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Analysis of subsidised fertiliser distribution efficiency using the lean thinking approach following the implementation of the zero ODOL policy: A case study of deliveries to Bojonegoro Regency

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ABSTRACT
The Zero Over Dimension Overload (Zero ODOL) policy, regulated by Minister of Transportation Regulation No. 60 of 2019, significantly impacted fertiliser distribution, decreasing truck transport capacity by 47%. This raised costs from Line I to Line III Bojonegoro Warehouse to Rp 26.2 billion annually. This study identifies inefficiencies and improvements using Lean Thinking with tools like Pareto Analysis, Ishikawa Diagram, and 5w+2 h. Manual loading and unloading caused waste through waiting, unproductive movements, defects, and repetition. The solution adopts pallets and forklifts to cut reliance on labour. Validated through a one-month operational pilot project managing 2,370 tonnes of fertiliser, Lean implementation structurally improved efficiency: logistics costs dropped to Rp 21 billion (20% savings), loading/unloading speed tripled from 250 to 750 tonnes/day, fertiliser damage reduced to 0.002%, and quantitative stakeholder satisfaction increased significantly. Lean delivers cost savings and enhances quality, safety, and sustainability amidst Zero ODOL challenges.

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1. INTRODUCTION

Fertiliser distribution plays a strategic role in sustaining agricultural productivity and national food security in Indonesia, as inefficiencies in availability and timeliness directly affect farm output and farmers' welfare [1], [2]. Within this system, subsidised fertiliser distribution is particularly critical because it is designed to ensure that fertiliser reaches farmers in the right quantity, at the right time, and at an affordable price [2]. As a state-owned enterprise, PT Pupuk Indonesia holds a central mandate to manage this distribution network, coordinating production, storage, and logistics across regions through multiple distribution channels. However, data shows that the effectiveness of fertiliser supply chains in Indonesia has been increasingly constrained by transportation and logistics challenges. These constraints have been exacerbated by the implementation of the Zero Over Dimension Over Load (Zero ODOL) policy, which strictly regulates vehicle dimensions and axle loads to reduce road damage and improve transport safety [3]. While the policy is essential for infrastructure sustainability, research shows that limited industry readiness, higher logistics costs, and reduced transport capacity have disrupted distribution efficiency, particularly for bulk commodities such as fertiliser [3], [4]. Consequently, the interaction between fertiliser distribution systems and the Zero ODOL policy has emerged as a significant challenge in maintaining the reliability of subsidised fertiliser supply and, by extension, Indonesia's food security.

The implementation of Zero ODOL has resulted in restrictions on load capacity in accordance with the Permitted Weight (JBI), leading to a decrease in average transport capacity of up to 47%. The impact of this policy is particularly significant in areas with high fertiliser allocations, such as Bojonegoro District, which has the highest annual allocation in East Java at 130,000 tonnes. The reduction in load capacity, which varies between 24% and 62% as can be seen in Table 1, has led to a surge in fleet requirements and potential bottlenecks in warehouses.

Table 1. Reduction in truck load capacity

No.	Truck Type	ODOL Qty (tons)	Zero ODOL Qty (tons)
1.	Trailer / Semi-Trailer	50	38.25
2.	Coupled Truck (Gandeng)	45	24.05
3.	3-Axle Rigid Truck (Tronton)	35	15.2
4.	2-Axle / Light Truck (Engkel)	20	7.7

Based on operational data, the total distribution cost from Warehouse Line I to Line III Bojonegoro increased to Rp 26.2 billion per year as can be seen in Table 2. This situation indicates inefficiency exacerbated by manual operational processes that create various forms of waste, such as waiting time, unproductive motion, and the risk of product defects.

Table 2. Total distribution costs to Bojonegoro Regency

No.	Component	Category	Cost (IDR)
1-1	Handling Out Cost - Line I	Variable Cost	Rp 683,064,515
1-2	Transportation Cost	Variable Cost	Rp 17,571,321,151
1-3	Handling In Cost - Line III	Variable Cost	Rp 1,863,182,520
1-4	Warehouse Rent	Fixed Cost	Rp 4,195,920,000
1-5	Management Fee	Fixed Cost	Rp 830,340,000
1-6	Handling Out Cost - Line III	Variable Cost	Rp 1,019,393,132
-	**Total distribution cost**	**-**	**Rp 26,163,221,318**

To mitigate the operational inefficiencies exacerbated by the Zero ODOL constraints, this study employs Lean Thinking to systematically eliminate non-value-added activities and redesign material handling workflows. By focusing on flow optimization rather than reactive capacity expansion, Lean provides a highly suitable framework for restoring cost efficiency and throughput under externally imposed payload reductions. Lean thinking is described as an approach that uses a continuous cycle of improvements, to focus on mapping and simplifying processes, preserving the steps that provide "value" through eliminating sources of waste [5]. In a process, there are value-adding steps and non-value-adding steps. These non-value adding steps or 'wastes' can be categorized: overproduction, waiting, conveyance, overprocessing, inventory, motion, and defects [6]. Lean Thinking is founded on a set of five principles: specifying value from the perspective of the customer, identifying the value stream, creating a continuous, uninterrupted flow, establishing a pull-based system that enables products to be created at the time of customer need and implementing excellence to pursue perfection [7]. Lean thinking helps an organization view the world differently, enhances processes and renders customers more satisfied. It enables all organizational levels, down to line workers, to develop novel ways of thinking about operations and innovative approaches [8]. While Lean Thinking initially addressed manufacturing system efficiency through waste elimination, literature shows that Lean concepts have since broadened to encompass supply chain operations, including material and information flows beyond the factory floor [9]–[11] Despite this extension, limited empirical research has examined Lean tools in operational logistics and warehouse optimisation under external shocks such as regulatory changes. However, existing work demonstrates that Lean approaches can improve warehouse operations and distribution performance by systematically reducing non-value-added activities [12], [13].

Previous studies have shown that Lean Thinking has been widely applied to improve efficiency in manufacturing systems and logistics/warehouse operations by reducing waiting time, excessive handling, and non-value-added activities, as evidenced in lean warehousing and distribution performance studies [12], [14]. However, most applications assume relatively stable transport conditions and do not explicitly address efficiency degradation caused by external regulatory interventions such as load capacity restrictions; recent research into lean-resilience integration highlights the vulnerability of traditional Lean systems under disruptive policy shocks [15], [16]. In practice, distribution actors often respond to load capacity reductions by increasing fleet size, labour, or storage capacity. All of these are reactive measures that may mitigate volume constraints but can escalate overall costs and operational complexity without fundamentally eliminating process inefficiencies [17]. Despite the widespread implementation of the Zero ODOL policy, limited operational evidence exists on how distribution systems, particularly subsidised fertiliser supply chains, can be redesigned to remain efficient under reduced transport capacity constraints. Thus, this study aims to explore how Lean systems could be used as a response to disruptive policy shocks, different from traditional Lean systems understandings that Lean system is vulnerable to disruptive policy shocks.

While previous research on ODOL has tried to map its prevalence and the intention behind it in Indonesia [18], and the negative effects of ODOL [19], [20], research on the policy itself is still relatively scarce. Most studies on the Zero ODOL policy have largely focused on regulatory and legal compliance, as evidenced by the enforcement-oriented research in Indonesian transport studies [4], [18], as well as how communications [21], [22], and the active role of the government [23], [24] can help with the compliance and enforcement of the policy. Specifically, research regarding how firms can mitigate the cost and impact of this policy is still heavily underresearched, especially for the specific context of fertiliser supply chains. This study addresses this gap by extending Lean supply chain applications beyond internal process optimization to explicitly manage regulatory-driven logistics disruptions, offering a novel empirical framework for restoring operational resilience under externally imposed transport capacity constraints.

This study contributes to the logistics and operations management literature by demonstrating how Lean Thinking can be effectively applied to mitigate inefficiencies caused by regulatory constraints in distribution systems. Practically, the findings provide a replicable framework for state-owned enterprises facing similar capacity and cost pressures due to transportation regulations. This study aims to analyse the root causes of fertiliser distribution inefficiencies following the Zero ODOL policy and to design process improvements using Lean analysis tools such as Pareto Analysis, Ishikawa Diagrams, and 5W+2H. The focus of the research is limited to the delivery of urea fertiliser from PT Petrokimia Gresik's Line I Warehouse to the Bojonegoro Line III Warehouse during the 2022-2023 period. Through the evaluation of alternative solutions, including the use of mechanisation such as forklifts and pallets, this research is expected to provide recommendations for a more cost-efficient, reliable, and sustainable distribution strategy in facing national transportation regulatory challenges. Accordingly, this study seeks to answer the following research questions:

RQ1: *What are the main sources of inefficiency in subsidised fertiliser distribution following the implementation of the Zero ODOL policy in Bojonegoro?*

RQ2: *How can Lean Thinking tools be used to redesign the fertiliser distribution process in Bojonegoro to improve cost efficiency, speed, and service quality?*

2. MATERIALS AND METHODS

This study adopts a case study approach that integrates qualitative and quantitative methods to analyse the efficiency of subsidised fertiliser distribution following the implementation of the Zero Over Dimension Over Load (Zero ODOL) policy. The methodological framework encompasses data collection, intervention design, and analytical procedures aimed at identifying inefficiencies and evaluating process improvements. Primary data were collected through direct field observations conducted over a one-month pre-intervention period and structured in-depth interviews guided by standardized written questionnaires. To ensure robust operational insights, purposive sampling was utilized, targeting 14 key informants directly engaged in executing the new operational standards during the pilot project. This cohort was selected based on direct operational involvement: 2 Destination Warehouse Heads (representing the implementation sites); 7 Forklift Operators (4 at the destination warehouse and 3 at the loading warehouse), chosen as their repetitive and standardized mechanical tasks ensure data saturation within a highly focused qualitative scope; and 5 Truck Drivers. The drivers served as the primary evaluators for time variables, specifically selected because they operated vehicle types directly restricted by the Zero ODOL policy (such as semi-trailers and coupled trucks) and delivered directly to the Talok and Sumberejo warehouses. These data were used to understand operational practices, bottlenecks, and constraints within the existing distribution system. Secondary data were obtained from the company's SAP system, particularly documentation related to the realisation of land transport work orders during the 2022–2023 period. The secondary data provided detailed information on shipment volumes, transport frequency, handling activities, and logistics costs.

The research was conducted at the Line III Support Warehouse in Bojonegoro Regency, East Java. This location was purposively selected because it represents the distribution node with the highest logistics costs in the region and has experienced one of the most significant operational impact following the enforcement of the Zero ODOL regulation. The quantitative scope of the study covers the distribution of urea fertiliser with a total volume of 131,242 tonnes and total logistics costs of approximately Rp 26.2 billion prior to process improvements. The study implements a process improvement intervention by modifying the distribution method from a manual handling system to a mechanised system. Performance comparisons are conducted under two operational conditions. In the pre-improvement condition, loading and unloading activities are performed manually by TKBM, resulting in limited handling speed and a higher risk of product damage. In the post-improvement condition, pallets and forklifts are introduced into the shipping and storage processes. Fertiliser products are stacked on pallets at the origin warehouse (Line I) and handled using forklifts during loading, transportation, and unloading at the destination warehouse (Line III). This intervention is designed to accelerate material flow, reduce handling waste, and improve operational consistency.

Lean Thinking tools are employed to identify sources of waste and develop improvement strategies. The Lean tools were applied in an integrated sequence. The Ishikawa Diagram was constructed through a structured group discussion involving warehouse managers and logistics staff, categorising root causes across four dimensions: Material, Method, Machine, and Human Capital. The identified causes were then weighted using Failure Mode and Effects Analysis (FMEA), with Risk Priority Number (RPN) scores determining priority through Pareto stratification. The highest-priority cause was subsequently addressed through a structured 5W+2H improvement plan. Pareto Analysis is used to prioritise distribution routes and cost components that contribute most significantly to inefficiency. Furthermore, FMEA was utilized to evaluate and prioritize risks. To minimize subjective bias, the RPN variables of Severity, Occurrence, and Detection were scored through a joint brainstorming session by the Transforklift Jatim Team and directly validated by a warehousing expert from PT Petrokimia Gresik. The 5W+2H method (What, Why, Where, When, Who, How, and How Much) is used to formulate structured and measurable improvement action plans. To ensure data reliability, operational data extracted from the SAP system are cross-checked with actual field observations. The validity of the analytical results is further strengthened through the implementation of a pilot project at the research site. This pilot project was conducted over a continuous one-month period, successfully handling a distribution volume of 2,370 tons, which allowed for a highly representative real-world evaluation of the proposed intervention. Data analysis is conducted using both quantitative and qualitative approaches. Quantitative analysis focuses on the calculation of Total Logistics Cost (TLC) to assess financial efficiency before and after the intervention, as well as a before–after comparison of key performance indicators, including loading and unloading speed (tons/day), fertiliser damage rate (%), and stakeholder satisfaction levels. To ensure objective measurement, stakeholder satisfaction was quantified using written questionnaires distributed to 50 active respondents across the supply chain.

Data was collected using a formal operational evaluation instrument distributed to 50 active respondents. The measurement utilized a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) to assess performance across five core Lean indicators: Delivery (speed and flow of truck queues), Safety (reduction of extreme fatigue and physical injury risks), Quality (physical integrity of the fertiliser sacks), Logistics and Administration (pallet circulation control), and Morale (overall work satisfaction). The instrument was independently developed by the researchers based on the standard Lean management framework. Because the objective of this instrument was to evaluate direct operational feedback following a pilot implementation rather than to test latent variable relationships, a descriptive mean analysis was utilized as the most appropriate method to quantify overall stakeholder satisfaction. The complete questionnaire list can be seen in Table 3. Qualitative analysis involves an in-depth interpretation of Lean tool outputs to explain observed waste patterns and process inefficiencies within the distribution flow. Statistical calculations and graphical visualisations are performed using Microsoft Excel, while quality management diagrams are developed using standard quality management software. To assess the robustness of the cost savings findings, a sensitivity analysis was conducted by systematically varying the assumed efficiency realisation rates across four key cost components: transportation savings, handling efficiency gains, warehouse consolidation savings, and pallet procurement costs. Each component was adjusted independently and in combination to evaluate the minimum conditions under which the palletisation intervention remains cost-positive. All scenarios are derived from the baseline cost data in Table 2 and the post-implementation figures.

Table 3. Questionnaire list

No	Operational Evaluation Statement
A. OPERATIONAL SPEED AND SMOOTHNESS INDICATORS (DELIVERY)	
1	The queue time for trucks in the warehouse parking area has become much shorter after the implementation of pallets.
2	The maneuvering process of the truck fleet in the loading and unloading area becomes more orderly and takes less time.
3	The speed of the loading/unloading process increases significantly compared to the manual per sack loading method.
4	The reduction in loading capacity per truck due to Zero ODOL restrictions and pallet arrangement can be offset by a much faster loading and unloading turnaround frequency.
5	The target for buffer stock availability at the Line III Warehouse was met more quickly thanks to the increase in daily loading and unloading capacity, which reached 750 tons/day.
B. OCCUPATIONAL SAFETY & SECURITY INDICATORS (SAFETY)	
6	The use of forklift mechanization minimizes the risk of physical injury to workers (uch as being hit by objects or sprains in the work area.
7	The circulation area inside the warehouse becomes safer and more orderly due to the minimal movement of Loading and Unloading Workers (TKBM) around the transport trucks.
8	Placing empty pallets in areas outside the warehouse's operational capacity does not interfere with the maneuvering of heavy equipment or truck fleets.
9	The risk of extreme work fatigue in field staff and TKBM is drastically reduced by replacing manual methods with forklifts.
C. QUALITY INDICATORS OF GOODS HANDLING (QUALITY)	
10	The physical condition of the fertilizer sacks is better maintained (not torn/broken) when moved using a forklift compared to the manual method (goad).
11	The pile of fertilizer on pallets in the warehouse looks much neater, more precise, and more

No	Operational Evaluation Statement
	sturdy.
12	The use of pallet bases effectively prevents fertilizer sacks from coming into direct contact with the warehouse floor, which is at risk of becoming damp or dirty.)
13	Visibility for physical checking of goods or daily stock taking activities becomes easier due to the uniform arrangement of pallets.)
D. PALLET MANAGEMENT & ADMINISTRATION INDICATORS (LOGISTICS & ADMINISTRATION)	
14	The process of withdrawing empty pallets from Warehouse Line III back to Warehouse Line I ran smoothly without disrupting the main shipping operational schedule.
15	Monitoring the availability and physical condition of pallets in the warehouse can be easily controlled and coordinated by warehouse management.
E. OVERALL SATISFACTION INDICATORS (MORALE)	
16	Overall, this shipping and storage method using pallets really helps to lighten the operational burden and increase job satisfaction in the field.

3. RESULTS

This section presents research findings from the implementation of mechanisation using pallets and forklifts and their discussion within the framework of Lean Thinking to answer research questions regarding distribution efficiency after the Zero ODOL policy. The initial step in this study was to map the existing conditions and the impact of regulations prior to intervention through the palletisation method. The data shows that inefficiencies were exacerbated by operational constraints at the Bojonegoro warehouse facility, caused by several factors. There has been a downward trend in the number of loading and unloading workers at the Bojonegoro Line III Warehouse over the past five years, from 111 people in 2019 to only 90 people in 2023 as shown in Figure 1. This has hampered the speed of manual loading and unloading amid the increasing frequency of truck arrivals.

In addition to the decline in the number of workers, observations of six existing warehouses showed significant variation in infrastructure suitability, as summarised in Table 4. The assessment evaluated warehouse suitability based on three objective infrastructure criteria required for safe forklift operations: (1) surface bearing capacity (requiring fully paved or cast concrete floors to support mechanical operational loads), (2) maneuverability space (requiring a minimum area of 2,000 m² to allow for safe forklift turning radii and queuing), and (3) access adequacy (requiring a minimum of 3 access doors and Class 1 road classification). Based on these thresholds, only two warehouses, Talok and Sumberejo, are structurally suitable for mechanised operations. The remaining warehouses rely partially or fully on soil-based flooring and have limited parking capacity and access points, making them unsuitable for forklift usage and vulnerable to congestion under increased delivery frequency. These infrastructure limitations become more critical following the implementation of the Zero ODOL policy. Reduced truck load capacity has increased the number of vehicle arrivals, thereby intensifying the need for sufficient queuing space and efficient loading and unloading facilities. Warehouses with limited parking capacity and soil floors experience longer waiting times, forced reliance on manual handling, and higher operational risk. This finding indicates that inefficiencies in the distribution system are not solely caused by labour constraints, but are structurally embedded in warehouse design and layout. Conversely, larger warehouses such as Sumberejo and Talok offer greater operational flexibility, enabling volume consolidation, higher material handling speed, and better utilisation of mechanised equipment. These conditions provide a critical foundation for the successful application of Lean Thinking, suggesting that infrastructure readiness is a prerequisite for waste elimination and flow optimisation in the post–Zero ODOL distribution environment.

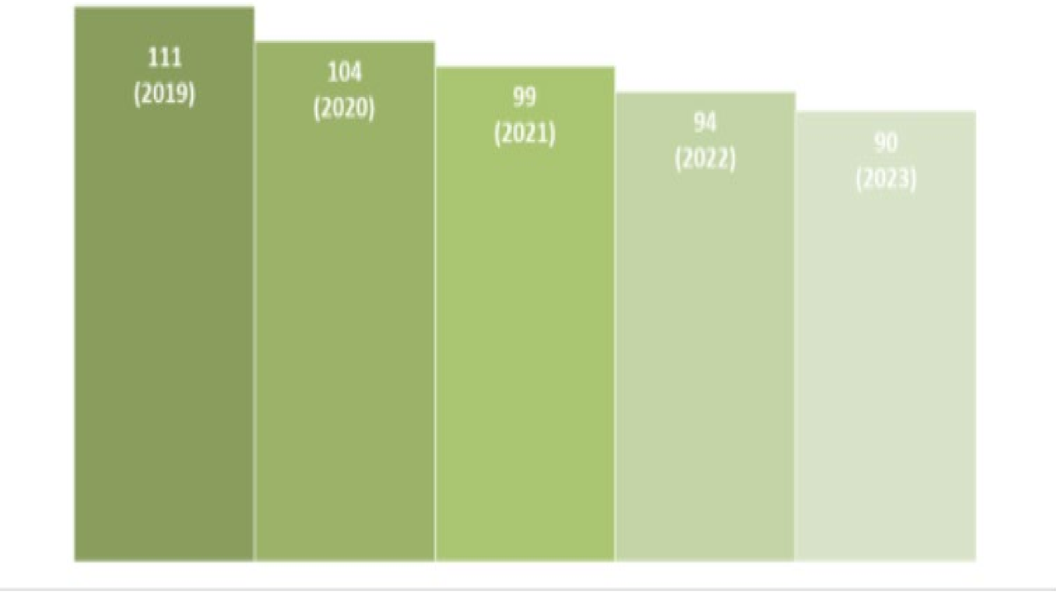

Figure 1. Decline in the number of workers at the Bojonegoro Line III Warehouse

Table 4. Summary of the physical condition of the Bojonegoro Warehouse

Warehouse	**Queue Space**	**Ground Floor Condition**	**Area / Warehouse Capacity**	**Warehouse Access**	**Road Class**
Bojonegoro 4 - Kalitidu	9 Three-Axle Rigid trucks	Partly cast concrete and partly dirt	Area: 2,667 m² Equivalent to: 6,000 tons	3 Doors	Class 1 Road
Bojonegoro - Talok	5 Trailer trucks	Fully Paved	Area: 2,069 m² Equivalent to: 4,657 tons	5 Doors	Class 1 Road
Bojonegoro 2 - Sumberejo	12 Coupled trucks	Full paved	Area: 3,555 m² Equivalent to: 8,000 tons	3 Doors	Class 1 Road
Bojonegoro 1 - Baureno	6 Trailer trucks	Fully paved	Area: 2,222 m² Equivalent to: 5,000 tons	8 Doors	Class 1 Road
Bojonegoro - Temayang	5 Three-Axle Rigid trucks	Dirt floor	Area: 889 m² Equivalent to: 2,000 tons	10 Doors	Class 2 Road
Bojonegoro 3 - Padangan	4 Three-Axle Rigid trucks	Dirt floor	Area: 445 m² Equivalent to: 1,000 tons	2 Doors	Class 1 Road

Table 5 presents the comparative distance analysis between distributors and alternative support warehouses under three operational scenarios: existing normal operations, palletised warehouses, and warehouses proposed for closure. Yellow indicates the closest warehouse to the distributor, while green indicate the second closest. The results indicate that warehouses selected for palletisation, Sumberejo and Talok, are geographically closer to the majority of distributors. Specifically, Sumberejo or Talok represents the closest warehouse option for seven out of ten distributors, with several distributors located within a radius of less than 10 km. In contrast, warehouses operating under normal conditions prior to the intervention, such as Padangan and Temayang, are often not the nearest option and, in some cases, require substantially longer travel distances. This suggests that while historical distribution patterns were not exclusively optimised for distance efficiency, they were likely shaped by a complex interplay of other logistical considerations, including inventory balancing, road accessibility, service coverage, and the historical availability of manual labour infrastructure. The analysis further shows that the proposed closure of smaller warehouses (Kalitidu and Baureno) does not significantly reduce service accessibility, as alternative palletised warehouses remain available at comparable or shorter distances for most distributors. The distance-based assessment supports the warehouse consolidation strategy, demonstrating that the implementation of palletisation not only enables mechanised handling but also improves spatial efficiency, thereby reinforcing Lean distribution principles through reduced transport waste and improved material flow.

Table 5. Distributor distance to buffer warehouse

Distributor	Buffer Warehouse Distance (km)					
	Normal Operation		Pallet Implementation		Proposed to Close	
	Padangan	Temayang	Sumberejo	Talok	Kalitidu	Baureno
CV Damakten Agro	35.5	18.3	21.5	18.6	20.7	33.5
CV Indo Baru Mandiri	48.6	25	7.3	31.7	33.8	19.3
CV Luas Nusa	49.4	25.7	6.4	32.5	34.6	18.4
CV Ruby Sinar Sejahtera	63	39.4	7.5	46.1	48.2	5.7
CV Sekar Arum	39.8	21.1	18.5	22.9	24.9	30.5
K3PG	26.2	25.2	28.9	9.3	11.4	40.9
KP Padangan	0.1	44.5	54.2	16	13.9	66.2
KP Sinar Baru	70.2	41.4	14.7	53.3	55.4	4.2
PT Ojo Lamban	49.4	25.7	6.3	32.4	34.5	18.3
UD Jaya Makmur	26.7	24.6	28.4	9.8	11.9	40.4

3.1 Root Cause Analysis

To understand why costs have ballooned and operations have been hampered, a cause-and-effect diagram (Fishbone Diagram) was used to map the factors that caused this situation, as follows. The fishbone diagram illustrates the root causes of high fertiliser shipment costs following the implementation of the Zero ODOL policy by classifying contributing factors into material, method, machine, and human capital dimensions. The analysis indicates that the reduction in truck fill capacity (Machine factor) acts as an external trigger that increases transport frequency but cannot be directly controlled by the distribution operator. While transport distance and fuel consumption per trip remain constant, the reduced payload per vehicle significantly increases total transportation costs. The most critical internal root cause is identified within the Method category, where loading and unloading activities continue to rely on manual processes. Despite a higher truck arrival rate, handling time per truck remains unchanged, resulting in congestion, extended waiting time, and increased overtime. Human capital factors further reflect this imbalance, as additional labour and longer working hours are required to compensate for limited handling speed, leading to higher labour costs and operational fatigue. Material-related factors, particularly limited parking capacity and the need to operate additional warehouses, act as structural amplifiers of inefficiency rather than primary causes. The intersection of all these factors are drawn in Figure 2 for clarity. The analysis demonstrates that high shipment costs arise from the interaction between an unavoidable external regulation and an inflexible internal handling process. Consequently, Lean improvement efforts are logically directed toward redesigning the loading–unloading method to increase process speed and resilience under reduced transport capacity conditions.

The FMEA analysis revealed that the Manual Loading and Unloading Process (1C) had the highest RPN value (576). To ensure the reliability and objectivity of this assessment, the Severity (S), Occurrence (O), and Detection (D) scores were determined through a consensus-building brainstorming session by the Transforklift Jatim Team, which was directly validated by a warehousing expert from PT Petrokimia Gresik. Although the decline in truck capacity (1A) was the trigger for the problem, it was the inefficiency of the manual process that made the system unable to adapt (low resilience). The manual system has poor problem detection (Detection score of 9) and a high frequency of problems (delays/queues). Therefore, the solution focuses on modernising the loading and unloading methods. After identifying various possible causes through a cause-and-effect diagram (Ishikawa) and weighting the risks using the FMEA method, the next step is to determine the priority of the root causes that must be addressed first. Based on the Risk Priority Number (RPN) calculations in Table 6, the problems stratified using the Pareto principle (80/20) as shown in Figure 3.

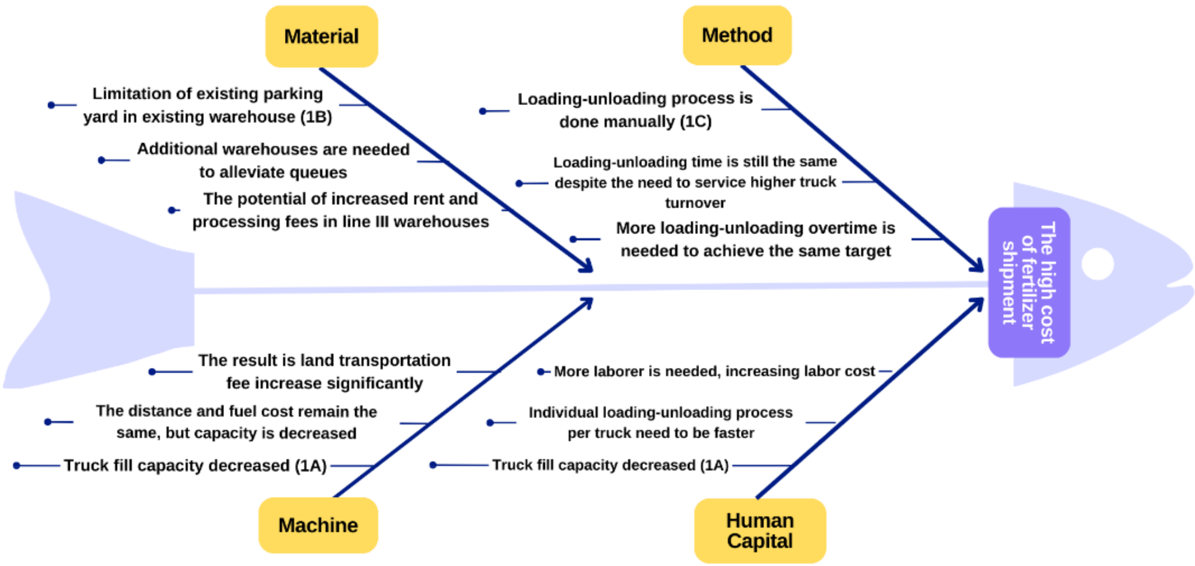

Figure 2. Fish bone diagram

Table 6. FMEA results

Code	Description of the Cause of the Problem	Severity (S)	Occurrence (O)	Detection (D)	RPN (S x O x D)	Rank
1C	Manual loading and unloading process	8	8	9	576	1
1A	The load capacity per lorry has decreased	6	8	8	384	2
1B	Limited warehouse parking space	7	5	8	280	3

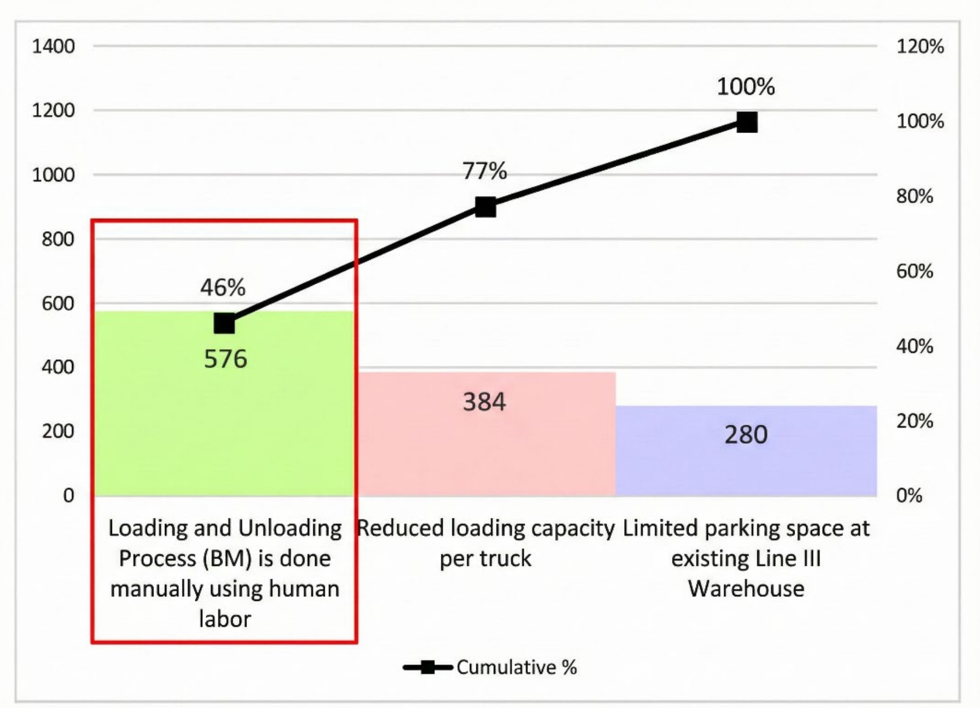

Figure 3. Pareto diagram of dominant root causes

Based on the FMEA results, three alternative improvement strategies were evaluated to address inefficiencies in the fertiliser distribution process. The evaluation focused on each alternative's ability to mitigate the dominant failure mode, manual loading and unloading (Code 1C), which recorded the highest Risk Priority Number. The first alternative involved increasing the number of loading and unloading workers (TKBM). While this option could temporarily increase handling capacity, it primarily compensates for inefficiencies through additional labour input. This approach is associated with higher variable handling costs, difficulties in labour availability, and continued exposure to human error, thereby failing to fundamentally reduce the severity or detectability of the identified failure mode.

The second alternative considered the addition of new warehouses to alleviate truck congestion and queuing. Although this strategy may reduce localised bottlenecks, it significantly increases fixed costs related to warehouse rental and management and complicates inventory control. Moreover, this option does not address the underlying inefficiency of the manual handling process, as loading and unloading speeds remain unchanged. The third alternative involves modifying the distribution and storage method through the implementation of palletisation and forklift-based handling. This approach directly targets the root cause identified in the FMEA by increasing loading and unloading speed, reducing repetitive manual handling, and improving operational consistency. Although this option requires investment in pallets and forklift rental, the resulting reduction in truck turnaround time, labour dependency, and product damage is expected to generate greater overall cost savings.

The three alternatives were systematically evaluated using a quantitative QCDSM framework (Quality, Cost, Delivery, Safety, and Morale), employing a weighted scoring matrix (1 = Poor, 3 = Moderate, 5 = Excellent) based on consensus from the operational team. As presented in Table 7, the palletisation approach demonstrated superior performance across all dimensions, achieving the highest cumulative score. Consequently, the modification of the loading–unloading method through palletisation was selected as the most effective and sustainable solution.

Table 7. Quantitative QCDSM evaluation of alternatives

Evaluation Criteria (QCDSM)	Alt 1: Increase Manual Labour	Alt 2: Add New Warehouses	Alt 3: Implement Palletisation (Selected)
Quality (Reduced product damage)	1	3	5
Cost (Reduced variable & fixed costs)	1	1	5
Delivery (Faster loading/unloading speed)	3	3	5
Safety (Reduced physical risk to workers)	1	3	5
Morale (Reduced worker fatigue)	1	3	5
Total Score	**7**	**13**	**25**

3.2. Developing an Improvement Plan

As an operational measure to ensure that the transition from a manual system to a mechanised system runs systematically and measurably, this study has developed an improvement action plan using the 5W+2H framework (What, Why, Where, When, Who, How, and How Much). This approach is designed to detail each stage of implementation, from the warehouse infrastructure evaluation phase to the pilot project launch phase, in order to ensure that the predetermined distribution efficiency targets are achieved. Based on the main root cause, which is the loading and unloading process that is still carried out manually, Table 8 explains the details of the improvement plan to be implemented.

The implementation was conducted in sequential phases. The first phase focused on technical feasibility and system design, including an assessment of warehouse physical conditions, simulations of pallet layouts and truck capacity under palletised loading, and benchmarking of existing pallet-based distribution practices. This phase ensured that the proposed solution was compatible with existing infrastructure and regulatory constraints. The second phase emphasised stakeholder alignment and decision approval. Evaluation results were formally submitted to management, followed by internal and external stakeholder socialisation involving warehouse operators, transport service providers, and distributors. This step was critical to reduce resistance to change and ensure operational readiness across the distribution network.

Table 8. Improvement plan

Root Cause (Why)	What (Solution)	How (Action Steps)	Where, When, Who	How Much (Cost)
Loading/Unloading process is done manually (human labor)	Using pallets in the delivery and storage process	1. Evaluate warehouse needs based on the physical feasibility conditions of the warehouse	Where: Bojonegoro Warehouse When: March 2023 PIC: Yogatama	Rp 2,000,000
		2. Simulate proper warehouse layout to calculate pallet requirements	Where: Meeting Room OD East Java 2 When: March 2023 PIC: Elok	Rp -
		3. Simulate truck size and capacity when using pallets	Where: Meeting Room OD East Java 2 When: March 2023 PIC: Elok	Rp -
		4. Benchmark the delivery and storage process using pallets	Where: Line I Warehouse PKG When: March 2023 PIC: Yoga	Rp -
		5. Submit evaluation results and request for additional service procurement to the ORP PI Dept.	Where: Meeting Room OD East Java 2 When: March 2023 PIC: Nurul & Beti	Rp -
		6. Socialize initial idea to internal stakeholders	Where: Online Discussion When: April 2023 PIC: Betlian	Rp -
		7. Evaluate Contract, HPS, TOR creation, and process to Planning Dept.	Where: Online Discussion via Zoom When: April 2023 PIC: Elok	Rp -
		8. Modify contract/ Procurement of transport services to include: truck types used, new delivery rates, and pallet retrieval rates to Line 1	Where: Online Discussion via Zoom When: April 2023 PIC: Elok	Rp -
		9. Modify contract/ Procurement of warehousing services	Where: Online Discussion via Zoom When: April 2023 PIC: Elok	Rp -

Root Cause (Why)	What (Solution)	How (Action Steps)	Where, When, Who	How Much (Cost)
		10. Socialize with all stakeholders (expedition partners, lessees, stockholders, distributors, and Sales Account Executives (AE) of Bojonegoro Regency)	Where: Online Discussion When: August 2023 PIC: Adhito	Rp -
		11. Administrative, technical, and non-technical preparation for readiness	Where: Meeting Room OD East Java 2 When: August 2023 PIC: Nurul	Rp -
		12. Ceremonial, Go Live, and Post-Activity Field Evaluation	Where: Bojonegoro When: August 2023 PIC: Betlian	Rp 2,000,000

The third phase involved contractual and administrative adjustments. Transport and warehousing contracts were reviewed and modified to accommodate pallet usage, revised truck specifications, new handling tariffs, and pallet return mechanisms. Administrative and technical preparations were also completed to support the transition from manual to mechanised handling. The final phase consisted of a pilot implementation (go-live) at the Bojonegoro distribution area, followed by post-implementation evaluation. This pilot approach allowed performance improvements and potential issues to be observed under real operating conditions before wider deployment.

3.3. Implementation

The implementation of the proposed palletisation strategy was carried out through a series of structured and sequential steps to ensure technical feasibility, operational control, and performance consistency. An initial audit was conducted on all six existing Line III warehouses in Bojonegoro to assess their physical suitability for forklift operations. The evaluation criteria included floor condition (flat concrete flooring), warehouse layout, and the adequacy of access doors for mechanised material handling. Based on this assessment, Talok and Sumberejo were identified as suitable for palletised operations. The remaining warehouses (Kalitidu, Baureno, Temayang, and Padangan) were found to be unsuitable due to soil or damaged flooring and limited access, which posed safety and operational risks for forklift usage. Following the audit, a strategic decision was made to close three structurally unsuitable warehouses (Kalitidu, Baureno, and Temayang) and to consolidate distribution volumes into the Talok and Sumberejo warehouses. This consolidation aimed to increase equipment utilisation, particularly forklifts, while simultaneously reducing fixed costs associated with warehouse rental and management.

Technical preparations included the development of pallet stowage plans to ensure load stability, compliance with vehicle dimension regulations, and optimal use of available truck capacity under the Zero ODOL constraints. In parallel, administrative preparations were undertaken to align contractual and operational arrangements with the new handling method. Transport contracts with freight forwarders were amended to accommodate pallet-compatible vehicles, with a preference for side-loading or wingbox trucks, and to adjust transportation tariffs to reflect reduced loading and unloading time. In addition, forklifts were procured through a rental arrangement, and pallets were mobilised from the production facility to the Line III warehouses to support continuous palletised operations.

The palletised distribution system was initially implemented through a pilot project, with the first shipment officially launched in August 2023. This pilot phase was executed over a continuous one-month period, successfully managing a total distribution volume of 2,370 tons. The pilot shipment was closely monitored throughout the entire distribution process, starting from palletised loading at the origin warehouse in Gresik using forklifts, through land transportation, and concluding with forklift-assisted unloading at the Bojonegoro warehouses. This pilot approach enabled real-time observation of operational performance, identification of potential issues, and validation of the effectiveness of the proposed solution under actual operating conditions.

3.4. Evaluation

This section evaluates the impact of mechanisation system interventions on the efficiency of fertiliser distribution in Bojonegoro Regency. After implementation, a comparative performance measurement was conducted between the conditions before (manual projection with Zero ODOL) and after improvement (palletisation). The financial impact of this innovation was very significant. Table 9 details the comparison of cost structures. Total distribution costs were successfully reduced to Rp 21.03 billion, well below the initial projection of Rp 26.16 billion. The largest savings came from transportation costs (Rp 2.3 billion) and warehouse rental rationalisation (Rp 1.5 billion). The new costs incurred for pallet management were relatively small compared to the savings achieved.

Table 9. Before and after comparison

Cost Components	Do Nothing Projection Zero ODOL	After Condition (Palettization)	Savings	Explanation
Handling Out Line I	Rp 683.064.515	Rp 0	Rp 683.064.515	Efficiency from using forklifts
Transportation	Rp 17.571.321.151	Rp 15.261.549.123	Rp 2.309.772.028	Route and tariffs optimization
Handling In Line III	Rp 1.863.182.520	Rp 978.304.796	Rp 884.877.724	Cheaper per tonnage using forklifts
Warehouse Rent	Rp 4.195.920.000	Rp 2.701.920.000	Rp 1.494.000.000	Closing small warehouses
Management Fee	Rp 830.340.000	Rp 405.168.000	Rp 425.172.000	Administrative efficiency
Handling Out Line III	Rp 1.019.393.132	Rp 1.523.157.760	(Rp 503.764.627)	Tariff optimization
New Pallet Purchasing	Rp 0	Rp 160.080.000	(Rp 160.080.000)	Pallet cost
TOTAL COST	**Rp 26.163.221.318**	**Rp 21.030.179.678**	**Rp 5.133.041.640**	**Down 20%**

In addition to cost efficiency, the implementation of palletised handling generated substantial improvements in operational performance. The loading and unloading speed at Line III warehouses increased significantly, from an average of 250 tonnes per day (31.25 tonnes/hour) under manual handling to approximately 750 tonnes per day (93.75 tonnes/hour) following the adoption of pallets and forklifts. This threefold increase in handling capacity contributed directly to reduced truck waiting time and improved delivery reliability. Quality and safety performance also improved markedly. The fertiliser damage rate attributable to handling activities decreased from 0.01% to 0.002%, reflecting greater load stability and reduced manual intervention. Furthermore, the mechanisation of loading and unloading effectively eliminated worker exposure to high-risk manual handling activities, reducing the occurrence of workplace accidents during these operations to zero during the observation period. To further validate the robustness of the reported savings, Table 10 presents a sensitivity analysis examining eight operational scenarios with varying assumptions on efficiency realisation and cost escalation. The analysis demonstrates that the intervention remains cost-positive across all tested scenarios, including the most pessimistic case combining 50% efficiency realisation with a fivefold increase in pallet costs. This confirms that the reported savings are robust to significant deviations from baseline assumptions and are not contingent on ideal operational conditions being sustained.

Table 10. Sensitivity analysis

Scenario	Net savings (Rp)	% of baseline	Cost-positive?
Baseline (as reported)	5.13B	100%	Yes
Conservative (80% efficiency)	3.99B	77.8%	Yes
Pessimistic (60% efficiency)	2.85B	55.6%	Yes
Pallet cost doubles	4.97B	96.9%	Yes
Pallet cost 5×	4.49B	87.5%	Yes
Transport savings only	3.21B	62.5%	Yes
No warehouse consolidation	3.21B	62.5%	Yes
Worst case (50% all, 5× pallet)	1.24B	24.2%	Yes

From an organisational perspective, structured quantitative assessments indicate a substantial improvement in operational conditions and stakeholder reception. Based on the self developed questionnaire, the descriptive analysis yielded an average score from the 50 respondents categorised at highest level or "Strongly Agree" across all evaluated dimensions of the Lean Framework. This positive consensus confirms that the improvements are also perceived by the employee who handle the fertilizer. Specifically, the mechanised pallet system was perceived to successfully alleviate extreme physical burdens, shortened truck queues, and improved overall workplace safety without introducing new operational friction. The detailed breakdown of the results can be seen in Table 11.

Table 11. Descriptive statistics of post-implementation operational evaluation

Evaluation Dimension (Lean Framework	Mean Score (1-5)	Interpretation
Delivery	4.63	Strongly Agree
Safety	4.87	Strongly Agree
Quality	4.77	Strongly Agree
Logistics & Admin.	4.94	Strongly Agree
Morale	4.91	Strongly Agree

4. DISCUSSION

The findings of this study indicate that Lean Thinking provides an effective adaptive response to inefficiencies induced by external regulatory interventions such as the Zero ODOL policy. The enforcement of Zero ODOL reduced truck load capacity by up to 47%, which, if left unaddressed, generated significant operational waste in the form of prolonged truck queues (waiting) and escalating transportation costs. Rather than compensating for this capacity loss through additional resources, the Lean-based intervention restructured the material handling process to restore flow efficiency. The introduction of palletisation and forklift-assisted handling eliminated several non-value-added activities inherent in the previous manual process. Consistent with the Lean principle of waste elimination along the value stream [11], mechanisation reduced excessive motion by enabling the movement of approximately 1.5 tonnes of fertiliser per handling cycle, replacing repetitive manual handling at the sack level. This consolidation of movement significantly improved handling productivity and reduced physical strain on workers.

In addition, the substantial increase in loading and unloading speed, approximately threefold, addressed waiting waste by accelerating truck turnaround time. Although the Zero ODOL policy constrained payload capacity per trip, faster turnaround enabled higher effective shipment frequency without creating bottlenecks at warehouse facilities. This finding supports the argument that throughput performance in regulated logistics systems depends not only on vehicle capacity but also on the stability and speed of material flow. These results align with the Lean Thinking framework proposed by Womack and Jones [25], which emphasises the organisation of value-creating activities in a continuous and disruption-free sequence. While the implementation of palletisation introduced new investment costs, such as pallet procurement and forklift rental, these costs were substantially outweighed by efficiency gains derived from reduced handling time, lower product damage rates, and distribution network rationalisation, including the consolidation of warehouses from six to three pallet-ready facilities. Sensitivity analysis further confirms that net savings remain positive even under conservative efficiency assumptions and substantially higher pallet costs, reinforcing the financial robustness of the intervention

The operational improvements observed in this study are consistent with emerging evidence on the effectiveness of Lean Thinking beyond traditional manufacturing contexts. Recent research on lean supply chain activities finds that Lean implementation significantly reduces overall supply chain costs and supports competitive advantage in SME and distribution settings, especially under resource constraints [26]. In warehouse environments, the application of Lean tools, including Lean Six Sigma frameworks, has been shown to raise process cycle efficiency and reduce non-value-added time by systematically identifying and eliminating waste [27]. Likewise, case studies in Lean Logistics demonstrate productivity gains and reduced waste in distribution operations following Lean implementation [28]. Furthermore, focused lean interventions in warehouse picking and handling have been associated with measurable improvements in operational performance. These findings corroborate our results, where palletisation and mechanisation dramatically improved handling speed, reduced waste and costs, and increased stakeholder satisfaction [29]. Taken together, the literature suggests that Lean principles can be effectively extended from manufacturing into logistics and warehousing domains, with tangible performance benefits when appropriate Lean tools and restructuring measures are applied. Importantly, unlike prior Lean logistics studies which largely assume stable operating conditions, this study extends the literature by demonstrating Lean's effectiveness as an adaptive mechanism under externally imposed regulatory disruption. While recent work on lean-resilience integration has highlighted the vulnerability of traditional Lean systems under disruptive shocks [15], [16], this study provides empirical evidence that proactive Lean redesign rather than reactive capacity expansion can successfully restore operational performance even when transport payload constraints are permanently imposed by regulation

Despite these significant efficiency gains, it is critical to acknowledge that the transition to a mechanised system introduces new operational trade-offs and implementation risks. The reliance on forklifts shifts the risk profile from manual labour fatigue to equipment downtime, necessitating strict scheduling and budgeting for ongoing forklift maintenance. Furthermore, the introduction of pallets creates a new reverse logistics requirement; pallet circulation between origin and destination warehouses must be rigorously tracked to prevent asset loss or damage. Finally, worker adaptation remains a critical challenge, requiring continuous training to ensure safe forklift interaction and cultural adjustment to the new workflows. Therefore, the long-term sustainability of this mechanised intervention heavily depends on proactive maintenance protocols and robust reverse logistics management.

While the empirical results of this study demonstrate significant performance improvements from the implementation of Lean Thinking in the context of subsidised fertiliser distribution, the broader literature indicates that Lean does not always yield uniformly positive outcomes across all settings. Some research suggests that Lean's potential benefits may be diminished in environments characterised by high supply chain complexity, where interactions among multiple actors, processes, and information flows can mediate or weaken the positive relationship between Lean practices and operational performance [30]. Another studies examining Lean implementation in small and resource-limited enterprises report high failure rates and significant implementation challenges, including cultural resistance, lack of managerial commitment, fragmented implementation, and inadequate skill development, which can prevent Lean initiatives from achieving targeted gains if these contextual factors are not adequately addressed [31]. These findings suggest that while Lean Thinking offers robust tools for waste elimination and flow improvement, its effectiveness is contingent on organisational preparedness, contextual fit, and systemic alignment. In the case of this study, the structured implementation plan and organisational readiness in the distribution context, with guided implementation by the researcher, likely contributed to the observed positive outcomes, as it directly counteracts cultural resistance, fragmented implementations, erroneous implementation, and lack of managerial commitment, showing the importance of situational and structural factors in realising Lean's full potential. From a managerial standpoint, these findings suggest that organisations facing externally imposed transport constraints should resist the instinct to expand capacity reactively, whether through additional fleet, labour, or warehousing, and instead direct improvement efforts toward internal process redesign. The results demonstrate that mechanising the loading and unloading interface is a higher-leverage intervention than adding resources upstream or downstream. Managers operating similar bulk commodity distribution networks should therefore treat warehouse infrastructure readiness and handling method modernisation as strategic priorities, particularly in regulatory environments where transport payload is constrained

5. CONCLUSION

This study examined the effectiveness of a Lean Thinking–based intervention in improving the efficiency of subsidised fertiliser distribution following the implementation of the Zero Over Dimension Over Load (Zero ODOL) policy in Indonesia. The Zero ODOL regulation imposed significant external constraints on transport capacity, which, if addressed through conventional responses such as increasing fleet size, labour, or storage capacity, would have resulted in escalating logistics costs and operational complexity. Instead, this study demonstrates that a process-oriented Lean approach can serve as an effective adaptive mechanism for maintaining and improving distribution system performance under regulatory pressure. Through a case study of the Line III distribution network in Bojonegoro Regency, the application of palletisation and forklift-assisted handling successfully eliminated key sources of waste in manual loading and unloading operations. Within the specific context of this one-month pilot evaluation, the intervention successfully improved material flow, increased handling speed, reduced product damage, enhanced operational safety, and lowered total logistics costs. However, given the absence of longitudinal data and complex statistical sensitivity analysis, these operational outcomes should be interpreted as context-specific rather than universally generalizable. While highly promising for similar resource-constrained environments, the exact magnitude of efficiency gains may vary across different supply chain configurations and infrastructure readiness levels. Importantly, these improvements were achieved despite the introduction of new investment components, indicating that efficiency gains from waste elimination and flow stabilisation can outweigh additional mechanisation costs. Beyond operational improvements at the process level, the study reveals that Lean Thinking can drive structural changes in distribution network design. The consolidation of warehouse infrastructure into fewer pallet-ready facilities improved equipment utilisation, reduced fixed costs, and simplified inventory control. This finding highlights Lean Thinking's potential not only as a tool for process optimisation but also as a strategic framework for reconfiguring logistics systems in response to external disruptions.

From a managerial perspective, the findings indicate that organisations operating under transport capacity constraints should prioritise improvements in material flow, handling speed, and waste elimination rather than relying on reactive capacity expansion strategies. The case demonstrates that mechanisation through palletisation can substantially improve operational efficiency by reducing handling time, stabilising truck turnaround, and lowering damage rates, even when transport payload is restricted. Managers are therefore encouraged to evaluate internal handling processes and warehouse configurations as critical levers for maintaining throughput and cost efficiency under regulatory or environmental disruptions. In addition, distribution network rationalisation, such as consolidating volumes into fewer, infrastructure-ready warehouses, can enhance equipment utilisation and reduce fixed costs without compromising service performance.

From a policy perspective, the results suggest that regulatory interventions such as the Zero ODOL policy do not inherently lead to inefficiencies within distribution systems, provided that supply chain actors are supported in adapting their operational processes. Policymakers should consider that compliance-related performance declines may stem from process inefficiencies rather than regulatory design alone. Facilitating or incentivising investments in standardised handling infrastructure, warehouse modernisation, and mechanised logistics systems can help ensure that regulatory objectives related to safety and road preservation are achieved without undermining distribution efficiency or supply reliability. These findings highlight the importance of aligning transport regulations with complementary operational capability development across the logistics sector.

This study is subject to several limitations. The analysis focuses on a single case within the subsidised fertiliser distribution system, and the results may not be directly generalisable to other commodities or regions with different infrastructure characteristics. In addition, the evaluation period captures short-term post-implementation performance; longer-term impacts on maintenance costs, pallet circulation management, and labour dynamics were not examined. Future research may extend this work by conducting comparative studies across multiple distribution regions, integrating quantitative simulation models to assess scalability, or exploring the interaction between Lean Thinking and digital technologies in regulated logistics environments. Despite these limitations, the findings provide practical and empirical evidence that Lean Thinking offers a robust and adaptable framework for enhancing logistics efficiency under externally imposed operational constraints.

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DECLARATION OF AI-TOOL USAGE

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