for 61 Tarahan cars.
- Emphasize operator training to ensure compliance with the revised SOP and improve loading efficiency.

3. Infrastructure and Scalability Enhancements

- Plan for future expansions, including additional train loops, to accommodate increased train frequencies and prevent potential congestion.
- Upgrade signaling and rail switching systems to enhance train flow coordination and operational safety during peak times.

4. Real-Time Monitoring and Performance Metrics

- Deploy an integrated monitoring dashboard for real-time tracking of train schedules, loading operations, and system performance.
- Use advanced analytics, such as machine learning, to predict delays or inefficiencies, enabling proactive scheduling adjustments.
- Track performance indicators like train turnaround time, SOP adherence, and average loading time, using insights to drive continuous improvements.

Implementation Plan and Justification

A phased implementation plan is essential to minimize disruptions during the upgrade:

1. **Phase 1: Engineering and Procurement (Q1-Q2 2025):**
   - List all the upgraded components for the conveyor upgrade and procure upgraded conveyor components.
2. **Phase 2: Installation and Testing (Q2–Q3 2025):**
   - Install and test upgraded systems, starting with conveyors, Weight Bin Accumulator and Actuators enhancements.
3. **Phase 3: Operational Integration (Q4 2025):**
   - Align train schedules, loading protocols, and monitoring systems with the upgraded infrastructure.
4. **Full Deployment (2026):**
   - Achieve seamless operation of the entire Load Out system at **2,500 TpH**, supporting the annual target of **10 million tonnes**.

This project addresses a critical need to optimize the Load Out system (CHF 3) at PT. XYZ to meet the ambitious 2026 production target of **2,381.24 TpH** and an annual coal delivery target of **10 million tonnes**. The urgency of this upgrade stems from the constraints identified in the current infrastructure, including insufficient conveyor capacity, limited Weight Bin efficiency, and train scheduling inefficiencies. By leveraging advanced technologies and operational strategies, this project aims to eliminate bottlenecks, enhance throughput, and align the entire system with future operational demands.

CONCLUSION

This study aimed to identify and address the bottlenecks in the Load Out system at CHF 3 of PT. XYZ, with the objective of achieving the 2026 production target of 2,381.24 TpH and an annual delivery goal of 10 million tonnes. Using the Theory of Constraints (TOC) and Stock and Flow analysis, the research identified three critical constraints: the conveyor system, the Weight Bin operations, and train scheduling inefficiencies.

The analysis demonstrated that the conveyor system, operating at a maximum of 1,500 TpH, was the primary bottleneck limiting throughput. Upgrading the conveyor system to 2,500 TpH was determined to be essential for meeting future production demands. Similarly, enhancements to the Weight Bin's hydraulic system were necessary to align with the increased throughput and ensure rapid discharge of coal into train carriages. Lastly, optimizing train scheduling and revising the Standard Operating Procedures (SOPs) for Tarahan trains were identified as key actions to reduce delays and synchronize operations.

The study concludes that by implementing these upgrades and process optimizations, PT. XYZ can eliminate current constraints, significantly improve system efficiency, and ensure alignment with its strategic production goals for 2026. Furthermore, the phased implementation plan provides a structured roadmap for achieving these objectives while minimizing operational disruptions.

REFERENCES

Affleck, F. (2005). *Exploration of some factors contributing to under-provision of infrastructure capacity: Coal railway networks in Queensland and the Hunter Valley of New South Wales. The University of Western Australia.*

Aryanezhad, M., Badri, S., & Komijan, A. (2010). Threshold-based method for elevating the system's constraint under theory of constraints. *International Journal of Production Research*, 48, 5075 - 5087. https://doi.org/10.1080/00207540903059505.

Chandravan, M. L., & Mukhopadhyay, A. K. (2017). Dynamic analysis of vibratory feeder and their effect on feed particle speed on conveying surface. *Measurement, 101*, 145–156. https://doi.org/10.1016/j.measurement.2017.01.031

Chen, H., Liu, W., Oldache, M., & Pervez, A. (2024). Research on train loading and unloading mode and scheduling optimization in automated container terminals. *Journal of Marine Science and Engineering*, *12*(8), 1415. https://doi.org/10.3390/jmse12081415

Dai, X., Zhao, H., & Chai, T. (2022). Dynamic scheduling, operation control and their integration in high-speed railways: A review of recent research. *IEEE Transactions on Intelligent Transportation Systems*, *23*(9), 14023–14036. https://doi.org/10.1109/TITS.2021.3131202

Fischer, H., & Gonzalez, C. (2016). Making sense of dynamic systems: How our understanding of stocks and flows depends on a global perspective. *Cognitive Science: A Multidisciplinary Journal*, *40*(2), 1–17. https://doi.org/10.1111/cogs.12239

Financial Services Authority (Otoritas Jasa Keuangan). (2017). Regulation No. 51/POJK.03/2017 on implementing sustainable finance for financial services institutions, issuers, and public companies. Jakarta, Indonesia: Financial Services Authority.

Forrester, J. W. (1961). *Industrial dynamics.* MIT Press.

Hendijani, R. (2021). The effect of thinking style on dynamic systems performance: The mediating role of stock-flow understanding. *Journal of Behavioral and Experimental Economics, 95*, 101778. https://doi.org/10.1016/j.socec.2021.101778

Homer, J. (2019). Best practices in system dynamics modeling, revisited: A practitioner's view. *System Dynamics Review, 35*(1). https://doi.org/10.1002/sdr.1630

Jansuwan, S., Chen, A., & Xu, X. (2021). Analysis of freight transportation network redundancy: An application to Utah's bi-modal network for transporting coal. *Transportation Research Part A: Policy and Practice, 151*, 154–171. https://doi.org/10.1016/j.tra.2021.06.019

Katadata. (2024). ESDM setujui 587 RKAB batu bara, rencana produksi 2024: 922 juta ton. Retrieved from https://katadata.co.id/berita/energi/65f9448d64ae7/esdm-setujui-587-rkab-batu-bara-rencana-produksi-2024-922-juta-ton

Lewandowska-Ciszek, A. (2018). Theory of constraints as a stimulus towards warehouse transformation process on the example of the distribution center. *Management and Production Engineering Review*, *9*(4), 96–105. https://doi.org/10.24425/119550

Li, W., Zuo, T., Xu, X., & Song, X. (2021). Bottleneck Identification and Performance Optimization in Coal Terminal Handling System. *2021 6th International Conference on Transportation Information and Safety (ICTIS)*, 1307-1314. https://doi.org/10.1109/ICTIS54573.2021.9798625.

Marinacci, C., Ricci, S., Rizzetto, L., & Lopez Lambas, M. E. (2019). Management and infrastructures in a maritime coal terminal: A decision-making methodology. *WIT Transactions on the Built Environment, 187*, 13–21. https://doi.org/10.2495/MT190021

Masoud, M., Kozan, E., & Liu, S. Q. (2016). A new constraint programming approach for optimising a coal rail system. *Optimization Letters, 10*(5), 971–988. https://doi.org/10.1007/s11590-016-1041-5

Mathu, K. (2014). Logistics implications in the South African coal mining industry supply chain. *Mediterranean Journal of Social Sciences, 5*(20), 2033–2040. https://doi.org/10.5901/mjss.2014.v5n20p503

Meadows, D. H. (2008). *Thinking in systems: A primer.* Chelsea Green Publishing.

Peng, H., Zhou, M., Liu, M., Zhang, Y., & Huang, Y. (2009). A dynamic optimization model of an integrated coal supply chain system and its application. *Mining Science and Technology (China), 19*(6), 842–846. https://doi.org/10.1016/S1674-5264(09)60153-8

Ragni, M., Steffenhagen, F., & Klein, A. (2011). Generalized dynamic stock and flow systems: An AI approach. *Cognitive Systems Research*, 12, 309-320. https://doi.org/10.1016/j.cogsys.2010.12.008.

Sarkar, B. D., & Shankar, R. (2021). Understanding the barriers of port logistics for effective operation in the Industry 4.0 era: Data-driven decision making. *International Journal of Information Management Data Insights, 1*(2), 100031. https://doi.org/10.1016/j.jjimei.2021.100031

Stefano, G. D. S., Lacerda, D. P., Morandi, M. I. W. M., Cassel, R. A., & Denicol, J. (2024). How important is the theory of constraints to supply chain management? An assessment of its application and impacts. *Computers & Industrial Engineering, 198*, 110717. https://doi.org/10.1016/j.cie.2024.110717

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world.* McGraw-Hill.

Watson, K. J., Blackstone, J. H., & Gardiner, S. C. (2007). The evolution of a management philosophy: The theory of constraints. *Journal of Operations Management, 25*(2), 387–402.

Woeppel, M. (2000). *Manufacturing at warp speed: Optimizing supply chain financial performance.* CRC Press.

Yu, Z., Li, Z., & Ma, L. (2023). Strategies for the resilience of power-coal supply chains in low-carbon energy transition: A system dynamics model and scenario analysis of China up to 2060. *Sustainability, 15*(9), 7154. https://doi.org/10.3390/su15097154

Zhao, L., & Lin, Y. (2011). Operation and maintenance of coal handling system in thermal power plant. *Procedia Engineering, 26*, 2032–2037. https://doi.org/10.1016/j.proeng.2011.11.240

Zonailo, G. W. (2013). Transportation by rail and sea in the coal industry. *Woodhead Publishing Series in Energy*. https://doi.org/10.1533/9780857097309.3.705