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Optimization of Coal Distribution System to Minimize Export Shipment Delays †

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Abstract

Coal distribution is crucial in Indonesia's mining industry. Due to the country's complex archipelagic geography, coal distribution has become a challenge for the mining industry. As one of the coal mining companies, XYZ company, which is located in South Sumatera, Indonesia, has experienced export shipment delays due to the reliance on transportation modes in the area. Therefore, we developed a coal distribution system which considers multimode transportation options using mixed integer linear programming to minimize delays and transportation cost. Based on the results, the distribution delays were reduced, as well as the transportation cost related to penalty of the delays.

Keywords: coal distribution; mixed integer linear programming (MILP); trucks; train; Port SDJ; port TAA; shipment delay; export deadline; penalty

1. Introduction

Indonesia's mining sector plays a vital role in the national economy, with coal serving as one of its primary export commodities. However, the country's archipelagic structure—comprising over 17,000 islands—poses significant logistical challenges. Poor multimodal integration significantly increases Indonesia's logistics costs [1].

PT XYZ, a mining company based in South Sumatra, currently employs a single-mode distribution system. Coal is transported from the mining pit to a stockpile at KM 36, then hauled via dump truck to Port SDJ. From there, it is shipped by barge to the anchorage point at Muara Tanjung Kampeh. Figure 1 shows the geographic layout of the coal logistics network, including the mining pit, the stockpile, and both ports (SDJ and TAA). The distances and travel paths between the origin and each port are compared to demonstrate the potential time advantage of using Port TAA due to its closer proximity to the anchorage.

The total transportation time includes approximately 18 h of sailing time, which is a problem because a lengthy route often results in shipment delays, port congestion, and financial penalties due to missed delivery deadlines [2]. Figure 2 illustrates several trips during a specific month in 2025. To address these issues, we developed a multimodal distribution strategy by integrating railway transport from the stockpile to Port TAA, which is closer to the anchorage point. The redesigned system is expected to improve efficiency, reduce total shipment time, and minimize the risk of late deliveries [3]. Figure 2 also illustrates the diagram of delays for the actual delivery time from the delivery deadline.

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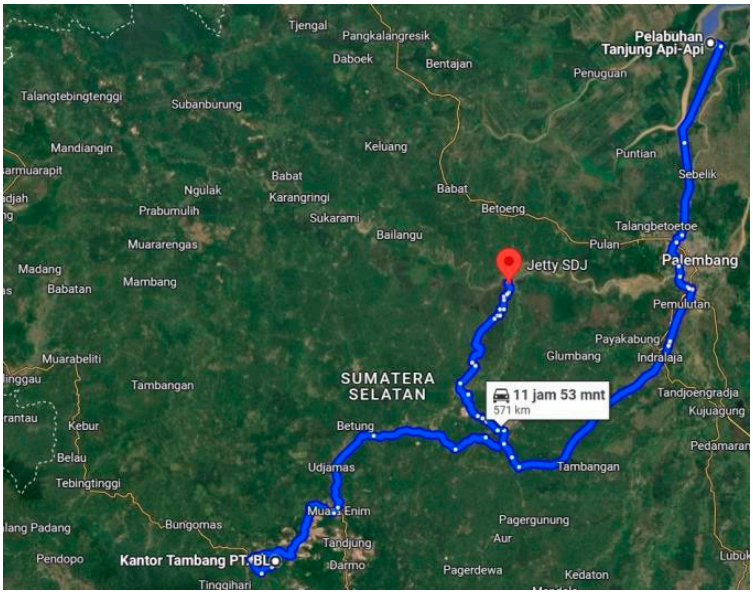


Figure 1. Coal logistics network of PT XYZ.

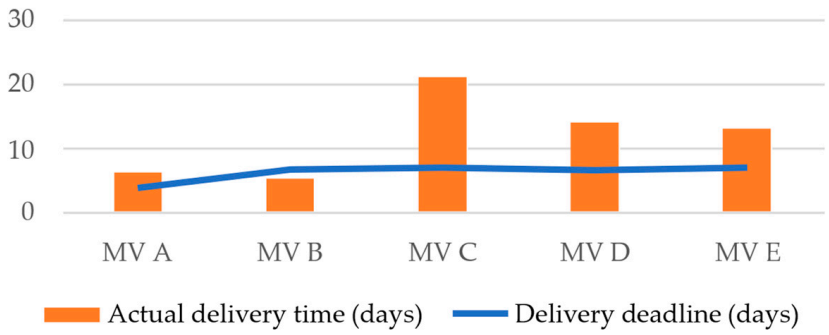


Figure 2. Delays of delivery time from delivery deadline.

We developed a mixed integer linear programming (MILP) model that optimally allocates coal volumes between the two transport routes and evaluates the benefits of the proposed dual-mode distribution approach in achieving timely exports.

2. Literature Review

Wicaksono et al. [4] explored the use of MILP in optimizing power generation schedules, showing relevance for coal logistics planning. Cao [5] and Wang and Han [6] discussed transportation algorithms using AI and ant colony optimization. Gao [7] and Bodhi et al. [8] supported the importance of optimization algorithms in improving routing decisions, especially in dynamic environments. Hevlie et al. [9] developed a route optimization model using linear programming for coal transportation in Indonesia. Prasetyo et al. [3] assessed productivity factors of heavy equipment used in coal mining, showing that transportation modes impact operational efficiency.

Chopra and Meindl [10] emphasized the strategic role of supply chain planning and its alignment with logistical execution. Suseno [11] analyzed internal and external delay factors in coal transportation, aligning with the operational issues faced by PT XYZ. Sariguna and Kennedy [12] explained that high logistics costs in Indonesia are strongly tied to long dwelling times and infrastructure issues. Nisa et al. [2] found that industrial concentration and high input costs decrease coal efficiency. Iskandar and Arifin [13] emphasized the importance of data-driven analysis for improving logistics performance across regions

in Indonesia. Rafi [14] further supports the need for a structured multimodal model in archipelagic nations like Indonesia.

While previous studies focused on general optimization methods, infrastructure limitations, or transportation cost efficiency, this research aims to address shipment timeliness by integrating multiple transport modes—truck and railway—into a dual-port dispatching system. The novelty lies in combining operational scheduling and port selection under MILP formulation to minimize total shipment duration, especially in the context of export readiness for coal logistics.

3. Problem Identification

The coal distribution problem at PT XYZ is modeled as an MILP optimization problem, which enables the selection of the most efficient transport mode combination (trucks and trains) for each shipment request. The solution helps minimize the total delivery time to the mother vessel by considering transport capacities, travel duration, number of vehicles, loading time, and sailing time to the anchorage point.

In this model, the main decision variables include the volume of coal allocated for delivery to Port SDJ using trucks and to Port TAA using trains, as well as the number of barges used from each port. The objective function was formulated to minimize the total delivery time, subject to constraints such as vehicle capacity, barge limits, delivery deadlines, and total demand fulfilment. This model supports efficient and timely routing decisions that help avoid delays and reduce penalty costs. Table 1 shows the sets, parameters, and variables defined in this study.

Table 1. Sets, parameters, and variables defined in this study.

Parameters	
D	Total coal demand in tons
C_{truk}	Truck capacity in tons/unit
C_{ka}	Train capacity in tons/carriage
$C_{tongkang}$	Barge capacity in tons/unit
R	Loading rate in tons/hour
T_{sdj}	Sailing time from Port SDJ to Anchorage in hours
T_{taa}	Sailing time from Port TTA to Anchorage in hours
M_{truk}	Maximum truck units in the deadline period
M_{ka}	Maximum train cars in a deadline period
$M_{tongkang}$	Maximum total barges available
T_{max}	Maximum time limit for shipment delivery
Variables	
x_1	Volume of coal shipped by truck to Port SDJ (tons)
x_2	Volume of coal shipped by rail to Port TTA (tons)
t_{sdj}	Number of barges from Port SDJ
t_{taa}	Number of barges from Port TTA

The objective function of this model (Equations (1)–(8)) is used to minimize the total shipment time. The objective function in this model, as formulated in Equation (1), minimizes the total coal shipment time to the mother vessel through two main transportation modes, namely dump trucks and trains. This function considers eight main constraints. The first constraint in Equation (2) ensures that the coal shipped via trucks and trains must be equal to the total demand of the mother vessel. The second constraint in Equation (3) limits the number of truck trips based on the mode capacity and the maximum number of units available during the deadline time. The third constraint in Equation (4) has the same function as the second constraint, but it applies to the rail transportation mode. The fourth constraint in Equation (5) ensures that the number of barges from Port SDJ is sufficient to

transport the volume of coal shipped. The fifth constraint is in Equation (6), which has the same function as the fourth constraint but applies to Port TTA. The sixth constraint in Equation (7) has the function of ensuring that the barge units at SDJ and Port TTA do not exceed the total barge limit. The seventh constraint in Equation (8) has the function of ensuring that the total time (sailing and loading) does not exceed the given deadline.

$$\min Z = t_{sdj} T_{sdj} + t_{taa} T_{taa} + \frac{x_1 + x_2}{R} \quad (1)$$

$$x_1 + x_2 = D \quad (2)$$

$$\frac{x_1}{Ctruk} \leq M_{truk} \quad (3)$$

$$\frac{x_2}{Cka} \leq M_{ka} \quad (4)$$

$$t_{sdj}. C_{tongkang} \geq x_1 \quad (5)$$

$$t_{taa}. C_{tongkang} \geq x_2 \quad (6)$$

$$t_{sdj} + t_{taa} \leq M_{tongkang} \quad (7)$$

$$t_{sdj} \, T_{sdj} + t_{taa.} \, T_{taa} + \frac{x_1 + x_2}{R} \leq T_{max} \quad (8)$$

4. Experiment

The data set used in this study was obtained from PT XYZ's historical shipment records, including shipment volumes, delivery deadlines, sailing duration, and penalty costs. These data were used to define parameters for the MILP model. The model was input into Gurobi Solver, translating the mathematical formulation into code using decision variables, constraints, and an objective function. After solving, the tonnage allocation results for each buyer were obtained. Based on these results, further scheduling was conducted to divide the shipments into delivery shifts using trucks for Port SDJ and trains for Port TAA, ensuring all deliveries align with operational capacity and time constraints. Using the Gurobi Solver, we simulated five scenarios as follows.

4.1. Mother Vessel A

The modeling results showed that the coal volume of 27,500 tons was divided into two distribution channels. A total of 15,000 tons was sent using truck mode to Port SDJ, while 12,500 tons was sent by train mode to Port TTA. The number of barges used at each port is two units. Based on the result in Figure 3, the export shipment process from Ports SDJ and TTA to the anchorage point where the mother vessel docks takes 59.33 h. This duration encompasses the transportation and loading of coal onto the barge, as well as the sailing time to the anchorage point. The total time remains within the buyer's export shipment deadline of 3.5 days (84 h), ensuring that PT XYZ avoids further delays in export operations. The transportation details for each mode are outlined in Table 2.

```
Status: Optimal
Volume via Truk (SDJ): 15000.00 ton
Volume via KA (TAA): 12500.00 ton
Tongkang SDJ: 2
Tongkang TAA: 2
Total Waktu: 59.33 jam
```

Figure 3. Results of Mother Vessel A.

Table 2. Results of logistics using truck and train.

Mode	Volume (tons)	Total Unit	Cost per Unit (USD)	Total Cost (USD)	Loading Time (hour)	Number of Shifts
Truck	15,000	500	255	127,907.67	500	167
Train	12,500	250	8	1,983.61	416.67	139

4.2. Mother Vessel B

The model calculations in Figure 4, showed that coal volumes were distributed through two channels: truck transport to Port SDJ and rail transport to Port TTA. A total of 53,785 tons was allocated, with 30,000 tons delivered by truck to Port SDJ and 23,785 tons by train to Port TTA. Four barges are employed at each port to transport coal to the anchorage point, where the buyer's mother vessel docks. Based on the results in Table 3, the combined loading and sailing process requires 117.86 h, remaining within the buyer's shipment deadline of 6.6 days (158.4 h). Consequently, PT XYZ avoids delays in export operations.

```
Status: Optimal
Volume via Truk (SDJ): 30000.00 ton
Volume via KA (TAA): 23785.00 ton
Tongkang SDJ: 4
Tongkang TAA: 4
Total Waktu: 117.86 jam
```

Figure 4. Results of Mother Vessel B.

Table 3. Results of logistics using truck and train.

Mode	Volume (tons)	Total Unit	Cost per Unit (USD)	Total Cost (USD)	Loading Time (hour)	Number of Shift
Truck	30,000	1000	255	255,815.39	1000	334
Train	23,800	476	8	3,776.79	793.33	265

4.3. Mother Vessel C

The coal volume totals 55,000 tons, divided into 30,000 tons by truck to Port SDJ and 25,000 tons by train to Port TTA. Again, four barges were used at each port. Based on the calculation in Figure 5, the shipping process to the anchorage point took 118.67 h, which is below the buyer's deadline of 6.9 days (165.6 h), ensuring timely delivery. Overall results for each transportation mode are outlined in Table 4.

```
Status: Optimal
Volume via Truk (SDJ): 30000.00 ton
Volume via KA (TAA): 25000.00 ton
Tongkang SDJ: 4
Tongkang TAA: 4
Total Waktu: 118.67 jam
```

Figure 5. Results of Mother Vessel C.

Table 4. Results of logistics using truck and train.

Mode	Volume (tons)	Total Unit	Cost per Unit (USD)	Total Cost (USD)	Loading Time (hour)	Number of Shift
Truck	30,000	1000	255	255,815.39	1000	334
Train	25,000	500	8	3,967.22	833.33	278

4.4. Mother Vessel D

This scenario involved 53,650 tons, with 30,000 tons transported by truck to Port SDJ and 23,650 tons by train to Port TTA in Table 5. Based on the calculations in Figure 6, Four barges were utilized at each port, and the shipping process requires 117.77 h. This duration remained within the buyer's deadline of 6.5 days (156 h), preventing delays in export.

Table 5. Results of logistics using truck and train.

Mode	Volume (tons)	Total Unit	Cost per Unit (USD)	Total Cost (USD)	Loading Time (hour)	Number of Shift
Truck	30,000	1000	255	255,815.39	1000	334
Train	23,650	473	8	3,752.99	788.33	263

```
Status: Optimal
Volume via Truk (SDJ): 30000.00 ton
Volume via KA (TAA): 23650.00 ton
Tongkang SDJ: 4
Tongkang TAA: 4
Total Waktu: 117.77 jam
```

Figure 6. Results of Mother Vessel D.

4.5. Mother Vessel E

In the 55,000-ton scenario presented in Table 6, 30,000 tons were sent by truck to Port SDJ and 25,000 tons by train to TTA. Four barges were employed at each port. The shipping process took 118.67 h, which is below the buyer's deadline of 6.9 days (165.6 h) shown in Figure 7, thereby ensuring compliance with export schedules.

Table 6. Results of logistics using truck and train.

Mode	Volume (tons)	Total Unit	Cost per Unit (USD)	Total Cost (USD)	Loading Time (hour)	Number of Shift
Truck	30,000	1000	255	255,815.39	1000	334
Train	25,000	500	8	3,967.22	833.33	278

```
Status: Optimal
Volume via Truk (SDJ): 30000.00 ton
Volume via KA (TAA): 25000.00 ton
Tongkang SDJ: 4
Tongkang TAA: 4
Total Waktu: 118.67 jam
```

Figure 7. Results of Mother Vessel **B**.

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5. Discussion and Analysis

Simulation results for five shipments to MV A through MV E demonstrated that all distribution scenarios achieved delivery times within the deadlines specified by each buyer. Under the developed system, no delays occurred, in contrast to the existing system, where PT XYZ experienced significant lateness, such as the 13-day delay recorded for MV C. These findings confirm that the developed MILP model effectively mitigates the risk of delays and enhances scheduling reliability for international buyers.

The MILP model enables optimized scheduling and load allocation across two transport modes. Compared with the current truck-only system, its dual-mode approach reduces sailing time, alleviates port congestion, and addresses truck operating constraints. Rail transport to Port TAA substantially decreases barge travel, thereby supporting timely deliveries and lowering costs. Results further indicate that the new routing scheme reduces total logistics expenses and operational risks associated with late penalties. Table 7 presents a comparison of distribution costs between the existing system and the proposed dual-mode system for each buyer.

Table 7. Comparison of distribution costs.

Buyer	Demand	Existing Cost (USD)	Proposed Cost (USD)
MV A	27.500	234,497.44	129,891.32
MV B	53.785	458,634.36	259,592.19
MV C	55.000	468,994.89	259,782.64
MV D	53.650	457,483.20	259,568.38
MV E	55.000	468,994.89	259,782.64

6. Conclusions

The developed MILP model for the effective coal distribution of PT XYZ minimizes delivery delays and optimizes transport costs. The integration of trucks and trains facilitates efficient shipment allocation, yielding significant cost savings and eliminating penalty risks. Overall, the model provides an effective decision-support tool for enhancing coal export performance under multimodal transport constraints.

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References

1. Rachman, I.N.A.; Alexander, S.W.; Latjandu, L.D. Analisis Break Even Point sebagai Alat Perencanaan Laba pada CV Angin Mamiri Bitung. *Manaj. Bisnis Dan Keuang. Korporat* **2024**, *2*, 236–247. [CrossRef]
2. Nisa, A.K.; Robiani, B.; Mukhlis, M.; Teguh, M. Pengaruh Konsentrasi Industri dan Biaya Input Terhadap Efisiensi di Industri Produk dari Batu Bara (KBLI 19100). *J. Èkon. dan Bisnis Dharma Andalas* **2024**, *26*, 235–244. [CrossRef]

3. Prasetyo, Y.T.; Paradise, M.; Mukarrom, F. Productivity Assessment of Digging and Loading Equipment (Cat 330D2L) and Hauling Equipment (Fuso 220PS) in Coal Mining at PT. Bhumi Sriwijaya Perdana Coal, Musi Banyuasin Regency, South Sumatra. *Indones. J. Earth Sci.* **2024**, *4*, A1226. [CrossRef]
4. Wicaksono, A.; Wibowo, R.S.; Negara, I.M.Y. Optimasi Perencanaan Operasi Pembangkit Listrik Berbasis Mixed Integer Linear Programming (MILP) Pada Sistem Isolated Selayar. *INTECOMS J. Inf. Technol. Comput. Sci.* **2024**, *7*, 727–737. [CrossRef]
5. Cao, J. Mathematical Model and Algorithm of Multi-Index Transportation Problem in the Background of Artificial Intelligence. *J. Adv. Transp.* **2022**, *2022*, 3664105. [CrossRef]
6. Wang, Y.; Han, Z. Ant colony optimization for traveling salesman problem based on parameters optimization. *Appl. Soft Comput.* **2021**, *107*, 107439. [CrossRef]
7. Gao, W. New Ant Colony Optimization Algorithm for the Traveling Salesman Problem. *Int. J. Comput. Intell. Syst.* **2020**, *13*, 44. [CrossRef]
8. Bodhi, G.; Charleen; Fitrianah, D. Ant Colony Optimization for Jakarta Historical Tours: A Comparative Analysis of GPS and Map Image Approaches. *J. RESTI (Rekayasa Sist. dan Teknol. Inf.)* **2025**, *9*, 153–165. [CrossRef]
9. Nazry, H.W.N.S.; Riza, F.; Rizky, F.; Gultom, Z.A.; Haris, M.; Barus, M.D.B. Model Optimasi Model Optimasi Rute Transportasi Berbasis Pemrograman Linear. *J. Sist. Inf. Triguna Dharma (JURSI TGD)* **2025**, *4*, 75–81. [CrossRef]
10. Chopra, S.; Meindl, P. *Supply Chain Management: Strategy, Planning, and Operation*; Pearson: London, UK, 2016; [Online]. Available online: https://books.google.co.id/books?id=m1XFoQEACAAJ (accessed on 3 February 2024).
11. Suseno, T. Analisis pola distribusi logistik dan infrastruktur batubara untuk PLTU skala kecil. *J. Teknol. Miner. dan Batubara* **2017**, *13*, 53–72. [CrossRef]
12. Kennedy, P.S.J. ANALISIS TINGGINYA BIAYA LOGISTIK DI INDONESIA DITINJAU DARI DWELLING TIME. *J. Econ. Resour.* **2019**, *1*, 136–145. [CrossRef]
13. Iskandar, T.; Arifin, R. NAVIGATING INDONESIA'S LOGISTICS AND SUPPLY CHAIN CHALLENGES: A DATA-DRIVEN ANALYSIS OF LOGISTICS PERFORMANCE INDEX. *J. BPPK Badan Pendidik. dan Pelatih. Keuang.* **2023**, *16*, 110–123. Available online: https://api.semanticscholar.org/CorpusID:266355010 (accessed on 3 February 2024). [CrossRef]
14. Rafi, S. Preliminary model development for archipelago country logistic system. *J. Manaj. Strat. dan Apl. Bisnis* **2024**, *7*, 161–172. [CrossRef]

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