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Airfreight Warehouse Simulation: A Free Storage Policy

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Abstract

This study examines a warehouse management service provider specializing in temporary airfreight storage. The current 48-hour free storage policy offers flexibility but results in inventory accumulation, causing inefficiencies in handling, storage, and retrieval. This research evaluates warehouse operations and simulates three alternative inventory policies (36, 24, and 12 hours) using Arena simulation software with a cross-docking strategy, where goods can be arranged on the floor instead of on shelves. Key performance metrics include customer time in the system, goods retention time, sorting process waiting time, and the number of workers required. Findings show that shorter storage durations significantly improve efficiency. The 12-hour policy achieves the highest gains, reducing customer processing time by 25%, goods retention by 76%, and sorting wait time by 27%. The 36-hour and 24-hour policies provide moderate benefits. In conclusion, reducing free storage duration enhances warehouse efficiency by minimizing wait times, reducing inventory retention, enhancing space utilization, and lowering labour demands.

Keywords: management, cross-docking, simulation, Arena, warehouse efficiency

INTRODUCTION

Air cargo transportation is a high-cost cross-border service that excels in meeting consumer demands due to its speed, making it the most suitable mode for urgent deliveries or perishable goods. Examples of such goods include machine parts, fashion products, fresh vegetables, fruits, and jewelry. Although the air freight industry was heavily impacted by the COVID-19 crisis between 2021 and 2023, it demonstrated a strong recovery in 2024, with an 11.8% growth in air cargo volume compared to the previous year. This recovery was primarily driven by the resurgence of the global economy and trade, along with supporting factors such as declining fuel prices, which helped airlines reduce operational costs (Dray et al., 2024; Sathapongpakdee, 2021). The rapid growth of the air freight industry has significantly increased the demand for efficient airport warehouse management. Effective warehouse operations are crucial for ensuring the speed and reliability of the logistics system, particularly in short-term storage management. Many airports worldwide have established different storage policies based on cargo type and size. For instance, the United States and Germany have set free storage durations at 24 to 48 hours, while Singapore Qatar, United Kingdom have set their limits at 48, 24, and 18 hours, respectively (Gebrüder Weiss Pte. Ltd., 2022; Qatar Aviation Services Cargo, 2019; Metro Global, 2022; Lufthansa Cargo., 2024; LUG Aircargo Handling GmbH, 2018).

To investigate the effectiveness of the free storage policy, a particular air cargo temporary storage service provider is considered, which handles approximately 900,000 tons of cargo and over 50,000 flights per year. The service provider offers 48 hours of free storage under the general storage system. Customers retrieving goods within this period pay a warehouse fee of 450 THB per shipment. After 48 hours, they incur the same warehouse fee plus an additional storage charge of 2.30 THB per kilogram per day. While this policy offers customers greater flexibility in retrieving their goods. However, this policy has resulted in huge cargo accumulation within the warehouse, reducing efficiency in handling, storage, and retrieval operations. The increasing need for personnel, handling equipment, and storage space has further strained operational capacity. To address these challenges, this study focuses on evaluating the current warehouse management process and proposing three alternative free storage policies to enhance efficiency: reducing storage time to 36 hours, 24 hours, and 12 hours. The 12-hour policy applies a cross-docking strategy due to time constraints, while the 24-hour and 36-hour policies do not. This minimizes cargo accumulation by eliminating shelving and placing goods directly on the ground for immediate dispatch. This research employs Arena simulation software to assess the effectiveness of these alternative policies based on key performance indicators, including the average time customers spend in the system, the average storage duration per item, and the waiting time in the sorting process. The findings are expected to offer insights to air cargo terminals in formulating the most effective free storage policy, leading to reduced warehouse congestion, lower operational costs, and improved overall logistics system efficiency.

LITERATURE REVIEW

The evolution of warehouse management aims to meet increasing logistics demands, with inefficient inventory management leading to higher costs and reduced competitiveness. Air cargo ground handling plays a crucial role in transportation speed and cost. Recently, a major ground handler at London Heathrow Airport raised handling and storage fees while reducing the free storage period, significantly increasing costs during warehouse congestion. Charges vary widely, with some handlers imposing four times higher fees than others. Additional costs, such as COVID surcharges and transport fees for timely collection, further impact expenses. High costs may push freight companies to avoid costly handlers, potentially reducing air cargo capacity in key markets like Asia and the Indian subcontinent. Despite these challenges, air freight teams continue to seek cost-effective solutions to optimize services (Metro Global, 2022).

The Just in Time (JIT) concept has been adopted to reduce inventory levels, which later evolved into the Cross-docking strategy. This concept has been proven to minimize reliance on storage space by focusing on transferring goods directly from inbound trucks to outbound trucks. As a result, storage costs are reduced, and logistics processes are optimized (Aickelin & Asap, 2008). This approach enables goods to move swiftly through warehouses without being stored on shelves. However, in practice, significant process restructuring is required, including resource management, personnel, technology, and investments in new infrastructure to ensure the system operates efficiently (Gue, 2007).

The concept of simulation was first introduced during World War II, with one of the earliest simulation methods being the Monte Carlo Method. This method was developed to calculate the behaviour of nuclear particles in the Manhattan Project, the U.S. nuclear weapons development program (University of Houston, 2000.). Later, computer-based simulations were applied across various industries, including logistics and manufacturing (1950s-1960s). Research utilizing simulations to analyse industrial processes has continued to evolve with diverse objectives. Studies on warehouse receiving area design have demonstrated that simulation can enhance efficiency and reduce operational time by 48%-57% (Ekren et al., 2012). Process improvement using Value Stream Mapping and Arena software has been studied, showing a 52% reduction in Work-In-Progress (WIP) inventory and an 81.3% reduction in production time in the food industry (Al-Khafaji & Al-Rufaifi, 2012). The application of Arena has also been proven to reduce truck waiting times in transportation by 70% (Emami et al., 2014). Arena has been used to optimize cross-docking systems by analysing different shipment dispatching rules, such as FIFO and EDD (Rajan, 2015). Additionally, integrating simulation with the Taguchi Method has been used to reduce production costs in the freshwater pump industry, achieving a cost reduction of 1,046 Indian rupees (Sankaran et al., 2015). Simulation Optimization and Discrete Event System Simulation (DESS) have also been applied to increase efficiency and reduce costs in the air conditioning industry (Aldurgam et al., 2019). Arena has been utilized to simulate queueing systems in Malaysian public clinics, revealing that key issues include excessive time spent by staff searching for medications and an overwhelming number of patients per doctor (Phang Yook Ngor et al., 2023). Similarly, analysing the queueing system of hospital medical records and outpatient departments with Arena has demonstrated that simulation models can accurately predict patient waiting times, with an error margin of only 1.18%-1.47% (Promjabok et al., 2024). In the field of robot navigation, Arena-Bench has been developed as a simulation platform for testing obstacle avoidance algorithms in dynamic environments (Kästner et al., 2022). This later evolved into Arena 3.0, which enables realistic simulations of human behavior and human-robot interactions (Kästner et al., 2024). Arena has also been applied in Boeing 747 engine maintenance simulations, demonstrating a 37% reduction in maintenance time and $1.44 million in cost savings per maintenance cycle (Shargawi et al., 2023). To address warehouse congestion and loading dock delays, which contribute to inefficiencies and high costs, a collaborative system between Freight Forwarders (FFs) and Ground Handlers (GHs) has been explored. This system utilizes Centralized Planning and a shared Gray Fleet to improve transport route allocation. Furthermore, Adaptive Large Neighbourhood Search (ALNS) has been integrated with Mixed Integer Linear Programming (MILP) to mitigate bottlenecks and truck waiting times at loading docks (Bombelli & Fazi, 2022).

METHODOLOGY

This study employs a simulation-based methodological framework grounded in established principles of discrete-event system modeling, as outlined by Law and Kelton (1991), Banks et al. (1996), and Barnes et al. (1997). The research methodology comprises four sequential phases, structured as follows:

Data collection and input analysis

Primary operational data on cargo management, storage protocols, and order-picking workflows were systematically gathered from an airport warehouse during April–May 2024. This included quantitative metrics such as processing times, material flow patterns, and qualitative observations of operational bottlenecks. Input analysis involved characterizing stochastic elements through distribution fitting to ensure alignment between empirical data and simulation parameters.

Development of baseline and improved policy models

A computational model replicating current warehouse operations was constructed using Arena simulation software. This baseline model, namely the 48-hour free storage policy, served as a foundation for evaluating policy enhancements targeting storage duration reduction and cross-docking implementation. Proposed strategies, namely 36-hour, 24-hour, and 12-hour free storage policies, were operationalized within the simulation environment to assess their theoretical efficacy.

Model verification and comparative evaluation

The simulation's logical consistency was verified through iterative debugging and face validity checks with domain experts. Policy outcomes were benchmarked against baseline performance indicators to quantify improvements in operational efficiency, ensuring methodological rigor while adhering to best practices in simulation modeling. There are four main metrics as follows.

The first key performance metric is the average time a customer spends in the system, which measures the total duration from entry to exit. Expressed in hours, this metric provides insight into overall warehouse efficiency from the customer's perspective. Longer times indicate delays in processing, storage, or retrieval, whereas shorter times suggest a more streamlined operation. This measurement is obtained using the Record module and calculated through Equation 1.

The second metric, average storage duration per item, represents the mean time an item remains in storage before being retrieved or shipped. It is determined by dividing the total storage time by the number of stored items and is also expressed in hours. Shorter storage durations indicate a high turnover rate and reduced holding costs, whereas longer durations suggest inefficiencies, such as slow-moving stock or excessive storage. This metric is similarly measured using the Record module and calculated through Equation 1.

Third, the waiting time in the sorting process measures how long an item waits in the sorting area before processing begins. This is tracked by the time difference between an item's arrival at the sorting station and the start of sorting, expressed in minutes or hours. Longer waiting times highlight bottlenecks, while shorter times indicate a more efficient process. This metric is recorded in the Process Module and displayed in the simulation report. Finally, the required number of workers is determined by gradually reducing the workforce until key performance indicators, such as customer time in the system, storage duration, and sorting waiting time, begin to decline from their baseline values.

$$\text{Item or Customer processing time} = \text{Time of exit} - \text{Time of entry}. \tag{1}$$

Next, the resource utilization is compared across the current model and four alternative storage policies: the 48-hour storage policy (Model 48), the 36-hour storage policy (Model 36), the 24-hour storage policy

(Model 24), and the 12-hour cross-docking storage policy (Model 12) within the studied warehouse. The key performance indicators (KPIs) include the average time customers spend in the system, the average storage duration per item, the waiting time in the sorting process, and the number of workers required. Following this, the total reduction in these metrics is estimated based on the decrease in time and the reduction in the number of workers, as calculated using Equation 2.

$$\text{Change Rate of the Metric } (\%) = \frac{(\text{Improved metric } - \text{ Current metric})}{\text{Current metric}} \times 100 \tag{2}$$

CASE ANALYSIS

Data collection

The case study examines an air cargo warehouse that handles short-term storage for inbound and outbound air cargo deliveries. Located at the airport, the warehouse provides convenient storage and delivery services to customers. This study focuses on inbound air cargo arriving from all over the world to Thailand. The company offers one-stop services for air cargo storage, including unloading goods from aircraft to a staging area, inspecting, sorting, and storing items in designated locations. Once customers arrive and pay the necessary fees, the goods are processed for release, ensuring smooth import and export operations. The warehouse operates in two shifts: Shift 1 runs from 6:00 AM to 6:00 PM, with a break from 12:00 PM to 1:00 PM, and Shift 2 runs from 6:00 PM to 6:00 AM, with a break from 1:00 AM to 2:00 AM. Workforce allocation per shift is recorded accordingly. If customers fail to collect their goods within the designated timeframe, employees move the items to a holding area. Items unclaimed for more than three months are disposed of, which accounts for 5% of the total incoming cargo.

The data collection included the number of resources such as staff and forklifts and the volume of cargo unloaded for storage (as shown in Tables 1 and 2). The activities were broken down, and their time durations under the current 48-hour free storage policy (as shown in Tables 3 and 4) were recorded and represented using a triangular distribution, denoted as TRIA(min, average, max) in minutes. This collected data serves as input for simulation modeling, which is used to compare the performance of different policies.

Table 1: Resources in the warehouse under the current policy

Resource	Quantity per Shift	Unit
Forklifts for loading goods onto ASRS shelves and picking	6	Machines
Staff for breakdown zone operations	6	Person
Staff for shelf vacancy recording	2	Person
Documentation staff	3	Person
Data entry staff	2	Person

Table 2: Number of goods delivered to the warehouse

Time		Number of Goods (Items per Hour)	Time		Number of Goods (Items per Hour)
6:00	**7:00**	38	**18:00**	**19:00**	7
7:00	**8:00**	0	**19:00**	**20:00**	11
8:00	**9:00**	7	**20:00**	**21:00**	14
9:00	**10:00**	11	**21:00**	**22:00**	27
10:00	**11:00**	7	**22:00**	**23:00**	24
11:00	**12:00**	7	**23:00**	**0:00**	4
12:00	**13:00**	7	**0:00**	**1:00**	0
13:00	**14:00**	11	**1:00**	**2:00**	0
14:00	**15:00**	24	**2:00**	**3:00**	0
15:00	**16:00**	21	**3:00**	**4:00**	0
16:00	**17:00**	24	**4:00**	**5:00**	7
17:00	**18:00**	17	**5:00**	**6:00**	41

Table 3: Duration of inbound activities for 4 policies (in minutes)

<table>
<tr><th rowspan="2">Job</th><th rowspan="2">Activity</th><th rowspan="2">Job precedence</th><th colspan="4">Policy</th></tr>
<tr><th>48</th><th>36</th><th>24</th><th>12</th></tr>
<tr><td>A</td><td>Goods unloaded from the aircraft to the waiting area</td><td>-</td><td>TRIA (10, 15, 20)</td><td>TRIA (10, 15, 20)</td><td>TRIA (10, 15, 20)</td><td>TRIA (10, 15, 20)</td></tr>
<tr><td>B</td><td>Goods waiting in the waiting area</td><td>A</td><td colspan="4">The number of items in the queue for the forklift process transporting goods to the sorting area is less than or equal to 30.</td></tr>
<tr><td>C</td><td>Goods waiting for inspection at the sorting area</td><td>B</td><td>TRIA (30, 60, 180)</td><td>TRIA (30, 60, 180)</td><td>TRIA (30, 60, 180)</td><td>TRIA (30, 60, 180)</td></tr>
<tr><td>D</td><td>Sorting, inspection, and initial placement evaluation</td><td>C</td><td>TRIA (10, 15, 20)</td><td>TRIA (10, 15, 20)</td><td>TRIA (10, 15, 20)</td><td>TRIA (8.5, 13.5, 18.5)</td></tr>
<tr><td>E</td><td>Forklift transporting goods to the placement area</td><td>D</td><td>TRIA (0.05, 0.1, 0.13)</td><td>TRIA (0.05, 0.1, 0.13)</td><td>TRIA (0.05, 0.1, 0.13)</td><td>TRIA (0.16, 0.26, 0.31)</td></tr>
<tr><td>F</td><td>Staff evaluating placement area</td><td>E</td><td>TRIA (0.05, 0.1, 0.13)</td><td>TRIA (0.05, 0.1, 0.13)</td><td>TRIA (0.05, 0.1, 0.13)</td><td rowspan="3">All goods are stored in a single location on the floor.</td></tr>
<tr><td>G</td><td>Goods with height between 120-160 cm were moved to shelves</td><td>F</td><td>TRIA (0.05, 0.1, 0.13)</td><td>TRIA (0.05, 0.1, 0.13)</td><td>TRIA (0.05, 0.1, 0.13)</td></tr>
<tr><td>H</td><td>Goods shorter than 120 cm moved to ASRS</td><td>F</td><td>TRIA (0.17, 0.25, 0.33)</td><td>TRIA (0.17, 0.25, 0.33)</td><td>TRIA (0.17, 0.25, 0.33)</td></tr>
<tr><td>I</td><td>Goods taller than 160 cm moved to oversized storage area</td><td>F</td><td colspan="3">TRIA(5, 5, 5)</td><td></td></tr>
</table>

Table 4: Duration of outbound activities for 4 policies (in minutes)

Job	Activity	Job precedence	Policy			
			48	36	24	12
J	Time goods remain in storage before pickup	-	TRIA (1440, 2160, 2880)	TRIA (1080, 1920, 2160)	TRIA (720, 1200, 1440)	TRIA (360, 480, 720)
K	The customer pays for customs taxes	J	TRIA (3, 6, 10)	TRIA (3, 6, 10)	TRIA (3, 6, 10)	TRIA (3, 6, 10)
L	The customer walks to the F3 document room	K	TRIA (2, 3, 5)	TRIA (2, 3, 5)	TRIA (2, 3, 5)	TRIA (2, 3, 5)
M	The customer collects the delivery slip and pays service charges	L	TRIA (2, 3, 5)	TRIA (2, 3, 5)	TRIA (2, 3, 5)	TRIA (2, 3, 5)
N	The customer walks to the queue desk	M	TRIA (0.5, 1, 3)	TRIA (0.5, 1, 3)	TRIA (0.5, 1, 3)	TRIA (0.5, 1, 3)
O	Staff locates the placement area	N	TRIA (1, 5, 10)	TRIA (1, 5, 10)	TRIA (1, 5, 10)	TRIA (1, 5, 10)
P	The customer waits for goods to be delivered	O	TRIA (5, 15, 20)	TRIA (4, 12, 15)	TRIA (3, 9, 13)	TRIA (1.5, 5.5, 10.5)
Q	The customer inspects goods for damage	P	TRIA (15, 30, 45)	TRIA (15, 30, 45)	TRIA (15, 30, 45)	TRIA (15, 30, 45)
R	The customer reports goods for pickup	Q	TRIA (0.5, 1, 3)	TRIA (0.5, 1, 3)	TRIA (0.5, 1, 3)	TRIA (0.5, 1, 3)
S	The customer reserves truck parking space	R	TRIA (1, 3, 5)	TRIA (1, 3, 5)	TRIA (1, 3, 5)	TRIA (1, 3, 5)
T	The customer loads goods onto the truck	S	TRIA (15, 30, 60)	TRIA (15, 30, 60)	TRIA (15, 30, 60)	TRIA (15, 30, 60)

Current operational situation and policies

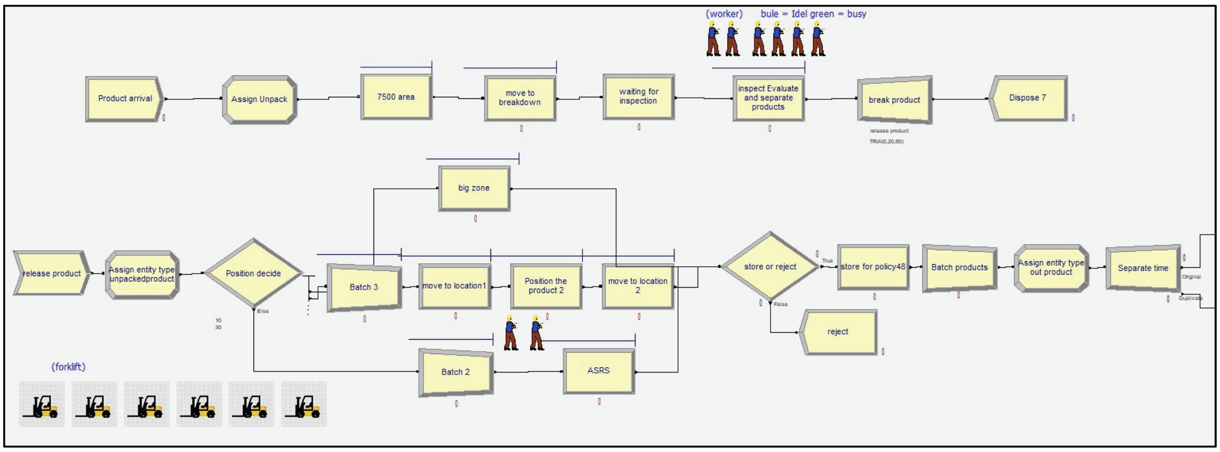
Activities of warehouse

The customer activities begin with document preparation and tax payment to customs authorities, followed by submitting documents at the document processing office. Employees verify the documents and print a receipt indicating the location of the cargo, allowing customers to locate their goods. Forklifts retrieve items from storage areas and deliver them to the customers. Customers then inspect for damages, notify staff at the warehouse exit point, and proceed to the designated loading bay where they load cargo onto their vehicles. The activities of goods begin when the cargo is unloaded from the aircraft and moved to the waiting area. From there, it is transferred to the breakdown area, where the goods are separated from ULD sheets into individual boxes for storage. Items with a height of less than 120 cm are transported to the ASRS. Items with a height of 120-160 cm are moved to the shelf. Items with a height of more than 160 cm are sent to the bulk cargo area and stored until the policy-defined retention period is met.

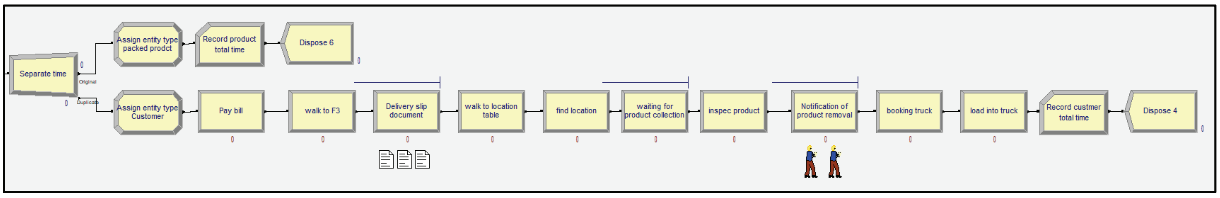
Simulation of goods and customer activities

The number of incoming goods per hour and the processing time at each stage under the current policy are used to simulate scenarios in Arena version 16.0. These simulations are illustrated in Pictures 1 and 2. A simulation is then conducted using the same methodology but with reduced storage durations based on three different policies: 36 hours, 24 hours, and 12 hours. For the 12-hour policy—the shortest storage duration—a different storage method is implemented. Instead of using the current shelving system, a single-area storage approach without shelving is applied. This change represents a strategic shift toward the cross-docking concept, which prioritizes speed and minimal storage time. The simulation results are shown in Picture 3. In this scenario, it is assumed that the designated storage area is sufficient to handle all incoming goods within the 12-hour window. This assumption eliminates space constraints from influencing the outcome, allowing for a more accurate comparison of the efficiency of each storage strategy.

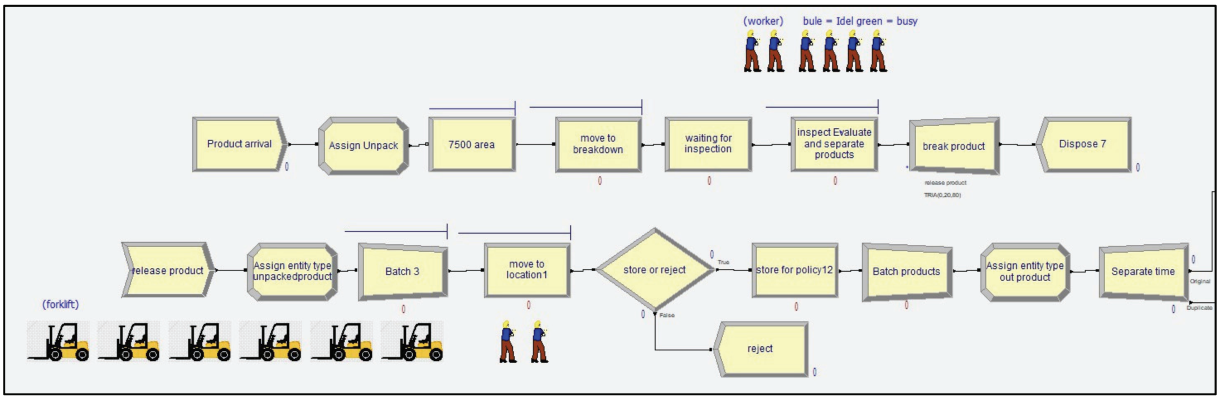
Picture 1: System simulation for goods in the current scenario.



Picture 2: System simulation for customers in the current scenario



Picture 3: System simulation for goods under the cross-docking model (12 hours)



RESULTS AND DISCUSSION

Research findings from the case analysis

The research findings highlight differences in efficiency across various models based on key performance indicators, including the average time customers spend in the system, the storage duration of goods in the warehouse, and the waiting time in the sorting process, as shown in Table 5. The 12-hour storage policy adopts a cross-docking strategy, where goods are stored in a single location without designated storage positions. Among the different policies, only the 12-hour policy significantly reduces customer time in the system, achieving a 25% decrease, while the 36-hour and 24-hour policies lead to minimal reductions of 4% and 10%, respectively.

Table 5: The average time customers spend in the system, the average time goods remain in the warehouse, and the waiting time during the sorting process (hours)

KPI	Policy				The Reduction Rate between the Current Policy (48) and		
	48	36	24	12	36	24	12
Average time customers spend in the system	2.20	2.10	1.99	1.65	-4%	-10%	-25%
Average time goods remain in the warehouse	47.41	35.65	23.91	11.22	-25%	-50%	-76%
Waiting time during the sorting process	0.30	0.30	0.30	0.22	0%	0%	-27%

Regarding the time goods remain in the system, the reduction aligns with shorter storage durations, with a 25% decrease in the 36-hour policy, 50% in the 24-hour policy, and a significant 76% in the 12-hour policy. This demonstrates that implementing cross-docking and reducing storage time effectively minimizes inventory backlog. Additionally, the waiting time in the sorting process remains unchanged for the 36-hour and 24-hour policies but decreases by 23% in the 12-hour policy due to the elimination of separate storage areas, which streamlines decision-making for storage placement. Overall, adopting cross-docking and reducing storage time under the 12-hour policy proves to be the most effective approach for minimizing customer time in the system and reducing inventory backlog. In contrast, the 36-hour and 24-hour storage policies result in only minor improvements and may not be cost-effective. Table 6 summarizes the waiting times for various warehouse processes across different models (48, 36, 24, and 12 with cross-docking). The waiting time for sorting and inspection decreased by 3% in Model 36, 16% in Model 24, and 23% in Model 12. The waiting time for loading into the ASRS decreased by 24% in Model 36 and 26% in Model 24, while storage waiting time in large storage zones and shelves saw reductions of 25% in Model 36 and 26% in Model 24. In Model 12, all goods were stored in a single location on the floor. Customers waiting to submit documents experienced a slight reduction of 1% in Model 36, 2% in Model 24, and 14% in Model 12. Customers waiting for order pickup saw a significant reduction of 64% in Model 12, 23% in Model 36, and 26% in Model 24. Finally, the waiting time for warehouse exit processing decreased by 4% in Model 36, 14% in Model 24, and 35% in Model 12. These results emphasize that implementing a 12-hour storage policy with cross-docking is the most effective strategy for optimizing warehouse efficiency and reducing delays.

The comparison of workforce reduction while maintaining efficiency and achieving cost savings reveals changes in employee numbers under the current and resource reduction policies. The number of forklift operators decreased from six to five, a 17% reduction. ULD sheet sorting staff in the Breakdown zone were reduced from six to three, a 50% decrease. Similarly, rack position recording staff and data recording staff each decreased from two to one, representing a 50% reduction. F3 document staff were reduced from three to two, a 33% decrease. The most significant reductions occurred in roles related to data recording and document management, while positions involved in goods movement, such as forklift operators, experienced the least reduction. As summarized in Table 7, the total workforce decreased from 19 to 12 employees, resulting in an estimated annual labor cost savings of 1,260,000 THB while maintaining the same workload and operational efficiency.

Table 6: Comparison of the reduction in customers and goods waiting in queues under the current policy and the 12-hour policy

<table>
<tr><th rowspan="2">Average Number Of Items Waiting In Queue At The Process</th><th colspan="4">Policy</th><th colspan="3">The Reduction Rate between the Current Policy (48) and</th></tr>
<tr><th>48</th><th>36</th><th>24</th><th>12</th><th>36</th><th>24</th><th>12</th></tr>
<tr><td>Inspection and Sorting</td><td>3.6</td><td>3.5</td><td>3.1</td><td>2.8</td><td>-3%</td><td>-16%</td><td>-23%</td></tr>
<tr><td>loaded into ASRS</td><td>31.8</td><td>24</td><td>23.7</td><td rowspan="3">location on the floor</td><td>-24%</td><td>-26%</td><td rowspan="3">location on the floor.</td></tr>
<tr><td>Stored in the large storage zone</td><td>26.7</td><td>20.1</td><td>19.7</td><td>-25%</td><td>-26%</td></tr>
<tr><td>Placed on shelves</td><td>26.4</td><td>19.9</td><td>19.5</td><td>-25%</td><td>-26%</td></tr>
<tr><td>Submit documents</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>-1%</td><td>-2%</td><td>-14%</td></tr>
<tr><td>Receive orders</td><td>1.7</td><td>1.3</td><td>1.2</td><td>0.6</td><td>-23%</td><td>-26%</td><td>-64%</td></tr>
<tr><td>Exit notification</td><td>0.2</td><td>0.1</td><td>0.1</td><td>0.1</td><td>-4%</td><td>-14%</td><td>-35%</td></tr>
</table>

Table 7: Comparison of employee numbers under the current policy and the 12-hour policy

Employees	Current Policy	Reduced Resource Policy	Percentage Reduction
Forklift Operators (for picking goods from Shelf + ASRS + Big and unloading area)	6	5	-17%
Employees for separating ULD sheets in the breakdown zone	6	3	-50%
Employees for recording empty shelf locations	2	1	-50%
F3 Document Employees	3	2	-33%
Data Entry Employees	2	1	-50%

The research findings suggest that the current policy of offering free storage for a set duration may not always be the most effective approach for managing air cargo warehouses. Reducing the free storage time from 48 hours to 36 and 24 hours results in a 4% and 10% reduction in the time customers spend in the system, respectively, but does not lead to a decrease in the waiting time during the sorting process. As such, these changes may not be attractive options. Conversely, a cross-docking policy offering 12 hours of free storage seems to be a more efficient and suitable choice. However, such a significant reduction in the free storage period from 48 to 12 hours could present challenges, particularly concerning customer satisfaction and cost, though the overall service time would be reduced. Customers may perceive the abrupt shortening of the free storage period as too drastic, which could potentially harm the provider's reputation.

The free storage policy is currently under review by top management, who require supporting data to guide their decision-making. Our study indicates that the 12-hour policy is the most effective approach. Given the short-term nature of this policy, goods are placed directly on the floor instead of being stored on racks. It is assumed that adequate floor space is available to accommodate incoming goods. However, the proposed solution has not yet been implemented. If adopted, adjustments to the warehouse layout may be necessary. Ultimately, the final decision lies with top management, and any policy changes should be clearly communicated to customers in advance to ensure they are well informed and adequately prepared.

Impact of Storage Time Optimization on Warehouse Operations

This research demonstrates that reducing storage time from 48 hours to 12 hours enhances warehouse efficiency by accelerating the flow of goods, reducing congestion in storage areas, and improving overall transportation efficiency. Comparing these findings with previous research, Mok (2005) found that shortening the storage period from 24 hours to 12 hours led to a 35% reduction in product movements. However, a key distinction is that while Mok's study focused on minimizing the burden on automated storage systems, this research emphasizes optimizing storage, putaway, and picking processes to enhance overall warehouse operations.

The cross-docking strategy has been recognized as an effective approach to minimizing inventory costs by eliminating long-term storage and improving distribution efficiency (Gue, 2007). However, this study applies cross-docking principles to streamline handling processes and reduce processing time rather than implementing a full cross-docking system. While traditional cross-docking eliminates the need for shelving stock, this research adopts the concept to minimize unnecessary handling and enhance workflow efficiency. Optimizing free storage duration in air cargo warehouses reduces the total volume of stored goods, thereby decreasing space requirements and improving the efficiency of item retrieval. This enhancement is particularly advantageous for manual systems, as it streamlines operational workflows and increases overall efficiency. Furthermore, implementing this policy would necessitate the reallocation of floor space to accommodate goods awaiting customer pickup rather than storing them in the ASRS. Consequently, adjustments to warehouse layout and workforce scheduling would be required to support the accelerated pickup process resulting from reduced free storage time. Future research should investigate strategies for optimizing pallet arrangement to enhance product flow and maximize warehouse space utilization.

CONCLUSION

The research findings show that the 12-hour storage policy with a cross-docking strategy significantly improves warehouse efficiency, reducing customer time in the system by 25%, goods retention time by 76%, and waiting time in the sorting process by 23%. These improvements result from the elimination of separate storage locations, streamlined operations, and minimized bottlenecks. In contrast, the 36-hour and 24-hour policies lead to only minor efficiency gains. Additionally, labor demand, particularly in administrative roles, decreased, reducing the workforce from 19 to 12 employees and achieving an annual labor cost savings of 1,260,000 THB. However, shortening storage durations may present challenges in coordinating transportation and customs procedures, requiring accurate forecasting and real-time inventory tracking. Future studies could investigate 3D palletizing solutions to optimize storage space, reduce pallet usage, and minimize labor requirements for material handling. In conclusion, the 12-hour cross-docking policy is the most effective for reducing waiting times, inventory levels, and labor costs, although its implementation should consider system readiness and process flexibility. The findings from the simulation will be presented to relevant stakeholders as a foundation for future implementation in real-world operations.

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