



Development of a Rework-Based Inventory Policy for Ordering Water Sports Equipment Bags: A Case Study of a Manufacturing Packaging Department

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Abstract: Inventory management plays a critical role in reducing operational costs and maintaining efficiency in competitive manufacturing environments. In the production of water sports equipment, packaging bags are essential supporting materials; however, the absence of structured ordering policies often leads to uncontrolled purchasing, excessive inventory, and increased sunk costs. This study aims to develop an improved inventory policy for packaging bags by comparing three ordering approaches: the Traditional Ordering Method, the Fixed Time Period System (FTPS), and a proposed rework-based inventory policy that incorporates rework rate and rework time into inventory planning. The research was conducted at a water sports equipment manufacturing company in Chonburi, Thailand, focusing on eleven models of packaging bags used in the packaging process. Production and inventory data were collected over three months, and the performance of each ordering method was evaluated based on average inventory level, sunk cost, and service reliability. The results indicate that the Traditional Ordering Method generated the highest inventory cost of 353,307 Baht due to excessive overstocking. The FTPS approach, which applies periodic review and safety stock principles, reduced inventory costs to 200,691 Baht and improved stock control, although inventory levels remained higher than actual demand. In contrast, the proposed rework-based inventory policy achieved the lowest average cost of 57,209 Baht by incorporating production variability through defect rates and rework cycle times. This method reduced costs by approximately 300,000 Baht compared with the traditional method and by 146,000 Baht compared with FTPS, while preventing stockouts during the observation period. These findings demonstrate that integrating rework-related variability into inventory planning can significantly improve cost efficiency and operational reliability. The study contributes to the inventory management literature by bridging theoretical inventory models with practical industrial implementation and by highlighting the potential of rework-sensitive policies as an effective framework for managing packaging materials in manufacturing systems.

Keywords: Inventory management; fixed time period system; rework rate; packaging process; manufacturing efficiency

1. Introduction

The global water sports equipment manufacturing industry has experienced increased competition driven by rising consumer demand, technological innovation, and growing interest in recreational water activities. As markets become more saturated and customer expectations continue to rise, manufacturers must improve operational efficiency and product quality to remain competitive. Previous studies have demonstrated that effective quality management and inventory control practices play a critical role in reducing operational costs while improving customer satisfaction in manufacturing environments [1–3]. Inventory management is particularly important in industries where production and packaging processes involve variability in demand, customization, and quality performance. Inadequate inventory policies often lead to overstocking, excessive holding costs, inefficient use of warehouse space, and reduced operational profitability [4, 5]. Conversely, well-structured inventory systems that incorporate operational data such as demand variability, defect rates, and production lead times can improve material flow, reduce excess stock, and optimize resource utilization [6, 7].

In the case study company examined in this research, an internal operational review revealed that packaging materials, specifically water-sports equipment bags, were frequently over-ordered due to the absence of systematic stock-monitoring and verification procedures. Employees tended to place orders based on perceived demand rather than actual inventory levels or production requirements. As a result, the packaging department accumulated excessive inventory, increasing sunk costs and creating inefficiencies in warehouse space utilization. To address this problem, this study investigates alternative inventory control strategies for managing packaging bag inventory in the production process. Three ordering approaches are evaluated: the Traditional Ordering Method currently used by employees, the Fixed Time Period System (FTPS) based on periodic inventory review, and a proposed inventory policy that incorporates rework rate and rework time into inventory planning. By integrating production variability into inventory control, the proposed approach aims to provide a more adaptive and realistic ordering framework. Despite the extensive literature on safety stock and periodic inventory review systems, limited studies have examined how rework-related variability can be incorporated into inventory planning for packaging materials in real manufacturing environments.

The objective of this research is to develop an improved ordering policy for packaging materials in the manufacturing packaging department to reduce excess inventory and associated sunk costs while maintaining reliable service levels. This study contributes to the literature in three ways. First, it integrates rework rate and rework time into a periodic inventory control framework for packaging materials. Second, the proposed model is validated using real operational data from a manufacturing packaging department. Third, the results demonstrate that incorporating rework-related variability into inventory planning can significantly reduce costs while maintaining service reliability.

2. Research literature

Effective inventory management has long been recognized as a critical factor in maintaining manufacturing competitiveness, ensuring customer satisfaction, and improving operational efficiency. In the context of packaging materials, particularly for specialized products such as water sports equipment bags, balancing stock availability with cost control poses unique operational challenges. These challenges become even more complex when quality-related factors, such as rework rate and rework time, influence production lead times and material availability. To develop an effective ordering policy that reflects these operational realities, it is necessary to examine prior research on safety stock management, periodic review systems, and inventory models that incorporate imperfect quality and rework conditions. Table 1 summarizes key studies on inventory control approaches, including economic order quantity (EOQ) models, periodic review or base-stock systems, safety stock strategies, and inventory models that account for rework or imperfect production quality. The table highlights how different studies have addressed various aspects of inventory control and provides a foundation for identifying research gaps relevant to this study.

Table 1. Summary of Previous Studies and Identified Research Gaps

No.	Reference	EOQ (Economic Order Quantity)	Periodic Review / Base-stock	Safety Stock Models	Rework / Imperfect Quality
1	Gonçalves et al. [8]			✓	
2	Barros et al. [9]			✓	
3	Demiray Kırmızı et al. [10]			✓	
4	Tagaras & Vlachos [11]		✓		
5	Chiang [12]		✓		
6	Sonntag & Kiesmüller [13]				✓
7	Alamri et al. [14]	✓			✓
8	Cárdenas-Barrón et al. [15]	✓			✓
9	Lin et al. [16]	✓			✓
10	Haque et al. [17]	✓			✓

A review of the existing literature indicates that substantial progress has been made in developing safety stock strategies and periodic-review inventory models. Several studies have focused on analytical approaches for determining safety stock levels and managing uncertainty in supply chains [8–10]. Other studies have examined periodic review systems and replenishment strategies, including emergency ordering policies and multi-supply modes designed to improve inventory responsiveness under uncertain demand conditions [11, 12]. In addition, research has investigated inventory models that incorporate imperfect production processes, including defective items and rework activities. These models extend classical EOQ frameworks by accounting for the impact of defective units and repair processes on production and inventory planning [13–16]. More recent studies have also explored sustainable manufacturing systems that integrate remanufacturing or environmentally conscious production processes within inventory decision models [17].

Despite these advances, several important research gaps remain. First, most existing studies focus on finished products or general manufacturing environments, with limited attention given to packaging materials that support production processes. Second, although some research considers defective items or rework, the combined effect of rework rate and rework time variability is rarely incorporated into periodic inventory review systems. Third, many existing models are primarily theoretical and lack empirical validation using real operational data from manufacturing environments. To address these gaps, this study develops an improved ordering policy for packaging materials, specifically water sports equipment bags, by integrating rework rate, rework time, and demand variability within a periodic review inventory framework. By applying the proposed approach to real operational data from a manufacturing packaging department, this research aims to bridge the gap between theoretical inventory models and practical industrial implementation. The findings provide both theoretical insights and practical guidance for improving inventory management in manufacturing systems where rework-related variability affects production flow.

3. Research Methodology

3.1 Study of the Production Process of Water Sports Equipment Bags.

A water-sports equipment manufacturing company in Chonburi Province, Thailand, specializes in producing a variety of composite-material products, including stand-up paddleboards (SUPs), surfboards, windsurfers, and motorized boards. The overall production process consists of 11 stages: (1) design and form development, (2) mold making, (3) foam cutting, (4) fiberglass lamination, (5) resin application, (6) color base coating, (7) surface finishing, (8) graphic application, (9) clear coat finish, (10) quality inspection, and (11) packaging. This study focuses on the packaging stage, where finished boards are wrapped in plastic, protected with cardboard, placed into packaging bags, inspected for packaging-related issues, and sealed for customer delivery. The packaging inventory consists of 11 types of water sports equipment bags, with an average unit value of 1,990 THB, as shown in Table 2.

Table 2. Average Unit Prices of Water Sports Equipment Bags

Product Name	Average Unit Price (Thai Baht)
FL1	1,886
FL2	1,725
FL3	1,577
FL4	1,422
AR1	1,700
AR2	1,792
AW1	2,034
JF1	2,615
JF2	2,761
RD1	2,096
RD2	2,282

Excessive stocking of these bags results in higher sunk costs because they can also be sold separately from finished water sports equipment. Therefore, holding excess packaging inventory represents an opportunity cost and increases the company's overall inventory burden. To illustrate the problem, the study first examined the ordering behavior associated with the FL1 bag model. The initial stock level was 10 units. Analysis of daily inventory records showed that employees repeatedly ordered more bags than needed, leading to a persistent increase in inventory over time.

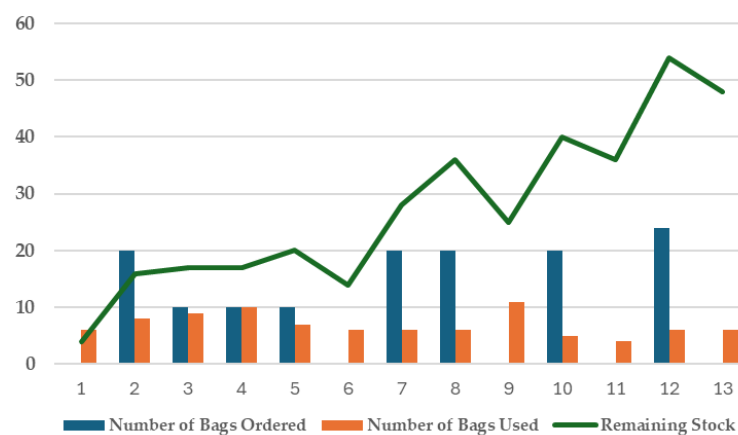


Figure 2. Daily Inventory Level of FL1 Bag Model

The figure shows that inventory levels for the FL1 bag model increased steadily during the observation period despite fluctuations in daily usage. The initial stock level was relatively low; however, repeated ordering without regard for actual consumption led to continuous inventory growth. By Day 11, inventory exceeded 50 units, well above the initial 10-unit level. This pattern indicates the absence of an effective inventory verification system and suggests that ordering decisions were not aligned with actual demand. To extend the analysis beyond the FL1 case, the inventory levels of all 11 bag models were examined under the traditional ordering approach, as summarized in Table 3.

Table 3. Inventory Levels of 11 Models of Water Sports Equipment Bags.

Product Code	Product Name	Average Inventory Level (Traditional Ordering Method)
12125639	FL1	45
12126499	FL2	28
12144353	FL3	17
12125642	FL4	10
12156832	AR1	15
12149837	AR2	19
12125153	AW1	12
12153261	JF1	12
12153262	JF2	8
12143298	RD1	9
12142614	RD2	10

As shown in Table 3, the average inventory levels of all 11 bag models were higher than operationally necessary. This finding confirms the existence of excess stock in the packaging department. The data used in this study were collected over a three-month observation period.

3.1.1 Packaging Department Workflow: The company's workflow begins with the production planning department, which generates production schedules based on customer orders. Once products complete stage 10, they proceed to final quality inspection (QC-Final), where both functional and aesthetic characteristics are assessed. At this stage, multiple defect types may be detected, each requiring a different amount of rework time. Table 4 summarizes the ten most frequently observed defects and their average correction times.

Table 4. Characteristics of Defects and Time to Fix

Item	Symptom	Time to Fix (Days)	Inspection Point
1	Peeling paint	3	QC-Final
2	Scratches not caused by heat	2	QC-Final
3	Surface scratches	2	QC-Final
4	Paint bubbling	3	QC-Final
5	Incorrect paint, bubble, or glue color	3	QC-Final
6	Dust or foreign objects in the coating	2	QC-Final
7	Surface adhesion issues	2	QC-Final
8	Improper finishing	3	QC-Final
9	Incorrect assembly alignment	2	QC-Final
10	Dirt contamination	2	QC-Final

3.1.2 Ordering and Warehouse Practices: Due to uncertainty caused by defects and rework, employees tend to order more packaging bags than required and do so without a formal stock verification system. This practice, combined with a daily ordering policy, contributes to stock imbalance and overstocking. The warehouse department supplies bags daily, with a replenishment lead time of approximately 1 day. Based on these observations, this study proposes applying a Fixed Time Period System (Periodic Review Policy) to better align bag inventory with actual production demand and rework variability. Such an approach has been widely recommended in the inventory control literature for balancing service levels, lead times, and delays due to defects [11-12, 15].

3.1.3 Final Quality Control (QC-Final): The QC-Final stage is responsible for inspecting both the structural and aesthetic quality of each product. Because the types and severities of defects cannot be predicted in advance, production flow is disrupted, and a strict First-In, First-Out (FIFO) sequence cannot always be maintained. On average, defect correction takes approximately 3 days, consistent with prior studies that highlight the impact of rework on production scheduling [13-14].

3.1.4 Packaging Process: After quality inspection, products proceed to the packaging stage. Because the production sequence may be delayed by rework, employees often place orders for packaging bags without knowing the exact timing of the final output. In the absence of a stock verification system, this practice leads to excessive ordering and increased holding costs [1, 10].

3.1.5 Warehouse Department: Upon receiving requisitions from the production department, the warehouse supplies the required bags daily. Although this practice ensures immediate material availability, it does not prevent over-ordering. Therefore, this study proposes an improved inventory control framework based on a Fixed Time Period Inventory System to synchronize ordering with actual production demand and rework variability [11-12, 15].

3.2 Analysis of Problems

This study analyzes the problem of excess inventory in the packaging department and evaluates alternative solutions by comparing three ordering approaches for water sports equipment bags.

3.2.1 Traditional Ordering Method. Under the traditional approach, employees order bags based on perceived demand without verifying stock levels. This practice results in excessive replenishment and high average inventory levels across the 11 bag models, as shown in Table 4. Such behavior is consistent with the literature, which indicates that ad hoc ordering increases holding costs and ties up working capital in unnecessary stock [1, 5].

3.2.2 Ordering with Inventory Control: Fixed Time Period System. The analysis of the packaging department workflow indicates that current employee ordering behavior already resembles a Fixed Time Period (Periodic Review) System, in which orders are placed at regular intervals. However, the system lacks formal target inventory levels. In this study, the Fixed Time Period System is used to calculate target inventory levels for each bag model, maintaining service reliability while reducing excess inventory. The target inventory level is calculated using Equation (1). [11-12]

$$\text{Target Inventory Level (T)} = \bar{d}(P + LT) + Z \sigma_d \sqrt{P + LT} \quad (1)$$

Where

$\bar{d}$	= average daily demand
σ_d	= standard deviation of daily demand
P	= ordering period (days)
LT	= lead time (days)
Z	= service level factor

A service level of 99% ($Z=2.33$) was selected to minimize the risk of stockouts in the packaging process, where product availability is critical for shipment reliability. Because packaging bags are required at the final stage before delivery, even a minor shortage can disrupt shipment schedules and degrade customer service performance. Therefore, a relatively high service level was considered appropriate for this case study. For the FL1 model (12125639), the input data were as follows:

The average daily demand: 8 units per day
 The standard deviation : 3 units per day
 Ordering period: 1 day
 Lead time: 1 day
 Desired service level: 99% ($Z = 2.33$)

$$\begin{aligned} \text{Target Inventory Level (T)} &= (8)(1 + 1) + (2.33)(3)\sqrt{1 + 1} \\ &= 26 \text{ units} \end{aligned}$$

Table 5. Inventory Target

No.	Product Code	Product Name	Inventory Target (Target)
1	12125639	FL1	26
2	12126499	FL2	21
3	12144353	FL3	5
4	12125642	FL4	8
5	12156832	AR1	7
6	12149837	AR2	7
7	12125153	AW1	10
8	12153261	JF1	6
9	12153262	JF2	5
10	12143298	RD1	5
11	12142614	RD2	5

Table 5 shows that the proposed Fixed Time Period System allocates inventory targets according to demand magnitude and variability. Products in the FL series require the highest target inventory levels, particularly FL1 and FL2, due to their relatively high daily demand and variability. In contrast, lower-demand models such as JF2, RD1, and RD2 require smaller target inventories. This approach replaces subjective ordering decisions with data-driven inventory control, helping reduce unnecessary stock while maintaining the desired service level. To further compare the existing and proposed approaches, Table 6 summarizes the key differences between the traditional ordering method and the Fixed Time Period System.

Table 6. Comparison of the Traditional Ordering Method and Fixed Time Period System

Criteria	Traditional Ordering Method	Fixed Time Period System (Proposed)
Average Inventory Level	High (FL1 = 45 units; overall average > 20 units across models)	Lower (calculated targets: FL1 = 26 units; overall average < 15 units)
Cost Impact	Increased holding costs and sunk costs due to excess stock. Storage space inefficiencies.	Reduced inventory holding cost, optimized working capital, and better warehouse utilization.
Ordering Practice	Ad-hoc ordering without verification. Employees tend to over-order daily.	Periodic review with target stock levels calculated using demand, variance, and service level.
Service Level	Not explicitly defined; often leads to a stock surplus rather than a balance.	Defined at 99% service level using statistical safety stock calculation.
Risk of Stockouts	Low (due to over-ordering), but at a high cost.	Controlled by the safety stock factor ($Z = 2.33$), balancing service level with cost.
System Alignment	Reactive and employee-dependent.	Structured and data-driven, aligned with inventory control theory.

In summary, the Fixed Time Period System offers a more structured, cost-efficient approach than the traditional ordering method. By aligning target stock levels with demand variability and service requirements, the system reduces excess inventory while maintaining high operational reliability.

3.2.3 Ordering with inventory control based on rework rate and rework time analysis

In real manufacturing environments, production imperfections are unavoidable, and defective items requiring rework can significantly affect both production scheduling and inventory requirements. To better reflect these operational conditions, this study incorporates rework rate and rework time into the ordering policy for packaging bags. This approach enables inventory decisions to account for both the proportion of defective items and the timing of reworked items' return to the production process. The FL1 model (12125639) was selected as a representative case for analyzing rework behavior. Table 7 presents inspection data over 15

days, including the number of inspected items, the number of passed items, the number of reworked items, the rework time, and the percentage reworked.

Table 7. Rework Rate Behavior of Water Sports Equipment Production Using FL1 Model Bags (12125639)

Date	Items Inspected	Items Passed	Items Reworked	Rework Time (Days)	Percentage Reworked
01.11	11	6	5	0	45%
02.11	7	7	0	0	0%
03.11	8	8	0	0	0%
04.11	9	9	0	0	0%
05.11	6	6	0	0	0%
06.11	8	8	0	0	0%
07.11	8	5	3	0	38%
08.11	11	11	0	0	0%
09.11	8	4	4	0	50%
10.11	8	8	0	0	0%
11.11	9	9	0	0	0%
12.11	8	8	0	0	0%
13.11	8	8	0	0	0%
14.11	6	6	0	0	0%
15.11	3	1	2	0	67%

Note: In Table 7, rework time is recorded as 0 because the table reports the day on which defects were identified, while the average repair cycle time is presented separately in Table 5 and discussed in the workflow analysis.

From Table 7, the rework rate for FL1 varies considerably across days, ranging from 0% to 67%, with an average rework rate of 20%. This indicates that one-fifth of inspected items required rework before they could proceed to packaging. The analysis was then extended to all bag models.

Table 8. Rework Rate Behavior of Selected Water Sports Equipment Bag Models.

No.	Product Code	Product Name	Rework Rate
1	12125639	FL1	20%
2	12126499	FL2	16%
3	12144353	FL3	17%
4	12125642	FL4	15%
5	12156832	AR1	9%
6	12149837	AR2	22%
7	12125153	AW1	19%
8	12153261	JF1	23%

The results indicate that rework rates differ substantially across product models. Models with higher rework rates require more conservative inventory policies to compensate for delays caused by defect correction and ensure continuity in the packaging process. To integrate rework information into inventory planning, this study adopts a stepwise procedure for determining the withdrawal plan and safety stock requirements.

1. Adjustment of Shipment Plan by Rework Rate. The production planning department issues a weekly shipment plan based on a 5-day workweek. Because not all produced units are immediately available for packaging, the initial withdrawal quantity must be adjusted to account for the expected number of defective items. The initial withdrawal quantity is defined as equation (2).

$$W = S - D \quad (2)$$

Where

S = shipment plan target (units)

D = expected number of defective units

W = withdrawal quantity required for packaging

The expected number of defective units is estimated using the observed rework rate as shown in Equation (3).

$$D = S \times r \quad (3)$$

Where

D = expected number of defective units requiring rework

S = shipment plan target (units)

r = rework rate (proportion of items requiring correction)

This formulation assumes that the number of defective items is proportional to the production quantity and the observed rework rate. Similar approaches are commonly used in inventory models under imperfect quality conditions. Table 9 provides an example of the weekly shipment plan for the FL1 model.

Table 9. Example of Packaging Targets (Shipment Plan)

Date	3.10	4.10	5.10	6.10	7.10	Total
FL1	5	5	5	5	5	25

Using Table 9, the shipment plan target for FL1 is 25 units per week. With an average rework rate of 20%, the expected number of defective items is:

$$D = S \times r = 25 \times 0.20 = 5$$

Accordingly, the adjusted withdrawal plan is:

$$W = S - D = 25 - 5 = 20$$

However, defective items are not permanently removed from the system. After rework is completed, these items re-enter the production process and become available for packaging. Since the average rework time is approximately three days, the effective withdrawal plan must account for both the immediately available units and the return of reworked items. Therefore, the adjusted withdrawal quantity is represented as equation (4).

$$W = S(1 - r) + R_t \quad (4)$$

Where

S = shipment plan target (units)

r = rework rate (proportion of items requiring rework)

S(1-r) = effective number of items immediately available for packaging

R_t = number of items returning from the rework process after t days

W = adjusted withdrawal quantity

Equation (2) represents the initial withdrawal estimate after excluding expected defective units, whereas Equation (4) extends the formulation by incorporating the return flow of reworked items. This reflects the actual production environment, in which defective units are repaired and reintroduced into the system rather than discarded [14,15].

2. Determination of Safety Stock. To mitigate discrepancies between planned withdrawals and actual production output, a safety stock buffer is required. Table 10 compares the packaging plan and actual output over the same period.

Table 10. Comparison of Bagging Plans and Actual Output of Water Sports Equipment.

Date	3.10	4.10	5.10	6.10	7.10	Total
Bagging Plan	4	4	5	5	5	23
Actual Output	4	6	4	6	3	22
Difference	0	-2	0	-1	2	-2

Table 10 shows that actual output does not always match the packaging plan. These deviations justify the inclusion of safety stock to absorb variability from rework and maintain service reliability without excessive overstocking. In summary, the proposed rework-based approach provides a more realistic and adaptive basis for managing packaging bag inventory. By adjusting the shipment plan to account for returned, reworked items and incorporating safety stock, the proposed method aligns inventory decisions more closely with actual production conditions, helping reduce excess inventory while preventing shortages.

4. Results

The primary objective of this study was to reduce excess inventory and associated sunk costs in the packaging process by applying inventory control techniques to determine more appropriate stock levels. To evaluate the effectiveness of alternative ordering approaches, three methods were compared: (1) the Traditional Ordering Method, (2) the Fixed Time Period System (FTPS), and (3) the proposed Rework-Based Ordering Method.

4.1 Traditional Ordering Method.

The first analysis examined employees' existing ordering behavior in the packaging department. Data collected during November showed substantial overstocking of packaging bags, as the quantities ordered frequently exceeded actual usage demand. As a result, a considerable amount of capital was tied up in inventory. The average inventory cost for each bag model under the traditional ordering method is presented in Table 11.

Table 11. Average Inventory Cost Using the Traditional Ordering Method

No.	Product Code	Product Name	Quantity Ordered	Product Value (Baht)	Cost Using Traditional Method (Baht)
1	12125639	FL1	45	1,886	84,870
2	12126499	FL2	28	1,725	48,300
3	12144353	FL3	17	1,577	26,809
4	12125642	FL4	10	1,422	14,220
5	12156832	AR1	15	1,700	25,500
6	12149837	AR2	19	1,792	34,048
7	12125153	AW1	12	2,034	24,408
8	12153261	JF1	12	2,615	31,380
9	12153262	JF2	8	2,761	22,088
10	12143298	RD1	9	2,096	18,864
11	12142614	RD2	10	2,282	22,820

The results indicate that the traditional ordering method yielded an average inventory cost of 353,307 Baht. This high cost was mainly caused by excessive stock accumulation beyond operational requirements, confirming the inefficiency of employee-based ad hoc ordering without inventory verification.

4.2 Fixed Time Period System Ordering Method.

To address inefficiencies in the traditional method, the Fixed Time Period System (FTPS) was implemented. This method determines a target inventory level for each bag model based on average demand, demand variability, lead time, and safety stock considerations. Table 12 compares the traditional order quantities with the FTPS target inventory levels and the corresponding inventory costs.

Table 12. Comparison of Inventory Levels and Costs Between the Traditional Ordering Method and the Fixed Time Period System

Product Code	Product Name	Traditional Method Order Quantity	Fixed Time Period System Target Inventory Level	Product Value (Baht)	Method 1 Traditional Ordering (Average Inventory Level)	Method 2 Inventory Target	Cost Reduction (Baht)
12125639	FL1	45	26	1,886	84,870	49,036	35,834
12126499	FL2	28	21	1,725	48,300	36,225	12,075
12144353	FL3	17	5	1,577	26,809	7,885	18,924
12125642	FL4	10	8	1,422	14,220	11,376	2,844
12156832	AR1	15	7	1,700	25,500	11,900	13,600
12149837	AR2	19	7	1,792	34,048	12,544	21,504
12125153	AW1	12	10	2,034	24,408	20,340	4,068
12153261	JF1	12	6	2,615	31,380	15,690	15,690
12153262	JF2	8	5	2,761	22,088	13,805	8,283
12143298	RD1	9	5	2,096	18,864	10,480	8,384
12142614	RD2	10	5	2,282	22,820	11,410	11,410
				Total	353,307	200,691	152,616

The application of FTPS resulted in a substantial reduction in target inventory levels for most bag models compared with the traditional ordering method. In financial terms, the total inventory cost decreased from 353,307 Baht under the traditional method to 200,691 Baht under FTPS, representing a cost reduction of 152,616 Baht. Importantly, no stockouts were observed during the trial period, indicating that the inventory reduction did not compromise operational reliability. These findings suggest that FTPS provides a more systematic and cost-efficient ordering approach than the traditional method by replacing subjective ordering behavior with statistically determined inventory targets.

4.3 Rework Rate and Rework Time-Based Inventory Control.

To further improve inventory performance under actual production conditions, the third method incorporated rework rate and rework time into the inventory planning process. This method adjusts inventory requirements based on the proportion of defective items and the timing of their return to the production process. Table 13 compares the average inventory levels obtained under the three methods using December data.

Table 13. Comparison of Average Inventory Levels in 3 Methods (December)

No.	Product Code	Product Name	Traditional Method Inventory Level	Fixed Time Period System Inventory Level	Rework Rate-Based Inventory Level
1	12125639	FL1	45	26	2
2	12126499	FL2	28	21	3
3	12144353	FL3	17	5	2
4	12125642	FL4	10	8	4
5	12156832	AR1	15	7	2
6	12149837	AR2	19	7	2
7	12125153	AW1	12	10	4
8	12153261	JF1	12	6	2
9	12153262	JF2	8	5	2
10	12143298	RD1	9	5	3
11	12142614	RD2	10	5	3

The results show that the rework-based method consistently produced the lowest inventory levels across all product models. This indicates that incorporating rework-related variability enables inventory to be more closely aligned with actual production requirements than either the traditional ordering method or FTPS.

To evaluate the financial impact of this method, Table 14 compares the average inventory costs of all three approaches.

Table 14. Comparison of Average Inventory Costs Using Three Methods

No.	Product Code	Product Name	Product Value (Baht)	Method 1 Cost (Baht)	Method 2 Cost (Baht)	Method 3 Cost (Dec) (Baht)
1	12125639	FL1	1,886	84,870	49,036	3,772
2	12126499	FL2	1,725	48,300	36,225	5,658
3	12144353	FL3	1,577	26,809	7,885	3,772
4	12125642	FL4	1,422	14,220	11,376	7,544
5	12156832	AR1	1,700	25,500	11,900	3,772
6	12149837	AR2	1,792	34,048	12,544	3,772
7	12125153	AW1	2,034	24,408	20,340	7,554
8	12153261	JF1	2,615	31,380	15,690	3,772
9	12153262	JF2	2,761	22,088	13,805	3,772
10	12143298	RD1	2,096	18,864	10,480	5,658
11	12142614	RD2	2,282	22,820	11,410	5,658

Based on the cost comparison, Method 3 achieved the lowest overall inventory cost. The proposed rework-based method reduced inventory cost by 298,613 Baht compared with the traditional method and by 145,997 Baht compared with FTPS. These results demonstrate that including rework rate and rework time in inventory planning can significantly improve cost efficiency while maintaining operational continuity. To assess the robustness of the proposed method, inventory levels under Method 3 were monitored over three consecutive months from December to February. The comparative results are shown in Table 15.

Table 15. Inventory Levels Under the Three Ordering Methods Across Three Consecutive Months

No.	Product Code	Product Name	Traditional Method Inventory Level	Fixed Time Period System Inventory Level	Rework Rate-Based Inventory Level (Dec)	Rework Rate-Based Inventory Level (Jan)	Rework Rate-Based Inventory Level (Feb)
1	12125639	FL1	45	26	2	3	3
2	12126499	FL2	28	21	3	3	3
3	12144353	FL3	31	24	2	3	3
4	12125642	FL4	10	8	4	3	3
5	12156832	AR1	15	7	2	3	3
6	12149837	AR2	19	10	2	3	3
7	12125153	AW1	9	10	4	3	3
8	12153261	JF1	8	10	2	3	3
9	12153262	JF2	5	5	2	3	3
10	12143298	RD1	5	5	3	3	3
11	12142614	RD2	5	5	3	3	3

The results indicate that the rework-based method maintained low and stable inventory levels throughout the three-month observation period without causing stock shortages. This finding suggests that the proposed method is not only cost-efficient but also operationally reliable over time. To further compare the cost implications across the observation period, Table 16 summarizes the average inventory costs for the three methods.

Table 16. Summary of Average Inventory Costs

No.	Product Code	Product Name	Product Value (Baht)	Method 1 Cost (Baht)	Method 2 Cost (Baht)	Method 3 Cost (Baht) (Dec)	Method 3 Cost (Baht) (Jan)	Method 3 Cost (Baht) (Feb)
1	12125639	FL1	1,886	84,870	49,036	3,772	5,658	5,658
2	12126499	FL2	1,725	48,300	36,225	5,658	5,658	5,658
3	12144353	FL3	1,577	26,809	7,885	3,772	3,772	3,772
4	12125642	FL4	1,422	14,220	11,376	7,544	7,544	5,658
5	12156832	AR1	1,700	25,500	11,900	3,772	5,658	5,658
6	12149837	AR2	1,792	34,048	12,544	3,772	5,658	5,658
7	12125153	AW1	2,034	24,408	20,340	7,554	7,544	7,544
8	12153261	JF1	2,615	31,380	15,690	3,772	5,658	3,772
9	12153262	JF2	2,761	22,088	13,805	3,772	3,772	3,772
10	12143298	RD1	2,096	18,864	10,480	5,658	5,658	5,658
11	12142614	RD2	2,282	22,820	11,410	5,658	5,658	5,658
Total				353,307	200,691	54,694	60,352	56,580

The comparative analysis confirms the superiority of the rework rate and rework time-based approach. While the traditional ordering method resulted in the highest inventory cost of 353,307 Baht, FTPS reduced it to 200,691 Baht; the proposed Method 3 achieved the lowest average cost of approximately 57,209 Baht across the three months. More importantly, Method 3 maintained service reliability by preventing stock shortages across all product categories during the observation period. Overall, the results highlight two important findings. First, incorporating production variability through rework rate and rework time enables more realistic and efficient inventory decisions. Second, the proposed model provides a stronger alignment between inventory planning and actual production conditions than conventional approaches. Therefore, the rework-based method offers a practical and effective framework for managing packaging inventory in manufacturing environments.

5. Discussion

The findings of this study demonstrate that different inventory control policies produce substantially different outcomes in terms of cost efficiency and service reliability. The traditional ordering method led to excessive inventory accumulation and high sunk costs, confirming earlier studies that have highlighted the risks of uncontrolled, experience-based ordering practices in manufacturing environments [1, 4]. Although this approach reduced the likelihood of stock shortages, it did so at the expense of tying up excessive capital in inventory. The Fixed Time Period System (FTPS) provided a more structured and theoretically grounded alternative. By incorporating demand averages, demand variability, and safety stock into the calculation of target inventory levels, FTPS reduced total inventory costs by more than 152,000 Baht compared with the traditional method. This result is consistent with prior studies on periodic review systems and safety stock policies, which suggest that statistically determined replenishment rules can improve cost control and inventory discipline [8, 11]. However, the results also show that FTPS alone was not sufficient to fully reflect the operational realities of the packaging process, particularly when rework-related disruptions affected the timing of product availability. The most important contribution of this study lies in the proposed rework-based inventory approach, which explicitly integrates rework rate and rework time into inventory planning. This method outperformed both the traditional method and FTPS by achieving the lowest average inventory cost while maintaining service reliability and preventing stockouts. The superior performance of this approach indicates that production variability caused by defects and rework should not be treated as a peripheral issue, but rather as a central factor in inventory decision-making. In this respect, the findings support earlier studies on imperfect quality and rework in production-inventory systems, particularly those of Sonntag and Kiesmüller [13], Alamri et al. [14], and Lin et al. [16], which emphasize the importance of incorporating

production imperfections into inventory models. From a practical standpoint, the results suggest that inventory policies for packaging materials should be closely aligned with actual production behavior rather than based solely on average demand or fixed replenishment intervals. In manufacturing systems where rework delays are common, an inventory policy that accounts for defect rates and rework cycle times can provide a more realistic balance between cost reduction and service continuity. Therefore, the proposed method offers not only theoretical relevance but also managerial value for firms seeking to improve inventory efficiency under imperfect production conditions. Overall, this study demonstrates that although EOQ, periodic review, and safety stock models provide a useful analytical foundation, more adaptive policies are required when production systems are affected by rework and quality variability. By integrating these operational factors into inventory planning, the proposed framework bridges the gap between theoretical inventory control models and practical implementation in manufacturing environments.

6. Conclusion

This study compared three inventory management approaches for water sports equipment bags in the packaging department: the Traditional Ordering Method, the Fixed Time Period System (FTPS), and the proposed rework rate and rework time-based inventory control method. The results showed that the traditional ordering method led to substantial overstocking and the highest inventory cost, amounting to 353,307 Baht. The FTPS improved inventory control and reduced total cost to 200,691 Baht; however, it still maintained inventory levels above actual operational requirements. In contrast, the proposed rework-based inventory approach produced the most effective results. By incorporating rework rate and rework time into inventory planning, the method achieved the lowest average inventory cost of 57,209 Baht over the three-month observation period while preventing stockouts across all product categories. These findings demonstrate that inventory policies can be significantly improved when operational variability is explicitly incorporated into planning decisions rather than relying solely on demand averages or fixed review cycles.

From a managerial perspective, the study suggests that manufacturing firms should adopt more adaptive inventory systems that reflect actual production conditions, particularly in environments affected by defects and rework. Integrating rework-related data into inventory decisions helps reduce excess capital investment, improve material availability, and strengthen operational reliability. Therefore, the proposed approach offers practical value not only for water sports equipment manufacturing but also for other industries characterized by rework-related uncertainty, such as automotive, electronics, and customized production systems. Despite its contributions, this study has several limitations. First, the analysis was based on a single case company, which may limit the generalizability of the findings. Second, the observation period covered only three months and may not fully capture seasonal demand variation or long-term operational changes. Third, the proposed model assumes relatively stable rework rates and rework times, whereas these factors may vary in practice due to workforce performance, technological conditions, or material quality. Future research should extend the analysis to multiple industrial settings and longer study periods, and incorporate stochastic modeling more effectively better to reflect uncertainty in both demand and production quality. Further investigation into sustainability outcomes, such as waste reduction and environmental impact, would also enhance the relevance of rework-based inventory policies in modern manufacturing.

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