Proceedings of the 2008 Winter Simulation Conference
S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, J. W. Fowler eds.

SIMULATION OF UNIT LOADING DEVICE INVENTORY IN AIRLINE OPERATIONS

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ABSTRACT

Commercial airlines often encounter imbalances in their inventory of unit loading devices (ULDs). A stochastic simulation model was developed to evaluate inventory policies. The structure of the simulation model is described. We evaluate a minimum ULD loading configuration policy and demonstrate how it reduces ULD shortages and helps balance ULD network flow and inventory. As a result, airlines can reduce operating expenses and improve customer service. Finally, we give future directions for studying ULD inventory.

1 INTRODUCTION

At present, there are approximately one million united loading devices in commercial service, at an asset value of $1.3 billion, according to the International Air Transport Association, which formed and maintains a central control over the interline movement of cargo (Aircargoworld 2008). *Unit Load Devices*, or ULDs, are pallets and containers used to load passenger baggage, freight, and mail on wide-body aircraft. Because demands are asymmetric and uncertain, the flow of ULDs in an airline network is often imbalanced. Consequently, one major challenge that an airline operation faces with ULDs is that it is difficult to maintain a sufficient supply of available ULDs at each airport, or *station*. Such shortages may lead to delayed baggage, mail, and freight delivery and unsatisfied customers. The most common way to resolve such shortages is to fly empty containers on flights that have available capacity.

We used the WITNESS Simulation software to develop a discrete event simulation model of ULD movement in an airline network. The primary purpose of this model is to test empty ULD movement policies that attempt to balance inventory at each station.

The model considers multiple types of demand for which the airlines must deliver in ULDs. The demand includes ULDs used to transport passenger baggage, mail, and freight. In addition, some freight customers pack their freight within their own ULDs, instead ULDs belonging to the airlines. We refer to this type of demand as *self-packed freight*, and we refer to freight that is packed by the airline as *regular freight.* Moreover, four types of wide-body aircraft--Boeing-777, Boeing-767-300, Boeing-767-200, and Airbus-300--and two types of ULDs--LD3s and LD8s--are considered. One of the inputs to the model is an external part file. The part file is a set of daily flight *schedules*, defined by an origin station, a destination station, a random demand arrival time, an aircraft body type, a flight time, and a flight number. The two most important metrics used in the simulation to evaluate a policy are the amount of ULD shortage and the number of empty ULD movements.

Using the simulation model, we evaluate a *minimum flight loading configuration policy* in which each flight transports at least a certain number of ULDs, whether they are empty or filled with demand. Several minimum configuration levels are tested. The minimum configuration policy creates a constant flow of ULDs in the network that helps reduce the amount of imbalance. However, it also transports a lot of empty containers, which may cause unnecessary fuel burn.

Section 2 of this paper reviews some related literature. In section 3, we describe the model, which contains twenty nine modules. Indeed, each module represents four events--an arrival event, a packing event, a loading event, and an unpacking event--that occur in each station. Section 4 discusses computational experiments of several minimum configuration levels, and the effects of different levels of total ULD inventory. Section 5 discusses conclusions and gives directions for future research.

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2 LITERATURE REVIEW

Hafizogullari, Chinnusamy, and Tunasar (2002) discuss how simulation is used to evaluate an airline's minimum connect time criteria with respect to the design and operational policies at its hub airports. Yan, Lo and Shih (2006) modeled cargo container loading plans for international air express carriers that will lead to lower operating cost. Huang, Lee, and Xu (2006) used a simulation and a mathematical model of a workload balancing problem at air cargo terminals. The simulation results show improved operational efficiently that can efficiently balance the workload and reduce cargo service time. Rosenberger *et al.* (2002) used SimAir, a simulation to evaluate plans, such as crew schedules, as well as recovery policies in a random environment However, a model to determine ULD shortages and empty ULD movements and discuss ULD inventory policies for an airline operation has not been considered in academic literature.

3 THE MODEL

Our model includes twenty-nine modules in which each module consists of four events: an arrival event, a packing event, a loading event, and an unpacking event. The arrival event generates an amount of demand and ULDs that enter the station. These events are included in each airport module, so that we can easily expand the network. Figure 1 gives a schematic representation of the process in the model.

3.1 Arrival Event

The arrival event is driven from an external part file that includes a commercial airline schedule. We assume that demands arrive at a *generating demand station* eight hours (480 minutes) before a flight departs. For each random demand that arrives at the station, the arrival event generates a random amount of demand on a particular departing flight based upon a triangle distribution. After the amount of demand has been sampled, it is sent to a particular demand *delay buffer* based upon whether it is passenger baggage, mail, regular freight, or self-packed freight. These delay buffers store demand until each demand packing time begins, which then draws from the departing stations ULD inventory. Sections 3.1.1 to 3.1.4 describe these delays.

3.1.1 Passenger Baggage Delays

After the amount of passenger baggage is sampled, it is sent to a delay bag buffer for 450 minutes. Because the original demand was sampled 480 minutes before the flight, the model assumes that passenger baggage will be packed in ULDs in a packing event 30 minutes before the flight departs.

3.1.2 Mail Delay

We assume that mail will be sent to the packing station as soon as the amount of mail is sampled, so it does not need to wait in a mail delay buffer. Consequently, after the amount of mail is sampled, the mail goes directly to a packing event. Because mail does not wait in a delay buffer, the model assumes that mail draws a ULD from inventory 8 hours before the flight departure.

3.1.3 Self-Packed Freight Delay

The self-packed freight demand is sent to a delay self-packed freight buffer for 120 minutes before it can move to the next event. Since self-packed ULDs do not need to go through a packing event, self-packed ULDs only consume capacity in aircraft, but they do not take any ULDs from the station. As a result, these demands can move directly from the arrival event to a *waiting self-packed freight buffer* that waits for a loading event.

3.1.4 Regular Freight Delay

A random amount of freight is sampled, and it is sent to a delay freight buffer for 120 minutes. After a minimum delay time of 120 minutes, these demands will move to a packing event. In other words, the model assumes that regular freight draws from ULD inventory 6 hours before the flight departure.

3.2 Packing Event

Three types of demand have to be packed with ULDs before loading them onto an aircraft. After passenger baggage, mail, and regular freight spend the minimum time in their respective delay buffers, they arrive in a packing event. Different ULDs fit in different types of aircraft. As shown in Table 1, Boeing-777 and Airbus 300 fit only LD3 ULDs. On the other hand, Boeing 767-300 and Boeing 767-200 fit both LD3 and LD8 ULD types, but they prefer to transport LD8s, because they provide additional capacity within each unit.

Table 1: Aircraft capacity and ULDs compatibility

Aircraft type	ULD type	Capacity
Boeing-777	LD3	30 LD3s
Boeing-763	LD8 (preferred)	13 LD8s
Boeing-762	LD8 (preferred)	10 LD8s
Airbus 300	LD3	22 LD3s

For simplicity, the demand that have been generated from an arriving event is converted to the appropriate ULD unit. Specifically, if a plane type is either a Boeing-777 or an Airbus 300, two units of demand equals one LD3 container unit. If the plane type is either a Boeing-767-300 or a Boeing 767-200, three units of demand equal one LD8 container unit.

After all demand is packed within containers based upon the aircraft body type, they all move to a waiting buffer to get ready for the next loading event.

3.3 Loading Event

Each flight has limited capacity, so we have to assign a priority to ULDs that will be loaded to the aircraft. The process steps of loading ULDs are listed below starting from the highest priority.

- Passenger baggage containers
- Mail containers
- Self-packed freight containers
- Regular freight containers

Because demand distributions are read from a part file, it is easy to consider seasonal changes in demand due to passengers and cargo. Because passenger baggage containers have the highest loading priority, mail and freight ULDs are more likely to be displaced during high passenger travel times. In addition, to seasonal variability, weight restrictions may also displace ULDs. However, since ULD loading is usually more likely to be constrained by the amount of available space instead of weight, the density of ULDs usually has a higher impact on fuel burn and consequently operating cost than on ULD operations.

We also include empty containers after we load these containers as defined by the minimum configuration policy.

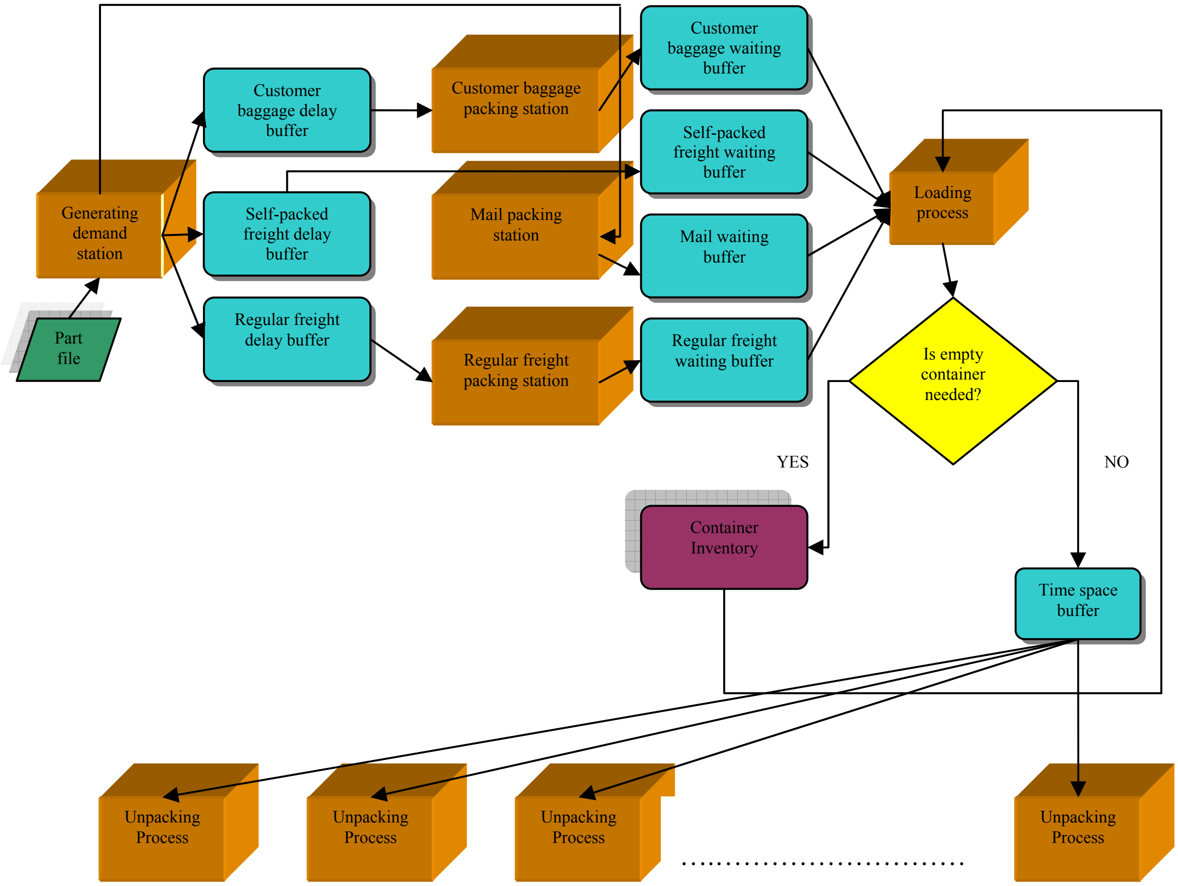

Figure 1: Schematic Representation of the Process Flow of the Model

3.3.1 Minimum Loading Configuration Policy

We consider sending empty containers on a flight if ULD demand is less than flight capacity. At a loading event, we determine the available capacity for LD3 and LD8 containers. Most of these aircraft fly international flights, so it usually requires at least 24 hours to send ULDs back on a flight. For example, suppose demand is 15 and flight capacity is 20; the policy might send as many as 5 empty containers on that flight. The available capacity to transport empty ULDs depends upon the aircraft capacity given in Table 1. The shortage of ULDs for a flight *j* is calculated by Equation (1)

$$L_j = \max\left\{D_j - \min\left(S, \max\left(P_j, D_j\right)\right)\ ,0\right\}, \quad (1)$$

where D_j is the total amount of demand of flight *j*; P_j is the minimum configuration level of flight *j*; and S is the current inventory at the departing station; If the demand D_j is less then the minimum configuration level, we may send some empty ULDs. The number of empty ULDs on a particular flight is given by Equation (2)

$$E_j = \left[P_j - D_j\right]^+. \quad (2)$$

As soon as all of the ULDs and self-packed freight are loaded onto the aircraft, they enter a time space buffer. The duration of the time that each aircraft spends in the time space buffer varies depending upon the flight time from the external part file schedule. Depending on the destination of each flight, all containers and self-packed freight on a particular aircraft will appear again at their destination at which an unpacking event occurs.

3.4 Unpacking Event

After each aircraft spends its flight time in a time space buffer, all ULDs enter an unpacking event. All demand will be unpacked from either LD3s or LD8s. Demand on that aircraft, including passenger baggage containers, mail containers, self-packed containers, and regular freight containers are sent to shipped, and LD3s and LD8s are sent to the inventory of the destination station.

4 COMPUTATIONAL EXPERIMENTS

We simulated 10,000 days of airline operations based upon a 232-daily flights schedule from a major US international carrier. The primary purpose of the experiments is to evaluate different minimum configuration levels with our model, and Table 2 displays the simulation results. The column labeled "%confi load" is the percentage of capacity that must be filled with ULDs on each flight. The columns labeled "Avg. short/empty LD3s/LD8s" show the average ULD shortage and empty ULDs transported per day per station. The results of Table 2 show that 100% compared with 25% ULD loading configuration significantly reduces the average shortage of LD3s and LD8s by 7.71 and 0.32 per day per station, respectively.

Table 2: The Results of Different Levels of ULDs Loading Configuration

%Confi Load	Avg. Short LD3s	Avg. Short LD8s	Avg. Empty LD3s	Avg. Empty LD8s
25%	7.71	0.32	0.03	0.00
50%	6.55	0.30	3.24	4.81
75%	0.02	0.00	23.45	10.18
100%	**0.00**	**0.00**	**49.93**	**19.99**

Moreover, we used our model to determine the effect of multiple levels of total inventory. Table 3 displays the results of multiple levels of total inventory with a 100%-loading configuration. The column labeled "Initial Inventory" is the percentage of initial inventory at each station. Table 3 shows that if we have enough ULDs at each station in initial inventory, there is no shortage of LD3s and LD8s. However, if we decrease the percentage of initial inventory, the average shortage of LD3s and LD8s will consistently increase.

Table 3: The Results of Multiple Levels of Initial Inventory with a 100%-Loading Configuration Level

Initial Inventory	Avg. Short LD3s	Avg. Short LD8s	Avg. Empty LD3s	Avg. Empty LD8s
Base	**0.00**	**0.00**	**49.93**	**19.99**
75%	3.28	0.51	45.57	18.61
50%	5.34	0.91	7.80	5.71
25%	18.10	2.63	7.55	5.12

Table 4 displays the results of multiple levels of initial inventory with only a 50%-minimum loading configuration. Table 4 shows that even though we have 100% base initial inventory, the average shortage of LD3s and LD8s are 6.55 and 0.30 per day per station, respectively.

Table 4: The Results of Multiple Levels of Initial Inventory with a 50%-Loading Configuration Level

Initial Inventory	Avg. Short LD3s	Avg. Short LD8s	Avg. Empty LD3s	Avg. Empty LD8s
Base	6.55	0.30	3.24	4.81
75%	7.64	0.32	2.92	1.36
50%	9.01	0.54	2.84	1.33
25%	23.52	1.25	1.21	0.86

The results of Table 3 and Table 4 show that reducing the minimum configuration by 50% significantly increases the shortage of LD3s and LD8s, even with the same total inventory. Therefore, we conclude that filling planes with empty ULDs is the best configuration to reduce the imbalances of ULDs in an airline network.

5 CONCLUSION AND FUTURE RESEARCH

One method to reduce the shortage ULDs in an airline network is to apply a minimum ULD loading configuration policy. Consequently by employing such policies, airlines can reduce operating expenses as well as improve customer service. For future research, we could test other inventory policies with our model and compare them with the minimum loading configuration policy to see which policies gives the least shortage of ULDs with minimum operating cost. Moreover, we could do research on more sophisticated models with disruptions like flight cancellation, airport congestion, or unscheduled repairs for ULDs.

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