An Integer Linear Programming Optimization of Handheld Radio Procurement Strategy: A Case Study

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Abstract—**An efficient procurement strategy planning is essential for companies, as it directly influences project outcomes, cost management, enhancing operational efficiency, and overall service delivery. A well-planned procurement process not only ensures value for money but also enhances operational efficiency and effectiveness across various sectors. These benefits collectively contribute to the overall success and growth of the company. Company A is a handheld radio distributor in Indonesia, which currently struggling with procurement strategy planning. Their current strategy results in procurement inefficiencies, causing an average 50% increase in excess stock by 2022. The Integer Linear Programming (ILP) optimization method was employed in this study to determine the optimal order quantity and timing, based on cost trade-off factors and inventory parameters, ultimately minimizing the total cost. The results indicated that the optimal procurement strategy proposed in this study suggests that the company could purchase 49.8% less than the initial order amount to meet the same demand, which leads to cost savings. Additionally, it demonstrated a reduction of 50.3% in total procurement costs while fulfilling all demands and maintaining safety stock throughout the planning horizon, compared to the current company's procurement strategy.**

Index Terms—**Optimization, Procurement Problem, Integer Linear Programming, Resource Efficiency.**

I. Introduction

EFFECTIVE supply planning and inventory control are essential components of supply chain (SC) optimization, enabling companies to deliver high-quality products at minimal cost and with precise timing. By strategically managing stock levels and determining optimal safety lead times, businesses can enhance operational efficiency, reduce excess inventory costs, and ensure seamless production and distribution processes [1]. The diverse range of stakeholders involved in handheld radio brand rights—including manufacturers, official distributors, and importers—has intensified competition for handheld radio sales in Indonesia. This situation underscores the need for an effective supply chain strategy, particularly in the procurement process, to enhance competitive advantage. An efficient procurement strategy in a company plays an important role as it leads to operational efficiency, cost savings, quality assurance, risk management, and sustainability. These benefits collectively contribute to the overall success and growth of the company in a highly competitive business environment [2], [3].

The product procurement process often involves third parties to maximize profits in the product supply chain system [4]. Similarly, distributor in this case study engages Chinese manufacturers in its procurement process for handheld radio products brand S (later mentioned as HT S Distributor). In general, procurement process of the HT S distributor in this case can be depicted as in Fig. 1. It starts with requesting the latest price list to the manufacturer to see quantity discount offers, which then is converted from yuan (¥) to US dollars ($) using the exchange rate. The procurement process aims to achieve optimal delivery quantities and costs [5]. However, offering quantity discounts often leads distributors to over-order, exceeding the actual consumer demand [6]. This practice is driven by the desire to secure the lowest purchase price, resulting in consistent procurement of 2,000 units per cycle. Due to a lack of cohesive purchasing strategy, the current order decisions are based solely on remaining warehouse stock, assuming constant high demand for HT S3. This recursive approach causes stockpiling and errors in future order planning.

Each type of HT brand S distributed by distributors exhibits unique and unpredictable demand patterns over time, which presents a significant challenge for distributors to accurately forecast the appropriate order quantities to meet consumer demands in a competitive market and manage effective inventory management. Effective inventory management is crucial for meeting competitive market demands, involving considerations such as safety stock (SS) and reorder point (ROP) to minimize instances of stock shortages or excesses [7]. However, the current reorder point for each type of HT brand S is uniform and excludes consideration of safety stock, highlighting a failure to incorporate recent demand trends specific to each HT brand S product type.

The procurement strategy adopted by distributors of HT brand S has led to excess stock, negatively affecting the Inventory Turnover Ratio (ITO) for these products.

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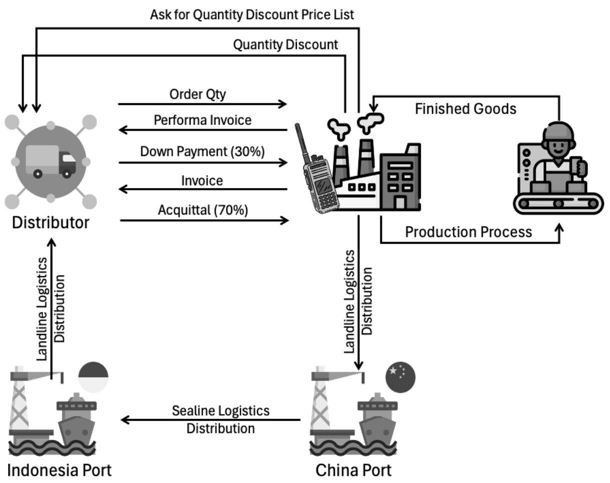

Fig. 1. Procurement Procedure at Company A

Companies typically strive to avoid low ITO ratios as they indicate inefficient management of procurement and inventory-related expenditure costs [8]. Excess stock also poses the risk of dead stock, tying up capital in warehouse inventory. Extended storage durations can degrade product quality and elevate the risk of obsolescence or damage [9].

The lack of optimal procurement planning strategies is evident in processes that fail to balance cost trade-offs, particularly purchasing, holding, and ordering costs associated with quantity discount schemes. While quantity discounts can reduce procurement frequency and ordering costs, they often result in excessive order quantities that exceed average demand, leading to inadvertently higher holding costs [6]. Additionally, distributors face challenges in determining appropriate order quantities and safety stock levels, further complicating procurement schedules and increasing ordering costs. Excessive orders contribute to high purchasing and storage expenses, while inefficient procurement scheduling escalates ordering costs. Therefore, an effective procurement planning strategy, such as appropriate lot-sizing techniques, is essential to minimize cost overruns for HT brand S distributors.

Based on the outlined background, the study identifies the following problems:

1) Quantity discount offers make it challenging for the distributor to determine the appropriate order quantity for each HT brand S product type.
2) The procurement frequency is ineffective because the reorder point does not consider safety stock values or current demand trends.
3) A mismatch between order quantity and demand can lead to excess stock.
4) Excessive stock can adversely affect the inventory turnover ratio (ITO), lead to obsolete or dead stock, and escalate total costs, ultimately posing a risk to the company's performance.

Numerous studies have addressed procurement challenges related to quantity discounts, showing that Integer Linear Programming (ILP) effectively solves lot-sizing problems. ILP models can be customized to optimize costs and meet demand efficiently, accommodating specific constraints faced by the research subject [10], [11], [12]. For HT brand S distributors, avoiding stockouts is critical. This research aims to develop an optimization model and analyze product procurement strategies for each HT brand S which can minimize procurement costs by incorporating safety stock (SS) variable to reduce stockout risks during procurement. The purpose is to provide distributors with procurement strategy on optimal procurement timing and order quantities for HT brand S, aligned with existing constraints.

II. Related Works

Managing procurement, production planning, and inventory control under demand uncertainty is a critical challenge in supply chain optimization. Several studies have addressed this issue by developing mathematical models to determine optimal purchasing volumes, vendor selection, and transportation methods. Prior research has explored integrating procurement and inventory decisions to minimize total costs while ensuring demand fulfillment. Additionally, optimization approaches such as mixed-integer programming and stochastic models have been widely applied to balance trade-offs between purchasing, storage, and production costs, and [13] builds upon these frameworks by simultaneously optimizing raw material procurement, transportation, and inventory management to achieve cost efficiency in materials and product warehouses.

Algebraic approaches, such as completing the square, arithmetic–geometric mean inequality, and cost difference comparison, have been proposed as intuitive alternatives to traditional calculus-based methods for decision making. Another research conducted by [14] has focused on providing algebraic solutions for fundamental inventory models, including the Economic Order Quantity (EOQ) and Economic Production Quantity (EPQ) models, demonstrating their applicability in practical decision-making contexts.

A study in the Philippines conducted by [15] applied an Integer Linear Programming (ILP) approach to optimize inventory management for a secondary plywood wholesaler, aiming to maximize net profit. Seasonal demand forecasts were generated using three years of sales data, and the ILP model incorporated constraints such as forecasted demand, crate and storage capacities, and trucking limits. Implemented in MATLAB, the model identified optimal monthly reorder quantities, balancing gross profit against overhead costs. This approach demonstrates the potential of ILP in addressing inventory challenges in resource-constrained settings.

A study conducted by [12] shows that a mixed-integer linear programming (MILP) model for a multi-product, multi-period inventory lot-sizing problem with supplier selection is proposed by considering alternative quantity discounts (all-units and incremental) and vehicle capacity constraints. The objective is to minimize total costs, including purchasing, ordering, transportation, and holding costs, while satisfying demand. The model determines optimal order quantities, supplier selection, and timing to balance trade-offs among cost components. Numerical results demonstrate that the MILP approach achieves efficient solutions within short runtimes, offering practical insights for procurement decision-making.

Similar study has been conducted by [16], in which a mixed-integer linear programming (MILP) model was proposed for an integrated inventory planning problem in a serial supply chain, incorporating a new supplier price break and discount scheme that accounts for order frequency and lead time. The model minimizes total costs, including procurement, inventory holding, production, and transportation, for a multi-period, multi-supplier, and multi-stage system with time-varying demand. By treating the time period length as a variable, the study demonstrated that subdividing time periods improves cost efficiency. Numerical experiments showed that shorter time periods significantly influence supplier selection, lot-sizing allocation, and inventory decisions, highlighting the trade-off between model complexity and cost savings. Similar with their study, this paper also considering supplier price break to find optimal procurement strategy.

A Mixed Integer Linear Programming (MILP) model has also been developed by [17] for optimizing industrial gas supply chains, incorporating supply contracts, production scheduling, truck and rail-car logistics, and inventory management under the Vendor Managed Inventory (VMI) framework. The model minimizes total operating costs, including raw material procurement, production, and transportation, while meeting customer demand. Key decisions involve production scheduling, raw material procurement, plant-to-customer allocation, transportation modes, and delivery timings. To enhance computational efficiency, a relaxation approach is proposed, and the model's applicability is demonstrated through an industrial case study.

In a study demonstrated by [18], lot-sizing issues in procurement can be effectively addressed using an integer linear programming (ILP) model. Their approach, which analyzed a single product and supplier over six periods, incorporated key factors such as demand, supplier and storage capacity, all-units quantity discounts, transportation limits, rejection rates, and delivery delays. Among nine evaluated solutions, the optimal total cost was achieved through three procurement phases, balancing trade-offs between purchasing, ordering, and holding costs. The study revealed that smaller lot sizes reduced storage costs but increased ordering costs, providing valuable insights into optimizing order timing, lot sizes, and transportation capacity for strategic decision-making.

Various studies have examined procurement issues involving quantity discounts, showing that integer linear programming (ILP) is effective for solving lot-sizing problems. The ILP method can be used to create models aimed at meeting demand efficiently by minimizing costs. Furthermore, ILP is flexible and can be adapted to the specific constraints of the research context, enabling realistic and applicable outputs [18], [12], [15]. Therefore, this study aims to improve a procurement planning in order to achieve an optimal inventory level and to optimize the purchasing policies by applying linear programming and forecasting models, which are corresponded with each of purchasing conditions [19]. In addition, in this case study, since stockouts are not allowed for HT brand S distributors, the safety stock (SS) variable is included to minimize the risk of shortages during procurement. The results are expected to aid distributors in making optimal decisions regarding order timing and quantity for each product type of HT brand S from Company A, while meeting all constraints.

III. Methodology

A. Data Collection

Data was collected through interviews, observations, and official company documents. Key data included the information on the HT brand S procurement processes; a list of product prices with quantity discount offers in 2022; demand data for each type of HT brand S from 2020-2022; transaction data on the procurement process, including order quantities, procurement timelines, and transaction values for 2022, distributor warehouse capacity; detailed cost components: purchase, ordering, and holding cost; and purchase order data in 2021 for service level calculation.

Before analyzing the procurement process, safety stock values were calculated to establish reorder points. The safety stock was determined for each HT brand S product type, based on the most recent demand data for each type in 2022. The safety stock calculation incorporated the service factor derived from the distributor's service level. The calculated safety stock was then used to compute the reorder point, considering current product demand trends. The safety stock values served as inputs for the model development, while the reorder point values were compared with the model results.

B. Model Development

In this study, we define the set of indices, parameters, and decision variables necessary to develop the proposed mathematical model. The index j represents the product type, where $j = 1, 2, \ldots, J$ and $J = 3$, corresponding to the three product types offered by the HT brand S manufacturer. Likewise, each price break in this study is indicated by the index k, where $k = 1, 2, \ldots, K$ and $K = 3$, reflecting the three-tiered pricing structure for purchasing costs. Additionally, the time period is indexed by $t = 1, 2, \ldots, T$, with $T = 12$, as the planning horizon in this study spans 12 months.

The parameters used in the model include X_{jt}, representing the number of units of product j received or planned to be received in period t; U_{jk}, the unit cost of product j at price break k; O, the fixed ordering cost; and H, the holding cost per unit per period. D_{jt} denotes the demand for product j in period t, while $C_{\max}$ represents the distributor's maximum storage capacity. The service level requirement for each product type is given by SL_j, and the corresponding safety stock is represented by SS_j. The inventory balance at the beginning and end of each period is indicated by IB_{jt} and IE_{jt}, respectively. The variable Sh_{jt} denotes the stock shortage of product j in period t. Exchange rate parameters include E_t, the rate at the time of down payment in period t, and E_{t+1}, the rate at the time of settlement in the following period. The model also incorporates key decision variables. $X_{j(t-2)}$ represents the planned order release for product j in period t, accounting for a two-period lead time. Additionally, a binary decision variable Z_t is introduced, where $Z_t = 1$ if an order is placed with the supplier in period t, thereby incurring the ordering cost. Otherwise, set $Z_t = 0$.

C. Model Assumption

Prior to the development of the mathematical model, several assumptions apply to this study, such as shortages are not allowed in HT brand S distributors, and lead time is not affected by production quantity nor depend on order quantity. The service level value and the demand for each product type in this study are assumed to match the service level based on purchase order data from the previous year, while the latter is determined based on historical data available at the beginning of the planning horizon. The tolerance for unfulfilled demand, or maximum shortages, should not exceed the service level for each product type, and backorders are not considered in this study.

Transactions are conducted in two stages, where a down payment is made at the time of ordering in period t, and the balance is settled in period $(t+1)$, which is one period after the order is placed. Orders are placed at the end of period t and arrive at the end of period $(t+2)$ after ordering. Each order incurs shipping costs, import taxes, and bank interest. Furthermore, manufacturer capacity is assumed to be unlimited and the time value of money or the depreciation of product stock is not considered in the total cost calculation. Lastly, the order quantity (planned order release) and demand occurring outside the observation period (planning horizon) are assumed to be zero.

D. Mathematical Model Formulation

The model development phase begins with a comprehensive analysis of the current circumstances faced by the research subject, focusing on the specific lot-sizing challenges encountered. This study focuses on a scenario involving a single supplier, multiple products, and multiple time periods, while also incorporating quantity discounts. Research by [20] was identified as particularly suitable due to its alignment with the characteristics of the research subject in this study and serving as a foundational reference for model development in this study. Key adaptations include:

1) Introduction of a product type index (j), thereby incorporating three index components: product type (j), price break (k), and time period (t).
2) Exclusion of considerations for transportation capacity, delay percentages, and product rejection percentages. Instead, emphasis is placed on introducing service level and safety stock parameters derived from Purchase Order data for 2021, assumed to be applicable for 2022.
3) Definition of decision variables encompassing order quantities for each HT brand S type and binary variables determining order placement in specific periods.
4) The objective function seeks to minimize total procurement costs, balancing purchasing costs—based on unit prices with quantity discount specifications—ordering costs (including expedition expenses), and holding costs (encompassing capital, operational, and handling costs).
5) Constraint functions ensure that procurement meets demand throughout the planning horizon, adheres to quantity discount intervals for order quantities, respects distributor storage capacity, adheres to maximum shortage limits linked to service levels, and maintains the integrity of integer and non-negative constraints for decision and binary variables.

According to the above notations of parameters and decision variables, the mathematical model in this study then can be formulated as an Integer Linear Programming (ILP). In Eq. 1, the objective function is to minimize total costs associated with product stock, encompassing costs incurred throughout the procurement process and inventory management. It consists of five parts: (1) the purchasing cost (B_1); (2) the ordering cost (B_2); (3) import taxes (B_3); (4) interest (B_4); (5) inventory holding cost (B_5), which expressed as follows:

$$Min\ Z = \sum_{t=1}^{T} B_1 + B_2 + B_3 + B_4 + B_5 \tag{1}$$

$$B_1 = (0.3 \times a) + (0.7 \times b) \tag{2}$$

where:

$$a = E_t \times \sum_{j=1}^{J} X_{j(t-2)} U_{jk}$$

$$b = 0,7 \times E_{(t+1)} \times \sum_{j=1}^{J} X_{j(t-2)} U_{jk}$$

$$B_2 = O \times Z_t \tag{3}$$

$$B_3 = 13.5 \times B_1 \tag{4}$$

$$B_4 = 2.5 \times (B_1 + B_2 + B_3) \tag{5}$$

$$B_5 = H \times \sum_{j=1}^{J} IE_{jt} \tag{6}$$

Subject to:

$$X_{j(t-2)} \geq D_{jp} + D_{j(p+1)} \quad \forall t \in T, \forall j \in J \tag{7}$$

$$IB_{jt} = IE_{j(t-1)} - D_{jt} \quad \forall t \in T, \forall j \in J \tag{8}$$

$$IE_{jt} = IB_{jt} + X_{jt} \quad \forall t \in T, \forall j \in J \tag{9}$$

$$IE_{jt} \geq SS_j \times arrival_t \quad \forall t \in T, \forall j \in J \tag{10}$$

$$\sum_{j=1}^{J} IE_{jt} \leq C_{max} \quad \forall t \in T, \forall j \in J \tag{11}$$

$$\sum_{t=1}^{T} Sh_{jt} \leq (1 - SL_j) \sum_{t=1}^{T} D_{jt} \quad \forall t \in T, \forall j \in J \tag{12}$$

$$Z_t \in \{0, 1\} \quad \forall t \in T \tag{13}$$

$$X_{jt}, IB_{jt}, IE_{jt} \geq 0 \text{ and } integer \quad \forall t \in T, \forall j \in J \tag{14}$$

Fulfilling demand for product j begins by identifying the p, an index representing the period t in which demand (D_{jt}) exceeds the initial stock (IE_{j0}). This period t marks the start of demand fulfillment throughout the procurement planning. Constraint (7) ensures that the planned order release for product j at the end of period t can meet the demand for product j in both the initial period, indicated by the index variable, and in the following period $p+1$. Constraints (8) and (9) define the beginning stock and ending stock of product j in period t, respectively. The former indicates the difference between the ending stock of product j from the previous period $(t-1)$ and the demand for product j in period t, while the latter is calculated by adding the beginning stock of product j in period t to the quantity of orders received (planned order receipt) at the end of period t. Constraint (10) ensures that the ending stock of product j in period t does not fall below the safety stock level for product j when the ordered products arrive in that period. Constraint (11) ensures that the cumulative stock of each product type j at the end of the previous period and the incoming order quantity in period t, does not exceed the distributor's maximum storage capacity. The total shortage of product j during the planning horizon should not exceed the predetermined service level for each product j. It is expressed in Constraint (12). Finally, Constrains (13) and (14) are used to force non-negative integer values and binary restrictions in the model.

IV. Numerical Example and Analysis

A. Data Collection

Product demand throughout the planning horizon and price break policy from supplier are given in Table I and Table II, respectively for numerical illustration in this study. Product demand is considered to follow sales quantity in 2022 as the planning horizon. The proposed ILP model is demonstrated to illustrate the optimal procurement planning strategy for each product type of HT in Company A, as the *basis scheme*. It will be optimized further to see whether a more efficient procurement strategy could be obtained, in terms of total cost and inventory turnover (ITO) ratio.

B. Analysis of Order Timing and Order Quantity

The computational model is analyzed in two schemes: *basis scheme* and *joint scheme*. The latter is a scheme that merges order period and quantity. The order quantity or planned order release from the basis scheme (EOQ) serves as a reference for determining order quantities in the joint scheme. Consequently, the computational model for the joint scheme involves a merging approach to represent experiments conducted to achieve an optimal procurement strategy as a reference for Company A.

The joint order scheme also referred as a combined scheme, is applied to maximize the objective function of cost minimization. Multiproduct procurement without order consolidation can lead to high expenditure costs [21].

TABLE I
Monthly Sales and Stock Data for HT S1, HT S2, and HT S3

Month	Demand HT S1	HT S2	HT S3
Initial Stock	**150**	**164**	**900**
January	62	22	80
February	11	38	70
March	44	33	610
April	19	16	100
May	6	12	11
June	80	37	201
July	95	24	180
August	128	54	91
September	73	32	45
October	75	23	57
November	71	25	41
December	135	20	44
Total	**799**	**336**	**1,530**
Average	**66.583**	**28**	**127.5**

TABLE II
Supplier Products Quantity Discount

Quantity Level	HT S1	HT S2	HT S3
$< 1{,}000$	35	33.5	33
1,000 - 1,999	34	32.5	32
$\geq 2{,}000$	33	31.5	31

All HT discounts are in USD

This type of procurement is commonly conducted using the economic order quantity (EOQ) approach, where each product type has its own procurement schedule. As a result, the ordering frequency becomes inefficient, which increases ordering costs and subsequently, fixed costs [22], [23].

In contrast, a procurement strategy with order consolidation (the joint scheme) considers product demand trends to determine ordering frequency. Products with lower demand will be ordered less frequently, while those with higher demand will be ordered more often, as noted in studies on demand-driven ordering strategies [24], [25]. This approach focuses on ordering costs as the main trade-off in cost components. By consolidating orders, the joint order scheme is expected to reduce ordering costs, ultimately lowering the total cost [26].

The result of the optimization model using ILP shows that the basis scheme places orders six times throughout the planning horizon, occurring from January to June. In detail, the basis scheme is procured more frequently due to various reorder point (ROP) values for each product. To meet all demand throughout the planning horizon, the company should procure HT S1 and HT S3 4 times starting in January and March, respectively, while HT S2 requires 3 times beginning in February as summarized in Table III. In particular, the joint scheme also results in a lower cumulative order quantity compared to the basis scheme. A significant difference occurs in the order quantity of HT S3. According to the basis scheme, the order quantity of this product throughout the planning horizon is 1,055 units, while the result from the joint scheme shows that the company only needs to order 974 units to fulfill all HT S3 demand throughout the planning horizon as shown in Table IV. Despite the decrease in the order quantity, it can still meet the safety stock constraint of HT S3 products in each period while simultaneously reducing holding costs.

On the other hand, this study aims to see whether it is beneficial for the company if the joint scheme is applied to improve the basis scheme, in which procurements are not always made according to its ROP, to satisfy long-term demand rather than short-term fluctuations by adjusting the planning for the order quantity. The objective is to ensure a balance that accommodates the expected demand over a more extended period and reduces the dependency on frequent procurements. Frequent procurements can lead to stockouts, increased shipping costs, and potential service disruption. Moreover, this approach aligns with theories on demand forecasting and inventory management, where planning for future demand is important in responding to immediate demands which can lead to more stable and efficient supply chain operations [27]. Hence, forecasting demand plays an important role in deciding the procurement strategy for the company. The Economic Order Quantity (EOQ) model is a foundational concept in inventory management that helps businesses determine the optimal order quantity that minimizes total inventory costs, including ordering and holding costs [28]. The EOQ model emphasizes the importance of forecasting demand accurately to avoid stockouts and excess inventory, which can disrupt supply chain efficiency [29], [30]. This consolidation allows orders to be placed only once a year, as shown in Table IV, and significantly reduces the high shipping costs associated with frequent orders within the planning horizon. Nevertheless, this strategy enhances the company's ability to ensure better product availability, effectively meeting consumer demand.

C. Analysis of Cost Components

The objective function of this study is to minimize total expenditure costs incurred from the procurement process to storage. Table V provides a summary of each cost component over the planning horizon for both the basis scheme and the joint scheme. In this context, the cost components classified as fixed costs include ordering and holding costs, which serve as trade-off components considered in determining the optimal procurement strategy. The elevated fixed costs in the basis scheme are predominantly driven by ordering costs, which account for 88.639% of the total fixed costs. This is due to the basis scheme's higher ordering frequency—six times more frequent than the combination scheme, which consolidates orders into a single instance. This disparity in frequency arises because the procurement process in the basis scheme is triggered whenever a reorder point (ROP) is reached, with each product type having a distinct ROP value.

However, the high ordering cost in the basis scheme has a greater impact compared to the high holding cost in the joint scheme. The low fixed costs in the joint scheme also affect the total cost which is 11.249% lower than the basis scheme. This shows that the increase in holding costs in the joint scheme, which is caused by the high average product storage time, is not greater than the efficiency results in the ordering costs obtained. In addition, it was also found that the increase in ordering costs has a more significant impact than holding costs on fixed costs. This makes the ordering cost have a higher cost ratio compared to holding costs in influencing the total cost. In accordance, a joint scheme that considers the combination of planned ordered release and has a low ordering frequency will be more desirable in a procurement planning strategy because it minimizes total costs. Therefore, the selected joint scheme is the optimal procurement strategy for this case.

D. Sensitivity Analysis

Sensitivity analysis was performed by considering changes in the value of three parameters susceptible to change, such as exchange rate parameters, unit price, and demand. Therefore, changes in the value of these parameters will affect decisions regarding the number of orders and the timing of orders.

1) Impact of Exchange Rate Variability: To assess the effect of exchange rate variability, we simulate ±1.68%, ±1.87%, and ±2.61% variations in the exchange rate and observe changes to the total cost, and each cost component. As shown in Fig. 2, in general, changes in the exchange rate parameter do not have a significant impact on the total cost. However, the total cost tends to increase as the exchange rate increases. This is because the exchange rate value also affects the purchasing cost (B_1) which is one of the components that form the total cost. The purchasing cost (B_1) has the largest cost among all cost components and exhibits a clear increasing trend. This suggests that B_1 is highly sensitive to exchange rate variability, yet not significant because the change in the inflation value each year is quite low, where the average inflation value is in the range of below 5%. The increase in the purchasing cost (B_1) has an impact on the import taxes (B_3) and interest (B_4) which also increase as the exchange rate increases. However, their contribution to the total cost is smaller compared to B_1.

On the other hand, order cost (B_2) and holding cost (B_5) remain constant, indicating that they are not directly affected by exchange rate fluctuations. Therefore, if the objective of the problem is to minimize total cost, then we should focus

TABLE III
RESULTS OF ORDER TIMING AND QUANTITY FOR EACH PRODUCT - BASIS SCHEME (EOQ)

	HT S1			**HT S2**			**HT S3**		
t	X_{t-2}	X_t	IE_t	X_{t-2}	X_t	IE_t	X_{t-2}	X_t	IE_t
1	175	0	88	0	0	142	0	0	820
2	201	0	77	78	0	104	0	0	750
3	146	**175**	208	55	0	71	381	0	140
4	247	**201**	390	117	**78**	133	136	0	40
5	0	**146**	530	0	**55**	176	179	**381**	410
6	0	**247**	697	0	**117**	256	359	**136**	345
7	0	0	602	0	0	232	0	**179**	344
8	0	0	474	0	0	178	0	**359**	612
9	0	0	401	0	0	146	0	0	567
10	0	0	326	0	0	123	0	0	510
11	0	0	255	0	0	98	0	0	469
12	0	0	120	0	0	78	0	0	425

TABLE IV
RESULTS OF ORDER TIMING AND QUANTITY FOR EACH PRODUCT - JOINT SCHEME

	HT S1			**HT S2**			**HT S3**		
t	X_{t-2}	X_t	IE_t	X_{t-2}	X_t	IE_t	X_{t-2}	X_t	IE_t
1	769	0	88	250	0	142	974	0	820
2	0	0	77	0	0	104	0	0	750
3	0	**769**	802	0	**250**	321	0	**974**	1,114
4	0	0	783	0	0	305	0	0	1,014
5	0	0	777	0	0	293	0	0	1,003
6	0	0	697	0	0	256	0	0	802
7	0	0	602	0	0	232	0	0	622
8	0	0	474	0	0	178	0	0	531
9	0	0	401	0	0	146	0	0	486
10	0	0	326	0	0	123	0	0	429
11	0	0	255	0	0	98	0	0	388
12	0	0	120	0	0	78	0	0	344

TABLE V
COSTS COMPARISON

Costs	EOQ	Joint Scheme	Current Scheme
B_1	1,017,775,852.389	938,956,595.742	1,898,241,650
B_2	61,753,878	10,292,313	20,584,626
B_3	137,399,740.072	126,759,140.425	256,262,622
B_4	30,423,236.762	26,900,201.229	54,377,222
B_5	7,914,813.180	11,156,975.340	11,205,802
Total Cost	**1,255,267,520.402**	**1,114,065,225.736**	**2,240,671,923.79**

on stabilizing exchange rates or finding strategies to mitigate the impact on B_1. Moreover, since B_2 and B_5 are not affected, from a managerial perspective, the findings suggest that cost control efforts should focus on B_1, B_3, and B_4.

2) Impact of Unit Cost Variability: The sensitivity analysis was also done to visualize the impact of different percentage changes in unit costs scenario, which fluctuates from -20% to +20% from the baseline and shows a significant corresponding change in total cost as shown in Fig. 3. The graph illustrates how the total cost and individual cost components (B_1 to B_5) vary under different unit cost change scenarios. The results indicate that total cost is highly sensitive to fluctuations in certain cost components, particularly purchasing cost (B_1), which contributes the most significant portion to overall expenditures. As unit costs decrease by 20%, total cost drops 19.64% below the baseline, whereas an increase of 20% raises 19.60%. This indicates a nearly linear relationship between unit cost changes and total cost. On the other hand, among the cost components, order cost (B_2) and holding cost (B_5) remain constant in all scenarios, suggesting that they do not influence the sensitivity. Meanwhile, the import taxes (B_3) and interest (B_4) exhibit moderate increases, reflecting their impact on cost fluctuations. The proportional increase in total cost highlights the strong dependence on B_1, which underscores the importance of managing B_1 efficiently, as even minor changes in its cost have a substantial impact on total expenses. The findings also emphasize that efficient management of B_1 and B_3 could significantly control the variation in total cost.

3) Impact of Demand Variability: This sensitivity analysis was simulated to evaluate how variations in demand parameters, from ±5%, ±10%, and ±15%, affect different cost components (B_1–B_5) and total costs. The selection of these percentages is based on acceptable confidence level values mentioned in [31]. Fig. 4 depicts the increase of total cost along with the increase in the number of demands and vice versa. This is attributed to the substantial increase in procurement costs associated with a higher volume of requests. The rising demand reflects a greater number of needs that must be fulfilled, necessitating distributors to increase their order quantities to meet all incoming requests. The increase in purchasing costs, which is one of the costs that forms the components of import tax costs and interest costs, also increases both cost components in line with the increase in demand. Hence, the graph shows that purchasing cost (B_1) contributes the most to the total cost, and its fluctuations strongly impact the overall expenses. When demand decreases by 15%, B_1 drops to IDR 721.26 million, reducing total costs to IDR 859.42 million. Conversely, when demand increases by 15%, B_1 rises to IDR 1.13 billion, pushing total costs to IDR 1.34 billion.

Ordering and inventory costs do not vary significantly when demand changes. Most of demand variability produces a single order quantity so that shipping costs remain unchanged. However, unlike other components, a dramatic spike found when demand increases by +10%, reaching a peak of over IDR 20 million. This suggests that component order cost (B_2) is generally insensitive to moderate changes in demand but becomes significantly more expensive at a specific higher demand level (+10%). This could indicate a step change in resources or a capacity constraint being hit at that point. However, this anomaly does not significantly affect total costs and indicates that B_2 has a minimal impact on cost fluctuations.

On the other hand, import taxes (B_3), interest (B_4), and holding cost (B_5) exhibit proportional increases as demand rises. B_3 reflects its moderate impact, B_4 shows a steady rise which indicates a consistent relationship with demand. Meanwhile, B_5, the smallest component, varies slightly between IDR 9.77 million (-15%) and IDR 12.60 million (+15%). In general, as demand increases, total costs follow a predictable upward trend. A 15% demand decrease leads to a 22.9% cost reduction, while a 15% increase results in a 20.6% cost surge. This shows that total cost is highly sensitive to demand variations, primarily due to B_1. We can conclude that the findings confirm that B_1 is the primary cost driver, contributing the largest impact to total cost. B_3 and B_4 have moderate impacts, while B_2 and B_5 play minor roles in cost sensitivity. This insight suggests that cost reduction strategies should focus on optimizing B_1, as changes in this component significantly affect total cost outcomes.

E. Impact of Demand Variability on Inventory Turnover Ratio

The graph shown in Fig. 5 presents a sensitivity analysis of two critical inventory performance metrics, Inventory Turnover (ITO) and Average Holding Time, under varying levels of demand variability, ranging from -15% to +15%. The results indicate a generally inverse relationship between the two indicators, which offers insights into the trade-offs between inventory efficiency and storage duration in response to changes in demand patterns.

As illustrated, the ITO ratio shows a relatively stable upward trend as demand variability increases. Begin at approximately 5.83 when demand variability is reduced by 15%, the ITO gradually increases to a peak value at +10% variability, suggesting improved inventory movement and responsiveness within the system. This pattern may reflect a more agile supply chain that adjusts efficiently to moderately fluctuating demand, thereby enhancing turnover rates.

In contrast, the average holding time initially exhibits a declining trend, implying that less time is required to store inventory as variability increases slightly. This could be attributed to a more dynamic inventory system that reduces excess stock and accelerates throughput. However, a marked deviation occurs at the +10% level of demand variability, where the average holding time spikes sharply to over 50 days. This anomaly may be indicative of operational inefficiencies such as overstocking, delayed order fulfillment, or a mismatch between supply planning and actual demand realization. However, electronic devices like handheld radios tends to have lower ITO ratio than fast-moving consumer electronics (e.g., smartphones) due to industry-specific factors. While a low ITO is often perceived negatively, in this sector, it can be a strategic necessity rather than poor management. In this study, the handheld device industry continues to face significant supply chain uncertainties, from semiconductor shortages to logistical bottlenecks. The elevated inventory levels serve as a crucial buffer against these disruptions to maintain a reliable supply to customers even during periods of manufacturing or shipping delays to maintain profitability. Therefore, a bulk purchasing strategy, due to quantity discount offered by the supplier, generates direct cost savings that outweigh the carrying costs of additional inventory. By consolidating shipments into larger and less frequent orders can reduce the effective tax burden per unit. This approach, while increasing our inventory levels, delivers a reduction in landed costs that directly enhances the gross margins. The duration then returns to a lower level at +15%, suggesting a correction or stabilization in the inventory process.

V. Discussion

The optimization of procurement strategy in determining order quantities indicates that the cumulative orders needed to meet the entire demand in 2022 are only 49.825% of the quantities under the existing company procurement strategy. The order allocation for the three product types based on the proposed method shows reductions in quantity orders of 23.10% for HT S1, 50% for HT S2, and 61.04% for HT S3 compared to the existing procurement strategy planning.

The reduction in order quantities is primarily attributed to the fact that, under the existing procurement strategy, the company focuses solely on quantity discounts and product demand, while the proposed model incorporates a broader perspective by considering cost trade-offs and inventory parameters, such as service levels and safety stocks. Currently, the company places orders whenever a product's ending stock reaches a predetermined reorder point (ROP) by ordering a minimum of 2,000 units in each procurement cycle to qualify for the lowest unit price offered through quantity discounts. The allocation of these orders among the three product types is driven purely by demand trends, without a comprehensive analysis of inventory parameters. This might result in excessive ordering frequencies and quantities, ultimately failing to align with optimal procurement strategies over the planning horizon. This approach inadvertently skews the allocation toward HT S3 products, which have the highest demand, resulting in their disproportionately large share in each procurement cycle. In contrast, the optimized procurement strategy, a refinement of the basis scheme, addresses these inefficiencies by considering variations in ROP values for each product type and optimizing both the timing and quantity of orders. This strategy not only aims to minimize total costs but also balances the trade-off between ordering and holding costs. Additionally, the optimized model imposes constraints to ensure that ending stock levels comply with the safety stock requirements throughout the planning horizon — an aspect which not considered in the current procurement strategy.

The findings highlight that the primary cause of inefficiency in procurement capital under the current strategy is the absence of effective procurement strategy planning. It is also proven that stockpiling is not the main driver of inefficiency, as the holding cost ratio is low and the HT products are not highly susceptible to damage or quality degradation during the planning horizon. Nevertheless, these risks should still be mitigated. Therefore, to achieve optimal procurement cost efficiency, the company must simultaneously determine order quantities based on demand prediction and inventory parameters, maximize the benefits of price breaks given by the suppliers, and optimize the timing of orders. This integrated approach ensures that the company can accurately prepare the necessary capital for an optimal procurement strategy while minimizing inefficiencies. Furthermore, forecasting demand plays an important role in deciding the procurement strategy for the company. Subsequently, improving the order determination process by incorporating cost trade-offs, demand, and inventory parameters holistically ensures more optimal order quantities that meet service level targets and reduce the risk of excessive stock accumulation. Analysis of the optimization results reveals that fewer orders are required to meet the same demand as the existing system. This difference significantly impacts the capital required for the procurement process, which is 50.28% lower than the capital required under the current procurement strategy. The reduction in capital is driven by changes in various cost components, as presented in Table V.

To enhance the effectiveness of the proposed procurement strategy and mitigate potential execution issues, the company should consider not only sales trends and supplier discounts but also cost trade-offs and inventory parameters such as service levels and safety stock [32]. Confirming unit prices prior to ordering is essential due to their significant impact on total cost. Moreover, tracking shortage rates, lost sales, and customer data during lead time is critical for accurate demand forecasting and inventory control. To manage exchange rate risks, a forward agreement with manufacturers could stabilize procurement costs and support financial performance [33], [34]. Finally, to address the risk of product obsolescence, the company should consider discount strategies and return agreements, ensuring these are integrated into COGS to safeguard cash flow and profit margins [35].

VI. Conclusion

This study has successfully proposed an efficient procurement strategy while minimizing total cost in comparison to the current procurement strategy. The result from the joint scheme shows that a procurement strategy which not solely made according to its ROP could still satisfy long-term demand rather than short-term fluctuations by adjusting the planning for the order quantity. Despite the increase in holding costs due to the longer average product storage time in the joint scheme, it shows a significant saving in ordering costs. Moreover, ordering costs have a greater impact on fixed costs compared to holding costs, making their reduction crucial in minimizing total costs. As a result, a joint scheme with low ordering frequency and planned order releases is preferable for procurement planning. Combining orders into fewer, larger shipments lowers the per-unit tax impact. Although this strategy results in higher inventory volumes, it significantly decreases landed costs, providing an immediate boost to gross margins.

Based on the findings of this research, the company should carefully consider the trade-offs between cost components, service level targets, and safety stock levels for each type of HT product in the company, as well as considering storage capacity, to determine optimal order quantities and timing.

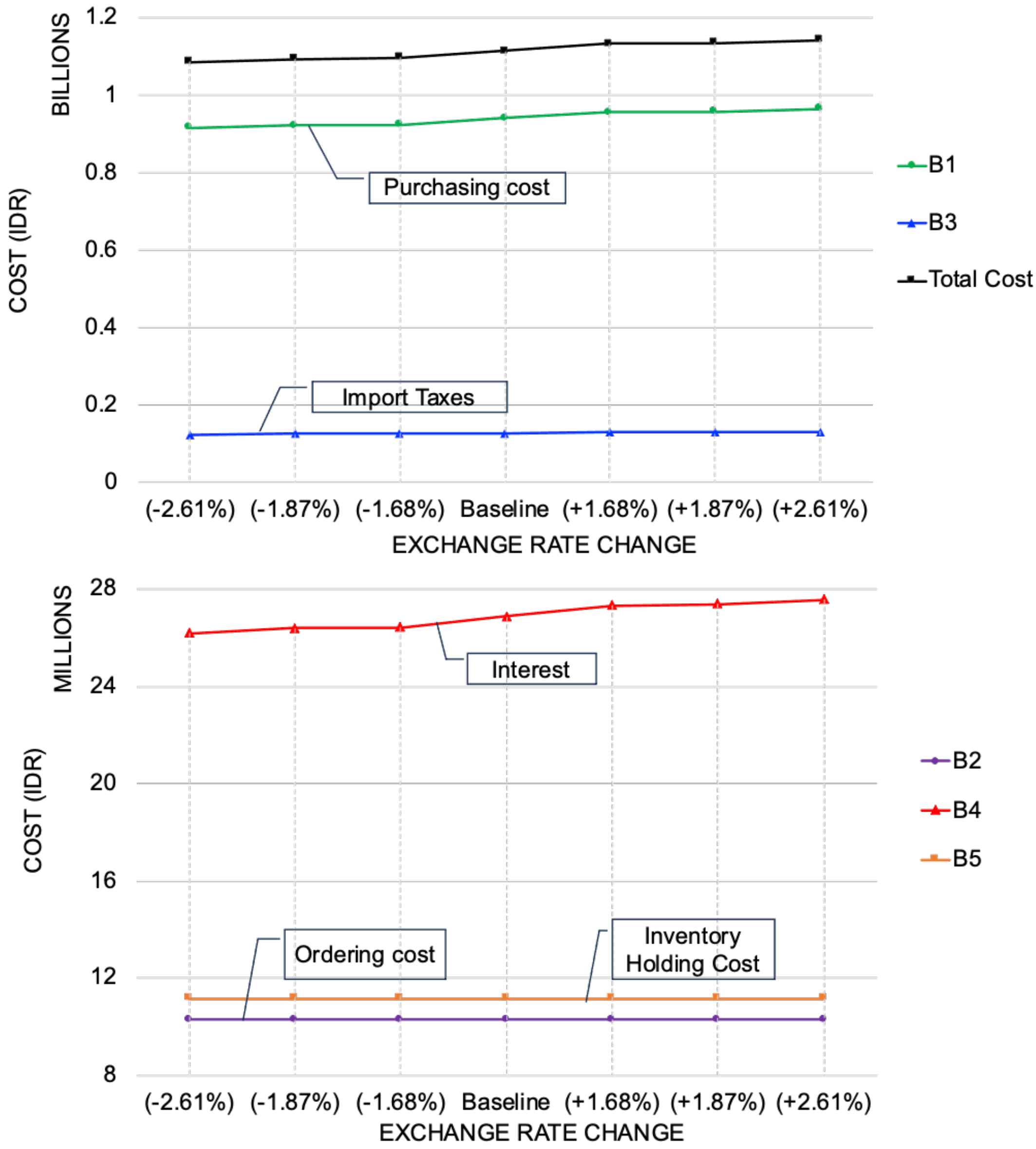

Fig. 2. Effect of Exchange Rate Change on Cost Components and Total Cost

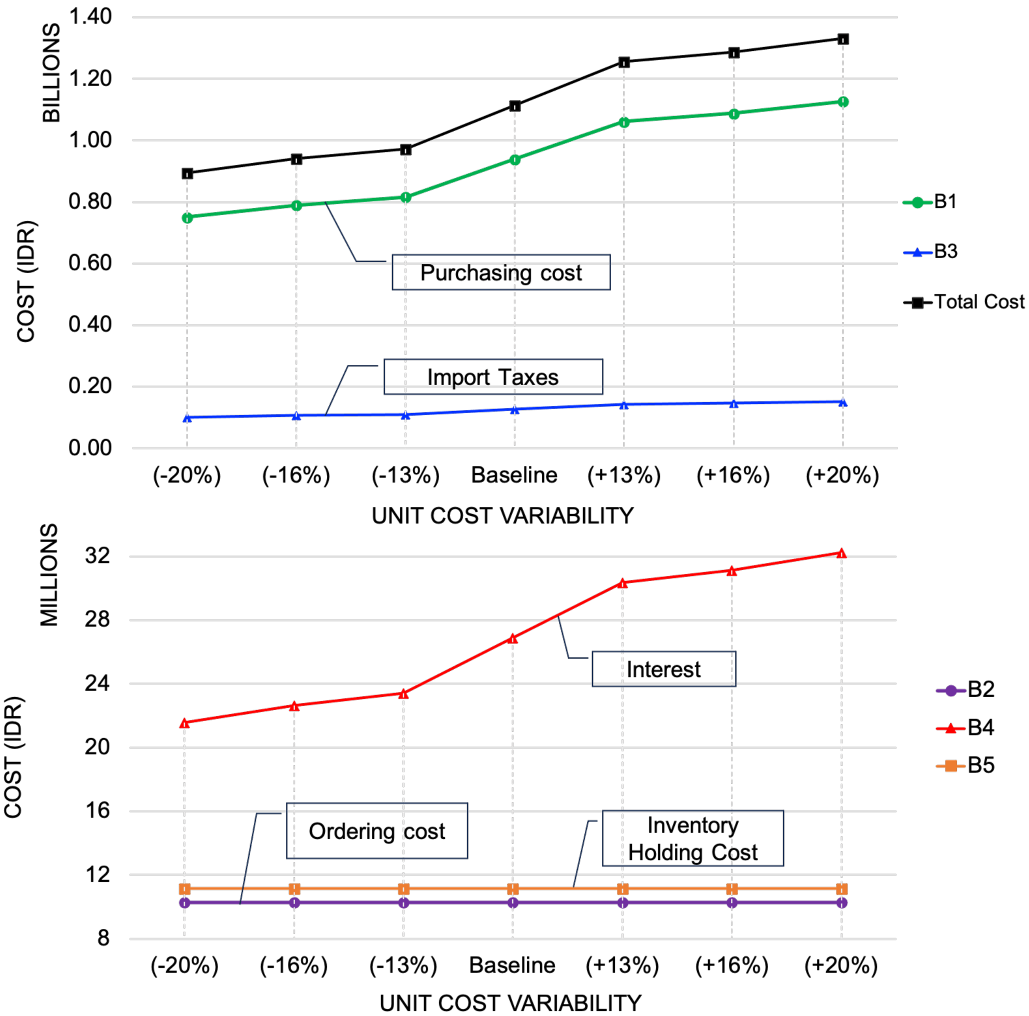

Fig. 3. Effect of Unit Cost Variability on Cost Components and Total Cost

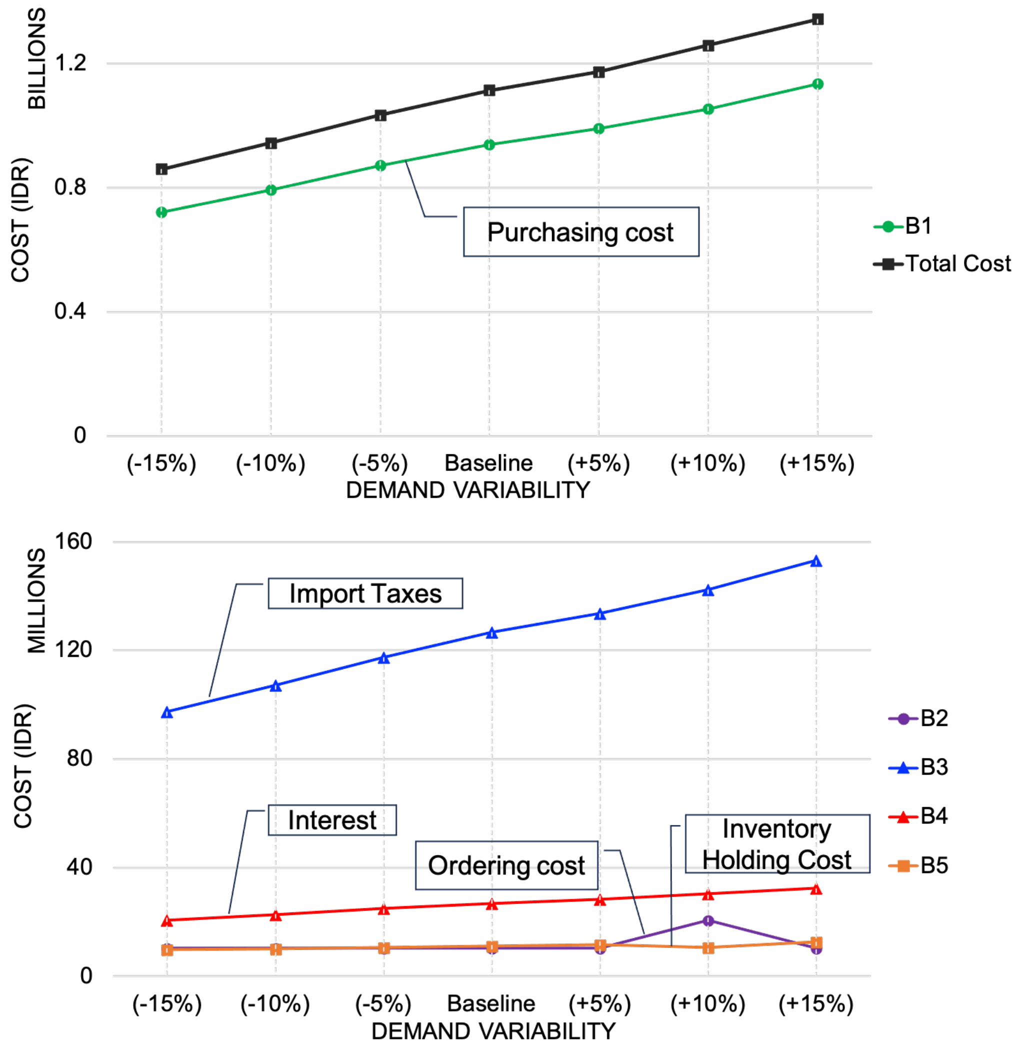

Fig. 4. Effect of Demand Variability on Cost Components and Total Cost

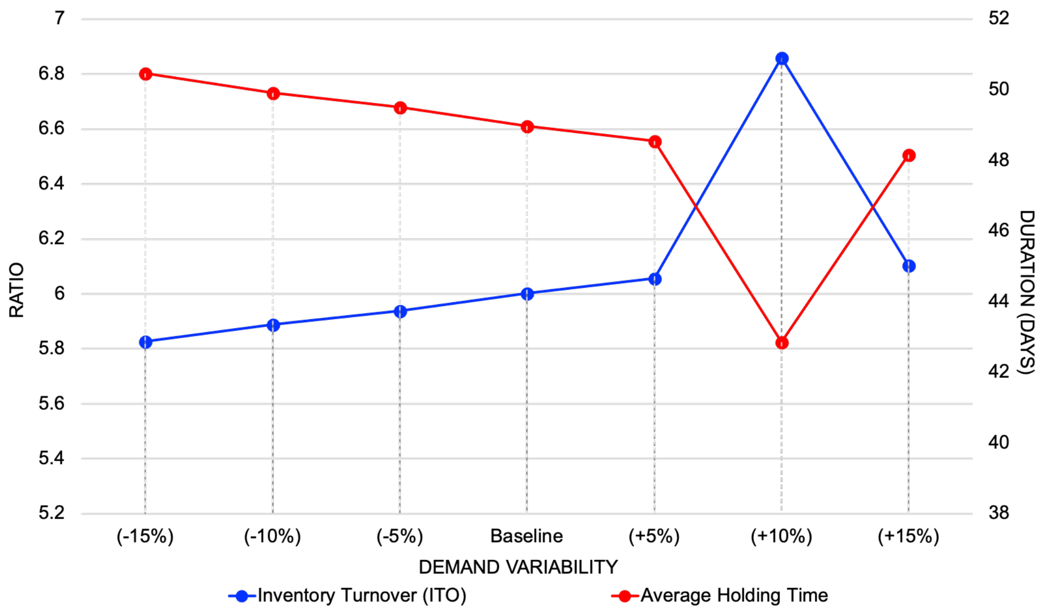

Fig. 5. Effect of Demand Variability on ITO and Holding Time

VII. Limitations and Future Works

Despite providing valuable insights into the relationship between demand variability, inventory turnover, and holding time, this study is subject to several limitations. First, the current study adopts a static model based on historical or simulated data without incorporating real-time adaptive inventory control mechanisms. This limits its ability to capture dynamic shifts in demand or supply disruptions that may occur in actual operational environments. In addition, the sharp anomaly observed at +10% demand variability, while noteworthy, is not fully explained by the current model, suggesting the need for a deeper investigation into potential causal factors, such as demand forecasting errors or system response delays.

Future works in similar cases could consider forecasting demand based on historical data to allow for more accurate procurement planning and should aim to extend the current analysis by developing a dynamic inventory modeling that incorporates real-time data and cost parameters. Such models could leverage advanced forecasting techniques, including machine learning algorithms, and optimization methods to better anticipate demand patterns and inform decision-making. Additionally, scenario-based simulations and stochastic modeling approaches can be employed to evaluate inventory performance under uncertainty and risk. Furthermore, additional cost components, such as shortage costs and obsolescence costs, could be integrated into the model to provide a more comprehensive analysis.

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