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SAFETY STOCK ESTIMATION OF UNIT LOAD DEVICES FOR INTERNATIONAL AIRLINE OPERATIONS

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SAFETY STOCK ESTIMATION OF UNIT LOAD DEVICES FOR INTERNATIONAL AIRLINE OPERATIONS

Hua-An Lu[1] and Chien-Yi Chen[2]

Key words: bridge, corrosion, pier, reinforced concrete, service life prediction.

ABSTRACT

Unit load devices (ULDs) are used to load air cargo and passengers' checked baggage for wide-bodied aircraft operations. Since ULDs are reusable at the destination, airlines can invest in an appropriate fleet size for their requirements. The estimation of safety stock levels for every operating airport is a premeditated task because airlines must prepare enough devices for the outbound consignments of each flight. The variance of the number of used devices for each arrival and departure flight will influence the stock level of an airport. For scheduled international services, this study proposes an analytic method based on a cyclically time-sequenced network that can be used to express ULDs moving in and out of an airport. The safety stock level is defined as the minimum quantity that can support the utilization for the entire next cycle at the period end. The results of a case study on one company reveal that the airline normally establishes a high safety stock level.

I. INTRODUCTION

Unit load devices (ULDs) are the standard equipment for loading air cargo and checked baggage in wide-bodied aircraft operations. According to the definition of the International Air Transport Association (IATA), ULDs can be many items [6]. In practice, ULDs are commonly defined as devices that can be used to load freight, such as containers and pallets. The utilization of ULDs assists airlines in the standardization and unitization of loading and discharging handlings at airports. Airlines can select customized types of ULDs for matching the inner contours of the main and lower decks of various aircraft sizes. Since ULDs are also accommodated with a variety of aircraft, airlines normally seek the benefit of commonality to purchase as many similar types of ULDs as possible.

ULDs can be reused after emptying freight at the destination. When import shipments are typically greater than the export quantities, empty ULDs will accumulate at the airport. On the contrary, an airport with greater export shipments than inbound freight will lack loading equipment. The airline must appropriately reposition ULDs between airports in order to balance the difference of supply and demand and keep a sufficient and economical fleet size. Therefore, it is important for an airline to properly estimate the safety stock level for each operating airport in order to cope with its ULD repositioning operation.

The safety stock level is a crucial element in inventory theory. Two alternative methods of determining the safety stock level are used [8, 20]. The first technique is the analytic method, which is always based on a computation of the variance of demand. The second method develops a simulation processes. Zizka [21] used these two approaches to determine safety stock levels and compared their quantified difference. Tan and Tang [15] examined the demand variable as a Gauss fuzzy variable to estimate safety stock levels for a case without historical demand data. Considering international air transport services, ULDs are normally moved with a fixed flight schedule and without consideration of a better lead time for arbitrary supplements.

Marine container transport is another industry that follows the same decision process regarding equipment safety stock levels. The issue of safety stock levels in ports normally appears in the discussion of empty container repositioning [3, 9]. Since containers delivered through the marine system are connected with their origins and destinations by truck or rail systems, their buildup and breakdown operations are mainly completed at depots or customers' factories. This procedure leads to uncertainties of timing and the quantities of empty containers reused [2, 4, 11, 14]. International air cargo services normally execute buildup and breakdown operations at the air cargo terminal.

In the airline business, several studies have dealt with various topics relative to air cargo operation and management. Cargo load planning is always viewed as a bin-packing prob-

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lem with either two dimensions [5] or three dimensions [1]. Mongeau and Bes [13] formulated an optimization model for container loads for a specific aircraft type, which considered the weight and balance problems caused by the placement of ULDs and the capacity constraints of the aircraft. Kasilingam [7] explored the difference between cargo revenue management (CRM) and passenger yield management (PYM). The complexity of CRM results from the uncertainty of available weights and volumes of carried freight that must be considered when balancing the estimated amount of passenger baggage and cargo. Yan *et al*. [18] and Yan *et al*. [19] examined the hub-and-spoke system of FedEx in the Asian transport network to formulate models for cargo loading under given demands and stochastic demands, respectively. Wu [17] presented a decision-making framework for air cargo forwarders to rent air containers from carriers.

A number of studies have also discussed ULD handlings inside airport terminals. Verwijmeren and Tilanus [16] explored resource programming and task scheduling for ULD buildup and breakdown operations. McAree *et al*. [12] explored the optimal design for a sort facility in a large hub terminal to deal with inbound and outbound palletized loads, linking together the breakdown and re-buildup operations of ULDs in a hub. Lau and Zhao [10] developed an event framework approach for the joint scheduling of different types of cooperating material handling equipment for an automated air cargo handling system.

The required quantities of ULDs prepared at each airport will influence the ULD relocation in short-term operation as well as the ULD fleet scale in long-term planning. Thus, the estimation of safety stock levels for each operational airport is vital for airlines. This study aims to design an analytic tool for international airlines to estimate the safety stock level of ULDs. From a long-term perspective, the scheduled airline services are cyclical with a fixed period, which is normally a week. The definition of a safety stock level in this research is the minimum ULD quantities that can support the utilizetion for the next whole cycle. This study proposes a time-sequenced network to express ULD moves at an airport. Based on the flow conservation principle, the analysis method can assess an appropriate safety stock level. A case study courtesy of a Taiwanese international airline was conducted for real-world application.

II. DETERMINANTS FOR ULD SAFETY STOCK LEVELS

The preparation of ULDs is predominantly concerned with the operational parameters and the flight pattern of an airport. The parameters reveal the efficiency of airport ground handling for cargo, baggage and ULD operations. The flight patterns influence the number of ULDs and the timing of moving ULDs in and out of the airport.

1. Ground Handling of ULDs

There are three main stages for ULD handling at the airport. The first stage is the ramp operation that includes discharging inbound ULDs from the aircraft, loading outbound ULDs onto the aircraft, and the transportation of ULDs between the aircraft side and the staging area. The second stage is the buildup and breakdown process at the baggage sorting/distributing area and in the cargo terminal. The final stage is the serviceability inspection of the ULDs.

1) Ramp and Terminal Operations

Ramp operations consist of many activities to serve the aircraft on the ground. ULD loading and discharging at the aircraft is one of these activities. The transportation of ULDs from the baggage sorting area and the cargo terminal to the aircraft follows the completion of buildup operations. Outbound ULDs, with the exception of last-minute changes, are normally ready beside the aircraft's location for rush transit and turnaround flights. Inbound ULDs can also be transported to the distribution area and to the terminal for baggage claim and cargo breakdown, respectively. Relatively, the operational performance of this sector is not as critical as the ULD handling in the terminal. Normally, the required working time for this sector is embedded in the entire ground service time of the aircraft.

For international operations, airport cargo terminals are designed to facilitate the conversion handlings between bulk freight and unitized loads. Air freight that accesses the terminal always accommodates the schedule of assigned departure or arrival flights. Shippers require the reservation of a buffer time for delivering outbound consignments to the terminal, in order to accommodate a series of procedures for customs declaration and inspection for international trade. Since export shipments might be eventually sent to the cargo terminal, the buildup tasks normally begin from a specific time prior to the flight departure. ULDs that are to be used for the departure flights must be ready before starting buildup.

For imports, the breakdown performance concerns the availability of reusing ULDs. The higher the quantities of ULDs for a flight, the longer the finish time for the breakdown tasks of the whole flight. Much more time is normally required to breakdown a pallet than a container with the same number of pieces in a shipment. Therefore, a passenger flight needs less time to empty the ULDs than the same aircraft type used for combination (combi) and freight flights, because it carries more containers but less pallets.

2) Serviceability Inspection for ULDs

For ensuring flight safety, on-time operations, and the prevention of damage to the loads, ULDs must be kept in a serviceable status. Airlines define the serviceability of ULDs according to the specifications of National Aerospace Standard (NAS) 3610 issued by the Aerospace Industries Association (AIA) [6]. Based on the ULD maintenance practices of the airlines, the serviceable conditions for containers and pallets are different. The former are more complicated than the latter because of their different structures, but containers are easier to inspect than pallets. Serviceable conditions for a container include the base, body, door, and the technical standard order (TSO). Damage to containers is normally identified by visualization. A serviceable pallet can only be checked at the base; its detoured level must be inspected and calibrated by a specialized machine. The time expenditure for inspecting one pallet is longer than for checking one container; however, repairing damaged containers can require much more time than the calibration of a pallet.

The ULD must be inspected for serviceability after emptying its load to ensure it is serviceable for reuse. However, international airlines cannot afford to set up inspection bases at all operating airports. The company studied in this paper only built a serviceable inspection center at the home airport because all aircraft depart and return there for the next duty assignment. When aircraft arrive, all return ULDs are staged to execute a batch inspection after breaking down. Thus, it can be ensured that all sent-out ULDs from the home airport are serviceable. Any ULD that is questionable or has known damage incurred from overseas stations must be sent back to the home airport. Intuitively, the time spent for ULD inspection and calibration will affect the timing of reuse.

2. Flight Pattern

The flight pattern of an airport can be represented by the arrangement of timing and sequences for departure and arrival flights, as well as the deployed aircraft type of each flight. The number of flights within a specific time window represents the intensity during this period. The intersection of arrival and departure flights stands for the complexity of an airport schedule. Sometimes, the airport schedule also reveals its role to the airline. The intensity and complexity of an airport schedule combined with ULD handling performance will affect its ULD stock level.

1) Intensity and Complexity of Flights

For an airline operating international services, its route structure normally forms a radial flight network. The home airport is the center of this network, while overseas stations are the spoke airports, which are linked with the hub by various routes. Each route consists of two flights departing from the home airport to a turnaround airport and then turning back from the opposite direction to the home airport. Each flight may be arranged to transit to additional airports in order to gather more passengers and freights. Turnaround airports require longer ground time to replenish the provision of the whole aircraft service. Transit airports are always arranged with shorter ground time for handling fewer passengers and freight than the entire aircraft's capacity.

The intensity of the home airport's schedule is naturally higher than that of other airports because it is the origin and also the end of all routes. The airline's schedule must consider many criteria, which include the preferences of passengers and shippers for flight departures and arrivals. The home airport's schedule always has peaks during certain time windows. Its complexity is also higher than that of other airports and depends on the intersection of long-haul and short-haul routes.

2) Aircraft Types

The aircraft type used for each flight represents the possible maximum amounts for ULD supply and demand with a specific timing. Different type scales are used for different aircraft sizes as well as different service categories. Larger wide-bodied aircraft normally carry more ULDs than medium and standard types. Passenger aircraft carry more containers than the same type of combi aircraft or freighter, but carry fewer pallets.

III. METHODOLOGY

The flight schedule for international airline services always recurs weekly. This paper assumes that the schedule for each week during the entire planning period maintains the same flight pattern. ULD movement is limited to around the airport area without the possibility of moving outside the airport. Shippers or consignees must deliver or pick up cargo to or from the airport. Moreover, the airline can acquire the distribution of the inbound and outbound quantities of ULD types for each flight from the historical data. A time-sequenced network is applied to express the ULD flows within the cyclic duration. It can be used to assess the safety stock level for each ULD type at each airport, including overseas airports and the ULD repositioning centers.

1. Time-sequenced Network

A time-sequenced network is defined as a network in which nodes are embedded with the element of the event time of occurrence and with arcs that are linked at two consecutive nodes by their time relationships. Since the movement of ULDs accompanies flight departures or arrivals, the flight schedule at the airport is the basis for constructing a time-sequenced network for ULD movement.

The loaded ULDs must be emptied before being reused, when the aircraft arrives at an airport. This breakdown period includes the unloading and transportation processes on the ramp, as well as the emptying and serviceability inspection in the warehouse. The ULD standby time before being loaded onto an aircraft requires taking into account the processes of cargo and baggage buildup, ramp transportation and loading operations beside the aircraft. Therefore, the time at which the ULDs are ready for reuse is later than the aircraft arrival time, while the stand-by time of ULDs for use is earlier than the aircraft departure time. This concept is described by the time-sequenced network illustrated in the upper part of Fig. 1. The number of p ULDs brought by the arrival flight can be reused at the time of node 3, while the required quantities of q ULDs for the departure flight must be prepared at the time of node 2. These relationships for ULD movement can then be directly simplified as depicted in the lower part of Fig. 1. The

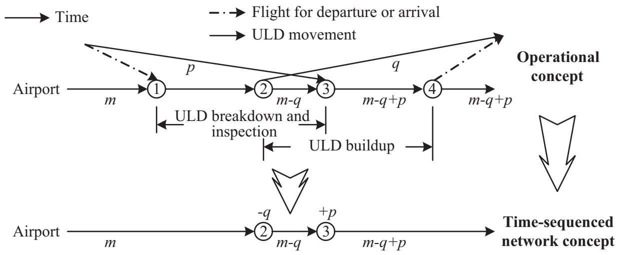


Fig. 1. Network concept transferred from flight schedule into ULD operation.

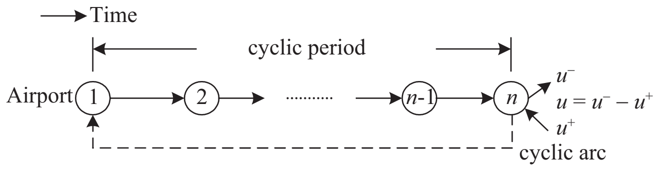


Fig. 2. Expression of a time-sequenced network for the movement of available ULDs.

move-in and move-out of the ULDs are considered supply and demand quantities of the nodes and are represented as positive and negative values, respectively. The arcs are then linked one-by-one for every two neighboring nodes. The arc flows can trace the ULD stock at the airport.

The airports that play the role of ULD reposition centers are required to consider the possibility of ULD maintenance. In a time-sequenced network, these cases can create another node according to the required time of completing ULD maintenance in addition to breakdown. The ULD supply quantities can be shared from the node representing the breakdown of the same flight by the estimated maintenance ratio.

According to the transferring method, the flight schedule of an airport can be constructed into a time-sequenced network for ULD movement. If the occurring times of two nodes are the same, the demand node will be set earlier than the supply node. Moreover, the scheduled airlines always operate a cyclically-fixed weekly timetable. The network can employ a week as the cyclic period and append a cyclic arc to link the last node to the first node to express this characteristic. Fig. 2 shows a time-sequenced network with n nodes for the movement of available ULDs at the airport. This cyclic network is set with two extra slack arcs, flow-in arc for flow increments and flow-out arc for flow decreases (marked as u^+ and u^- respectively), at the last node in order to calculate the imbalance flows within the cyclic period. An unrestricted sign variable, u, is further defined as the difference of u^- and u^+, i.e. $u = u^- - u^+$.

2. Properties of a Time-sequenced Network

In the network flow model, the flow conservation is held for every node. Every node in the time-sequenced network shown in Fig. 2 has only one flow-out arc and one flow-in arc, with the exception of the last node. The flow conservation relationships can therefore be expressed as Eqs. (1) to (3), where x_{ij} is the flow of arc (i, j), with u^+ and u^- standing for the flows of the slack arcs at the last node and b_i representing the supply or demand quantities of node i (positive for supply and negative for demand).

$$x_{ij} - x_{ji} = b_i, \forall i \neq \textit{the last node} \tag{1}$$

$$x_{ij} + u^- - u^+ - x_{ji} = b_i, \textit{ if } i = \textit{the last node} \tag{2}$$

$$x_{ij} \geq 0\ \forall(i,\ j),\ u^+,\ u^- \geq 0 \tag{3}$$

Property 1: The least arc flow of x_{ij} must be 0.

Proof: The time-sequenced network is cyclic if slack arcs are neglected. No matter what the values of b_i are, a certain number of arc flows of x_{ij} can be deducted at the same time until the least arc flow equals 0. If the non-negative restriction is temporarily violated for x_{ij}, a certain number can also be added at the same time until the least arc flow equals 0, which then satisfies the non-negative restriction. □

If there are n nodes in a time-sequenced network, variable u is equal to the sum of the supply and demand quantities of all nodes.

Property 2: $u = u^- - u^+ = \sum_{i=1}^{n} b_i$

Proof: According to Eqs. (1) and (2),

$$x_{12} - x_{n,1} = b_1,$$
$$x_{23} - x_{12} = b_2,$$
$$\cdots$$
$$x_{n-1,n-2} - x_{n,n-1} = b_{n-1}, \text{ and}$$
$$x_{n,1} + u^- - u^+ - x_{n-1,n} = b_n.$$

Taking the summation for the left and right sides of the equal sign, all x_{ij} will be deleted. It can then be obtained that

$$u = u^- - u^+ = b_1 + b_2 + \ldots + b_{n-1} + b_n = \sum_{i=1}^{n} b_i. \qquad \square$$

Variable u represents the net supply and demand of the cycle period. When $u \geq 0$, the supply quantities are larger than the demand quantities during a cyclic period, and the airline can move out u ULDs from the airport. Inversely, it means that the demand quantities are larger than the supply quantities when $u < 0$, and the airline should move $|u|$ ULDs to the airport. Supposing the planner does not take any repositioning steps, then the ULD stock (T) at the phase between two consecutive cycles are the sum of $x_{n,1}$ and u, as shown in Eq. (4).

Table 1. Example for $u \geq 0$.

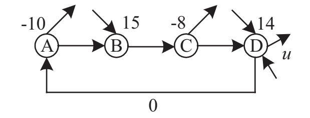
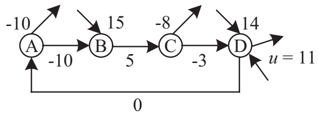
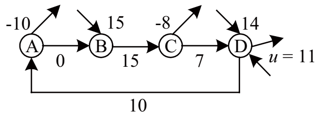
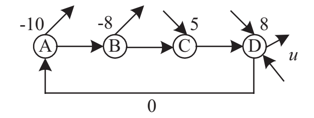
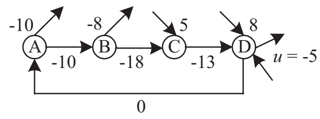
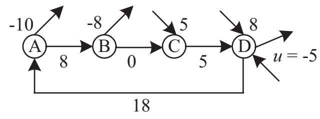
Network Flows	Calculation Steps
	Step 1: Let $x_{DA} = 0$
	Step 2: Calculate the flows of x_{AB}, x_{BC}, x_{CD} and u
	Step 3: $\delta = \|-10\| = 10$ Step 4: Add 10 to x_{AB}, x_{BC}, x_{CD}, and x_{DA}

Table 2. Example for $u < 0$.

Network Flows	Calculation Steps
	Step 1: Let $x_{DA} = 0$
	Step 2: Calculate x_{AB}, x_{BC} , x_{CD} and u
	Step 3: $\delta = \|-18\| = 18$ Step 4: Add 18 to x_{AB}, x_{BC}, x_{CD}, and x_{DA}

$$T = x_{n,1} + u = x_{n,1} + \sum_{i=1}^{n} b_i \tag{4}$$

Given b_i, the arc flows in the time-sequenced network for the movement of available ULDs can be calculated by the following steps.

Step 1: Let $x_{n,1} = 0$.
Step 2: Calculate flows according to Eqs. (1) and (2).
Step 3: Check the arc flows. If any arc flow is less than 0, let δ equal the absolute value of the least flow and go to step 4.
Step 4: Add δ for all $x_{i,j}$.

An example for $u \geq 0$ is illustrated in Table 1. There are four flights for ULD movement at a certain airport. According to the flow calculation steps, $u = 11$, $x_{DA} = 10$. As a description in Property 1, the critical arc with flow equaling 0 is x_{AB}. The value of u equals the sum of the supply or demand quantities of all nodes, satisfying Property 2. The ULD stock at the end of the cyclic period is equal to the sum of u and x_{DA}, $T = 11 + 10 = 21$.

The example for $u < 0$ is illustrated in Table 2. It is same as the last example, with four flights for ULD movement, but with a different flight pattern. According to the same steps, $u = -5$, $x_{DA} = 18$. The ULD stock at the end of the cyclic period is equal to the sum of u and x_{DA}, $T = 18 – 5 = 13$.

3. Estimation Approach

After introducing the network structure and its characteristics, the stochastic case can be discussed for covering the variances resulting from the node supply and demand quantities. Assume that the demand or supply quantities of the ULDs for nodes are random variables, referred to B_i. Although they may have the same flight number, they are independent to each other, because they occur at different times during a cycle. For a long-term observation, they should have their own distributions without any influence on each other. The random variable of the slack variable is defined as U. According to the linear combination of random variables and Eq. (4), the expectation value of U, E(U) or μ, is the sum of the expectation values of B_i as shown in Eq. (5). The variance of U, $Var(U)$, is the sum of the variances of B_i as shown in Eq. (6). Hence, ULD stock at the final stage can be expressed as Eq. (7).

$$\mathrm{E}(U) = \sum_{i=1}^{n} \mathrm{E}(B_i) \tag{5}$$

$$Var(U) = \sum_{i=1}^{n} Var(B_i) \tag{6}$$

$$T = x_{n,1} + \mathrm{E}(U) = x_{n,1} + \sum_{i=1}^{n} \mathrm{E}(B_i) \tag{7}$$

This paper suggests that the planner can take a conservative strategy when estimating the safety stock of ULDs (*ST*), meaning more ULDs should be kept at the airport to be ready for any situation. The standard deviation of U, σ_U, can be applied. According to Chebyshev's Inequality, the probability of a random variable falling into the range between plus and minus k times the standard deviation is not less than $1 – 1/k^2$ for any distribution. This is shown in Eq. (8). At $k = 2$, the probability increases to 75%, while the probability increases to 88.9% at $k = 3$. When the random variable follows the normal distribution, the probability is 68% at $k = 1$, 95.5% at $k = 2$ and 99.7% at $k = 3$. Regarding a single-tail value, the probability will not be less than $1 – 1/2k^2$ to cover the variance of this random variable.

$$\Pr(\mu - k\sigma \leq x \leq \mu + k\sigma) \geq 1 - 1/k^2 \tag{8}$$

Hence, the reposition-out quantities can be set as the expectation value of U minus k times of σ_U, when $\mathrm{E}(U) \geq 0$. The reposition-in quantities can be set as the absolute value of the expectation value of U plus k times of σ_U at $\mathrm{E}(U) < 0$. Com-

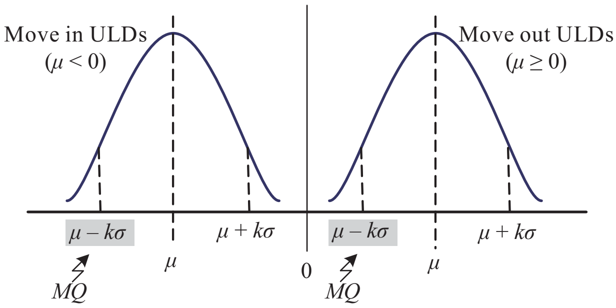


Fig. 3. Move quantities of ULDs set at different E(*U*).

bining these two concepts, the movement quantities of ULDs (*MQ*) can be expressed in Eq. (9). The setting principle is displayed in Fig. 3. The safety stock equals the ULD stock minus *MQ*, as shown in Eq. (10). Because the standard deviation of *U* could be real, the maximal integer value larger than *ST*, *i.e.* $\lceil ST \rceil$, can represent the integral number of ULD safety stock.

$$MQ = \mathrm{E}(U) - k\sigma_U \tag{9}$$

$$ST = T - MQ = x_{n,1} + \mathrm{E}(U) - (\mathrm{E}(U) - k\sigma_U) = x_{n,1} + k\sigma_U \tag{10}$$

From the ULD flow analysis, the planner can consider a standard deviation range to calculate the safety stock level using Eq. (10). This level can ensure a certain probability to cover the ULD requirements, no matter what distribution the supply or demand variables follow. According to Property 1, there must be a critical arc with the least positive flow, which is called $\overline{x}_{ij}$ in the time-sequenced network. The planner can use Eq. (11) as the safety stock level for short-term application (*STc*). The maximal integer larger or equal to it, *i.e.* $\lceil STc \rceil$, can be set as the minimal quantity of ULD stock at the airport.

$$STc = \overline{x}_{ij} + k\sigma_U \tag{11}$$

IV. CASE ANALYSIS

This section applies the submitted method to estimate the safety stock level for the studied company (an international airline in Taiwan). This company owns three main types of ULDs (AKE, PMC and PAG), in addition to others for loading special freight. AKE is a standard container for loading baggage and small consignments. PMC and PAG are pallets mainly used for loading freight. The following analysis is based on the winter schedule for 2008 and only focuses on these three types of ULDs. Estimated results will be compared with the controlled stock at the end of March 2009.

1. Background of the Test Cases

Before executing the numerical estimation, the flight schedule and data relative to the ULD handling, the aircraft, and the demand assumptions were collected courtesy of the company.

Table 3. Times required for handling ULDs.

Unit: hour

Service Category	Arrival		Departure	
	Container	Pallet	Container	Pallet
Passenger	6	6	6	6
Combi	10	10	6	6
Freighter	12	12	6	6
Repair	72	24	–	–

Table 4. Planning capacities of loading ULDs for each type of aircraft.

Aircraft type		Type of ULD		
		AKE	PMC	PAG
B747-400	Passenger	18	3	2
B747-400	Combi	14	8	4
B777-300ER	Passenger	20	6	2
A330-200	Passenger	14	3	2
A320	Passenger	7	0	0
B747-400	Freighter	12	24	12
MD-11	Freighter	11	20	12

Time parameters for the ULD handling of arrival flights vary with different service categories and aircraft types. This test only considered the service categories because all arrival ULDs are always staged in the terminal and treated by batch. According to the suggestion of the studied company, the total required time for containers and pallets to be ready for reuse is set as six hours for arriving passenger flights. The discharge of ULDs from combi aircraft requires 10 hours to empty and inspect and requires 12 hours for cargo freighters. In the reposition center, the average required time for repairing damaged ULDs is 72 hours for containers and 24 hours for pallets. The average number of damaged ULDs is less than one ULD per flight in practice. The test value was set as one unit per flight for each ULD type.

As for the departure flight, all freight starts to build up in the terminal six hours prior to flight departure, regardless of the aircraft type or service category. Therefore, the required time for a ULD to be ready to build up is consistent. All handling performance is listed in Table 3.

The aircraft fleet of the studied company consists of the following types: B747-400, B777-300ER, B767-300, MD-90, A330-200 and A320 for passenger service, B747-400 combi, and B767-300, B747-400 and MD-11 freighters. The planning capacities of loading ULDs for each type of aircraft are displayed in Table 4, which excludes the B767-300 and MD-90 types. Since B767-300 passenger and cargo airplanes are used on alliance services with All Nippon Airways, the studied company did not count the utilization in these routes. In addition, The MD-90 is a narrow-bodied aircraft that does not use ULDs to load cargo and baggage.

The studied company operates from a total of 43 airports

Table 5. Estimated average utilization ratios of ULDs for various routes.

Route	Asia roundtrip	Asia to Europe	Asia to N.A.	Europe to Asia	N.A. to Asia
Passenger	0.8	0.8	0.8	0.8	0.8
Cargo	0.8	0.8	0.8	0.6	0.5

throughout Asia, Europe and North America. The variance of ULD utilization is small in round-trip passenger flights due to passengers generally traveling two ways. In contrast, ULD demand quantities are quite different in round-trip cargo flights, since there is an imbalance of the trade traffic. In considering the operating properties of the studied company and the general concept of world trade, the load factors of used ULDs in various routes were set as the list in Table 5 for passenger and cargo flights. Flights departing from Asia have a higher utilization ratio than those departing from Europe and North America to Asia.

The Mean of populations for every ULD type of each flight can be calculated from Tables 4 and 5. For conducting the numerical test, 100 values were randomly generated for every ULD type of each flight so that all would follow the standard normal distribution with Z (0, 0.33). Each case randomly selected 52 samples out of 100 existing values to be the demand quantities in a year. This assumption for the demand quantities to follow the normal distribution ensured that the estimation could cover 84% of the variances with the standard deviation (k = 1) and 98.725% of the variances with two times the standard deviation (k = 2), respectively.

2. Estimated Results and Comparisons

1) Asian Airports

Taipei (Taoyuan airport) is the home airport of the studied company and also its unique ULD repositioning center. All routes consist of flights radially spreading from this airport and then back. The Taipei stock is not limited in the controlled rules of this company because all extra ULDs from overseas airports will be sent back to this location. In the estimation by this paper, Taipei must prepare the largest quantities of ULDs for 625 flights per week. The stock at Kaohsiung, Macau, Phnom Penh, Hanoi, Nagoya, Miyazaki and Komatsu would be zero, as their flights were served by narrow-bodied aircraft (MD-90) without using ULDs in the selected schedule. Hong Kong had larger stores of ULDs, to meet the possible requirements of progress between mainland China and Taiwan in the spring of 2009.

At k = 1, stock levels of other Southeast Asian and Australian airports were all revealed to be less than the levels of the studied company. Some airports' safety stock for various types of ULDs were estimated higher than the levels of the studied company, at k = 2, such as PAG pallets and AKE containers at Singapore, in addition to PAG pallets at Bangkok, Jakarta and Brisbane.

Among Northeast Asian airports, the estimation was higher than the company's level, other than those for PMC pallet stock at Osaka, Narita and Seoul, AKE containers and PMC pallet stock at Fukuoka, and all types at Nagoya. Estimated AKE container stock levels at Seoul were also less than the practical quantities, at k = 1. The detailed estimation and comparison with the studied company for Asian and Australian airports is listed in Table 6.

2) European and American Routes

Flights between Asia and Europe or between Asia and North America require a transit station for the deployed aircraft. The studied company selects airports in the Middle East as the transshipment stations for Asia/Europe routes, while Anchorage is the landing airport for refueling for Asia/North America routes. Table 7 lists a detailed estimation and comparison with the studied company for airports served by these two routes.

Brussels is the cargo center of the studied company in Europe. PMC pallet stock levels at this airport are obviously higher than at other European airports. However, the gap between practice and the estimation in this study, which only takes the number of flights per week into account, is quite large. Among other European airports, most ULD stock levels were estimated to be lower, except for the AKE quantities at Vienna and Amsterdam. PAG pallet stock levels at Vienna were closer than the practice. At Middle Eastern airports, the estimation for all ULD types was higher than the practice no matter if k = 1 or 2, except for PMC pallet stock levels of k = 1 at Delhi.

Among North American airports, the estimation was almost always less than that for the studied company. Exceptions only occurred at Seattle, Newark and Dallas for AKE container stock levels. A portion of the practical quantities slightly fell into the estimation for k = 1 and 2, such as AKE container stock levels at San Francisco, Vancouver and Atlanta, and pallet stock levels at Seattle. Anchorage had null stocks because of its technical role for landing.

3) Stocks at the ULD Positioning Center

This section takes the stock status of the ULD positioning center, i.e., Taipei airport, at k = 1 as the example to explain the preparation of safety stock. Fig. 4 displays the case of AKE container levels when the airline complements ULDs at the end of a week for the utilization of the next week. The airline needs to retain a total of 546 AKE containers at the end of a week. With 255 containers left from the previous week, the extra number to be prepared is 291. This means that the airline must hold an additional 291 containers, no matter whether repositioning from other stations or purchasing new ones, in order to cover the possible variances of demand and operational requirements. If so, the smallest stock level is 99 containers for a week, which is also the standard deviation of the supply and demand variance for AKE containers. The greatest stock level is 693 containers for a week.

Table 6. Safety stock levels for Asian and Australian airports.

Area	Airport/City	Flights/week		AKE			PMC			PAG		
		Pax.[a]	Cargo	Studied Co.	This study (k = 1)	This study (k = 2)	Studied Co.	This study (k = 1)	This study (k = 2)	Studied Co.	This study (k = 1)	This study (k = 2)
Southeast Asia & Australia	Taipei	518	107	N.A.	546	644	N.A.	435	488	N.A.	97	132
	Kaohsiung	34	0	0	0	0	0	0	0	0	0	0
	Hong Kong	98	20	230	109	153	280	49	76	280	27	42
	Singapore	10	14	70	21	42	80	29	49	25	17	27
	Bangkok	69	12	80	67	107	80	30	52	40	32	43
	Jakarta	10	2	50	38	51	30	11	18	10	7	12
	Macau	84	0	100	0	0	50	0	0	30	0	0
	Manila	14	0	40	15	30	35	4	8	20	4	8
	Phnom Penh	14	0	2	0	0	0	0	0	1	0	0
	Ho Chi Minh	30	0	45	40	64	50	28	39	30	16	23
	Surabaya	4	0	10	7	14	10	5	7	0	4	6
	Hanoi	10	0	5	0	0	15	0	0	8	0	0
	Kuala Lumpur	10	0	40	26	39	30	7	10	15	6	9
	Denpasar	14	0	7	14	22	0	0	0	0	0	0
	Penang	0	8	15	25	36	35	29	42	8	16	24
	Brisbane	8	0	20	11	21	10	3	6	3	3	6
Northeast Asia	Osaka	26	3	30	49	72	70	39	49	10	20	27
	Tokyo (Narita)	56	1	30	32	52	30	9	14	5	8	13
	Fukuoka	14	0	25	9	16	10	4	8	0	4	8
	Sendai	4	0	0	20	27	0	5	7	0	4	6
	Nagoya	10	0	16	0	0	15	0	0	5	0	0
	Sapporo	14	0	16	27	41	2	7	11	0	6	10
	Miyazaki	4	0	0	0	0	0	0	0	0	0	0
	Komatsu	4	0	0	0	0	0	0	0	0	0	0
	Seoul	14	0	30	27	41	30	7	11	0	6	10

[a] Pax. means passenger flight.

Table 7. Safety stock levels for airports in European and North American routes.

Area	Airport/City	Flights/week		AKE			PMC			PAG		
		Pax.[a]	Cargo	Studied Co.	This study (k = 1)	This study (k = 2)	Studied Co.	This study (k = 1)	This study (k = 2)	Studied Co.	This study (k = 1)	This study (k = 2)
Europe & Middle East	London	12	4	60	16	31	75	23	46	35	14	27
	Vienna	6	0	15	21	30	20	7	9	5	5	7
	Amsterdam	8	0	25	33	47	25	9	13	15	5	8
	Paris	0	2	30	8	15	30	10	19	25	4	8
	Brussels	0	8	45	19	28	120	13	26	30	6	11
	Frankfurt	0	2	15	8	15	80	10	19	20	5	9
	Dubai	0	12	10	22	34	15	26	41	8	14	22
	Delhi	0	10	15	17	27	30	24	38	8	10	17
North America	Los Angeles	34	14	110	76	109	80	38	55	45	21	31
	Seattle	8	4	30	43	60	20	19	28	15	10	16
	Anchorage	6	78	0	0	0	0	0	0	0	0	0
	San Francisco	20	0	45	39	61	30	11	18	15	6	10
	Vancouver	12	0	35	26	40	8	8	11	15	6	9
	Newark	6	0	25	26	38	15	5	9	10	4	6
	Chicago	0	12	40	13	25	45	24	36	15	12	19
	Atlanta	0	6	25	20	33	90	24	36	30	12	18
	Dallas	0	12	10	16	24	50	23	36	20	12	19
	New York	0	6	60	10	19	50	9	18	20	6	11

[a] Pax. means passenger flight.

Table 8. Total safety stocks of ULDs for various areas.

Area	ULD (hold number of the studied company)								
	AKE (3200)			PMC (4000)			PAG (1961)		
	Studied Co.	This study ($k = 1$)	This study ($k = 2$)	Studied Co.	This study ($k = 1$)	This study ($k = 2$)	Studied Co.	This study ($k = 1$)	This study ($k = 2$)
Asia (Taipei excluded)	861	537	828	862	266	407	490	180	274
Asia (Taipei included)	N.A.	1083	1472	N.A.	703	897	N.A.	313	442
Europe & Middle East	215	144	227	395	122	211	146	63	109
North America	380	269	409	388	161	247	185	89	139
Total (Taipei excluded)	1456	950	1464	1645	549	865	821	332	522
Total (Taipei included)	N.A.	1496	2108	N.A.	984	1353	N.A.	429	654

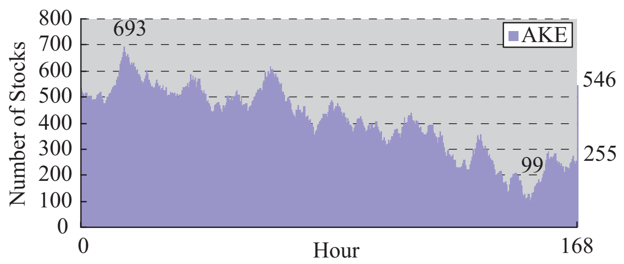


Fig. 4. Stock status of AKE containers in the positioning center estimated by k = 1.

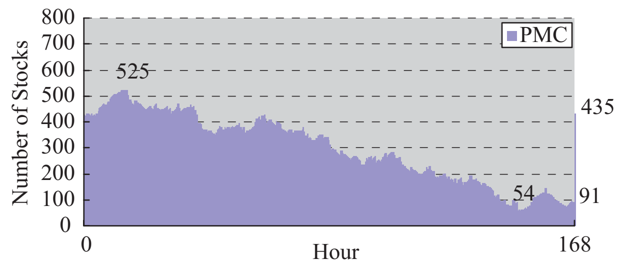


Fig. 5. Stock status of PMC pallets in the positioning center estimated by k = 1.

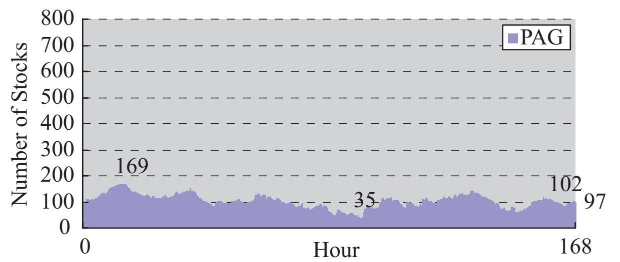


Fig. 6. Stock status of PAG pallets in the positioning center estimated by k = 1.

The case of PMC pallets, as shown in Fig. 5, is similar to that of AKE containers on the final flows at the end of one week. The airline must prepare a total of 435 PMC pallets for the circulation of the next week. Among these pallets, 91 are left from the last week and 344 extra pallets must be prepared. During the whole week, the lowest stock level is 54 pallets, while the highest is 525 pallets.

The case of PAG pallets, shown in Fig. 6, is opposite to the last two cases due to a contrary demand pattern. At the end of the week, the airline needs to prepare a total of 97 PAG pallets to use for the next week. The airline can move out five pallets, as there are 102 pallets left from the previous week. During the whole week, the lowest stock level is 35 pallets, while the highest is 169 pallets.

2. Discussion

From Tables 6 and 7, the safety stock level is higher for more flights as well as for flight intensity. The summary of safety stock levels for different areas is shown in Table 8. The subtotals for the whole of Asia for the three types of ULDs are all less than the levels of the studied company, no matter if k = 1 or 2, when Taipei stocks are excluded. The estimated AKE container stock levels in European and North American airports are higher, with several higher than the sum of the practice at k = 2. Other comparisons are similar to the Asian results. In all, the estimation of this study is less than the safety stock level of the studied company (excluding the stock at Taipei). Although the hold number of each ULD type might not represent the safety stock level of the whole company, it can be a precise target to compare with the estimation of this study. The company owns these three types of ULDs at roughly two times, four times and three and a half times the safety stock estimation for AKE containers, PMC, and PAG pallets, respectively.

V. CONCLUSIONS AND FUTURE RESEARCH

This study has discussed how to set the safety stock level of ULDs at an airport for an airline that provides international services. From a long-term perspective, the ULD safety stock level is defined as the minimum amount that can support utilization for the next whole planning period. Employing the cyclic characteristics of scheduled flights, this study has submitted an analytic method based on the application of a time-sequenced network for calculating ULD safety stock levels. As seen from the case study for the studied company, airlines normally prepare more stock to avoid the risk of lacking available ULDs, as the cost to purchase ULDs is insignificant relative to the entire airline's operating costs.

The key factor that influences the assessment result is finding the long-term distribution of ULD supply and demand for each arrival and departure flight. This study did not evaluate the actual distribution for the studied company due to the difficulty of data collection. However, it is easy to follow using the discussion of section 3.3 if airlines have prepared the available data. Airlines can then decide how many times the standard deviation should be used in order to cover the risks.

It should be noted that the safety stock level is dynamic. Airlines should survey transport requirements continuously when assessing the stock level of each airport. The estimations of this study can provide airlines with bottom lines for ULD stock levels at operating airports. These results can be used as fundamental requirements for exploring the problems of ULD fleet sizing and repositioning. In particular, airlines that operate hub-and-spoke service networks normally set their repositioning centers at the hub airport. How to best plan a ULD reposition among airports to satisfy the safety stock level is another valuable issue both in practice and in theory. The proposed method in this study can also be applied to liner carriers in estimating the container safety stock for operating ports. It must be kept in mind that the characteristics of container circulation for inland operations are more complex than for international airline services.

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