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Supply Chain Network Optimization Model on Cement Industry to Minimize Distribution Costs in the Sumatra Island, Indonesia

Dwi Wulandari[1], Iwan Vanany[2]

[1,2] Department of Industrial and System Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

ABSTRACT: Supply Chain Management (SCM) plays an important role in maintaining operational cost efficiency and customer satisfaction. However, the challenges faced by companies in managing the supply chain are increasingly complex due to changes in the dynamic global business environment. One industry that experiences these challenges is the cement industry. To maintain supply chain performance, PT. XYZ implemented an acquisition strategy in cement companies in the Sumatra region to maintain its effectiveness in the region, but cement distribution in the Sumatra region still shows an imbalance. The main objective of this study is to minimize distribution costs from production facilities to Sumatra Island as a market. The researcher used the MILP method with Lingo 21 software to create an optimal distribution system optimization model. The results of the analysis show that the application of the optimization model can significantly improve system performance. In terms of utilization, there was a more even redistribution of production loads between facilities, as well as increased capacity utilization in facilities that were previously less than optimal. Meanwhile, in terms of costs, the total supply chain costs were successfully reduced by 4% or around 451 billion rupiah, which came from production cost efficiency of 3% and distribution of 7%. The highest efficiency was recorded in the distribution process from the cement plant to the packing plant which reached 44%.

KEYWORDS: Cement Industry, Distribution Cost, MILP, Multi-Product Logistic, Optimization Distribution

I. INTRODUCTION

Supply Chain Management (SCM) is a network of organizations, people, activities, information, and resources involved in the process of planning, manufacturing, and distributing products or services from raw material suppliers to end consumers (Abbaspour, 2019). In the era of globalization, *an effective and efficient supply chain* is essential for companies to achieve competitive market advantages, such as managing information flows, physical products, customer satisfaction and operational cost efficiency (Chopra & Meindl, 2016; Crandall et al., 2015). However, the challenges faced by companies in managing *the supply chain* are increasingly complex due to dynamic changes in the global business environment (Agarwal et al, 2022). These challenges include demand uncertainty that can lead to excessive supply accumulation, competitive market prices, fluctuations in raw material prices (Shahbaz et al., 2019). One of the industries that experienced these challenges was the cement industry.

The cement industry is one of the industrial sectors that has a vital role in infrastructure development in Indonesia, such as the construction of buildings, bridges, and other facilities. PT. XYZ is one of the multinational companies in the cement industry in Indonesia that plays an important role in meeting the domestic cement market share. With its presence in various regions, PT. XYZ faces significant complexity in managing its supply chain to ensure its products reach the market in a timely, well-conditioned, cost-efficient manner of distribution. It is known that the cement market in Indonesia has been oversupplied since 2014. The increase in supply is also due to the existence of 15 new cement industry companies with a capacity of 1.7 – 4.4 million tons of cement per year. This condition has resulted in a decrease in the utilization rate of the cement industry in Indonesia. In addition, PT. XYZ in 2023 reached 24.75% of the cost of revenue due to a suboptimal distribution system.

To managed supply chain performance, PT. XYZ implemented a strategy with the acquisition of cement companies in several regions such as Java and Sumatra in 2019 so that it can remain the main company in cement supply in Indonesia. Although cement companies in the Sumatra region have been acquired by PT. XYZ, the distribution of cement supply and demand is still unbalanced. It is known that the Sumatra region still needs supplies from existing supplier facilities in Java with capacity and has an impact on increasing logistics costs. This is due to the geographical characteristics of Sumatra which has a large landscape, uneven infrastructure, and the level of logistics connectivity between regions that is still developing. The imbalance between supply and demand capacity in the Sumatra region makes this region a strategic focus in research.

Thus far, the optimization model-based approach has been widely used in problems in the field of distribution or supply chain. One of the most widely adopted methods in the development of optimization models is Mixed Integer Linear Programming (MILP) (Temiz et al., 2020). This method is able to handle mathematical problems involving a combination of discrete and continuous variables, with objective function structures and linear constraints (Klibi et al., 2010). The advantage of MILP lies in its flexibility in formulating various complex problems in a real context, such as production planning, warehouse location determination, distribution scenario selection, operational cost management, delivery time, inventory management, resource allocation, facility location determination, to routing and scheduling problems (Pacharatham et al., 2023; Reyes et al., 2016). This appearances that MILP is an adaptive and relevant optimization framework to address challenges in data-driven planning and decision-making, especially in dynamic industrial sectors such as the cement industry. According to Jeremy, et al (2023), using MILP for logistics network design in the dairy milk industry aims to minimize total distribution costs, reduce carbon emissions and food waste. The results showed that the use of the MILP model affected the increase in total costs, improved the efficiency of the terminals of each distribution, and the transportation network.

In conclusion, this study aims to solve the problems of cement companies by considering strategic locations for distribution centers to reduce cement supply chain costs. This research focuses on the distribution of OPC and PCC cement products of PT. XYZ in regions 1 and 2, namely the Sumatra region. The researcher researched the downstream segment of the supply chain, which includes all activities of delivering cement products to end customers. This activity includes production, distribution, transportation, and after-sales services. The main goal of this research is to increase the company's profits by reducing supply chain costs. This is expected to be achieved through the improvement of the distribution system. The researcher used the MILP method to create a distribution system optimization model that can reduce the company's operating expenses and increase the company's profits.

II. LITERATURE REVIEW

A. Supply Chain Management dan Metode Mixed Integer Linear Programming

In business management, the implementation of effective supply chain management is oriented towards optimizing assets, product flow, information, and finance. This aims to maximize the overall supply chain surplus (Chopra & Meindl, 2016). The flow of goods that flows from upstream to downstream, i.e. raw materials sent by suppliers and then processed, assembled, and packaged into finished products that are ready to be shipped to consumers. The flow of money moves from consumers to suppliers in the form of payments for products purchased. Information flows, which play an important role in driving the other two streams, can occur in two directions: from upstream to downstream and vice versa. The design of the supply chain network is a strategic decision that determines the physical layout and overall infrastructure of the supply chain. This decision has a long-term impact on the company and involves the selection of supply source locations, production facilities, warehouses, and distribution centers (Papageorgiou et al., 2008). The main goal of network design is to minimize the annual total cost of the supply chain, which includes procurement and production costs, inventory storage, facilities (fixed costs, storage, and handling), and transportation. In supply chain management, the selection of transportation modes and delivery strategies involves consideration of the trade-off between cost and speed of response. Prioritizing high speeds can result in cost spikes, especially when shipping volumes are small and economies of scale are not achieved. In addition, cargo also affects the choice of transportation mode with consideration between the value of goods and their weight (Pujawan & Mahendrawati, 2017).

The Mixed Integer Linear Programming (MILP) algorithm is one of the variants of LP in which some or all of its variables are delimited as integer numbers. The use of the MILP technique is necessary when binary variables or integers are included in the optimization problem. For example, in an intelligent charging scheme, the charging status, discharging, and driving of an EV can be represented by binary values. The advantage of MILP lies in its flexibility in formulating various complex problems in a real context, such as production planning, warehouse location determination, distribution scenario selection, operational cost management, delivery time, inventory management, resource allocation, facility location determination, to routing and scheduling problems (Pacharatham et al., 2023; Reyes et al., 2016).

B. Condition of the Cement Industry Supply Chain in Indonesia

Cement is one of the most widely used materials for infrastructure development in line with the growth of the population in Indonesia. The use of cement as a concrete constituent has grown rapidly since the second half of the 20th century (Kristanto et al., 2024). In Indonesia, the construction industry is growing rapidly due to large-scale infrastructure development projects and the expansion of urban areas that require residential housing. However, problems also come from the imbalance between production capacity and regional demand often causes excess capacity in some regions, while in other regions there is a shortage of supply. This leads to inefficiencies in distribution and high logistics costs.

The cost of the cement supply chain is one of the dignified stages in the cement industry supply chain. Supply chain costs are defined as all costs incurred related to activities in the supply chain of a company or organization including logistics costs associated with distribution, transportation, and warehousing costs (Lapinskaitė & Kuckailytė, 2014). Cement distribution plays an important role in the overall supply chain of the cement industry, this is because cement distribution involves significant costs. One of the cement industries in the 2023 report is known that the distribution cost of cement products reaches 24.75%. This figure shows that distribution activities significantly contribute to overall costs. So that cement distribution optimization is one of the important strategies in reducing overall supply chain costs.

III. RESEARCH METHODOLOGY

This study uses a quantitative approach with *the Mixed Integer Linear Programming* (MILP) method to minimize the total distribution cost in the cement supply chain network in the Sumatra region The data used includes the type of cement used, the production and supply capacity of the *cement plant* (CP), the demand needs in each destination district, transportation costs between nodes, and the structure of the distribution network that includes the line from CP to *grinding plant* (GP), from CP to *packing plant* (PP), and from CP/GP/PP to districts.

After all the necessary data has been collected, the second stage is the preparation of a mathematical model using the MILP approach to solve the transshipment problem, which is the problem of distributing goods that involves shipping through several intermediate points. This model was developed to represent multi-stage distribution flows in complex cement supply chain networks. Notation, objective functions, and constraint have been identified. The third stage is the development of an optimization model using LINGO software. This software is used to complete model formulation to obtain optimal solutions based on the objective function of minimizing distribution costs.

Furthermore, model verification is carried out to minimize errors in the mathematical model formulation input process in the Lingo 21 software. The model will be run and analyzed whether the value of the operation result between the parameter and the variable is correlated and meets the constraints that have been set. The process continues with validation using a sensitivity test to find out whether the data and models have met the problem of supply chain network design including data consistency, the output produced can explain the problem. Finally, the output solver will be analyzed which includes comparing the total distribution cost of the actual (existing) system with the cost generated from the optimization model. This step aims to measure the potential efficiency and savings that can be achieved if the developed model is applied in real operations.

IV. MODEL FORMULATION

The distribution of cement in the Sumatra region uses ship and or truck transportation modes. Ships are used to transport bulk cement from the factory to the packing plant as a transhipment facility, and trucks are used to transport cement bags and/or bulk cement from CP or GP/PP to the marketing city. Within the scope of this research, there are 2 types of cement, 4 cemen plants, 2 griding plants, 4 packing plants, and 126 marketing cities. In the preparation of this distribution model, it is assumed that all types of roads that connect distribution points can be passed by distribution vehicles such as trucks and cement transport ships from the Narogong Cement Plant (CP). This model does not take into account any disturbances to road conditions such as congestion or road damage. Thus, the delivery process is assumed to run smoothly without infrastructure obstacles that can affect the vehicle's travel time. The modeling notation in detail can be illustrated as follows.

Indeks:

i: types of cement, $n \forall P \ (n = 2 \ unit)$

j: cement plant, $n \forall J \ (n = 1, \ldots, 4 \ unit)$

k: griding plant, $n \forall K \ (n = 1{,}2 \ unit)$

l: packing plant, $n \forall L \ (n = 1, \ldots, 4 \ unit)$

n: marketing district, $n \forall N \ (n = 1, \ldots, 126 \ distrik)$

Parameters:

c_{ij}^{P} : production cost of cement i in cement plant j (Rp/Ton)

c_{ik}^{P} : production cost of cement i in griding plant k (Rp/Ton)

c_{il}^{P} : production cost of cement i in packing plant l (Rp/Ton)
c_{ijk}^{D} : production cost of cement i from cement plant j to griding plant k (Rp/Ton)
c_{ijl}^{D} : production cost of cement i from cement plant j to packing plant l (Rp/Ton)
c_{ijn}^{D} : distribution cost of cement i from cement plant j to marketing district n (Rp/Ton)
c_{ikn}^{D} : distribution cost of cement i from griding plant k to marketing district n (Rp/Ton)
c_{iln}^{D} : distribution cost of cement i from packing plant l to marketing district n (Rp/Ton)
D_{in} : demand of cement i on marketing district n
Cp_{ij} : production capacity of cement i in cement plant j
Cp_{ik} : production capacity of cement i in griding plant k
Cp_{il} : production capacity of cement i in packing plant

Outcome variables:

x_{ijk} : the amount of cement *volume i* sent from *cement plant j* to *griding plant k*
x_{ijl} : the amount of cement *volume i* sent from *cement plant j* to *packing plant l*
x_{ijn} : the amount of cement *volume i* sent from *cement plant j* to distrik pemasaran *n*
x_{ikn} : the amount of cement *volume i* sent from *griding plant k* to distrik pemasaran *n*
x_{iln} : the amount of cement *volume i* sent from *packing plant l* to distrik pemasaran *n*
Y_k : griding plant k remains in operation if it is valued at 1 and vice versa if it is valued at 0
Y_l : packing plant l remains in operation if it is valued at 1 and vice versa if it is valued at 0

The objective function of this study is to minimize the cost of the cement supply chain illustrated in equation 4.1. The equation has components consisting of production costs, distribution costs between supply facilities, distribution costs of supply facilities to the location of the marketing district.

$$\begin{aligned} Min\ Z1 = & \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{k=1}^{2} x_{ijk}\,c_{ij}^{P} + \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{l=1}^{4} x_{ijl}\,c_{ij}^{P} + \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{n=1}^{126} x_{ijn}\,c_{ij}^{P} + \sum_{i=1}^{1}\sum_{k=1}^{2}\sum_{n=1}^{126} x_{ikn}\,c_{ik}^{P} \\ & + \sum_{i=1}^{1}\sum_{l=1}^{9}\sum_{n=1}^{126} x_{iln}\,c_{il}^{P} + \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{k=1}^{2} x_{ijk}\,c_{ijk}^{D} + \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{l=1}^{4} x_{ijl}\,c_{ijl}^{D} + \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{n=1}^{126} x_{ijn}\,c_{ijn}^{D} \\ & + \sum_{i=1}^{1}\sum_{k=1}^{2}\sum_{n=1}^{126} x_{ikn}\,c_{ikn}^{D} + \sum_{i=1}^{1}\sum_{l=1}^{4}\sum_{n=1}^{126} x_{iln}\,c_{iln}^{D} \qquad (3.1) \end{aligned} \quad (4.1)$$

Constraints in this study are limitations on the production capacity of cement zak in each supply facility, the fulfillment of demand for cement zak in each marketing district, and the constraint of non-negativity. The function of the constraint will be described in detail as follows:

1. Production capacity in supply facilities

The volume of cement sent from the cement plant to the griding plant, packing plant, and marketing district must not exceed the production capacity of the cement plant. The constraint is illustrated in equation 4.2. Meanwhile, the amount of cement volume sent from the griding plant, packing plant, to the marketing district must not exceed the capacity of the griding plant, packing plant. The constraint is illustrated in equation 4.3.

$$\sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{k=1}^{2} x_{ijk} + \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{l=1}^{4} x_{ijl} + + \sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{n=1}^{126} x_{ijn} \leq Cp_{ij} \quad ,\forall i, \forall j \qquad (4.2)$$

$$\sum_{i=1}^{1}\sum_{k=1}^{2}\sum_{n=1}^{126} x_{ikn} \leq Cp_{ik} \quad ,\forall k \qquad and \qquad \sum_{i=1}^{1}\sum_{l=1}^{4}\sum_{n=1}^{126} x_{iln} \leq Cp_{il} \quad ,\forall l \qquad (3.3) \qquad (4.3)$$

2. Demand of cement in marketing district.

The amount of demand in each marketing district in Sumatra island must be met. The constraint is illustrated in equation 4.4.

$$\sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{n=1}^{126} x_{ijn} + \sum_{i=1}^{1}\sum_{k=1}^{2}\sum_{n=1}^{126} x_{ikn} + \sum_{i=1}^{1}\sum_{l=1}^{4}\sum_{n=1}^{126} x_{iln} \geq D_{in}, \forall n \qquad (3.4) \qquad (4.4)$$

3. Transhipment Balance

The amount of cement sent to the griding plant, packing plant from the cement plant must be equal to the volume of cement sent from the griding plant and packing plant to the marketing city in equations 4.5 and 4.6.

$$\sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{k=1}^{2} x_{ijk} = \sum_{i=1}^{1}\sum_{k=1}^{2}\sum_{n=1}^{126} x_{ikn}, \quad \forall i, \forall k \qquad (3 \quad (4.5)$$

$$\sum_{i=1}^{1}\sum_{j=1}^{4}\sum_{l=1}^{6} x_{ijl} = \sum_{i=1}^{1}\sum_{l=1}^{4}\sum_{n=1}^{126} x_{iln}, \quad \forall i, \forall l \qquad (3 \quad (4.6)$$

4. Non-negativity

Variables in supply chain flows are not negative. The constraint is illustrated in equation 4.7.

$$x_{ijk}, x_{ijl}, x_{ijn}, x_{ikn}, x_{iln} \geq 0 \quad \forall i \qquad (3.7) \qquad (4.7)$$

5. Binery

Variables in supply chain flows are of binary value where decisions for griding plants and packing plants to operate must be of binary value. The constraint is illustrated in the equation 4.8.

$$Y_k \in \{0,1\}, \forall k \in K \qquad Y_l, \in \{0,1\}, \forall l \in L \qquad (3.8) \qquad (4.8)$$

V. RESULT AND DISCUSSION

A. Data Processing

The optimization model developed in LINGO software consists of 2,588 variables and is solved using the Mixed Integer Linear Programming (MILP) approach with the Branch-and-Bound (B-and-B) method. The computation time required to obtain a solution is only one second, which shows the efficiency level of the B-and-B algorithm and the linear structure of the model. To prevent the allocation of supply facilities to sales districts that are not relevant in the planning scenario, a penalty in the form of a large-order constant is applied. This approach ensures that the allocation is not selected so that the feasibility of the solution is maintained. Before the optimization process is run, the total supply chain cost is first calculated based on the initial input data. The cost value is then compared with the optimization results to measure the effectiveness of the model in reducing overall distribution costs.

Furthermore, to ensure the validity of the model to real conditions in the field, a verification process is carried out through analysis of the model formulation, especially in the constraints section. This verification aims to ensure that all constraints have been designed to reflect the real limitations of the distribution system. Based on the optimization results shown in Table 1, it can be concluded that the utilization of cement plant (CP), grinding plant (GP), and packing plant (PP) in optimum conditions does not exceed the maximum capacity of the existing facilities. All used capacities at each facility are recorded at or below the existing capacity limit, thus strengthening the belief that the solution generated by the model is feasible to be implemented operationally.

Table 1. Capacity of Each Facility 2024 (Ton/Years)

Supply Facilities	Name of Supply Facility	Capacity of Facilities (Ton)	Optimum Capacity Used (Ton)	Verification
Cement Plant (CP)	CP Baturaja	6,820,800	4,886,481	feasible
	CP Narogong SBI	6,144,282	6,144,282	feasible
	CP Lhoknga SBA	2,028,500	1,724,100	feasible
	CP Indarung	7,030,000	5,966,521	feasible
Grinding Plant (GP)	GP Panjang	748,720	-	feasible
	GP Dumai	767,337	713,837	feasible

Packing Plant (PP)	PP Teluk Bayur	1,123,256	440,958	feasible
	PP Aceh Malahayati	374,400	304,400	feasible
	PP Belawan SBA	1,298,200	622,521	feasible
	PP Bengkulu	378,800	378,800	feasible

The next verification process is carried out by checking the transhipment balance limits of each cement plant, griding plant, and packing plant. This limit ensures that the number of products entering the GP/PP must be comparable to the number of products leaving the GP/PP. From Lingo's calculations, each product entering the GP and PP has the same value as the one leaving. Details of the transhipment balance verification in Table 2.

Table 2. Transhipment Balance Verification

Supply Facilities	Capacity of Facilities	Supplied by	Quantity Supplied (Ton)	Total Outgoing (Ton)	Verification
GP Dumai	767,337	CP Baturaja	767,337	713,837	feasible
PP Teluk Bayur	1,123,256	CP Indarung	440,958	440,958	feasible
PP Aceh Malahayati	374,400	CP Lhoknga SBA	304,400	304,400	feasible
PP Belawan SBA	1,298,200	CP Indarung	622,521	622,521	feasible
PP Bengkulu	378,800	CP Baturaja	378,800	378,800	feasible

B. Data Analysis and Discussion

Analysis of the results of supply chain cost calculations is carried out by comparing the results of the total supply chain cost calculations from the existing allocation conditions. Table 3 presents a comparison between the existing supply chain costs and the cost results obtained from the optimization model generated by LINGO. In general, the implementation of the optimization model is able to produce total cost savings of Rp451,271,216,091 or equivalent to 4% of the total initial cost. These savings indicate that the distribution strategy and facility allocation generated by the model provide significant efficiency to the supply chain system.

From the production side, the total production cost was reduced from Rp8,792,762,077,919 to Rp8,485,205,972,926, resulting in savings of Rp307,556,104,993 or around 3%. The largest savings in production cost components are in the grinding plant, with a cost reduction of Rp20,385,051,614 or 28%. This shows that optimization of capacity allocation and location of grinding facilities has a significant impact on production cost efficiency. Savings on production at the cement plant are in the range of 3% or equivalent Rp285,104,266,311. Meanwhile, savings on packaging costs at the packing plan are in the range of 2% or equivalent Rp66,787,069.

Table 3. Comparison of Existing Supply Chain Costs and Optimal Supply Chain Costs

Description	Existing Supply Chain Costs (Rp)	Cost of Supply Chain Optimization (Rp)	Savings (Rp)	Presentase
Production cost of cement plant	8,610,789,126,576	8,325,684,860,266	285,104,266,311	3%
Production cost of griding plant	72,579,368,633	52,194,317,019	20,385,051,614	28%
Production cost of packing plant	109,393,582,710	107,326,795,641	66,787,069	2%
Sub total of production cost	8,792,762,077,919	8,485,205,972,926	307,556,104,993	3%
Shipping cost from cement plant to griding plant	15,003,022,178	12,338,145,297	2,664,876,881	18%
Shipping cost from cement plant to packing plant	111,594,304,791	62,273,959,677	49,320,345,114	44%
Shipping cost from cement plant to marketing city	1,737,000,150,327	1,702,299,478,622	34,700,671,705	2%
Shipping cost from the griding plant to the marketing city	86,639,730,480	68,652,063,005	17,987,667,475	21%
Shipping cost from packing plant to marketing city	102,222,580,660	63,181,030,738	39,041,549,923	38%

Sub total of distribution cost	2,052,459,788,437	1,908,744,677,339	143,715,111,098	7%
Total Cost	10,845,221,866,356	10,393,950,650,265	451,271,216,091	4%

On the distribution side in Table 3, there was a cost reduction from Rp2,052,459,788,437 to Rp1,908,744,677,339, which means an efficiency of Rp143,715,111,098 or around 7%. The distribution component shows a greater opportunity for savings compared to production, with the highest contribution of savings coming from shipping costs from the cement plant to the packing plant reaching 44%, followed by shipping from the the grinding plant to the marketing city at 21%, followed by shipping from the cement plant to the grinding plant at 18%, and from the cement plant to marketing city at 2%. This indicates that the optimization strategy implemented has succeeded in reducing the distance traveled or increasing the efficiency of the allocation of facility locations to demand points. Thus, the optimization results not only provide a reduction in total costs as a whole, but also show substantial efficiency in the distribution aspect. The effectiveness of this model underlines the importance of a quantitative approach in supply chain planning to achieve cost efficiency and improve overall logistics performance.

Analysis was also conducted by identifying the use of production facilities in existing conditions with optimization conditions. Table 4 presents a comparison between actual utility conditions and optimal conditions at four cement factory facilities. The optimization results show a redistribution of production loads aimed at increasing the efficiency of the overall distribution system. At CP Baturaja, there was a decrease in production from 6,490,258 tons to 4,886,481 tons, which caused the utility level to decrease from 95% to 72%. This is because production costs at this facility are more expensive than other facilities.

Meanwhile, at CP Indarung, production increased from 4,980,156 tons to 5,966,521 tons, with an increase in utility from 71% to 85%. This indicates that although there was a reduction in output at several facilities, the optimization process succeeded in allocating production loads to other facilities with higher efficiency. The allocation was also caused by the production processing model at the facility which had more efficient production costs than the existing conditions. In contrast, CP Narogong SBI maintained a maximum production rate of 6,144,282 tons under optimal conditions, which is equivalent to its installed capacity, resulting in 100% utilization. This indicates that the facility has a strategic role in the optimal distribution scenario, due to its proximity to major demand centers or having a large capacity with more competitive distribution costs. Meanwhile, CP Lhoknga SBA showed a significant increase in utilization rate, from 60% to 85%. The implication of this finding is that CP Lhoknga, although underutilized in actual conditions, has the potential for greater capacity to be utilized optimally in a coordinated distribution scenario. Overall, this comparison suggests that the optimization approach is not only able to balance utilization between plants, but can also direct the distribution system towards greater efficiency. Optimizing plant capacity utilization allows for reductions in logistics costs, carbon emissions, and excess load on certain facilities, which collectively support the achievement of mortality and operational efficiency goals in the national cement supply chain.

Table 4. Comparison of Cement Plant Utilities in Existing and Optimal Conditions

Facilities	Capacity (Ton)	Kondisi Utilitas Eksisting		Kondisi Utilitas Optimasi	
		Produksi (Ton)	Utilitas	Produksi (Ton)	Utilitas
CP Baturaja	6,820,800	6,490,258	95%	4,886,481	72%
CP Narogong SBI	6,144,282	6,047,054	98%	6,144,282	100%
CP Lhoknga SBA	2,028,500	1,227,106	60%	1,724,100	85%
CP Indarung	7,030,000	4,980,156	71%	5,966,521	85%

Further, an analysis was conducted on the use of the griding plant as a facility that plays a role in the second processing of products delivered by the cement plant. Table 5 illustrates significant changes in the utilization of the grinding plant facility in actual conditions compared to optimal conditions. In actual conditions, GP Panjang and GP Dumai each showed a utilization rate of 76% and 71%, respectively. However, in optimal conditions, the role of GP Panjang was completely eliminated (utility 0%), while GP Dumai experienced a significant increase in utilization to reach 93%. The cessation of GP Panjang operations in the optimal scenario can be interpreted as a result of cost efficiency considerations or a less strategic geographical location. On the other hand, the increase in GP Dumai shows that this facility is more efficient and strategic in supporting cement distribution in the optimized logistics system configuration. In other words, GP Dumai is more efficient in delivering products to marketing areas on Sumatra Island. This emphasizes the importance of adaptive workload allocation based on location and superior logistics performance.

Table 5. Comparison of Griding Plant Utilities in Existing and Optimal Conditions

Facilities	Capacity (Ton)	Existing Utility Conditions		Optimization Utility Conditions	
		Production (Ton)	Utility	Production (Ton)	Utility
GP Panjang	748,720	569,877	76%	-	0%
GP Dumai	767,337	541,118	71%	713,837	93%

Furthermore, an analysis of the use of packing plants in the model was conducted to analyze the CP that produces the most optimal costs. Table 6 illustrates the distribution of capacity utilization at four packing plant facilities. In actual conditions, there is a significant imbalance in utilization. For example, PP Aceh Malahayati shows an over-utilization of 111%, while PP Bengkulu is very under-utilized with only 11% utilization. In optimal conditions, there is a significant adjustment. PP Aceh Malahayati experienced a decrease in production to avoid overload, with utilization dropping to 81%. PP Belawan SBA also experienced a decrease in utilization from 57% to 48%, indicating a redistribution of the load to other more strategic facilities. One of the most striking changes occurred at PP Bengkulu, where utilization increased drastically from 11% to 100%, indicating full utilization of its capacity for the first time. This shows that in optimal conditions, previously under-utilized facilities now play an important role in supporting the efficiency of the distribution network as a whole. Meanwhile, PP Teluk Bayur showed a decrease in production from 544,401 tons to 440,958 tons, and its utility decreased from 48% to 39%. This decrease could be caused by the relocation of production volume to other facilities that have a more advantageous logistic position from the marketing area or lower distribution costs.

Table 6. Comparison of Packing Plant Utilities in Existing and Optimal Conditions

Facilities	Capacity (Ton)	Existing Utility Conditions		Optimization Utility Conditions	
		Production (Ton)	Utility	Production (Ton)	Utility
PP Teluk Bayur	1,123,256	544,401	48%	440,958	39%
PP Aceh Malahayati	374,400	414,391	111%	304,400	81%
PP Belawan SBA	1,298,200	733,495	57%	622,521	48%
PP Bengkulu	378,800	40,479	11%	378,800	100%

VI. CONCLUSIONS

From the discussion that has been presented, it can be concluded that:

1. Cost analysis shows that the application of the optimization model with MILP is able to reduce the total supply chain cost from Rp10.85 trillion to Rp10.39 trillion, resulting in an efficiency of Rp451 billion or equivalent to 4%. The production cost component experienced savings of 3%, with the highest efficiency at the grinding plant. On the distribution side, cost efficiency reached 7%, with the highest savings recorded in shipping from the cement plant to the packing plant.
2. In terms of utilization, there was a more even redistribution of production loads across all types of facilities. Several facilities previously experienced under-utilization. Conversely, facilities that previously experienced over-utilization showed a decrease in workload towards a more ideal level. In addition, the optimization results also eliminated the operation of low-efficiency facilities such as GP Panjang, and simultaneously increased GP Dumai utilization by 93%.

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