Optimizing Air Cargo Handling at an International Airline Hub for AbOvo

MSc Data Analytics and Decision Science RWTH Aachen University

Ilkim Canoler
Luckshan Sivakumar
Nikhil Kulkarni
Karthikeyan Ramasubbu
Shekhar Dure

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Abstract

In this study, an operational planning problem in the air cargo industry is being tried to be solved. For all shipments in an international airline hub that need to catch their related flight on time, a mathematical model was constructed. Working with our industrial partner AbOvo, we formalize the problem constraints and our objective. Besides, the necessary data is collected from AbOvo and we started working on it simultaneously. We are trying to establish a comprehensive view of tasks in an air cargo terminal and develop a suitable solution apporoach. Furthermore, our goal is to solve this model by using Gurobi solver as a full planning puzzle. In this paper, all explanations and details about our mathematical model and the data we have, can be found.

Contents

1 Introduction

An international airline hub needs to plan the air cargo movement so that all shipments catch their connecting flights or road connections. Air cargo shipments are transported in so-called unit load devices (ULDs). A ULD contains many shipments which need to go different final destinations. Hence, at the first step of the whole process, the incoming ULDs are broken down at the arrival. Here in the breakdown zone (BD), ULDs have to be unpacked and seperated. The seperate shipments are transported in the warehouse to wait for the build up call. These shipments are then moved to packing area which is called buildup zone (BU). At the end, outbound ULDs are constructed with these shipments and they are taken to the outbound flight for loading. All zones have different attributes such as number of workstations, capacities, transportation times between zones and the warehouse. Shipments also have different attributes such as priority and weight. Regarding all the attributes, constraints and the parameters which are stated in detail in problem description, the goal of the optimization process is to build up all ULDs as soon as possible to make them catching their connections.

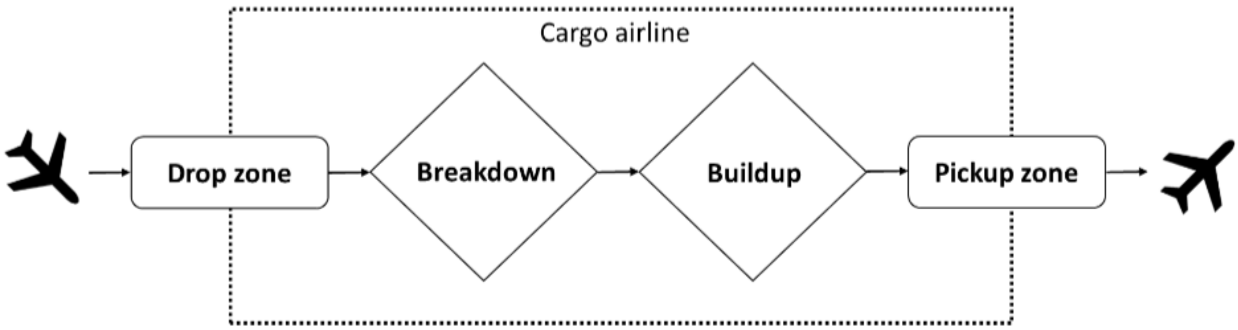


Figure 1: The processes that take place at a hub, with respect to air cargo

Figure 1: The Process That Takes Place at a Hub

2 Problem Description

The process of one shipment begins in drop zone when it comes to the airport in an inbound ULD. ULDs are unloaded from an aircraft by the ground handling agent and placed in a drop zone (not part of our planning puzzle). There are 4 drop zones and each drop zone has different number of workstations. Each ULD has a scheduled arrival and at a later stage an actual arrival time. From drop zone, each ULD has to be taken to the breakdown zone to get unpacked. Our problem also starts here. There are different distances between each drop zone and each breakdown zone. The sample distances between some of the drop zones and some of the BD zones are given below in the table:

BreakDownZoneName	DropZoneName	TransportDuration
B BD NRML-1	DZ NRML-1	0:25
B BD NRML-2	DZ NRML-1	0:11
BD NML-1	DZ NRML-1	0:19
BD CLD-1	DZ NRML-1	0:24
BD NRML-1	DZ NRML-1	0:05
BD NML-2	DZ NRML-1	0:15
BD NRML-2	DZ NRML-1	0:19
BD NRML-3	DZ NRML-1	0:25

Figure 2: Sample Distances Between Drop Zone and Break Down Zone

In BD zone, ULDs are seperated into shipments. There are 12 different BD zones in the hub. So they are located at different places of the airport. Thus all BD zones have different attributes. Attributes related to BD zones are below:

- Different characteristics for each BD zone for example some of the BD zones are for animals, some of them are for cooled products and the others are normal BD zones.
- Different number of workstations within the BD zone.
- Different transportation times to the warehouse.
- Different handling times per ULD.

Within the BD zone, the decision needs to be taken in which order the ULDs should be unpacked. ULDs need to be broken down early enough, so all shipments can make their connections or promised pickup time. There are 3 different shipments within the hub. Cooling products, normal products (NRML) and animals (NML). Also each shipment has different priorities in these BD zones. Because some of the shipments may be animals or cooled products which are mentioned above and need to be processed before the regular shipments. ULDs contain a shipment with a high priority, need to be unpacked earlier than the others. Each shipment within the ULD is either in transit and needs to catch the connecting flight or will be further transported on the road usually by truck (not part of our planning puzzle) or is picked up from the warehouse by a customer. When the shipments are in transit

Name	NumberOfWorkstations	SequenceNumber	TransportationTimeToWH	TargetProcessName	HandlingTimePerULD
B BD NRML-1	33	1	0:30:00	NORMAL	0:24:00
B BD NRML-2	10	2	0:25:00	NORMAL	0:24:00
BD NML-1	4	3	0:40:00	ANIMAL	0:13:00
BD CLD-1	8	4	0:30:00	COOLED	0:17:00
BD NRML-1	5	5	0:30:00	NORMAL	0:20:00
BD NML-2	3	6	0:25:00	ANIMAL	0:13:00
BD NRML-2	6	7	0:40:00	NORMAL	0:20:00
BD NRML-3	3	8	0:40:00	NORMAL	0:20:00
BD CLD-2	5	9	0:30:00	COOLED	0:17:00
BD NML-3	5	10	0:25:00	ANIMAL	0:20:00
BD NRML-4	3	11	0:30:00	NORMAL	0:13:00
BD CLD-4	1	12	0:40:00	COOLED	0:15:00

Figure 3: Break Down Zone Attributes

and unpacked, depending on the scheduled departure time of the connection flight on which cargo is booked, it is either stored temporarily in the warehouse or directly sent to build up process. The warehouse (WH) is fully automated and with the assumption, that there are never capacity constraints in the WH. As soon as enough stock is available in the storage WH to build up one ULD for a specific aircraft, these can be requested to be provided to the BU zone.

In a next step the shipments are built up again to ULDs depending on their connecting flight. This is done within a build up zone (BU zone). A departing aircraft type has a link to a specific BU zone, so with the provided information which aircraft the shipment should go on, the BU zone is known. Here again a shipment with a high priority has to be built up earlier then the other shipments. There are 8 different BU zones and each BU zone has different number of workstations within. At each work station one ULD can be built up at the same time. The shipments are provided from the storage WH to the chosen work station. If the building up of two ULDs for the same aircraft are planned at one work station, it is not allowed to build up a ULD for a different aircraft in between, even if there is some idle time. The reason is that after building up one ULD there might be some shipments with the same destination left. It should be avoided to move those around, so they would stay at the work station for the build up of the next ULD for the same aircraft. From each BU zone, there are different transportation times to each flight. In addition to this, there are different default processing times for each flight which is also given in the data. This means each ULD has additional processing time before the regarding flight. Here for all ULDs, the capacity is the same which is 400 kg. For some of the flights, there is a pre-processing buffer time necessary to consider. Sample tables related to these characteristics are given below for a clear understanding:

- Different handling times and transport times from the WH for each BU zone.
- Sample workstations within some BU zones.

Name	HandlingTimePerULD	TransportationTimeToWH
BU FT-1	0:24:00	0:50:00
BU FT-2	0:24:00	0:45:00
BU NML-1	0:13:00	0:40:00
BU CBD-1	0:17:00	0:50:00
BU NRML-1	0:20:00	0:50:00
BU NML-2	0:13:00	0:45:00
BU NRML-2	0:20:00	0:40:00
BU NRML-3	0:20:00	0:40:00

Figure 4: Handling Times and Transportation Times from Warehouse to BU Zones

WorkStationID	Name
FT-2-4	BU FT-2
FT-2-5	BU FT-2
FT-2-6	BU FT-2
NML-1-1	BU NML-1
NML-1-2	BU NML-1
NML-1-3	BU NML-1
NML-1-4	BU NML-1
CBD-1-1	BU CBD-1
CBD-1-2	BU CBD-1
CBD-1-3	BU CBD-1

Figure 5: Workstations in BU Zones

- Sample flights related to some BU zones and the transportation time between the flight and the BU zone.

FlightNumber	BU Zone	TransportationDistance
5	BU FT-1	12:05:00 AM
6	BU FT-1	12:15:00 AM
13	BU FT-2	12:11:00 AM
14	BU FT-2	12:17:00 AM
15	BU NML-1	12:12:00 AM
16	BU NML-1	12:16:00 AM
39	BU NML-2	12:24:00 AM
40	BU NRML-1	12:05:00 AM

Figure 6: Sample Flights Related to BU Zones and Transpotation Times

- Pre-processing buffer times for the flights.

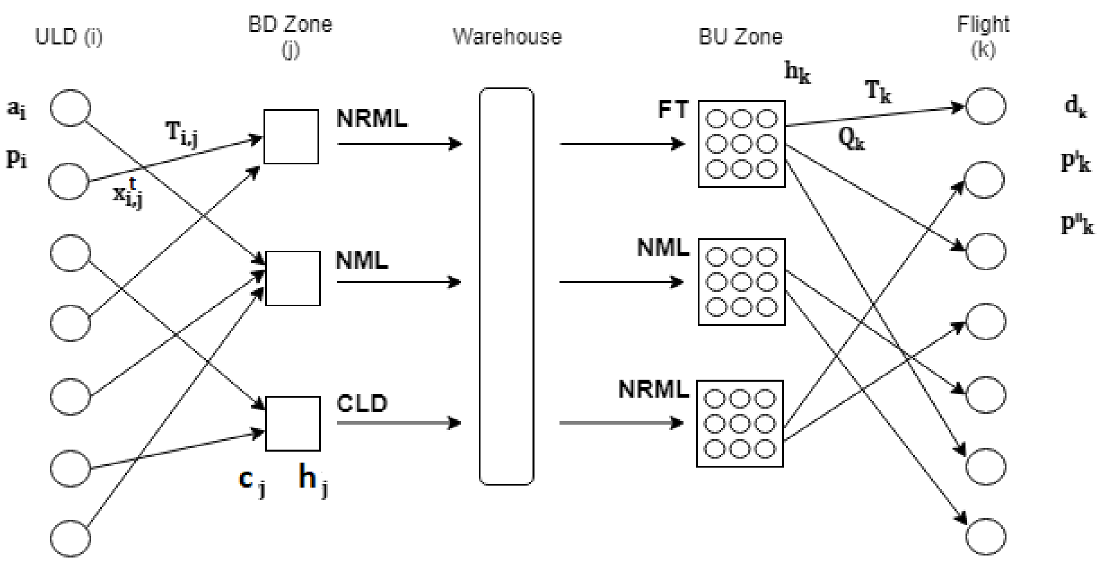
The goal is to build up all ULDs as soon as possible to make the connections, while the work should be processed in batches, to avoid unnecessary transportation within the BU zone.

FlightNumber	Weekday	PreProcessingBufferTime
3	*	0:10:00
17	*	0:10:00
20	7	0:10:00
30	*	0:15:00
31	6	0:05:00
31	7	0:15:00
40	*	0:25:00
47	7	0:10:00
49	7	0:15:00
78	7	0:15:00

Figure 7: Pre-Processing Times of the Flights

3 Mathematical Model for the Problem

Our mathematical model for this problem is a combination of two puzzles, which are Break Down Zone and the Build Up Zone assignments.



3.1 Break Down Process

In BD zones, our model has arrival time parameters for each ULD. Similar to this, each BD zone has its own capacity, handling time and transportation time from drop zone. Each ULD is a part of the ULD set I and each BD zone is a part of the BD zones set J. Time is discretized into minutes in set T.

ULD i $\in$ I = {1,2,3,...,N}

BD zone j $\in$ J = {1,2,3,...,M}

Time horizon t $\in$ T = {1,2,3,...,T}

Shipments l in ULD i $\in$ Li = {1,2,3....,L}

a_i : Arrival time of ULD i in drop zone
d_i : Earliest Departure time of a shipment in ULD i
c_j : Capacity of BD zone j
h_j : Handling time in BD zone j
T_{ij} : Time taken to transport an ULD i to BD zone j
T_j : Time taken to transport shipments from i to BD zone j to Warehouse

3.1.1 Decision Variables for Break Down Process

In the Break Down zone, the decision needs to be taken which ULDs should be assigned to which BD zone at which time. For this reason, the decision variable has to be binary. 1 for the ULD i is assigned to BD zone j at time t, 0 for the ULD i is not assigned to BD zone j at time t.

$x_{ij}^t \in \{0,1\}, \forall i \in I, j \in J, t \in T$: if a ULD i is assigned to BD zone j at time t or not.

y_{lij}^t is another binary decision variable which indicates whether each shipment l in ULD i is assigned to a BD zone j at time t or not

$y_{lij}^t \in \{0,1\}, \forall i \in I, j \in J, j \in L_k, t \in T$

3.1.2 Constraints for Break Down Process

For BD zone processes we have three constraints. The first one (1) is the constraint that ensures that the ULD is assigned at a feasible time, the second one (2) is an assignment constraint which means all ULDs have to be assigned to exactly one BD zone and the third one (2) is the capacity constraint.

The time at which Break down of ULD i starts, $t_{i,start} = \sum_{j \in J} \sum_{t=a_i}^{d_i} t.x_{ij}^t$

Each ULD takes i T_{ij} time to travel to its assigned BD zone j, therefore the following constraint ensures that the start time of ULD i is greater than the sum of its arrival time and transportation time :

$$\sum_{j \in J} \sum_{t=a_i}^{d_i} t.x_{ij}^t \geq a_i + T_{ij}, \qquad i \in I \tag{1}$$

Each ULD i must be assigned to a BD zone j before the earliest departure time of the shipment it contains. We will further tighten this time limit in other constraints that follow. The following constraint ensures that each ULD is assigned :

$$\sum_{j\in J}\sum_{t=a_i}^{d_i} x_{ij}^t = 1 \qquad \forall i \in I \tag{2}$$

For multiple dropzone ULD's

$$\sum_{j\in J_{NML}}\sum_{t=a_i}^{d_i} x_{ij}^t = 1 \qquad \forall i \in I \tag{3}$$

$$\sum_{j\in J_{NRML}}\sum_{t=a_i}^{d_i} x_{ij}^t = 1 \qquad \forall i \in I \tag{4}$$

In the third constraint (3), we say that if ULD's in subset i are started to be processed at time t, no more ULDs than the remaining capacity of the BD zone j can start before $t + h_j$, because the process of breaking down the current ULDs needs to be completed. If ULDs in subset i start at t in BD zone j, then other ULDs are in $u \in I \setminus \{i\}$. In the first part of the constraint, we are calculating the remaining capacity for the BD zone at time t . For the second part of the constraint, we are stating that whatever will be assigned in next time period $t + h_j$ should be less than or equal to remaining capacity.

$$c_j - \sum_{i\in I} x_{ij}^t \geq \sum_{u\in I\setminus\{i\}}\sum_{\tau=t+1}^{t+h_j-1} x_{ij}^{\tau} \qquad \forall t \in T, \forall j \in J \tag{5}$$

The effect is no more ULDs than the capacity of BD zone are assigned at any time.

ULD i is broken down at time, $t_{i,end} = \sum_{j\in J}\sum_{t=a_i}^{d_i}(t+h_j).x_{ij}^t$

Lets consider the journey of each shipment. Each ULD i has $l \in L_i$ shipments in it. If ULD i is assigned at time t to BD zone j, then it also means that all shipments in ULD i are assigned at that time t to BD zone j.

$J_{NML} \bigcup J_{NRML} = J$

$$\sum_{j\in J_{NML}}\sum_{t=a_i}^{d_i}(t+h_j).x_{ij}^t \leq \sum_{j\in J_{NRML}}\sum_{t=a_i}^{d_i}(t).x_{ij}^t \tag{6}$$

At this phase, priorities are not considered in our model in BD zones.

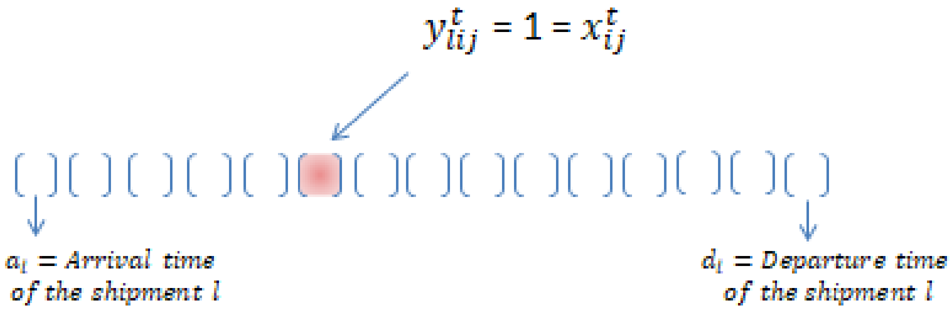


Figure 8: Journey of Shipment

3.2 Build Up Process

We define parameters for flights and Build up zones :

Flight k $\in$ K = {1,2,3,...,K}

BU zone for flight k has Workstations m $\in M_k$ = {1,2..,M}

Capacity of ULD in Kgs (W)= 400

Weight of each shipment= w_l

Time taken to build up a ULD in BU zone for Flight k= b_k

Pre-processing time for each Flight k= p_k

3.2.1 Decision Variables for Build Up Process

In the Build Up zone, the decision needs to be taken regarding which shipments should be assigned to which workstation at what time in a given Build up zone. For this reason, we introduce a decision variable: z_{lkm}^{t}

Shipment l having departure flight k is assigned to one of "m" workstations in its BU Zone.

$$z_{lm_k}^{t} \in \{0,1\}, \forall i \in I, l \in L_i, m \in M_k, t \in T$$

Q_{mk}^{t} is our binary decision variable to decide if the the Workstation m is assigned to build ULD for Flight k at time t or not.

$$Q_{mk}^{t} \in \{0,1\}, \forall k \in K, m \in M_k, t \in T$$

3.2.2 Constraints for Build Up Process

All shipments must be assigned to a workstation in its designated Build up zone.

$$\sum_{m \in M} \sum_{t=a_l}^{d_l} z^t_{lm_k} = 1 \qquad \forall k \in K, \forall l \in L_k \tag{7}$$

If shipments in subset $l \in L_k$ start at t in m^{th} workstation, other shipments in subset $p \in L_k \setminus \{l\}$ cannot start before $t + b_k$

$$Q^t_{mk}.W - \sum_{l \in L_k} z^t_{lm_k}.w_l \geq \sum_{p \in L_k \setminus \{l\}} \sum_{\tau=t+1}^{t+b_k-1} z^\tau_{pm_k}.w_l, \qquad \forall k \in K, \forall m \in M_k, \forall t \in T \tag{8}$$

The number of workstation in the Build up zone that are to be assigned to build ULDs for flight k shall not exceed the number of ULDs that go into the flight and hence we need the following constraint to take care of this.

$$\sum_{m \in M_k} \sum_{t=a_l}^{d_k} Q^t_{mk} \leq \frac{\sum_{l \in L_k} \sum_{m \in M} \sum_{t=a_l}^{d_k} z^t_{lm_k} w_l}{W} + 1, \qquad \forall k \in K \tag{9}$$

If a workstation 'm' in a buildup zone is assigned to flight k at time t, then no other flight can start building its ULDs in that workstation before time t+bk.

$$1 - Q^t_{mk} \geq \sum_{q \in K \setminus \{k\}} \sum_{\tau=t}^{t+b_k} Q^t_{mq}, \qquad \forall k \in K, \forall m \in M_k, \forall t \in T \tag{10}$$

3.2.3 Precedence constraints

In the entire timeline of a shipment from its arrival to departure we have a precedence contraint on processes a shipment goes through. The Break down process preceeds the Build up process and hence The assigment for BD zone should happen before Workstation assignment in a BU Zone.

The end time of ULD i in Break down process and the summation of transportation time needed to reach Warehouse shall be less that the time at which the shipment l is assigned to a workstation 'm' in Build up zone of flight k.

$$\sum_{j \in J} \sum_{t=a_l}^{d_i} (t + h_j + T_j).x^t_{ij} \leq \sum_{m \in M_k} \sum_{t=a_l}^{d_l} z^t_{lm_k}.t \qquad \forall i \in I, \forall l \in L_i \tag{11}$$

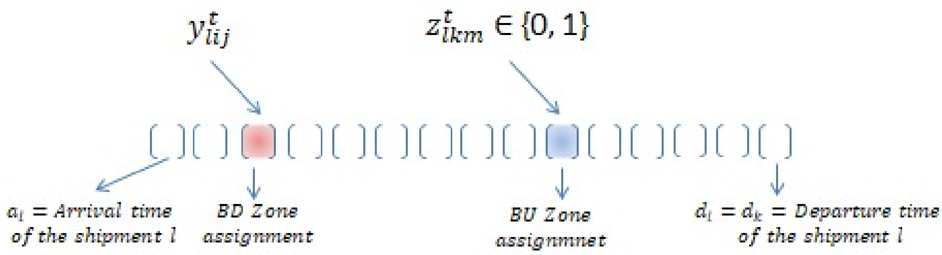


Figure 9: Journey of Shipment - 2

For Multiple DZ ULDs we have to consider only NRML BD zone assignments for writing precedence constraint :

$$\sum_{j \in J_{NRML}} \sum_{t=a_l}^{d_i} (t + h_j + T_j).x^t_{ij} \leq \sum_{m \in M_k} \sum_{t=a_l}^{d_l} z^t_{lm_k}.t \qquad \forall i \in I, \forall l \in L_i \tag{12}$$

3.3 Objective Function

Slack for each shipment is given by difference in departure time and the time at which shipments are built up into ULDs. Let this slack time for each shipment be greater than s_{min}

$$(d_l + p_k) - (z^t_{lm_k}.(t + b_k)) \geq s_{min} \qquad \forall i \in I, \forall l \in L_i, \forall k \in K, \forall t \in T \tag{13}$$

$$s_{min} \geq 0 \tag{14}$$

By maximising the minimum slack of all shipments we ensure that each shipment is ready well before its departure time.

$$\max s_{min}$$