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# Optimization Of Polio Vaccine Packaging Through Changes in Reusable Packaging Become a Singleuse Using Dmaic

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**ABSTRACT**

The use of reusable plastic crates for storing polio vaccine products is intended to reduce warehouse operating costs because the crates can be used repeatedly. However, their use presents several operational challenges, including prolonged reuse cycle times due to lower product shipment volumes relative to production output. Furthermore, inefficient storage space utilization increases operating costs by necessitating additional warehouse rentals to accommodate inventory. To address these challenges, this study evaluates the transition from reusable plastic crates to single-use corrugated cardboard cartons, which offer improved storage space utilization. Specifically, the study aims to compare the operational efficiency, lead times, and warehouse operating costs associated with both packaging systems. The research employs the Define, Measure, Analyze, Improve, and Control (DMAIC) framework, Value Stream Mapping (VSM), and Life Cycle Cost Analysis (LCCA). The findings indicate that single-use carton packaging can reduce warehouse operating costs by up to 71% compared with reusable plastic crates. Additionally, future-state VSM estimates suggest that the packaging transition could reduce the relevant process lead time from 301 to 60 days, representing an approximately 80% reduction. These findings suggest that adopting single-use carton packaging could improve warehouse operational efficiency, optimize storage capacity utilization, and provide a more cost-effective alternative to reusable plastic crates in polio vaccine distribution operations.

## INTRODUCTION

Over the past decade, the manufacturing industry across various countries has undergone significant transformations, particularly in the management of production and distribution systems (Chirumalla et al., 2025; Hughes et al., 2022; Moghrabi et al., 2023; Mourtzis & Panopoulos, 2022). Companies are increasingly required to improve operational efficiency, adapt to changing market demands, and incorporate sustainability considerations into their business operations. Intensifying global competition, evolving environmental regulations, and the growing need for reliable supply chain systems have encouraged

companies to comprehensively evaluate their operational activities. One aspect receiving increasing attention is the packaging system. From an industrial engineering perspective, packaging is no longer regarded solely as a means of protecting products but also as a critical component influencing operating costs, cycle times, storage capacity, and material flow efficiency (Accorsi et al., 2025). Therefore, selecting an appropriate packaging type and design represents a strategic decision that directly affects overall operational efficiency.

At the global level, single-use packaging has been increasingly adopted in the pharmaceutical industry, where stringent hygiene and safety standards are essential. According to Zadbuke et al. (2013), single-use packaging can help minimize potential cross-contamination risks associated with improperly managed reusable packaging and simplify distribution processes by eliminating the need for reverse logistics. Nevertheless, reusable packaging remains a viable option because it can provide long-term economic benefits when supported by an efficient circulation system (Huang et al., 2024; Kim et al., 2023; Yadav et al., 2024). However, reusable packaging systems require effective return logistics, cleaning procedures, storage management, and inventory control to prevent additional indirect operating costs (Bartolotti et al., 2025). In Indonesia, increasing pharmaceutical and healthcare product distribution activities have similarly encouraged companies to reassess the effectiveness of their packaging systems in terms of product quality, operational efficiency, and cost management.

Within Indonesia's pharmaceutical industry, PT XYZ operates in the life sciences sector, primarily focusing on vaccine manufacturing. One of its products is the polio vaccine, which is supplied for the national routine immunization program and exported to various countries to support global immunization initiatives. Polio vaccines are temperature-sensitive biological products that require controlled cold-chain storage and distribution conditions to maintain their stability, potency, and quality (Fahrni et al., 2022; Ren et al., 2021). Consequently, maintaining appropriate temperature conditions throughout storage and distribution is essential to preserving product integrity and ensuring compliance with applicable pharmaceutical quality standards.

Currently, PT XYZ stores polio vaccine products in reusable plastic crates stacked on plastic pallets within temperature-controlled cold storage facilities. The operational process begins with the storage of products following the filling stage, followed by visual inspection, labeling, packaging, and distribution. The period from postproduction storage to the completion of packaging is approximately two months, whereas the lead time associated with the plastic crate reuse cycle can reach ten months. This substantial discrepancy is partly attributable to customer-owned inventory held in storage, as shipment schedules depend on individual customer requirements, preventing plastic crates from being promptly returned and reused. Furthermore, monthly production volumes exceeding shipment volumes contribute to increasing inventory accumulation within the warehouse. Consequently, warehouse space utilization continues to rise, requiring the company to expand its storage capacity by renting additional warehouse facilities. These conditions significantly increase annual warehouse operating costs, particularly those associated with additional storage facility rentals (Barasin et al., 2024; Chen et al., 2024; Mohamud et al., 2023).

To address these operational challenges, the company has begun considering alternative packaging solutions to replace reusable plastic crates, particularly single-use corrugated

cardboard cartons. Advances in packaging materials and structural design have expanded the potential applications of corrugated cardboard packaging in pharmaceutical logistics. Modern corrugated board can be engineered to provide adequate structural strength, moisture resistance, and product protection under specified storage and handling conditions. However, its performance must be validated against relevant packaging requirements, particularly those associated with temperature-controlled pharmaceutical storage. Compared with reusable plastic crates, appropriately designed single-use cartons may offer improved dimensional efficiency and warehouse space utilization. Furthermore, single-use packaging eliminates the need for crate return, cleaning, and reuse inventory management, potentially reducing the overall packaging circulation lead time while simplifying logistics and warehousing operations. Improved volumetric storage efficiency may also increase effective warehouse capacity without requiring additional floor space, thereby reducing dependence on external warehouse rentals and the associated operating costs (Moica et al., 2025).

Based on these operational challenges, this study aims to compare reusable plastic crates and single-use corrugated cardboard cartons for storing polio vaccine products at PT XYZ. The research applies the Define, Measure, Analyze, Improve, and Control (DMAIC) framework to systematically identify operational inefficiencies, analyze their underlying causes, and develop appropriate improvement strategies (Adeodu et al., 2023; Khan et al., 2023). Value Stream Mapping (VSM) is employed to visualize material and information flows, identify non-value-added activities, and assess opportunities for reducing process lead times (Hidayat et al., 2025; Rahman & Kirby, 2024; Wahyunengsih & Hartayu, 2025). Additionally, Life Cycle Cost Analysis (LCCA) is used to evaluate and compare the total costs associated with both packaging alternatives over a defined analysis period, including relevant acquisition, storage, handling, return logistics, and disposal costs (Inayah & Widjajati, 2020; Iskandar et al., 2016). By integrating these three analytical approaches, this study seeks to provide a comprehensive comparison of the operational and economic performance of reusable and single-use packaging systems. The findings are expected to support evidence-based packaging decisions, improve warehouse space utilization, reduce logistics-related inefficiencies, and identify the most cost-effective packaging alternative while maintaining the quality and integrity of polio vaccine products.

## METHOD

This study was conducted in five stages: preliminary investigation, data collection, data processing, analysis and discussion, and conclusion. The preliminary stage involved field observations at PT XYZ's cold-chain storage warehouse, a literature review, and discussions with the warehouse operations team to identify operational problems and establish the research objectives. Primary data were collected on production output, inventory levels, warehouse capacity, reusable plastic crate utilization, product configurations, and warehouse rental costs. Secondary data included estimated procurement costs for single-use cartons and reusable plastic crates. Data were processed using the Define, Measure, Analyze, Improve, and Control (DMAIC) framework. The Define phase established the research scope and developed a current-state Value Stream Map (VSM). The Measure phase assessed reusable crate cycle times, ranging from two to eight months, and identified value-added and non-

value-added activities. The Analyze phase examined operational inefficiencies and their root causes using VSM and a fishbone diagram. The Improve phase developed a future-state VSM and proposed an alternative packaging system to reduce dependence on product shipment schedules for crate reuse. The Control phase proposed monitoring mechanisms, revised standard operating procedures (SOPs), and a pilot implementation plan to sustain the anticipated improvements. Subsequently, the findings were analyzed and discussed to evaluate operational inefficiencies and the potential benefits of the proposed packaging alternative. Finally, conclusions were drawn, and recommendations for future research were formulated.

## RESULTS AND DISCUSSION

The supply chain cycle is the most crucial thing for a company, especially in the manufacturing sector. Research shows that ineffective and efficient handling will directly affect the company's performance and operational costs. After identifying problems and solving problems, it is hoped that there will be benefits for the company in the form of increased productivity, cost efficiency and continuous improvement, as the foundation of a continuous improvement system The discussion in this chapter is prepared based on the (Hama Kareem et al., 2022) (Schroeder et al., 2008). *Define, Measure, Analyze, Improve, Control* (DMAIC) approach to ensure that the process of analysis and design of improvements is carried out systematically and structured according to the research methodology used.

### Object Analysis

The product that is the object of the research is a vial-shaped pharmaceutical product packaged in secondary packaging. In Figure 4.1 Vaccine Products, each secondary package contains 10 vials. This product requires special storage conditions at low temperatures down to -20 °C, so the entire process of handling, storage, and distribution is carried out in a *cold chain* system.

Each plastic basket can hold 112 boxes of secondary packaging or the equivalent of 1120 vials. These plastic baskets are used to facilitate the *handling* and storage process in *cold storage*.

Next, the baskets are arranged on pallets with a pattern of 5 x 5 x 5 x 5 plastic baskets arranged in stacks. The dimensions of the plastic baskets used are 565 x 400 x 260 mm, with effective dimensions for product storage are 470 x 350 x 250mm. Figure 4.3 Basket Storage Configuration on Pallets, shows the product storage dimensions of 1200 x 1000 x 1500 mm. With this configuration, the number of products stored can accommodate up to 28,000 vials at the maximum capacity for each pallet.

In the product storage facility, the available product storage capacity consists of 8 internal storage rooms owned by the company with a capacity of 1250 plastic baskets each and 3 additional rental warehouse facilities with a capacity of 1250 plastic baskets each. So that the total available product storage capacity is 13,750 plastic baskets. Table 1 shows the total product stock of 10,370,672 vials stored in the warehouse or equivalent to 9,260 baskets. The storage capacity of the company's warehouse is 10,000 plastic baskets plus the storage capacity of the rental warehouse is 3,750, so the total storage capacity of the warehouse is 13,750 plastic baskets.

**Table 1**. Product Flow Data & Cart

| Moon | Products (vials) | | | Storage Packaging (Krj) | | | Warehouse Utilization | |
|---|---|---|---|---|---|---|---|---|
| | Production | Distribution | Stick | Production | Distribution | Stick | Warehouse Capacity | Utilization (%) |
| January | 13.000.000 | 2.629.328 | 10.370.672 | 11.607 | 2.348 | 9.260 | 13.750 | 67% |
| February | 4.417.857 | 4.630.744 | 10.157.785 | 3.945 | 4.135 | 9.069 | 13.750 | 66% |
| March | 4.784.632 | 3.656.986 | 11.285.431 | 4.272 | 3.265 | 10.076 | 13.750 | 73% |
| April | 3.316.644 | 3.369.689 | 11.232.386 | 2.961 | 3.009 | 10.029 | 13.750 | 73% |
| May | 2.902.696 | 3.199.667 | 10.935.415 | 2.592 | 2.857 | 9.764 | 13.750 | 71% |
| June | 3.852.335 | 2.171.886 | 12.615.864 | 3.440 | 1.939 | 11.264 | 13.750 | 82% |
| July | 3.515.155 | 2.949.698 | 13.181.321 | 3.139 | 2.634 | 11.769 | 13.750 | 86% |
| August | 2.835.651 | 2.522.188 | 13.494.784 | 2.532 | 2.252 | 12.049 | 13.750 | 88% |
| September | 3.460.536 | 3.014.463 | 13.940.857 | 3.090 | 2.691 | 12.447 | 13.750 | 91% |
| October | 1.460.098 | 2.068.452 | 13.332.503 | 1.304 | 1.847 | 11.904 | 13.750 | 87% |
| November | 2.147.422 | 3.218.055 | 12.261.870 | 1.917 | 2.873 | 10.948 | 13.750 | 80% |
| December | 6.702.870 | 7.095.828 | 11.868.912 | 5.985 | 6.336 | 10.597 | 13.750 | 77% |
| | | | | 46.782 | 36.185 | 12.447 | | |
| | | | | TOTAL | TOTAL | MAX | | |

*(Source: Data Collection)*

Stok awal tahun vial $= Jumlah\ Hasil\ Produksi - Jumlah\ Distribusi$

Stok Vial $= 13.000.000 - 2.629.328$

Stok Vial $= 10.370.672$

With a capacity of 1200 vials per basket, then:

$$\text{Stok dalam satuan Keranjang} = \frac{Jumlah\ produk\ (Vial)}{Kapasitas\ keranjang\ (Vial)}$$

$$\text{Stok dalam satuan Keranjang} = \frac{10.370.672\ vial}{1.200\ vial}$$

Stok dalam satuan Keranjang $= 9.260$ **Cart**

With an installed storage capacity of 13,750 baskets and a stock of 9,260 plastic baskets in January, then:

$$\% \text{ Utilisasi Gudang } = \frac{Jumlah\ stok\ produk\ (keranjang)}{Kapasitas\ Penyimpanan\ (Keranjang)}$$

$$\% \text{ Utilisasi Gudang } = \frac{39.26070}{13.750}\ x\ 100\%$$

$$\% \text{ Utilisasi Gudang } = 67\%$$

Table 4. 2 shows a series of activities using plastic baskets starting from the process of storing production products, visual inspection, labeling, packaging to the product distribution process. Activities value added (VA) for 6 days and activities non-value added for 295 days, so the total time is 302 days. The activity that has the longest duration is storage activities after the packaging process is completed for 240 days. This activity is affected by the demand for product delivery according to customer needs, causing the storage duration of products to be longer.

**Table 2**. Cycle of Use Re-Usable Plastic Basket

| Activities | VA | NVA | Remarks |
|---|---|---|---|
| Storage of Production Results | - | 15 days | Storage of production products |
| Visual Inspection | 2 days | - | Product Testing |
| Storage | - | 25 days | Product storage |
| Labeling | 1 day | - | Label attachment process |
| Storage | | 15 days | Product storage |
| Packaging | 2 days | - | Production Process |
| Storage | - | 240 days | The Storage Process During the Packaging process |
| Distribution | 1 day | - | Plastic basket return process |
| TOTAL | 6 days | 295 days | Total Cart Use Cycles |

*(Source: Data Collection)*

***Analyze* (Analysis)**

The analyze stage is carried out to further examine the root causes of the problems that have been identified at the stage *measure*, especially the relationship between the length *lead time* supply chain cycle to the company's financial-operational condition, as well as assessing the feasibility of packaging alternatives *single-use* box as a repair solution.

**Financial-Operational Impact Analysis**

The results of VSM mapping at the measure stage show that post-packaging product storage activities have a duration of 240 days, or around 79.7% of the total *lead time* overall 301 days. The length of this storage duration causes products that are physically ready for distribution to be held for a long time in the warehouse, resulting in a continuous accumulation of product stock throughout the observation period.

This is in line with the findings in Table 1, where the number of plastic baskets used for storage (46,782 units) is not proportional to the number of baskets that return to the cycle

after the distribution process (36,185 units), with a difference of 22%. This difference indicates that the rate of product entry and exit from the warehouse is unbalanced, where the production and storage rates are faster than the distribution rates. As a result, the available warehouse space is increasingly insufficient to accommodate the growing volume of products.

The relationship between causes and effects can be arranged in the following series:

*Long storage lead time* (240 days) → product stock accumulates → existing warehouse capacity is insufficient → warehouse utilization increases → companies rent additional warehouses → operational costs (warehouse rental) increase by IDR 3,000,000,000 per year.

This series shows that the additional warehouse rental costs incurred are not caused by an increase in production volume alone, but rather due to the retention of products in the warehouse due to the long waiting time before distribution. In other words, these costs are a direct consequence of activities *non-value added* In the cycle of using plastic baskets, it is not a cost that provides added value for the product or the customer. This condition confirms that the root of the company's financial-operational problems lies in the inefficiency of the packaging use cycle *re-usable*, especially at the post-packaging storage stage.

**Feasibility Analysis of Single-use Box Packaging Alternatives**

Based on the results of the financial-operational impact analysis above, it is known that the root of the main problem lies in the dependence of the distribution process on the plastic basket return cycle. As long as the plastic basket is still used as the main packaging, the packaged product cannot be immediately removed from the warehouse without considering the availability and schedule of the return of the basket for reuse in the next production cycle. This characteristic makes the post-packaging storage duration the activity with the largest *non-value added* contribution in the entire cycle.

Alternatively, the use of *single-use* box packaging is considered because of its nature that does not require a *return cycle* like plastic baskets. With *single-use* box packaging, each packaging unit is only used once for one delivery cycle, so that the product packaging and distribution process no longer depends on the availability and return schedule of the packaging from customers. This characteristic directly has the potential to break the dependence that has been the cause of product retention in the warehouse for a long time.

In terms of operational feasibility, the use of *single-use* boxes is also in line with the pattern of delivery requests that are tailored to customer needs, because products can be directly packaged and distributed without the need to wait for the availability of the returned basket. Thus, conceptually, the use of *single-use boxes* has the potential to shorten the duration of post-packaging storage activities, while reducing the accumulation of product stock in the warehouse which has been a trigger for an increase in additional warehouse rental costs.

In addition to the conceptual aspects above, the feasibility of using *single-use boxes is also* analyzed in terms of storage capacity. The configuration of single-use box packaging as presented in Figure 4.5 has the potential to increase the storage capacity of the product for each pallet, because *the material of single-use* boxes has a lower thickness than plastic baskets, so the utilization of storage space volume is more optimal. The capacity comparison shows that one single-use box pallet is able to accommodate 46,080 vials, while one plastic basket pallet only holds 28,000 vials, there is a capacity difference of 18,080 vials or equivalent to a 64.5% increase in capacity per pallet.

The company currently operates 11 warehouses with a total installed capacity of 550 pallets. By converting the capacity per pallet into the total storage capacity of the product (vial), a comparison is obtained as presented in Table 5. The results of the comparison show that without increasing the number of warehouses or pallets, the switch to box packaging *single-use* potentially increasing total product storage capacity by 64.6%. This increase in capacity directly has the potential to reduce the need for additional warehouse rentals, as existing storage space can accommodate larger volumes of products.

**Table 3**. Compare Product Storage Capacity

| Packaging Type | Number of Warehouses | Pallet capacity | Vial/pallet capacity | Capacity in vial |
|---|---|---|---|---|
| *Re-usable* Plastic Basket | 11 | 550 | 28.000 | 15.400.000 |
| So *single-use* | 11 | 550 | 46.080 | 25.344.000 |
| Differences | | | | 9.994.000 (64%) |

*(source: Data Processing)*

Nevertheless, the switch to packaging *single-use* It is also necessary to consider the cost aspect, considering that this packaging is disposable so that it has the potential to incur recurring purchase costs that are different in characteristics than the investment and maintenance costs of reusable plastic baskets. Therefore, to ensure that the switch to packaging really provides overall cost efficiency in the long term, further analysis is needed through the *Life Cycle Cost Analysis (*LCCA) over a 10-year period, which will be discussed at the *Improve*.

***Improve* (Fix)**

The improve stage is carried out to design a proposed improvement for the bottlenecks that have been identified at the stage *analyze*, through planning *future state* VSM with a single-use box usage scheme, as well as long-term financial feasibility measurement through the *Life Cycle Cost Analysis* (LCCA).

**Perancangan *Future State Value Stream Mapping***

Based on the results of the analysis in the previous stage, the root cause of the long lead time of the supply chain cycle lies in the dependence of post-packaging storage activities on the return cycle of plastic baskets. As a proposed improvement, a future state VSM is designed with a scheme to use single-use box packaging to replace plastic baskets at the stages of storing production products, visual inspection, labeling, packaging, and product distribution, as presented in Figure 4.6.

On the scheme *future state*, post-packaging storage activities no longer depend on the availability or return schedule of packaging, as single-use boxes are directly used once for a single delivery cycle without the need to wait for the return process from the customer. Thus, the duration of the activity *non-value added* At this stage, it can be shortened from 301 days to 60 days (reduction *lead time* 80%). Comparison *lead time* between conditions *current state* and *future state* presented in Table 6.

**Table 4**. Comparison Lead Time Current State and Future State VSM

| Activity Categories | *Current State* (hari) | *Future State* (day) | Differences (day) |
|---|---|---|---|
| *Value Added* (VA) | 6 | 5 | 1 |
| *Non-Value Added* (NVA) | 295 | 55 | 240 |
| Total *Lead Time* | 301 | 60 | 241 (80 %) |

*(source: Data Processing)*

In addition to shortening *lead time*, use of the box *single-use* also increase the storage capacity of the product as analyzed at the *analyze* (Table 5), which is an increase in total storage capacity by 64.6% without an increase in the number of warehouses and pallets. This increase in capacity has a direct impact on reducing the need for additional warehouse rentals, thereby reducing the burden of operational costs that have arisen due to warehouse rental costs of IDR 3,000,000,000 per year.

To project the need for the number of warehouses after the implementation of single-use box packaging, a calculation simulation was carried out based on the highest product stock storage load during the observation period, which was 13,940,857 vials in September. With box packaging capacity *single-use* of 46,080 vials per pallet (Table 5), then the storage requirement is equivalent to:

**13.940.857 vial÷ 46.080 vial/puck ≈ 303 puck**

Based on the existing installed capacity of 50 pallets per warehouse (550 pallets ÷ 11 warehouses), the number of warehouses needed to accommodate 303 pallets is:

**303 pallets ÷ 50 pallets/warehouse ≈ 7–8 warehouses**

Taking into account the capacity margin to anticipate demand fluctuations, the use of 8 warehouses with a total capacity of 400 pallets is simulated, so that the warehouse utilization level is obtained as follows:

303**llets ÷ 400 pallets ≈ 75.75% (≈76%)**

The results of this simulation show that after the application of the box packaging *single-use,* The need for product storage at peak load can be met with only 8 of the 11 warehouses that the company has operated so far (including additional rental warehouses). Thus, there is a surplus capacity of 3 warehouses that are potentially no longer needed, so that the company can eliminate the need to rent additional warehouses which have been incurring operational costs of IDR 3,000,000,000 per year. The amount of cost savings in detail will be further calculated through the Life Cycle Cost Analysis (LCCA) analysis in the next sub-chapter.

**Analisis *Life Cycle Cost Analysis* (LCCA)**

To ensure that the proposed improvements provide overall cost efficiency, an analysis was carried out *Life Cycle Cost Analysis* (LCCA) on both packaging options during the 10-year projection period. as a cost estimate calculation, the cost of purchasing a plastic basket per unit is Rp. 200,000, as well as the purchase of a box of packaging *single-use* is Rp. 15000. Box needs *single-use* It can be calculated by dividing the number of vials according to the capacity of the single-use box which is as many as 480 vials per box. Meanwhile, the need for the basket can be calculated by dividing the number of vials according to the capacity of the basket as many as 1120 vials per basket.

The approach taken is by simulating product storage operations based on the highest product stock storage load during the observation period, which was 13,940,857 vials in September. This analysis focuses on two main cost components, namely the cost of purchasing packaging and the cost of renting a warehouse, considering that these two components are costs that are directly and significantly affected by changes in the type of packaging, while other cost components (such as handling and labor costs) are assumed to be relatively not significantly different between the two options and are therefore not included in the scope of this calculation.

**Table 5**. Basic Data and Assumptions

| Parameter | Plastic Basket (*Re-usable*) | So (*Single-Use*) |
|---|---|---|
| Price per unit (1st year) | IDR 200,000 | IDR 15,000 |
| Capacity per unit | 1,120 vial | 480 vial |
| Production volume/ year | 13,940,857 vials (constant) | 13,940,857 vials (constant) |
| Nature of purchase | Initial investment (*one-time*), no replacement (*loss rate* 0%) | Recurring |

*(source: Data Processing)*

**Table 6**. Additional Cost and Inflation Assumptions

| Parameter | Plastic Basket (*Re-usable*) | So (*Single-Use*) |
|---|---|---|
| Additional warehouse rental costs | IDR 3,000,000,000 (1st year) | IDR0 (Existing warehouse capacity is sufficient) |
| Inflation assumptions | 5% per annum | 5% per annum |
| Projection period | 10 years | 10 years |

*Source: Original data/source attribution requires author verification.*

**Calculation of Packaging Unit Requirements**

**Plastic basket (initial investment, one-time**

**13,940,857÷1,120=12,447.19→12,448 units**

**Initial Investment Cost of *Re-usable* Plastic Basket**

**12,448 units×Rp200,000=Rp2,489,600,000**

Single-use *box* (needed annually):

**13,940,857÷480=29,043.45→29,044 units/year**

Projected Cost of Single-Use Boxes per Year (Price Increase by 5%/Year) and Discount (10%).

**Table 7**. Calculation Present Value — Box Option Single-Use (10% Discount)

| Year | Price/Unit (Rp) | Requirements (units) | Annual Fee (Rs) | *Discount Factor* | *Present Value* (Rp) |
|---|---|---|---|---|---|
| 1 | IDR 15,000 | 29.044 | IDR 435,660,000,00 | 0,9091 | IDR 396.054.545 |
| 2 | IDR 15,750 | 29.044 | IDR 457,443,000.00 | 0,8264 | IDR 378.052.066 |
| 3 | IDR 16,538 | 29.044 | IDR 480.315.150.00 | 0,7513 | IDR 360,867,881 |
| 4 | IDR 17,364 | 29.044 | IDR 504.330.908.00 | 0,683 | IDR 344,464,796 |
| 5 | IDR 18,233 | 29.044 | IDR 529.547.453.00 | 0,6209 | IDR 328,807,305 |
| 6 | IDR 19,144 | 29.044 | IDR 556.024.826,00 | 0,5645 | IDR 313,861,518 |
| 7 | IDR 20,101 | 29.044 | IDR 583,826,067,00 | 0,5132 | IDR 299.595.086 |
| 8 | IDR 21.107 | 29.044 | IDR 613.017.370.00 | 0,4665 | IDR 285,977,127 |
| 9 | IDR 22,162 | 29.044 | IDR 643,668,239,00 | 0,4241 | IDR 272.978.167 |
| 10 | IDR 23,270 | 29.044 | IDR 675,851,651,00 | 0,3855 | IDR 260.570.069 |
| | Total | | IDR 5,479,684,664,00 | | IDR 3,241,228,561 |

*(source: Data Processing)*

*Discount Factor* in the 1st year:

$$DF_t = \frac{1}{(1+i)^t}$$

$$DF_1 = \frac{1}{(1+10\%)^1} = 0{,}9091$$

*Present Value* in the 1st year:

$$\mathrm{PV} = FV_t \times \mathrm{DF}_t$$

$$PV_1 = 435.660.000\ x\ 0{,}9091 = \ 396.054.545$$

Projected Warehouse Rental Cost – Plastic Basket Option (Up 5%/Year) and Discount (10%).

**Table 8**. Calculation Present Value — Plastic Basket Option (10% Off)

| Year | Nominal Fee (Rp) | Discount Factor | Present Value (Rp) |
|---|---|---|---|
| 1 | IDR 5,489,600,000 *(initial purchase + rental)* | 0,9091 | IDR 4,990,545,455 |

| | | | |
|---|---|---|---|
| 2 | IDR 3,150,000,000 | 0,8264 | IDR 2,603,305,785 |
| 3 | IDR 3,307,500,000 | 0,7513 | IDR 2,484,973,704 |
| 4 | IDR 3,472,875,000 | 0,683 | IDR 2,372,020,354 |
| 5 | IDR 3,646,518,750 | 0,6209 | IDR 2,264,201,247 |
| 6 | IDR 3,828,844,688 | 0,5645 | IDR 2.161.283.008 |
| 7 | IDR 4,020,286,922 | 0,5132 | IDR 2,063,042,872 |
| 8 | IDR 4,221,301,268 | 0,4665 | IDR 1,969,268,196 |
| 9 | IDR 4,432,366,331 | 0,4241 | IDR 1.879.756.005 |
| 10 | IDR 4,653,984,648 | 0,3855 | IDR 3,283,352,725 |
| Total | IDR 40.223.277.607 | - | IDR 24,582,507,708 |

*(source: Data Processing)*

*Discount Factor* in the 1st year:

$$DF_t = \frac{1}{(1+i)^t}$$

$$DF_1 = \frac{1}{(1+10\%)^1} = 0{,}9091$$

*Present Value* in the 1st year:

$$\mathrm{PV} = FV_t \times \mathrm{DF}_t$$

$$PV_1 = 5.489.600.000\ x\ 0{,}9091 = \ 4.990.545.455$$

The results of the calculation using *the Present Value approach* in Table 10 show that the total cost of the plastic basket option at the current value is IDR 24,582,507,708, while the single-use box option is IDR 3,241,228,561. The difference between the two options reaches IDR 21,341,279,147, or the equivalent of 86% of the percentage value which is practically identical to the nominal calculation result (86%), although the absolute value is much smaller.

**Table 9**. LCC Total Comparison Recap: Nominal vs. PV

| Pendekatan | Plastic Basket (Rp) | So Single-Use (Rp) | Difference (Rp) | % Efficiency |
|---|---|---|---|---|
| Nominal (*Undiscounted*) | IDR 40.223.277.607 | IDR 5,479,684,662 | IDR 34,743,592,945 | 86 % |
| *Present Value* (diskonto 10%) | IDR 24,582,507,708 | IDR 3,241,228,561 | IDR 21.341.279.147 | 86 % |

*(source: Data Processing)*

This significant cost difference is mainly due to the additional warehouse rental cost component, which in the plastic basket option continues to increase every year following inflation and accumulates to Rp 21,341,279,147 (*Present Value*) over 10 years, far exceeding the investment cost of the packaging itself. On the other hand, in the *single-use* box option, although the cost of purchasing packaging is recurring every year and the total (Rp5,479,684,662) is greater than the initial investment cost *of the re-usable* plastic basket (Rp2,489,600,000), the absence of the need for additional warehouse rental makes the total overall cost of this option much lower.

Thus, the results of this LCCA reinforce the findings of the previous stage (*future state* VSM and warehouse capacity simulation), that the switch from plastic baskets to single-use boxes provides significant operational cost efficiencies in the long run, while supporting improvements *lead time* the company's supply chain cycle.

***Control* (Control)**

Stages *Control* to ensure that the proposed improvements at the *improve* i.e. the transition from packaging *re-usable* Plastic basket into box packaging *single-use* can be applied consistently and sustainably, so that the benefits of improvement in the form of shortening *lead time* supply chain cycles and operational cost efficiencies do not return to their original condition.

Implementation of new things regarding the addition of an internal supply chain system from the use of *re-usable* Plastic basket becomes the use of the box *single-use* After the process *packaging*, of course, will involve various parties in its implementation. For this reason, it is necessary to have support from the company and cooperation from various parties so that the implementation of the use of the box *single-use* can run well according to plan. Table 12 presents the stages that need to be carried out for the implementation of the use of the box *single-use* from the development stage to routine operations.

**Table 10**. Stages of Implementation of Single-use Dus

| No. | Activities | ***Person In Charge* (PIC)** |
|---|---|---|
| 1 | Socialization of implementation<br>Provide information to all related work units to obtain information about the background, workflow of the work process, how to use and the purpose of using *single-use boxes* | All related work units |
| 2 | Box feasibility study<br>Ensuring that the materials and dimensions used meet specifications and meet the durability for routine use. As well as ensuring the ease of supply of goods and procurement costs | Production, *Quality Control, Quality Assurance, Procurement* |
| 3 | Configure validation<br>Ensure that *the single-use* box to be used meets quality standards and maintains product quality during use. | Production, *Quality Assurance* |
| 4 | Specification registration | Supply Chain |

| No. | Activities | *Person In Charge* (PIC) |
|---|---|---|
| 5 | Reference documents are available for material procurement, testing and approved design<br>Creation of Operational Procedures<br>Contains procedures for use, preparation and reporting if necessary | Produksi, *Warehouse, Quality Control, Quality Assurance* |

*Source: Original data/source attribution requires author verification.*

**Table 11**. Stages of Implementation of Single-Use Boxes (continued)

| No. | Activities | *Person In Charge* (PIC) |
|---|---|---|
| 6 | Training<br>Ensure that all work units know the procedures for use, storage and inspection | All related trade unions |
| 7 | Socialization to customers<br>Ensure customers have obtained product information before receiving products with new packaging | Sales & Marketing |
| 8 | Socialization to regulatory guarantors<br>Ensure that *the single-use* box to be used is legally registered and is approved packaging | *Quality Assurance, Regulator* |
| 9 | Implementation<br>Ensure the use of *single-use* boxes has gone according to plan. | Produksi, *Warehouse, Quality Control, Quality Assurance* |
| 10 | Monitoring<br>Conducting routine inspections to find out obstacles or opportunities for *sustainability* improvement. As well as evaluating the cost calculation between the plan and the results of the implementation of routine operational activities. | All related work units |

Source: Attribution requires author verification.

## CONCLUSION

Based on the findings, the transition from reusable plastic crates to single-use corrugated cardboard cartons demonstrated substantial potential to improve warehouse operational efficiency and reduce storage costs for polio vaccine products. The Define and Measure phases of the Define, Measure, Analyze, Improve, and Control (DMAIC) framework revealed that the existing reusable plastic crate system had a total lead time of 301 days. Production volumes exceeding distribution volumes contributed to increasing warehouse space utilization, necessitating additional storage capacity through external warehouse rentals. The Analyze phase, supported by Value Stream Mapping (VSM), identified the delayed return of reusable plastic crates as the primary operational bottleneck, with a return cycle of 240 days following packaging completion due to customer-dependent distribution schedules. The

predominant forms of waste were prolonged waiting times and excessive inventory accumulation, which increased non-value-added activities and resulted in additional warehouse rental costs of IDR 3,000,000,000 annually. The future-state VSM indicated that adopting single-use corrugated cardboard cartons could reduce the total lead time from 301 to 60 days, representing a reduction of 241 days (80.1%), by eliminating the reusable crate return cycle. Furthermore, Life Cycle Cost Analysis (LCCA) estimated total undiscounted costs of IDR 40,223,277,607 for reusable plastic crates and IDR 5,479,684,662 for single-use cartons, representing potential savings of IDR 34,743,592,945, or approximately 86.4%. The proposed packaging system was also projected to increase effective storage capacity to 9,994,000 vials (64%), potentially eliminating the need for additional warehouse rentals. These findings suggest that single-use corrugated cardboard cartons represent a more cost-efficient packaging alternative for PT XYZ, subject to validation of their suitability for temperature-controlled vaccine storage. To sustain the anticipated improvements, the Control phase should include the establishment of standardized operating procedures (SOPs), periodic monitoring of process lead times and warehouse capacity utilization, and regular evaluations of operating costs. Future research should assess the long-term operational performance, packaging integrity, and environmental implications of adopting single-use packaging in pharmaceutical cold-chain logistics.

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**CONFLICT OF INTEREST**

The authors state that there are no conflicts of interest in this study, whether personal, commercial, or financial, that could potentially affect the objectivity of the research and the presentation of the results in this manuscript.

**AUTHOR CONTRIBUTIONS**

Aryanto[1] contributes 90% to the preparation of the manuscript, including the development of ideas, the implementation of research, data analysis, and the writing of manuscripts. Muchammad Fauzi[2] contributes 10%, with the main responsibility for reviewing and providing input for the improvement of the manuscript.

**GENERATIVE AI STATEMENT**

In the preparation of this manuscript, the authors use Artificial Intelligence (AI) technology to a limited extent, i.e. only to help improve grammar and check the accuracy of language use. All ideas, analysis, and substance of the manuscript are entirely the result of the authors' thoughts and responsibilities.

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