IMPROVING THE AIR CARGO TERMINAL OPERATIONS THROUGH OPTIMIZATION

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SUMMARY

With the recent shift of world economy towards globalization, air transportation has become a common and integral part of the supply chain process. Hence, in order for any country to stay competitive in the world market, it is imperative that the air cargo industry can meet up with the industrial needs in the most efficient way.

One of the key components of the air transportation is the air cargo terminal that provides support and value-added services to the carriers and the customers. It usually acts as a ground handling agent for the carriers. In order to stay competitive, productivity is a very crucial element to the success of an air cargo terminal. Optimization methods are introduced in this work aiming to help the air cargo terminal to make good use of the current resources and equipments available without incurring a high investment. In addition, this work further shows the possible savings without compromising to the customer service level.

After performing some studies on the current air cargo terminal operations, two areas of improvements within the export terminal are identified. The first research is done on the Automated Storage/Retrieval Systems (ASRS) storage policy of the export terminal. The new policy of storing the loose cargo in the terminal is aiming to help reduce the number of handlings required in the terminal and hence increase the productivity. A quantitative model to evaluate the operational policies of assigning cargoes to storage bins is presented. Two performance measurements are proposed. One is the labor required to handle the cargoes and the other one is the storage capacity required to store the cargoes. Based on the model, a comparison is made between an existing policy against a few proposed policies in which time is used to segregate storage bins. The results show that the proposed policies give rise to a great reduction in both manpower and the storage capacity requirement. These results are further confirmed by a simulation study in which simplicity assumptions on the analytical model are removed.

The second research work is regarding the manpower allocation problem at the export terminal. The terminal is currently facing some problems in allocating its manpower such as unbalanced workload amongst the workers and low customer service level due to the shortage of manpower during peak periods. This work is done to help the terminal generates the shift schedule effectively as well as utilizing its manpower efficiently by matching the manpower availability to its actual demand level. The problem is first solved by a shift scheduling model where all the shifts' start and end times are determined. Then, these shifts found are used as input to the roster model to form a complete roster for the workers. Savings of more than 10% were shown compared to the current operation in terms of man hours. When compared in terms of the number of Checking Teams required, the approach presented in this work gives rise to a saving of two teams in total.

NOMENCLATURE

AO	Acceptance Officer.
Apron	Worker who loads the pallets and containers into the aircraft.
ASRS	Automated Storage/ Retrieval System.
AVI	Livestock.
AWB	Airway Bill.
BT	Baggage Trolley.
Build-up	Same as palletization.
CC	Carousel cargo
Close flight	The completion of the process of building-up all the cargoes that is planned to be uploaded to an aircraft.
Consignor	Same as Shipper.
CR	Cold Room to store loose perishable cargo.
DGR	Dangerous Goods.
EO	Equipment Owner.
ETD	Estimated Time of Departure.
ETV	Elevated Transfer Vehicle.
FG	Floor Goods, refer to cargo on skid and/or too big to be stored in the ASRS bin.
Freight forwarder	An agent that accepts cargo from shippers (possibly to be subsequently consolidated into a larger unit) to be tendered to an airlines to transport to the shipper's destination. Generally, a freight forwarder is responsible for handling the freight booking, import and export documentation, break bulk and delivery.

Ground Handler	An agent or company appointed by airlines to provide ground handling services.
Manifest	The official document summarizing a list of cargoes being carried by an aircraft.
P1P/P6P	Pallet identification code.
Palletization	Cargoes are consolidated and built on a metal pallet plate or placed into container.
PCHS	Pallet Container Holding System.
Pre-check flight	To build-up cargoes of the flight for the next Checking Team.
Pre-manifest	An internal document circulating within the airport cargo terminal with a list of cargoes planned to be uploaded into an aircraft.
Queue-Lane	Mechanized roller used as a temporary storage of pallets and containers at the ramp side of the air cargo terminal building.
RQL	Refrigerated Queue-Lane
Shipper	A company that owns the cargo to be shipped.
STD	Scheduled Time of Departure.
Terminal operator	Same as Ground Handler.
ULD	Unit Load Device.
VAL	Valuable cargo
VC	Vulnerable cargo
X_{ij}	Number of cargoes of category i stored in bin j.
a_{ij}	Number of cargoes of category i in bin j.
A_i	Total number of cargoes in category i, where $A_i = \sum_j a_{ij}$

k	Denotes the number of bins required at certain time interval, i.e. 1,…,N.
M	Total number of cargo categories.
m	Cargo category.
v	Bin capacity.
N	Total number of bins required.
Segment $B1^a$	First time interval, i.e 20th to 24th hours, of Bin Type 1.
Segment $B1^b$	Second time interval, i.e. 24th to 28th hours, of Bin Type 1.
Segment $B1^c$	Third time interval, i.e. 28th to 32nd hours, of Bin Type 1.
Segment $B2^a$	First time interval, i.e 20th to 24th hours, of Bin Type 2.
Segment $B2^b$	Second time interval, i.e. 24th to 28th hours, of Bin Type 2.
Segment $B2^c$	Third time interval, i.e. 28th to 32nd hours, of Bin Type 2.
Segment $B3^a$	First time interval, i.e 20th to 24th hours, of Bin Type 3.
Segment $B3^b$	Second time interval, i.e. 24th to 28th hours, of Bin Type 3.
Segment $B3^c$	Third time interval, i.e. 28th to 32nd hours, of Bin Type 3.
HT_B1^a	Expected number of handlings for Segment $B1^a$.
HT_B2^a	Expected number of handlings for Segment $B2^a$.
HT_B3^a	Expected number of handlings for Segment $B3^a$.
HT_B1^b	Expected number of handlings for Segment $B1^b$.
HT_B2^b	Expected number of handlings for Segment $B2^b$.
HT_B3^b	Expected number of handlings for Segment $B3^b$.
HT_B1^c	Expected number of handlings for Segment $B1^c$.
HT_B2^c	Expected number of handlings for Segment $B2^c$.
HT_B3^c	Expected number of handlings for Segment $B3^c$.
HT^a	Expected number of handlings for the first time interval.

HT^b	Expected number of handlings for the second time interval.
HT^c	Expected number of handlings for the third time interval.
HT_{total}	Total number of handlings for the three time intervals.
HT	Expected total number of handlings to retrieve the cargoes for each time interval.
AT_B1^a	Average cycle time for Segment $B1^a$.
AT_B1^b	Average cycle time for Segment $B1^b$.
AT_B1^c	Average cycle time for Segment $B1^c$.
AT_B2^a	Average cycle time for Segment $B2^a$.
AT_B2^b	Average cycle time for Segment $B2^b$.
AT_B2^c	Average cycle time for Segment $B2^c$.
AT_B3^a	Average cycle time for Segment $B3^a$.
AT_B3^b	Average cycle time for Segment $B3^b$.
AT_B3^c	Average cycle time for Segment $B3^c$.
AT^a	Estimated cycle time of a bin for the first time interval.
AT^b	Estimated cycle time of a bin for the second time interval.
AT^c	Estimated cycle time of a bin for the third time interval.
AT	Estimated cycle time per time interval.
T_a	Time for an arrival of a loose cargo for a flight.
U	Random number that lies between 0 and 1.
NM	New Model
u	A stipulated time before STD.
z	A stipulated hours before ETD.
t_n	Total normal working hours per week.
t_{ot}	Total working hours per week inclusive of the overtime.

t_b	Break hours required between two working shifts.
t_w	Total working hours per 24-hour day.
N_{job}	Numbers of jobs with a new ID.
x	A stipulated hour used to serve as a cut-off time to distinguish the urgent job from non-urgent job.
h	{1, …, Helper Number} denotes a set of h helpers.
n	Number of intervals which is set to 168 to cover a planning horizon of one week in this case.
H^1	Number of hours for shift duration type 1, i.e. 8 hours.
H^2	Number of hours for shift duration type 2, i.e. 9 hours.
H^3	Number of hours for shift duration type 3, i.e. 10 hours.
x^1_t	Number of shift with working hour starts at t^{th} hour and ends at $(t + 6)^{\text{th}}$ hour assuming the last hour is the break time, where $t = 1,\ldots, n$.
x^2_t	Number of shift with working hour starts at t^{th} hour and ends at $(t + 7)^{\text{th}}$ hour assuming the last hour is the break time, where $t = 1,\ldots, n$.
x^3_t	Number of shift with working hour starts at t^{th} hour and ends at $(t + 8)^{\text{th}}$ hour assuming the last hour is the break time, where $t = 1,\ldots, n$.
b_q	Demand or workload requirement during time interval q, where $q= 1, \ldots, 168$.
x_s	Denotes 1 if shift pattern s is chosen, 0 otherwise.
H_s	Shift duration in hours for shift s.
β_{fs}	Denotes 1 if flight f is covered by shift s, 0 otherwise.

F	Total number of flights need to be covered.
N_{night}	Max {Number of night shifts required in day 1, …, Number of night shifts required in day 7}.
$N_{morning/afternoon}$	Max {Number of morning and afternoon shifts in day 1, …, Number of morning and afternoon shifts in day 7}.
d	Denotes the calendar day, i.e. $d = 1, 2, \ldots, 7$.
w	Number weeks required to form a roster.
i	A dated night-shift work stretch pattern, starting with a rest day, followed by a few working days and followed by two rest days.
j	A dated day shift cum afternoon shift work stretch pattern.
D	Denotes a dated day, i.e. $D = \{1,2,\ldots,7*w\}$
α_{id}	assuming a value of 1 if date d ($d \in D$) is a working day in pattern i, 0 otherwise.
β_{jd}	assuming a value of 1 if date d ($d \in D$) is a working day in pattern j, 0 otherwise.
η^1_{il}	assuming a value of 1 if pattern i has an 8-hour night shift on the l^{th} day of a calendar week, 0 otherwise.
η^2_{il}	assuming a value of 1 if pattern i has a 9-hour night shift on the l^{th} day of a calendar week, 0 otherwise.
η^3_{il}	assuming a value of 1 if pattern i has a 10-hour night shift on the l^{th} day of a calendar week, 0 otherwise.
θ^1_{jl}	assuming a value of 1 if pattern j has an 8-hour work morning shift on the l^{th} day of a calendar week, 0 otherwise.

θ^{2}_{jl}	assuming a value of 1 if pattern j has a 9-hour morning shift on the l^{th} day of a calendar week, 0 otherwise.
θ^{3}_{jl}	assuming a value of 1 if pattern j has a 10-hour morning shift on the l^{th} day of a calendar week, 0 otherwise.
ζ^{1}_{jl}	assuming a value of 1 if pattern j has an 8-hour afternoon shift on the l^{th} day of a calendar week, 0 otherwise.
ζ^{2}_{jl}	assuming a value of 1 if pattern j has a 9-hour afternoon shift on the l^{th} day of a calendar week, 0 otherwise.
ζ^{3}_{jl}	assuming a value of 1 if pattern j has a 10-hour afternoon shift on the l^{th} day of a calendar week, 0 otherwise.
N^{1}_{l}	total number of 8-hour night shifts required on the l^{th} day of a calendar week
N^{2}_{l}	total number of 9-hour night shifts required on the l^{th} day of a calendar week
N^{3}_{l}	total number of 10-hour night shifts required on the l^{th} day of a calendar week
D^{1}_{l}	total number of 8-hour morning shifts required on the l^{th} day of a calendar week
D^{2}_{l}	total number of 9-hour morning shifts required on the l^{th} day of a calendar week
D^{3}_{l}	total number of 10-hour morning shifts required on the l^{th} day of a calendar week
A^{1}_{l}	total number of 8-hour afternoon shifts required on the l^{th} day of a calendar week

A^2_l	total number of 9-hour afternoon shifts required on the l^{th} day of a calendar week
A^3_l	total number of 10-hour afternoon shifts required on the l^{th} day of a calendar week
x_i	1 if pattern i is selected in the rotation and 0 otherwise
y_i	1 if pattern j is selected in the rotation and 0 otherwise
γ_{il}	0 if pattern i has no rest day at the l^{th} day of a calendar week, 1 if pattern i has a rest day at the l^{th} day of a calendar week and 2 if pattern i has two rest day at the l^{th} day of a calendar week.
R_l	the total number of rest days allowed for the l^{th} day of a week, which is $w- N^1_l-N^2_l- N^3_l- D^1_l- D^2_l- D^3_l- A^1_l- A^2_l- A^3_l$.
s_l	Number of Rest day on day l.
p	Minimum of all the s_l's.
N_{ws}	Number of night-shift work stretches.
N^R	The current number of interval gaps between the night-shift work stretches which have not been assigned.
D^R	Number of days which have been assigned for the morning and afternoon shift stretches.
i_n	Number of night-shift work stretches have been assigned to the roster.
UD	Upper bound of the weeks in between any two night-shift work stretches.
LD	Lower bound of the weeks in between any two night-shift work stretches.
D^u	The calendar day of the unassigned shift.

S^u	The unassigned shift.
w^c	Week ID within the roster.

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Chapter 1

Introduction

Today, air cargo is no longer confined to the speedy shipment of emergency supplies. On the contrary, it is often the most advantageous and economical means of transport. With the recent shift of world economy towards globalization, air transportation has become a common and integral part of the supply chain process. Hence, in order for any country to stay competitive in the world market, it is imperative that the air cargo industry can meet up with the industrial needs in the most efficient way.

One of the key components of the air transportation is the air cargo terminal that provides support and value-added services to the carriers and the customers. It usually acts as a ground handling agent for the carriers. The support and services provided by the terminal operator include import/export and transit cargo handling, cargo documentation handling, cargo tracing, cargo storage, Unit Load Device (ULD)/pallet handling, cargo palletizing, claims processing, surveys and mail handling. Among these services, cargo handling and storage remain the core activities in the air cargo terminal.

In order to stay competitive, productivity is a very crucial element to the success of an air cargo terminal. Installing high-end equipment and facilities helps to improve the productivity. However, this often comes with a huge price. Optimization methods are introduced in this work aiming to help the air cargo terminal to make good use of the current resources and equipments available without incurring a high investment. In addition, this work further shows the possible savings without compromising to the customer service level.

After performing some studies on the current air cargo terminal operations, two areas of improvements within the export terminal are identified. These two main research works are presented in this dissertation. First, the Automated Storage/Retrieval Systems (ASRS) storage policy of the export terminal is presented in Chapter 2. The current policy used to store cargoes in the ASRS is discussed followed by the proposal of a new storage policy. The new policy of storing the loose cargo in the terminal is aiming to help reduce the number of handlings required in the terminal and hence increase the productivity. Second, the manpower allocation problem at the export terminal is presented in Chapter 3. The terminal is currently facing some problems in allocating its manpower such as unbalanced workload amongst the workers and low customer service level due to the shortage of manpower during peak periods. Currently, the manpower planning problem is being done manually based on the supervisor’s experience. This work is done to help the terminal generate the shift schedule effectively as well as utilizing its manpower efficiently by matching the manpower availability to its actual demand level. Lastly, conclusions of this work are presented in Chapter 4.

Before moving to the next chapter, overviews of the air cargo industry followed by the general export process of the physical cargo within air cargo terminals are provided. Only the export process is described here as the works which will be presented in Chapters 2 and 3 later focus on the export operation.

1.1 Overview of the Air Cargo Industry

This section describes the key logistics activities of the air cargo. The general process of the air cargo movement involves the shipper, freight forwarders, terminal operators, air carriers and the consignee. Normally, the shipper will contact its appointed freight forwarder when there is shipment ready for delivery to the consignee. The freight forwarder will then contact the airline for space booking. When the space is confirmed, the freight forwarder will arrange a truck to pick up the cargo from the shipper's location. The cargo will then be lodged in to the airport terminal after the completion of all the required documentations. The terminal operators or the ground handlers are responsible for uploading cargoes into the aircraft. When the aircraft arrives at the destination airport, the cargoes will be unloaded to the terminal where the freight forwarder will collect the cargoes from the ground handlers. These cargoes will then be sorted and delivered to the respective consignees. Figure 1.1 shows the generic air cargo flow.

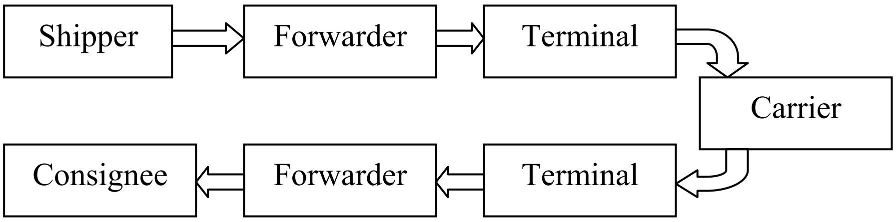

Figure 1.1: Generic air cargo flow

In some airports, the cargoes may be lodged in to the terminal either loose or palletized. A loose cargo is any shipment lodged in to the terminal loosely and without being combined with other shipments to form a ULD (Unit Load Device); while a palletized cargo may be a combination of many shipments to be shipped as a ULD. The ULD can be a closed container consisting of many shipments or an open pallet where many shipments are wrapped and tied-up with nets to form a solid cubical block. The size of the palletized cargo varies according to the aircraft type and its location in the aircraft. Lodging-in loose cargoes generally is inefficient as this will require additional work at the terminal as well as space for build-up areas. As there can be hundreds of departure flights per day during the peak period, building up full pallets to meet the flight departure time for each flight may be a challenging task given both the space and manpower constraints.

Since the research work is focusing on export operations, the following sections give an overview on the export team organization and a detailed description of the air cargo terminal operations. This is based on the observation done mainly at one of the air cargo terminals, with information from two major freight forwarders and one small forwarder, and two multinational shippers.

1.2 Export Team Organization

This section aims to provide some information of the export team organization and each team member's job function in order to get the reader familiarized with some of the job names before moving into the detailed description on the process flow. The organization chart of the export team is shown in Figure 1.2.

On top of the chart is the Cargo Supervisor. The Cargo Supervisors are working on a roster specially designed for them and it is different from the Checking Team rosters. The Cargo Supervisor mainly deals with the judgmental issue such as which cargo shall be bumped off if the cargo space is limited when the offloading priority list is unable to assist the Checking Team to judge.

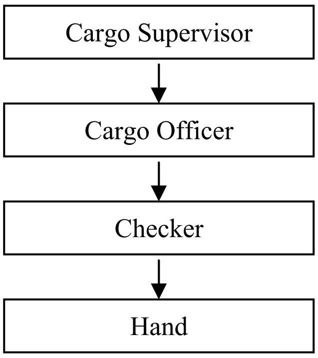

Figure 1.2: Organization chart for export terminal.

One level down below the Cargo Supervisor is the Cargo Officer. The Cargo Officers have another roster to follow which is again different from the Checking Team rosters. The Cargo Officer is responsible to assign the break time for the Checker and Hand as well as approving the overtime work for the Checking Team. In summary, the Cargo Officer is responsible for the following activities:

i. Allocation of flight to the Checking Team.
ii. Allocation of the pre-checking jobs.
iii. Approving the overtime for the Checker and Hand.
iv. Approving the break time for the Checker and Hand.

Next is the Checking Team which consists of one Checker and one Hand. The Checking Team's responsibility is to retrieve the cargoes from various storage locations and build the cargoes into ULD. The Checker will have a higher responsibility than the Hand where instructions of retrieving the cargoes are given by the Checker to the Hand before they start retrieving the cargoes. A more detailed description of the Checking Team's job function is described in Section 1.3 later together with the export process flow. At the airport terminal under study, there are four groups of passenger flight Checking Teams at the export terminal. The grouping of these Checking Teams is to serve two purposes. First is to have each group handling flights for different sectors or different geographical regions. For instance, Group 1 is to handle South East Asia flights, Group 2 is to handle Europe flights and so on. However, due to addition of more flights throughout the years and the inherent difficulty of constructing a new roster manually, some of the Checking Teams, except Group 1 Checking Teams, are assigned to handle cross-sectors flights. Second, it is not easy to manage so many Checking Teams as a big group; hence an easier way is to manage them in smaller number of teams. The performance metrics of the Checking Team is based on the amount being handled and the number of mishandlings.

Another group of workers assisting the Checking Teams, which is not shown in the chart, is called Equipment Operators (EO). There are two different EO namely the ETV (Elevated Transfer Vehicle) EO and the forklift EO. The ETV EO operating the ETV will help the Checking Team to retrieve the ULD from the PCHS (Pallet Container Holding Systems) when being requested by the Checker. Normally, the Checker can request the ULD to be retrieved through the in-house centralized IT system or write down the ULD number on a piece of paper and pass it to the EO directly. The forklift EO's job is to fork the empty bins as well as the bins with certain shipments already been retrieved by the Checker back to the ASRS or to the dedicated area. They are also responsible to fork those empty pallets/ ULD from the import terminal to the export terminal.

1.3 Air Cargo Export Process Flow

In order to appreciate the works being discussed in the next two chapters, it is necessary to gain a good understanding of the export process. This section provides an overview of the sequential flow of the physical processes required to move the cargo from the forwarder premises to the airport cargo terminal and it is shown in Figure 1.3. Below are the descriptions of the steps in relation to Figure 1.3.

Step 1

The forwarder prepares the necessary documentations and taking down the physical measurements of the cargo i.e. weight, volume and number of pieces. Then, the freight forwarder will make the arrangements to lodge in the cargo into the air cargo terminals.

Step 2

The freight forwarder arrives at the terminal cargo acceptance counter with all the necessary documents. The documents are handed in to the acceptance counter before the freight forwarder is called to handover the physical cargo to the terminal.

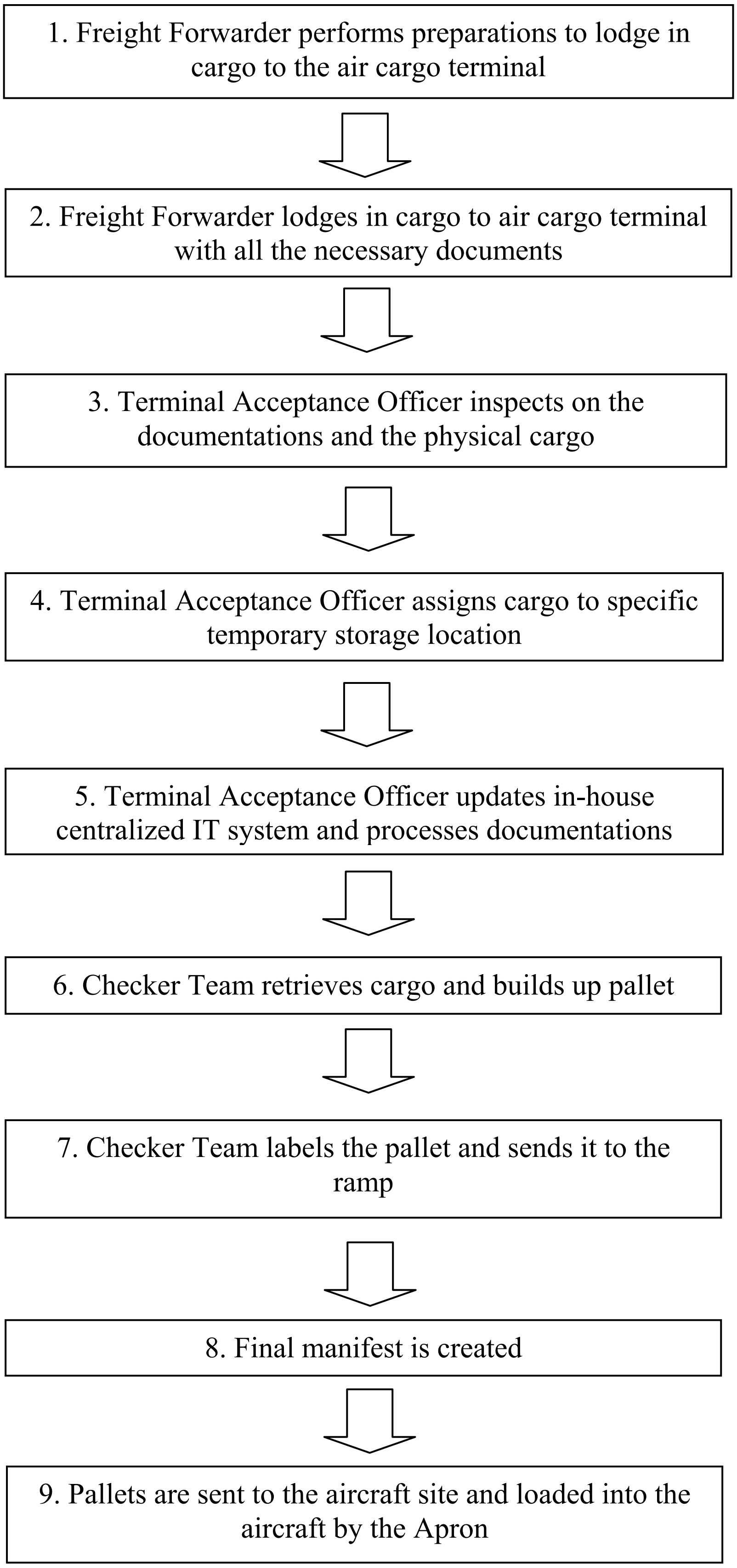

Figure 1.3: Export process flow for physical cargo.

Step 3

The Acceptance Officer on duty will process these documents before accepting the cargoes. Documentation processing steps include confirming the booking status of cargoes, checking all the declared information/details, updating the internal system with complete details and collecting handling charges (if any). The forwarder is then asked to move the cargoes to the weighing machine in order to perform a final check on the cargoes' measurements declared on the Airway Bills (AWBs).

Step 4

After the Acceptance Officer's inspection on the physical cargo and making sure that all the documentations are correct, he will direct the workers to store the cargo in the respective storage area. To date, the terminal has some policies to direct the cargoes to different locations. First of all, if the cargo is for the freighter flight, it will be directed to the freighter team section which is separated from the passenger flight section. As the freighter flight's cargo is being handled by a separate team, it is not under the scope of this study.

Secondly, if the cargo is for the passenger flight, the Acceptance Officer will decide if it should be directed to the temporary storage areas or sent to the build-up workstation within the passenger flight section. The normal guideline is, unless being specified by the Checking Team, to send the cargo with the flight's ETD (Estimated Time of Departure) less then a stipulated hours, say x hours from the time of acceptance to the build-up workstation, while the cargo for the flight with ETD more than x hours from the acceptance time will be sent to the temporary storage locations depending on the cargo's attribute. The following are the different storage locations:

1. Floor Good (FG) – for cargo on skid and/or too big to be stored in the ASRS bin.
2. ASRS (bin) – for loose and medium size cargo, currently based on the First-in-first-fit rule to fill up the bins.
3. Cold Room (CR) – for loose perishable cargo.
4. Refrigerated Queue-Lane (RQL) – for palletized perishable cargo.
5. Vulnerable cargo (VC) area – for easily damaged or valuable cargo (but not too high value).
6. Carousel (CC) area – for small size cargo.
7. Valuable cargo (VAL) area– for highly valuable cargo.
8. Pallet Container Holding Systems (PCHS) – for palletized general cargo (normally being lodged in at a separate counter).
9. Dangerous Goods (DGR) area– for any dangerous cargo specified by the authority.
10. Livestock (AVI) area– for any live animals.

Step 5

The Acceptance Officer will record the cargo locations and update into the in-house centralized IT system for cargo track and trace purposes. This task is required for cargo tracking. Meanwhile, all the documents of the cargoes will be sorted according to the destination and placed into the respective mailboxes. The freight forwarder usually will send a pre-notification note to the receiver site to alert them on the expected arrival time for special cargo after being lodged in.

Step 6

The Checking Team will start the build-up activity when it is close to the flight departure time. Usually, different terminals would have different guidelines on the exact hour to start this activity.

Basically, the Checking Team needs to handle cargoes coming from two different channels. One of them is the local export where the cargo agents lodge in the cargo at the air cargo terminal, and an Acceptance Officer will attend to the cargo agents to accept the cargo as described earlier. Another channel is the transshipment cargo where the cargo is brought in from an overseas airport and being processed by the import Checking Teams at the import terminal before sending it over to the export terminal to be exported to the final destination. Ideally, the transshipment cargo will be placed at the respective temporary storage area at the export terminal as mentioned in the previous steps. Due to the short flight connecting time and hence the cargo may be needed urgently by the export Checking Team, it is often that the export Checking Team members have to search for the cargoes at the import terminal cargo break bulk workstations.

Next, the cargo's location (the pallet or container number) after being palletized, will be recorded by the Checking Team during the build-up for tracking purposes. The information will then be updated into the in-house centralized IT system upon completion of the build-up.

Step 7

A label or tag will be tagged on the palletized cargo once the Checking Team completes the build-up for one pallet or container. The weight of the whole pallet or container will be taken and updated into the in-house centralized IT system too. The operator at the ramp site will then pull the pallet/container to the Queue-lane waiting to be towed to the aircraft pre-loading area.

Step 8

The cargo manifest is being revised during the process until the completion of all the build-up activities for a particular flight. A manifest is a master list of all the cargoes being loaded into a particular flight. It usually contains the AWB number, the number of packages per AWB, the description of the goods, the cargo weight, and the cargo's origin and destination. The final manifest will be finalized and printed approximately t_1 hours for passenger flights and t_2 hours for freighter flights before the flight departure. All the related documents will be gathered and matched against the final manifest and put into a big envelope. The envelope is called the pouch. The pouch will be sent to the station at the Queue-lane once it is completed.

Step 9

At the same time, the dead load weight statement will be finalized and the load sheet department will start to work on the cargo plan, namely the load sheet, which indicates the pallet location in the aircraft. The aircraft guidelines such as aircraft type, limitation/criteria for certain aircraft, airline specifications, weather condition, forward/aft (front or tail of the aircraft) and zone limit must be followed during the planning process.

The master loader and the Apron will analyze the cargo plan and starts on the loading activity t_3 hour before the flight departure. Normally, the pallet-loading task will be completed a few minutes before the departure time. This task is followed by loading of loose cargoes (cargoes that are not palletized), mails, and passengers' baggages, which will be completed around 5 minutes before the departure time.

Chapter 2

Storage and Retrieval Operations of Loose Cargo

2.1 Introduction

Since the general loose cargoes handled by the air cargo terminals are usually largely varied in sizes, many air cargo terminals are equipped with three main automated storage systems, namely:

1. Unit load storage for palletized cargoes or ULD
2. Regular-size storage for loose cargoes
3. Mini-load storage for small-size cargoes or mails.

Generally, small-size cargoes do not require much handling partly due to the size as well as the volume and weight of the small-size cargoes; while cargoes lodged in as palletized or ULD form are much preferred by the terminal operators as they simplify the handling process. On the other hand, the medium-size loose cargoes require much more manpower in the handling process.

For airports with limited space, automated storage/retrieval systems (ASRS) are common storage systems used for storing the medium-size loose cargoes. A medium-size loose cargo, if lodged in early, has to be placed in an ASRS to be stored temporarily, and later to be retrieved for palletization with other loose cargoes. However, loose cargoes come in various sizes and may be bulky. The normal unit load ASRS systems are not efficient in handling products of non-uniform sizes. The storage slot would need to be big enough to accommodate the largest size of the loose cargoes. To maximize the usage of storage space, standard-size bins are usually designed to contain these loose cargoes in the air cargo terminals. These bins have large dimensions and are heavy, and have the capacity to store several pieces of loose cargoes. A picture of the bin being carried by a forklift is shown in Appendix A.

Due to operational and space constraints, a forklift is required to move the bins between the acceptance area (receiving area where loose cargoes are lodged in) and the ASRS input/output points to make space for arriving cargoes. As frequent retrieval and storage requests from the ASRS will cause traffic congestion and potential hazard especially when the volume of the loose cargoes lodged in is high, it is therefore preferred to have the bins filled to its capacity before they are sent back to the ASRS.

Ideally, the operational policy for cargo storage should have features such as fast acceptance, fast retrieval, less movements for storage and retrieval, less sorting and shorter turnaround time for the bins. Unfortunately, these desirable features do not coexist. For example, a fast acceptance policy being practiced by an international air cargo terminal operator is to store the incoming cargo in bins according to the first-come-first-fit rule. Conceivably, this policy will lead to a time consuming and labor intensive sorting and retrieval at a later time.

At the other extreme end where sorting is eliminated, another policy being practiced by another international air cargo terminal operator, is to store each piece of cargo in a dedicated bin. Clearly, a lot of movements and bins are required for this policy, and it is pragmatic only when the volume of medium-size loose cargoes handled is not very large. In order to develop a good policy for storage and retrieval, it is essential that desirable features related to handling can be measured quantitatively.

In this chapter, given that a storage system such as ASRS had been installed, the focus is on the storage policies to assign the cargoes to the bins rather than the storage locations in the system. To avoid congestion at the receiving area and to maximize the storage utilization, it is preferred that bins are filled up to capacity before they are sent back to the ASRS. The decisions on assigning cargoes to bins at the acceptance/receiving area become important as they will subsequently affect the amount of handling needed to retrieve the cargoes. Due to the nontrivial effort required to handle the bins, the number of handling and not the travel time becomes a more pertinent measure of the productivity.

Intuitively, it is preferred to assign all cargoes of a particular flight to the same bins. However, this practice may not be feasible, as it would require a large acceptance area to hold the bins for the respective flights. Therefore a practical and fair policy is to receive cargoes on the principle of first-come-first-serve, in which incoming cargoes are stored in the first available bin until it is full. This is indeed practiced by an international airport observed during the course of study. In this work, the attempt is to evaluate this fast acceptance policy statistically. In particular, the average number of bins required to be handled during the retrieval and storage process and its average cycle time of a bin in the storage system are measured. The cycle time defined here is the amount of time a bin stays in the system before being emptied and released for new cargoes. This is a quantitative measure for the bin or storage space utilization. Good policies in terms of less average number of bins that are required to be handled and shorter average cycle time, which does not compromise much on the simplicity of acceptance, are also proposed. The methodology proposed is generic and can be applied to other air cargo terminals based on the observations of several international cargo terminals.

This chapter is organized as follows. A review of some previous related works in literatures can be found in Section 2.2. In Section 2.3, the current storage policy being used at the air cargo terminal observed is reviewed. The proposed new policies are introduced in Section 2.4 and in addition, a methodology to evaluate the performance of these policies is presented. Section 2.5 provides a comparison study via simulation on the performance of the current storage policy against the proposed new policies.

2.2 Literature Review

The area of planning and control of automated warehousing systems has received considerable attention in the last three decades with recent emphasis on developing a fast order picking system that can achieve a short response time. A recent survey paper by Berg (1999) provided a comprehensive review on the planning and control techniques employed such as storage assignment policies, routing, sequencing, scheduling and order batching. An area that is related to the problem being discussed here is storage assignment policies. Generally, most of these works are done to determine the strategic storage locations where the respective products are to be stored such that the total distance to pick orders can be minimized on average. These references will be discussed in further detail in the following.

Warehousing involves all movements of goods within the warehouse premises such as receiving, storage, order-picking, accumulation, sorting and shipping. Hausman et al. (1976), Graves et al. (1977) and Schwarz et al. (1978) were amongst the earliest to introduce the new research topics in automatic warehousing systems since this was the era that management interest shifted from productivity improvement to inventory reduction in 1970s. A substantial research had been done on warehouse planning and control over the past decades according to Berg (1999). However, there are only limited literatures found on automated warehousing for air cargo terminals. Oudheusden and Boey (1994) presented a case study on the design of Thai Airways Cargo Terminal. They presented a mathematical model based on a general model formulated by Ashayeri, et al. (1985) trying to minimize the total cost of the storage system. The optimal design with certain flexibility for growth in the throughput rate was found.

One the other hand, Luk (1990) presented a simulation model built by using Automod II attempting to imitate the Hong Kong Air Cargo Terminals Limited (HACTL) Terminal II. Models were built for both the Bulk Storage System (BSS) and Container Storage System (CSS). The simulation models were built to help the planning team model the complex distribution and storage system quickly, accurately and in a cheaper way. The models helped them to identify design deficiencies early in the design stage when correction was easily and inexpensively accomplished.

Since there are not many literatures found which is related to the automated warehousing in the air cargo terminal while most of the literatures found are done on warehouse planning and control, the following two sections discuss the works done on these two areas in details.

2.2.1 Warehouse Planning

Warehouse planning usually refers to the storage location assignment problem. Storage assignment policy is developed to match the incoming products with available storage location. Often, the objectives of the storage assignment problems are to minimize the material handling costs or maximize the throughput, or minimize the inventory holding costs and reordering costs. Hausmann et al. (1976) introduced the class-based turnover assignment rule. In their study, racks and pallets were clustered into *k* classes based on the one-way travel time and turnover respectively. Pallets with the highest turnover were assigned closest to the Input/Output (I/O) point while pallets with the lowest turnover were assigned further to the I/O point. This is a good way to reduce the overall travel time by partitioning the storage system according to the turnover rate; however, it may not be an optimal solution.

Hackman and Rosenblatt (1990) developed a heuristic procedure to solve the ASRS assignment/ allocation problem. The heuristic was to maximize the profit and they proved that it actually outperformed the ranking methods based on the number of requests, which was similar to Hausmann et al.'s (1976) approach. Oudheusden and Tzen (1988) pointed out that the space utilization was essential for analyzing storage policies. They also recommended a graphical "clustering" method by making use of the "ABC" demand curve to solve the problem since the optimal design of the classes cannot be easily achieved by minimizing the analytical model of expected travel time.

It is commonly known that certain products in a warehouse are often ordered together and such products are referred to as correlated products. Intuitively, clustering or storing the correlated product close to each other will help to reduce the travel time. Frazelle and Sharp (1989) presented a simple rule to determine the product correlations from a given order set. A simulation study of a mini-load ASRS where correlated products were stored together in the same bin was performed. The results showed that there was a reduction of 30% to 40% in the required retrievals compared to the random assignment policy. Rosenwein (1994) also showed that clustering the items that tend to be ordered together would reduce the total distance traveled; hence, the picking effort. This clustering problem was formulated as a p-median 0-1 integer program. The objective function was to select the p items as medians such that the sum of the distances from all the items within the cluster to the median was minimized. Compared to the random clustering strategy, the new clustering strategy could save approximately 14% of the total expected travel distance.

Goetschalckx and Ratliff (1990) showed that in contrast with the dedicated storage policy, the shared storage policies that were based on the duration of the stay of the unit load required much less travel time and rack space. Accordingly, for a perfectly balanced system, defined as a system where the number of departing units that had the duration of stay of p was equal to the number of arriving units that had a duration of stay of p for all p, the optimal shared storage policy was to establish a storage zone of size z_p for units that had a duration of stay equaled to p. Even though it seemed very unlikely to develop optimal policies for general shared storage systems, they believed that the shared storage policies generally required less space than dedicated storage policies and resulting in the reduction in travel times.

2.2.2 Warehouse Control

Warehouse planning provides a framework on ways to store items within the storage system. While control of warehouse operations concerns the actual sequencing, scheduling and routing of the movement of the goods, order picking for an ASRS involves determining a sequence to visit one or more locations where each item is stored within the storage systems. Elsayed (1981) studied the algorithms for optimal order picking in an automated warehousing system. Hwang et al. (1988) studied the way to pick up the items ordered from the ASRS by listing all the orders to be picked, separated them into tours and solved it as a traveling salesman problem (TSP). Daniels et al. (1998) formulated a model that simultaneously determined the assignment location and sequence that minimized the total cost of fulfilling order requirements.

On the other hand, Graves et al. (1977) and Schwarz et al. (1978) developed a deterministic model to study the combined effect of interleaving, storage assignment, and job sequencing. Han et al. (1987) proposed a “nearest-neighbor” sequencing rule to improve the throughput capacity of a unit load ASRS. Lee and Kim (1995) considered the scheduling problem under a JIT environment with dual-command operation. Bozer and White (1984) studied the alternative I/O locations, various dwell point strategies and the travel time models for the ASRS. Various studies had been done on travel time models since then trying to improve the storage (Elsayed et al. (1989), Sarker et al. (1995), Chew et al. (1999) and Wen et al. (2001)). Egbelu (1991) provided a framework for dynamic dwell points of storage/retrieval machines. The problem was solved by linear programming with the objective of minimizing the service response time in an ASRS. Muralidharan et al. (1995) introduced a shuffling strategy by combining both the class-based and random storage assignment policies. The random storage assignment policy was employed at the beginning and the items were then shuffled and relocated within the storage systems according to the class-based policy whenever the storage/retrieval machines were idle.

2.3 Current Practice

A recent study was conducted to observe the existing storage and retrieval operations of loose cargoes in one of the leading international airports. The physical flow of the process is briefly described here.

The air cargo terminal provides a 24-hour free storage before the Estimated Time of Departure (ETD) for all the outbound cargoes. There is a tendency that customers lodge in their cargoes much earlier than the flight departure time. Cargoes that arrive as loose cargoes may need to be palletized. For those cargoes that are lodged in early, they will be stored at the ASRS systems. A cutoff time which is 4 hours from ETD is set such that cargoes being lodged in before the cutoff time are stored in the ASRS while cargoes being lodged in after the cut-off time will be directed to the built-up area for palletizing. Eventually all the cargoes stored in the ASRS will need to be retrieved for palletization.

Historical data on the cargo lodge in times over a week were collected from a major freight forwarder and plotted into a histogram shown in Figure 2.1. The horizontal axis (x-axis) indicates the time the cargoes stay in the terminal, which is the duration from the time when loose cargoes are accepted by the terminal operator to the time when the cargoes are uplifted by carriers. The vertical-axis (y-axis) in the figure indicates the number of cargoes while the vertical line cutting through the histogram indicates the 4 hours cut-off time before the ETD. From Figure 2.1, it is shown that the cargo arrival density follows a triangular distribution.

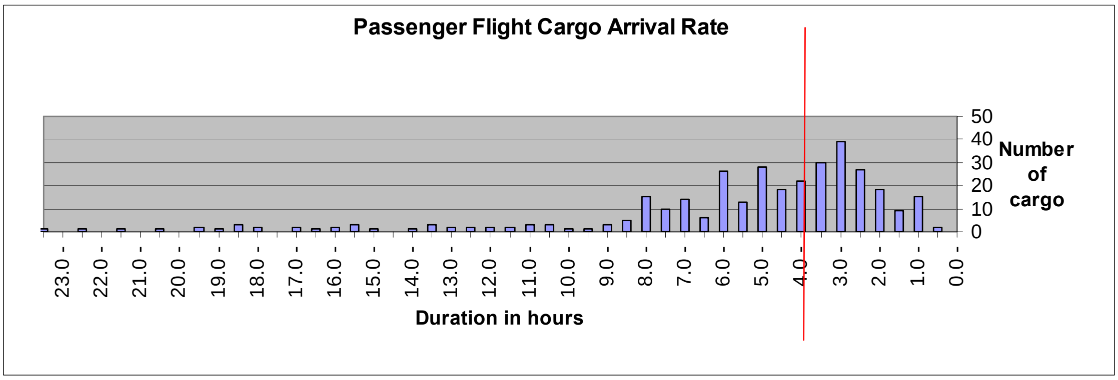

Figure 2.1: Cargoes lodged in for passenger flight.

2.3.1 Current Policy

The process of storing the loose cargoes is as follows: For those cargoes received before the cut-off time, the cargoes will be put on a first-come-first-fit basis into a standard sized bin specially designed to fit into the racks of the ASRS systems. Once the bin is full, it is placed back to the ASRS by a forklift and it is replaced by an empty bin to store the next arriving cargoes. With this, cargoes of different flights are mixed together. The reason for this practice is to reduce congestion at the receiving area and to maximize the storage utilization because of space limitation and the high volume of loose cargoes received daily.

To retrieve the cargoes from the ASRS, picklists are generated at every four hours. The picklist would contain information of loose cargoes which belong to flights departing within the next 12 hours. The reason for the 4-hour interval is because information on new arrivals of cargoes is only updated in batches due to the limitation on the terminal's computer system. In order to meet the tight departure schedule due to the constraint of the ASRS retrieval time, dedicated teams, known as the Retrieval Teams, are used to do the picking of the loose cargoes from the bins stored in the ASRS based on the picking list and to do the sorting on cargoes according to the flight numbers. Once these tasks are completed, the teams will hand the cargoes over to the other teams, called the Checking Teams. The Checking Teams are responsible for palletizing cargoes, and also for retrieving the remaining cargoes from the ASRS that the Retrieval Teams have not been able to pick. In this study, we would like to evaluate the work content of the Retrieval Teams. It is observed that each time a Retrieval Team retrieves a cargo from a bin, the team will search and take out the particular cargo from the bin. The bin will be placed back to the ASRS for the subsequent retrieval if it is not completely empty. Otherwise, it will be released to the pool of empty bins to be used to receive new cargoes.

Since the cargoes could be lodged in to the terminal at any time within the 24-hour time window before the flight departure, and the bins are filled based on the first-come-first-fit rule, there is a high chance where a bin might contain cargoes for different flights with large differences of as much as 20 hours in their departure times. This will result having the same bin to be retrieved a few times since the picking list would only contain flights departing within the next 12 hours. Clearly the amount of works and movements involved in the retrieval process is proportional to the number of times each bin is being called out and the bin cycle time is proportional to the cargo dwelling time in the bin. To illustrate, Figure 2.2 depicts a snapshot of the cargo arrivals of five flights which are departing at different times. It is worthwhile to mention that since the first cargo of a flight may arrive as early as 24 hours before the ETD while the last cargo to be accepted must be at least 4 hours before the ETD, the cargoes for each flight is assumed to arrive over a 20-hour time span. It is obvious that the bins used to store cargoes which arrive between 1600hours and 2000hours of Day 1 may have a mixture of cargoes which are supposed to be retrieved at different times due to the different flight departure times. The bin shown in Figure 2.2 shows the bin contains cargoes appearing on four different retrieval lists, which means this bin will be handled four times before it is released back to the empty bin pool for new cargoes. The duration of the bin being filled with the first piece of cargo until it is emptied and released back to the empty bin pool is the bin cycle time or dwell time. The terminal ASRS capacity is highly dependent on the bin cycle time as the longer the bin cycle time is, the lower the ASRS capacity will be.

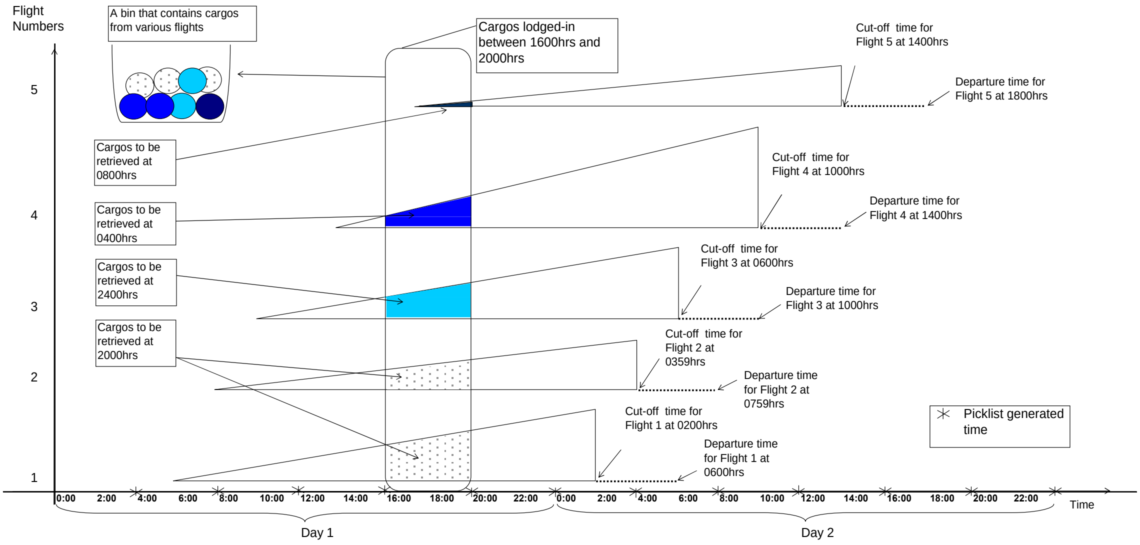

Figure 2.2: A snapshot of cargoes arrivals.

If we examine the current policy, the strategy used for storing loose cargoes is very much like a random strategy. It is known in warehouse literature that such policy is usually inefficient, and in our case, the current policy may generate large amount of retrievals. Hence we would like to find an alternative storage strategy that would help reduced the number of retrievals. As given in the example, the number of times a bin has to be retrieved depends on the number of retrieval lists its cargoes belong to. To reduce the number of retrievals, we want to cut down the probability of cargoes that fall on too many retrieval lists. One way is to force the maximum possible number of retrieval lists to which a bin's cargoes belong to be small. This condition can be created by clustering the flight departure times into several time windows, where each bin is dedicated to each time window. To retain the simplicity of implementation and to work within the space limit, cargoes arriving within a group of flights belonging to a time window are still filled on a first come first served basis similar to the current policy. Having different time windows, the range of the flight departure times within a time window will be smaller compared to the current policy without any time window and this will help to reduce the maximum possible number of retrieval lists a bin's cargoes can belong to. This idea of clustering the flight departure times is to increase the probability that if one loose cargo is picked at one bin, then the other cargoes in the same bin will also be picked. This will reduce the average number of times a bin has to be retrieved compared to the current policy.

To implement such a policy, the cargo terminal would have to keep a few bins at the receiving docks that are dedicated to store cargoes belonging to different time windows. It is not apparent what would be the amount of improvement on the terminal operation by requiring the extra effort in clustering the cargoes and additional space for placing the bins at the receiving dock. In the warehouse planning literature, these types of studies were only done through simulation due to its complexity and stochastic variability (Frazelle and Sharp (1989)). To gain insight on the magnitude of improvement to weigh against the tradeoff, a few assumptions on the cargo arrival distribution and the cargo size are first made so as to allow us to establish a closed form to evaluate the expected number of times a bin needs to be retrieved and the bin's expected cycle time. These two performance measurements are then compared between the current policy and the proposed clustering policy. To extend the comparison to the actual scenario, a simulation study is further carried out in which the simplified assumptions are removed.

The simplified assumptions being used for the analytical study are listed below.

Assumptions:

1. All flights have the same cargo arrival rate before the cut-off time, which has a triangular shape with a uniform increment of one cargo in every two hours.
2. During the two-hour interval (just before the cargo arrival rate increases), cargoes arrive randomly and independently of the flights.
3. Bins used to store cargoes that arrive during the two-hour interval are fully filled before sending back to the ASRS.
4. A flight will depart at every two hours.
5. All cargoes are of the same size.
6. Each bin can store 5 cargoes.

2.3.2 Analytical Approach of the Current Policy

For illustration, Figure 2.3 gives a slice of the cargo arrival pattern before the cut-off time for a forty-hour interval.

As implied from Assumption 1, the total number of cargoes arriving before the cut-off time for any flight is 10(1+10)/2 or 55 pieces. To evaluate the amount of work and movements required by the Retrieval Teams, it suffices to count the expected number of bins that have to be handled in order to retrieve the cargoes lodged in during any four-hour interval as the same pattern repeats itself. For example, it suffices to count the number of bins that need to be called out to retrieve cargoes lodged in at the 24th hour to the end of the 25th hour, and at the 26th hour to the end of the 27th hour, where the retrieval list is generated at the 28th hour and each of the two intervals has 55 pieces of cargoes and these cargoes are stored in exactly (55/5) = 11 bins. It is worth while to point out that in actual practice the last 10 pieces of cargoes belonging to flight f_4 are retrieved at the 26th hour on an urgent basis as flight f_4 is supposed to take off at the 30th hour. To simplify the presentation they are treated as part of the Retrieval Team's work at the 28th hour.

Consider the interval at the 26th hour to the end of the 27th hour. These cargoes can be classified into four categories. The first category contains cargoes belonging to flights f_5 to f_9, which are departing within the next 12 hours. The second category contains cargoes belonging to flights f_{10} and f_{11}, which are departing in the next 12 to 16 hours. The third category contains cargoes belonging to flights f_{12} and f_{13}, which are departing in the next 16 to 20 hours. The fourth category contains cargoes belonging to flight f_{14}, which is departing in the next 20 to 24 hours. The number of times a bin needs to be called out is determined by the number of categories of cargoes that it contains. For instance, a bin containing only cargoes from categories 1 and 2 has to be called out during the retrieval time starting at the 28th hour. After the retrieval, the bin will be placed back to the ASRS and to be called out again during the retrieval time starting at the 32nd hour.

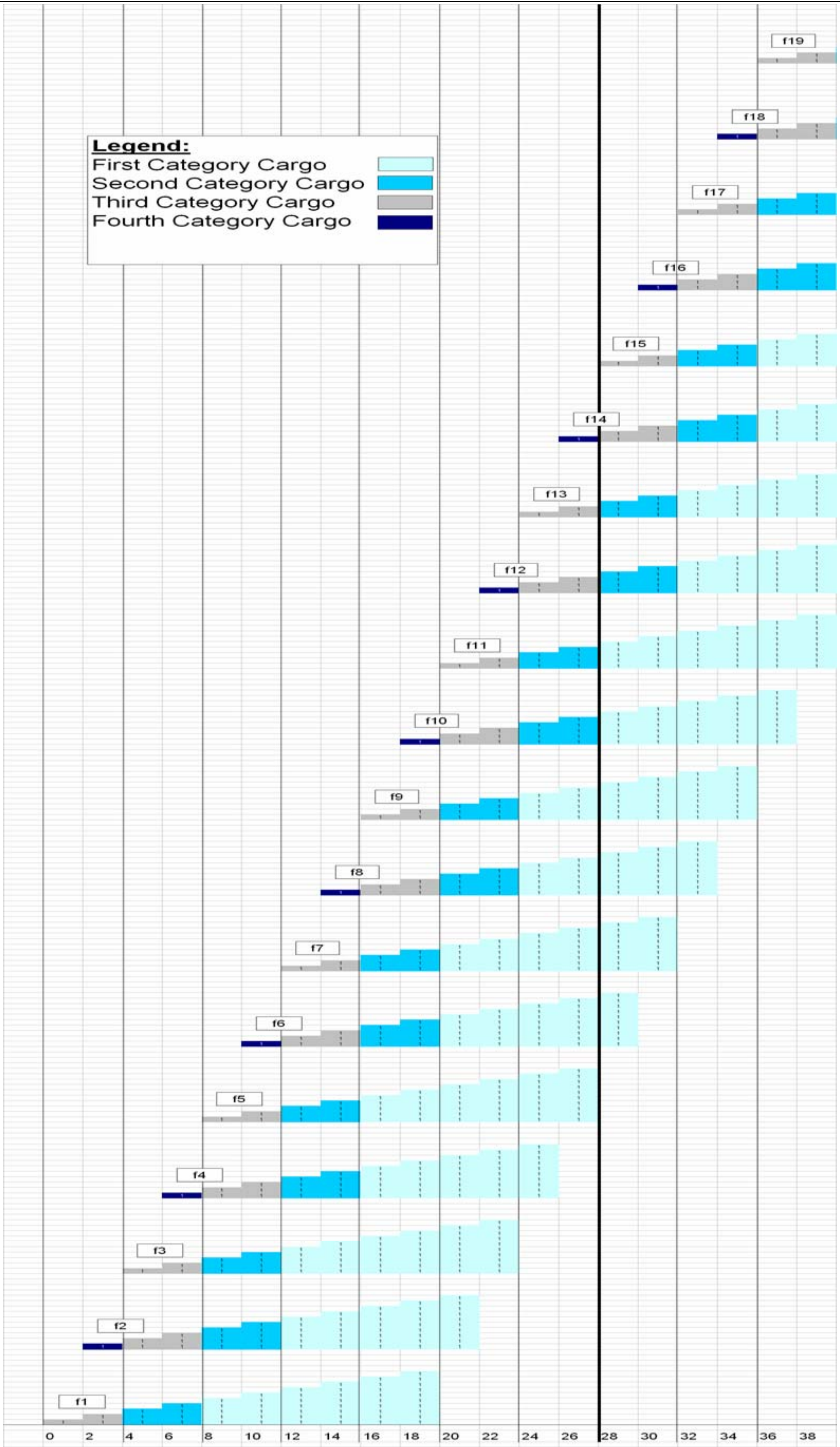

Figure 2.3: Cargo arrival pattern

Assumption 2 allows us to formulate the problem as follows: The cargoes in the first bin are the first five cargoes randomly selected from the 55 cargoes without replacement and the cargoes in the second bin are the next five cargoes randomly selected without replacement from the remaining 50 cargoes, and so on until the last bin (the eleventh bin) is filled. Consider the *n*th bin where a sample size of 5 is to be randomly chosen without replacement from a population of 55 – 5(n-1) cargoes and each cargo picked can belong to any of the four categories. Then the numbers of cargoes associated with the respective categories found in the *n*th bin follow a 4-dimensional hypergeometric distribution. Hence, the numbers of cargoes associated with the respective categories in the 11 bins follow a joint 44-dimensional hypergeometric distribution. In other words, if X_{ij} is the number of cargoes of category i stored in bin j, then

Prob ($X_{ij} = a_{ij}$ for i=1,2,3,4 and j=1,2,...,11) =

$$\frac{\binom{A_1}{a_{11}}\binom{A_2}{a_{21}}\cdots\binom{A_4}{a_{41}}}{\binom{A_1+A_2+A_3+A_4}{v}} \times \frac{\binom{A_1-a_{11}}{a_{12}}\binom{A_2-a_{21}}{a_{22}}\cdots\binom{A_4-a_{41}}{a_{42}}}{\binom{A_1+A_2+A_3+A_4-v}{v}} \times\cdots\times$$

$$\frac{\binom{A_1-a_{11}-\cdots-a_{1,j-1}}{a_{1j}}\binom{A_2-a_{21}-\cdots-a_{2,j-1}}{a_{2j}}\cdots\binom{A_4-a_{41}-\cdots-a_{4,j-1}}{a_{4j}}}{\binom{A_1+A_2+A_3+A_4-(j-1)v}{v}} \times\cdots\times$$

$$\frac{\binom{A_1-a_{11}-\cdots-a_{1,9}}{a_{1,10}}\binom{A_2-a_{21}-\cdots-a_{2,9}}{a_{2,10}}\cdots\binom{A_4-a_{41}-\cdots-a_{4,9}}{a_{410}}}{\binom{A_1+A_2+A_3+A_4-9v}{v}} \times 1 \tag{2.1}$$

where,

a_{ij} = number of cargoes of category i in bin j.

$$\sum_{j=1}^{11} a_{ij} = A_i \text{, for } i = 1,2,3,4,\ A_1=40, A_2=9, A_3=5, A_4=1. \tag{2.2}$$

$$\sum_{i=1}^{4} a_{ij} = v = 5 \text{, for } j=1,2,\ldots,11 \tag{2.3}$$

$a_{ij} \geq 0$, for $i = 1,2,\ldots,4$ and $j = 1,2\ldots,11$

With this known distribution, the expected number of categories found in each bin and the average cycle time before a bin becomes empty can be computed. However, a joint multi-dimensional hypergeometric distribution is more difficult to evaluate compared to the joint multi-dimensional binomial distribution since the former has the cargoes randomly selected from a population size that is different from one bin to the next bin. Furthermore, the population sizes between the bins are dependent (not IID). Because of the different population sizes and the dependency between the bins, it is not obvious that the marginal distribution of each bin can be evaluated easily. However, it turns out as shown in Theorem 2.1 that the marginal distribution of the numbers of cargoes found in the respective categories is the same for different bins.

Under assumptions 1 to 6 mentioned earlier, we have the following theorem.

Theorem 2.1. The marginal distribution of the k^{th} bin, k = 2,…,11, has the same marginal distribution as the first bin.

Proof of Theorem 2.1

By grouping the terms in expression (2.1) in their respective categories, the probability becomes

$$\left(\binom{A_1}{a_{11}}\binom{A_1-a_{11}}{a_{12}}\cdots\binom{A_1-a_{11}-\cdots-a_{1,k-1}}{a_{1k}}\cdots\binom{A_1-a_{11}-\cdots-a_{1,9}}{a_{1,10}}\binom{a_{1,11}}{a_{1,11}}\times\right.$$

$$\binom{A_2}{a_{21}}\binom{A_2-a_{21}}{a_{22}}\cdots\binom{A_2-a_{21}-\cdots-a_{2,k-1}}{a_{2k}}\cdots\binom{A_2-a_{21}-\cdots-a_{2,9}}{a_{2,10}}\binom{a_{2,11}}{a_{2,11}}\times\cdots\times$$

$$\left.\binom{A_4}{a_{41}}\binom{A_4-a_{41}}{a_{42}}\cdots\binom{A_4-a_{41}-\cdots-a_{4,k-1}}{a_{4k}}\cdots\binom{A_4-a_{41}-\cdots-a_{4,9}}{a_{4,10}}\binom{a_{4,11}}{a_{4,11}}\right)$$

$$\Bigg/\binom{A_1+A_2+A_3+A_4}{v}\cdots\binom{A_1+A_2+A_3+A_4-9v}{v}\binom{v}{v} \tag{2.4}$$

The above expression can be simplified to

$$\frac{\dfrac{A_1!}{a_{11}!\ldots a_{1k}!\ldots a_{1,11}!}\times\dfrac{A_2!}{a_{21}!\ldots a_{2,k}!\ldots a_{2,11}!}\times\cdots\times\dfrac{A_4!}{a_{41}!\ldots a_{4k}!\ldots a_{4,11}!}}{\dfrac{(A_1+A_2+\ldots+A_4)!}{(v!)^{11}}} \tag{2.5}$$

Rearranging the terms such that a_{ik} (i = 1,2,…,4) appears as the first term in the denominator of each respective category set, where

Pr($X_{ik} = a_{ik}$ for i=1,2,3,4 and $X_{ij} = a_{ij}$ for $j \neq k$, j=1,2,...,11 and i=1,2,3,4)

$$=\frac{\dfrac{A_1!}{a_{1k}!a_{11}!\ldots a_{1,11}!}\times\dfrac{A_2!}{a_{2k}!a_{21}!\ldots a_{2,11}!}\times\ldots\times\dfrac{A_4!}{a_{4k}!a_{41}!\ldots a_{4,11}!}}{\dfrac{(A_1+A_2+A_3+A_4)!}{(v!)^{11}}} \tag{2.6}$$

Therefore

Pr(X_{i1} = x_i for $i=1,2,\ldots,4$)

$$= \sum_{\substack{\sum_{s=1}^{4} a_{sj} = v \ \ for\ s=1,\ldots,4,\, j=2,\ldots,11, \\ a_{sj}\ge 0}} \Pr(X_{i1} = x_i \ \ and \ \ X_{sj} = a_{sj} \text{ for s} = 1,\ldots,4 \text{ and j } = 2,\ldots,11)$$

$$= \sum_{\substack{\sum_{s=1}^{4} a_{sj} = v \ \ for\ s=1,\ldots,4,\, j=1,\ldots,11,\, j\neq k \\ a_{sj}\ge 0}} \Pr(X_{ik} = x_i \ \ and \ \ X_{sj} = a_{sj} \text{ for s} = 1,\ldots,4 \text{ ; j } = 1,\ldots,11;\text{ j} \neq \text{k})$$

= Pr(X_{ik} = x_i for i=1,…,4)

And the marginal distribution of bin k has the same distribution as the first bin. ☐

Theorem 2.1 shows an interesting result. Namely, although the subsequent bin depends on the previous bins, the marginal distribution of the first bin can be used to compute the probability of any of the 11 bins containing cargoes of a given number of categories. In particular,

Pr (a bin contains exactly m categories out of a total of M categories)

$$= \sum_{1\le i_1 < i_2 < \ldots < i_m \le M} \Pr\left(exactly\{i_1, i_2, \cdots, i_m\}categories\right) \tag{2.7}$$

$$= \sum_{1\le i_1 < i_2 < \ldots < i_m \le M} \left(\sum_{\substack{(a_{i_1},\cdots,a_{i_m}), \\ a_{i_1}+\cdots+a_{i_m}=v, \\ a_{i_j}>0,\, j=1,\cdots,m}} \frac{\binom{A_{i_1}}{a_{i_1}}\binom{A_{i_2}}{a_{i_2}}\cdots\binom{A_{i_m}}{a_{i_m}}}{\binom{A_1+\cdots+A_M}{v}} \right) \tag{2.8}$$

In equation (2.8), a_{i_j} (j = 1,…,m) are required to be positive and their sum is equal to the bin capacity because the probability of a bin containing “exactly” m categories out of a total of M categories of cargoes is being considered. This probability can be computed by taking the difference of the probabilities of two

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events, i.e., the events that a bin contains at most m and m-1 categories respectively. This is listed in equation (2.9) below.

$$\sum_{1\le i_1<i_2<\ldots<i_m\le M}\Bigg(\sum_{\substack{\left(a_{i_1},\cdots,a_{i_m}\right),\\ a_{i_1}+\cdots+a_{i_m}=v,\\ a_{i_j}\ge 0,\, j=1,\cdots,m}}\frac{\binom{A_{i_1}}{a_{i_1}}\binom{A_{i_2}}{a_{i_2}}\cdots\binom{A_{i_m}}{a_{i_m}}}{\binom{A_1+\cdots+A_M}{v}}-\sum_{j=1}^{m}\sum_{\substack{\left(a_{i_1},\cdots,a_{i_m}\right),\\ a_{i_1}+\cdots+a_{i_m}=v,\\ a_{i_j}=0}}\frac{\binom{A_{i_1}}{a_{i_1}}\binom{A_{i_2}}{a_{i_2}}\cdots\binom{A_{i_m}}{a_{i_m}}}{\binom{A_1+\cdots+A_M}{v}}\Bigg) \tag{2.9}$$

Using the inclusion-exclusion principle, the following is found:

$$\begin{aligned}
&=\sum_{1\le i_1<i_2<\ldots<i_m\le M}\Bigg(\frac{\binom{A_{i_1}+\cdots+A_{i_m}}{v}}{\binom{A_1+\cdots+A_M}{v}}-\Bigg(\left(-1\right)^{1+1}\sum_{j=1}^{m}\sum_{i_1\le i_{j_1}\le i_m}\frac{\binom{A_{i_1}+\cdots+\hat{A}_{i_{j_1}}+\cdots+A_{i_m}}{v}}{\binom{A_1+\cdots+A_M}{v}}\\
&\quad+\left(-1\right)^{2+1}\sum_{j=1}^{m}\sum_{i_1\le i_{j_1}<i_{j_2}\le i_m}\frac{\binom{A_{i1}+\cdots+\hat{A}_{i_{j_1}}+\hat{A}_{i_{j_2}}+\cdots+A_{i_m}}{v}}{\binom{A_1+\cdots+A_M}{v}}\\
&\quad+\left(-1\right)^{3+1}\sum_{j=1}^{m}\sum_{i_1\le i_{j_1}<i_{j_2}<i_{j_3}\le i_m}\frac{\binom{A_{i1}+\cdots+\hat{A}_{i_{j_1}}+\hat{A}_{i_{j_2}}+\hat{A}_{i_{j_3}}+\cdots+A_{i_m}}{v}}{\binom{A_1+\cdots+A_M}{v}}+\cdots\\
&\quad+\left(-1\right)^{m}\sum_{j=1}^{m}\sum_{i_1\le i_{j_1}<\cdots<i_{j_{m-1}}\le i_m}\frac{\binom{A_{i1}+\cdots+\hat{A}_{i_{j_1}}+\cdots+\hat{A}_{i_{j_{m-1}}}+\cdots+A_{i_m}}{v}}{\binom{A_1+\cdots+A_M}{v}}\Bigg)\Bigg)
\end{aligned} \tag{2.10}$$

$$= \left[\sum_{1 \le i_1 < i_2 < \ldots < i_m \le M} \frac{\binom{A_{i_1} + \cdots + A_{i_m}}{v}}{\binom{\sum_{i=1}^{M} A_i}{v}} \right] - \left[\binom{M-(m-1)}{1} \sum_{1 \le i_1 < \cdots < i_{m-1} \le M} \frac{\binom{A_{i_1} + \cdots + A_{i_{m-1}}}{v}}{\binom{\sum_{i=1}^{M} A_i}{v}} \right.$$

$$\left. - \binom{M-(m-2)}{2} \sum_{1 \le i_1 < \cdots < i_{m-2} \le M} \frac{\binom{A_{i_1} + \cdots + A_{i_{m-2}}}{v}}{\binom{\sum_{i=1}^{M} A_i}{v}} + \cdots + \binom{M-1}{m-1} (-1)^m \sum_{j=1}^{M} \frac{\binom{A_j}{v}}{\binom{\sum_{i=1}^{M} A_i}{v}} \right] \qquad (2.11)$$

The expected number of handling can then be determined by multiplying the probability listed in equation (2.11) with the total number of bins required, N, and the number of categories a bin contains, m. That is,

Expected number of handling

$$= \sum_{m=1}^{M} \text{Pr(exactly } m \text{ out of a total of } M \text{ categories)} * N * m. \qquad (2.12)$$

Similarly, the expected number of handling during the 24th hour to the 26th hour can be computed from the same argument except that in this case it has only three categories of cargoes. Summing up the expected numbers of handling during the two intervals together, the expected number of handling during a four-hour interval is obtained. Denote this method as a 2-hour analysis since it is computed by summing up the expected number of handling at intervals of two hours.

It appears that the computation above is dependent on the cargo arrival pattern. That is, more intervals need to be considered for computing the expected number of handling if there are more changes in the cargo arrival rate within a repeating cycle and hence it seems more counting will be required. To simplify the counting, let us randomize the cargo arrivals between two retrievals. In other words, let us assume that given the total number of cargoes lodged in from all the flights between two retrieval times, each cargo is equally likely to be lodged in at any time during that interval. In the previous example, this means that all the 110 cargoes arriving during the 24th to the 28th hour will be placed randomly into 22 bins. Though this assumption deviates from the actual cargo arrival pattern between the retrieval times, the result turns out to be rather robust. Denote this method as a 4-hour analysis. Table 2.1 compares expected total numbers of handling per hour between the 4-hour analysis and the 2-hour analysis.

Table 2.1: Comparison of results between 2-hour analysis and 4-hour analysis

Total no. of cargoes between retrievals	**4-hour analysis**		**2-hour analysis**	
	Expected no. of handling/hr	**Cycle Time (hr)**	**Expected no. of handling/hr**	**Cycle Time (hr)**
110	10.538	6.521	10.58075	6.511

The result shows that the difference in the expected number of handling per hour between the 2-hour analysis and the 4-hour analysis is very marginal. To further confirm the results as well as to make the process more realistic, the analysis is broken down into smaller time intervals. Let us look at the 1-hour analysis where the expected number of handling per hour for each respective cargo arrival pattern that has a uniform increment of 1, 2, 4, 8 and 16 pieces of cargoes in every one hour is calculated. All other assumptions remain the same. Table 2.2 summarizes the expected numbers of handling per hour for the 1-hour analysis, 2-hour analysis, and 4-hour analysis respectively.

Table 2.2: Comparisons among the analytical results of the current policy based on 4-hour analysis, 2-hour analysis and 1-hour analysis.

Total no. of cargos between retrievals	4-hour analysis		2-hour analysis		1-hour analysis	
	Expected no of handling/hr	Cycle Time (hr)	Expected no of handling/hr	Cycle Time (hr)	Expected no of handling/hr	Cycle Time (hr)
420	39.210	6.248	39.153	6.198	39.280	6.197
840	78.350	6.242	78.168	6.185	78.283	6.169
1680	156.630	6.238	156.198	6.178	156.290	6.156
3360	313.190	6.237	312.258	6.175	312.310	6.149
6720	626.313	6.236	624.380	6.173	624.350	6.146

The results clearly indicate that the differences among them are negligible. Thus, the assumption of random arrival of cargoes between retrieval times is robust enough to be used for computing the expected number of handling when the actual cargo arrival is uniformly increasing with time.

To compute the average cycle time of a bin in the storage system, we first observe that the longest cycle time of a bin is 14 hours. This is because retrievals start at every four hours. To illustrate, the first cargo for flight f_4 is being lodged in around the 6th hour and it will only be retrieved starting at the 20th hour. It cannot be retrieved earlier as the Retrieval Team only retrieves the cargoes with departure time in the next 12 hours. Earlier on, this cargo is defined to be of the fourth category. It is clear that, among the four categories of cargoes, this category stays in the system with the longest time. The bin containing this cargo can be released for the acceptance of new cargoes only after it is retrieved which starts at 14 hours later. On the other hand, the 2nd to the 6th cargoes of the same flight will be retrieved starting at around 8 to 12 hours later as they are lodged in at the 8th to the end of 11th hour and will be retrieved starting at the 20th hour. These cargoes belong to the third category. Subsequently, the 7th to the 15th cargoes will be retrieved starting at around 4 to 8 hours later and these cargoes belong to the second category. Finally, cargoes of the first category are those being retrieved within the next 4 hours. To approximate the cycle time of a bin based on the 4-hours analysis, the followings are assumed:

- bin containing cargoes of category 4 will stay in the system for 14 hours.
- bin containing cargoes of category 3 and no cargoes from a higher category will stay in the system for 10 hours.
- bin containing cargoes of category 2 and no cargoes from a higher category will stay in the system for six hours.
- bin containing cargoes of category 1 only will stay in the system for two hours.

Then

Pr (a bin contains at least 1 cargo of category *m* and no cargoes from a higher category)

$$= \frac{\binom{A_1 + A_2 + \ldots + A_m}{v}}{\binom{A_1 + \cdots + A_M}{v}} - \frac{\binom{A_1 + A_2 + \ldots + A_{m-1}}{v}}{\binom{A_1 + \cdots + A_M}{v}} \tag{2.13}$$

Hence, the average cycle time of a bin in the storage system that contains cargoes with *M* categories is

$= \sum_{m=1}^{M}$ [Pr (a bin contains at least 1 cargo of category *m* and no cargoes from a higher category) $*((m * 4\text{hr}) - 2\text{hr})$] (2.14)

Table 2.1 shows the expected cycle times of a bin for the 2-hour analysis and the 4-hour analysis respectively while Table 2.2 shows the expected cycle times of a bin for the 1-hour analysis, 2-hour analysis and 4-hour analysis respectively. This time, different numbers of cargoes arrive between the retrievals are used and they are indicated in the first column of Table 2.2. Again, the differences in the expected cycle times are very marginal, indicating that the assumption of the random arrival of cargoes between retrieval times can be used as a good approximation for computing the average cycle time.

2.4 Time Zoning Strategy

New policies are proposed by dedicating the bins to store cargoes for flights departing in different time windows. For example, the 12-hour policy is to divide one whole day into two time windows or time zones, say midnight to noon and noon to midnight. Cargoes received belonging to flights departing in the two time zones are assigned to different types of bins. However, cargoes belonging to flights departing within the same time zone are assigned to a common type of bins based on a first-come-first-fit rule.

2.4.1 Analytical Approach of the Time Zoning Strategy

As a start, let us divide a 24-hour day into two consecutive time zones and name it 12-hour policy. For a 12-hour policy, a minimum of three bins is required to store the incoming cargoes as opposed to one bin for the current policy. Figure 2.4 shows the scenario when the 12-hour policy is implemented on the same example mentioned in Section 2.3 without changing the Retrieval Team's working schedule. In the new policy, all 110 pieces of cargoes arriving at the same time interval, say from the 24th to the 28th hour, are placed into three different types of bins. Bin Type 1 is to store the cargoes with flights departing from the 30th to the 36th hour. Bin Type 2 is to store cargoes with flights departing from the 36th hour to the 48th hour, and Bin Type 3 is to store cargoes with departing flights in the following 12 hours after the 48th hour. Since a spare bin may be required for the first two time zones respectively due to a higher cargo arrival rate, altogether five bins will be needed at the cargo acceptance area to receive new cargoes at the same time. The accepted cargoes are assigned to the respective types of bins on a first-come-first-fit basis depending on the time zones to which the flights of the cargoes belong. A bin will be placed back to the ASRS once it is full. The Retrieval Teams will begin to retrieve the cargoes belonging to flights that are departing within the next 12 hours at every four hour interval based on a pick list generated by the terminal computer system.

To illustrate, consider the 110 pieces of cargoes that arrive between the 24th to the 28th hour in Figure 2.4. 61 pieces of them belong to flights f_4 to f_7, which will be departing in the interval from the 30th to the 36th hour. They will be stored in the Type 1 bins. Since these flights are departing within the next 12 hours, the cargoes belonging to these flights are considered to be of category 1 and it is important to note that during this interval all the Type 1 bins contain cargoes of category 1 only. These bins will be retrieved only once since all the cargoes placed in them will be cleared at the time of retrieval. After the retrieval, these bins will be released back to the pool of empty bins to be used again for storing new arriving cargoes.

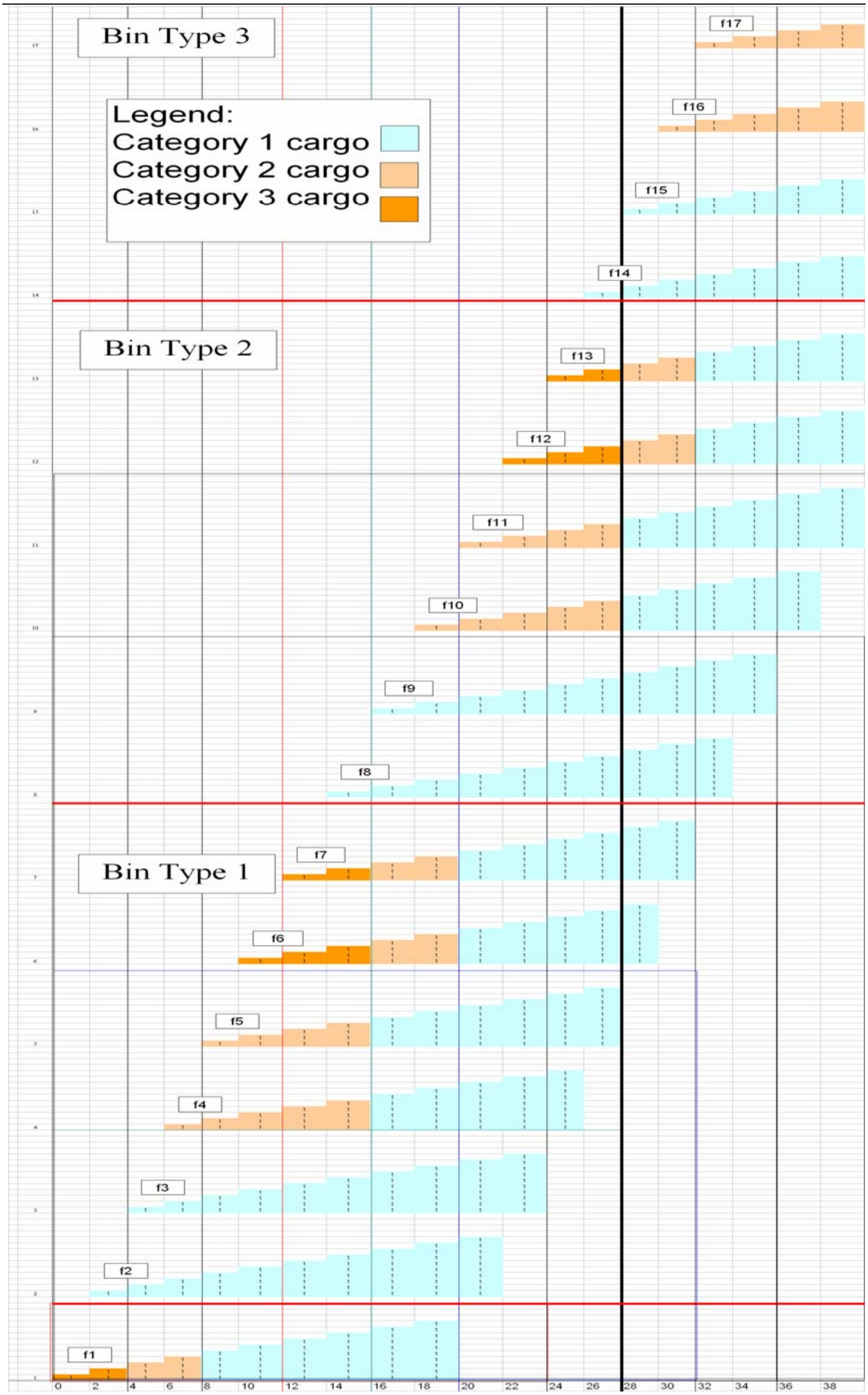


Figure 2.4: 12-hour policy cargo arrival distributions for each flight.

On the other hand, there are 48 pieces of cargoes that belong to flights f_8 to f_{13}. They will be stored in Type 2 bins. As before these cargoes can be classified into three categories. The first category contains cargoes belonging to flights f_8 and f_9, which are departing within the next 12 hours. The second category contains cargoes of flights f_{10} and f_{11} with the departing time in the next 12th to the 16th hour. The third category contains cargoes belonging to flights f_{12} and f_{13}, which will depart in the next 16th to the 20th hour. As explained earlier in the case of the current policy, the bins that contain cargoes of a pure category will be called out only once from the ASRS, whereas the bins containing cargoes of 2 categories will be retrieved twice and so on. Lastly, cargoes to be loaded into flight f_{14} will be placed in Type 3 bins. These cargoes will be retrieved when the team starts work at the 40th hour and onwards.

By dividing the 24-hour free storage time window evenly into two windows, the probability of having cargoes of fewer categories in a bin is higher, resulting in less handling. However, to implement this policy, more space will be needed to place these bins at the cargo acceptance area.

To evaluate the performance of this policy, more computations are required as the cargo category distribution repeats itself in every 12 hours and furthermore cargoes are segregated in three types of different bins. Equations (2.8) through (2.14) can be used as a basis for the evaluation provided that the expected numbers of handling and the estimated cycle times are computed separately for three consecutive time intervals of four hours and for the three types of bins. For the case depicted in Figure 2.4, time intervals from 20th to 24th hours, from 24th to 28th hours and from 28th to 32nd hours are considered for illustration purposes. As separate computation efforts are required for each of these time intervals of different bin types, they are divided into nine different segments and the nomenclatures of these segments are introduced below before moving on to the details:

Segment $B1^a$ = Time interval from 20th to 24th hours of Bin Type 1.
Segment $B1^b$ = Time interval from 24th to 28th hours of Bin Type 1.
Segment $B1^c$ = Time interval from 28th to 32nd hours of Bin Type 1.
Segment $B2^a$ = Time interval from 20th to 24th hours of Bin Type 2.
Segment $B2^b$ = Time interval from 24th to 28th hours of Bin Type 2.
Segment $B2^c$ = Time interval from 28th to 32nd hours of Bin Type 2.
Segment $B3^a$ = Time interval from 20th to 24th hours of Bin Type 3.
Segment $B3^b$ = Time interval from 24th to 28th hours of Bin Type 3.
Segment $B3^c$ = Time interval from 28th to 32nd hours of Bin Type 3.

First, the probability of exactly m out of M categories is calculated for each of the segments introduced above. The number of categories of cargo for each of the segments can be different. For instance M for Segment $B1^a$ and $B1^b$ equals 1 as there is only one category of cargoes within these segments. The same goes to M for Segment $B1^c$ which equals to 1. Similarly, for the cargoes of Bin Type 2, M for Segment $B2^a$ equals 3, M for Segment $B2^b$ equals 3 and M for Segment $B2^c$ equals 2. Lastly, as there is no cargo in Segments $B3^a$, this segment will not be considered in the computation. Segment $B3^b$ and Segment $B3^c$ are considered in this case where Ms for these two segments equal one and two respectively.

Next, the expected number of handling for each of these segments is calculated by using the expression (2.12). For instance, the total number of cargoes in Segment $B1^a$ is 85 pieces and the total number of bins, N, required for all these cargoes is $\lceil (85/5) \rceil = 17$, assuming a bin capacity of five pieces of cargoes. Hence, the expected number of handling for Segment $B1^a$, termed HT_B1^a is:

$$HT\_B1^a = \sum_{m=1}^{M} \Pr(\text{exactly } m \text{ out of a total of } M \text{ categories}) * N * m$$

$$= \sum_{m=1}^{1} \Pr(\text{exactly } m \text{ out of a total of 1 categories}) * 17 * m$$

The computations of the expected numbers of handling for the rest of the segments are done in the similar way. Then, the number of handling required for each time interval is obtained by summing up the expected numbers of handling from the respective time intervals. For instance, the expected number of handling for time interval from 20th to 24th hours, termed HT^a, will be

$$HT^a = HT\_B1^a + HT\_B2^a + HT\_B3^a \qquad (2.15)$$

In this case, $HT\_B3^a = 0$ as there is no cargo in this segment. The expected number of handling for time interval 24th to 28th hours, termed HT^b, will be

$$HT^b = HT\_B1^b + HT\_B2^b + HT\_B3^b \qquad (2.16)$$

Lastly, the expected number of handling for time interval 28th to 32nd hours, termed HT^c, will be

$$HT^c = HT\_B1^c + HT\_B2^c + HT\_B3^c \qquad (2.17)$$

The number of handling for the three time intervals, termed HT_{total}, is found by taking the sum, i.e.,

$$HT_{total} = HT^a + HT^b + HT^c \qquad (2.18)$$

Lastly, the expected total number of handling to retrieve the cargoes for each time interval, *HT*, is obtained by taking the simple average. In this case, it will be $HT_{total}/3$, as three time intervals are considered here.

The estimated cycle time of a bin can be computed through an almost similar method by first classifying the three consecutive time intervals with different bin types in nine segments mentioned earlier. Then, expression (2.13) is used to calculate the probability of a bin having at least one cargo of category *m* and no cargo from a higher category for each of the segments. Next, the average cycle time of a bin in the storage system for each segment can be found by using expression (2.14). Let us call the average cycle times for each of the nine segments as $AT\_\ B1^a$, $AT\_\ B1^b$, $AT\_\ B1^c$, $AT\_\ B2^a$, $AT\_\ B2^b$, $AT\_\ B2^c$, $AT\_\ B3^a$, $AT\_\ B3^b$ and $AT\_\ B3^c$ respectively. Then, the estimated cycle time of a bin for each time interval can be found by taking the weighted average. For example, the estimated cycle time of a bin for time interval from 20th to 24th hours, termed AT^a, can be found by the expression presented in the following:

$$\begin{aligned} AT^a = {} & \frac{\text{total number of cargoes in Segment } B1^a}{\text{total number of cargoes in Segments } B1^a, B2^a \text{ and } B3^a} * AT\_B1^a \\ & + \frac{\text{total number of cargoes in Segment } B2^a}{\text{total number of cargoes in Segments } B1^a, B2^a \text{ and } B3^a} * AT\_B2^a \\ & + \frac{\text{total number of cargoes in Segment } B3^a}{\text{total number of cargoes in Segments } B1^a, B2^a \text{ and } B3^a} * AT\_B3^a \qquad (2.19) \end{aligned}$$

Similarly, the estimated cycle time of a bin for time interval from 24th to 28th hours, termed AT^b, and the estimated cycle time of a bin for time interval from 28th to 32nd hours, termed AT^c, can be found by the expressions below:

$$AT^b = \frac{\text{total number of cargoes in Segment } B1^b}{\text{total number of cargoes in Segments } B1^b, B2^b \text{ and } B3^b} * AT\_B1^b$$

$$+ \frac{\text{total number of cargoes in Segment } B2^b}{\text{total number of cargoes in Segments } B1^b, B2^b \text{ and } B3^b} * AT\_B2^b$$

$$+ \frac{\text{total number of cargoes in Segment } B3^b}{\text{total number of cargoes in Segments } B1^b, B2^b \text{ and } B3^b} * AT\_B3^b \qquad (2.20)$$

$$AT^c = \frac{\text{total number of cargoes in Segment } B1^c}{\text{total number of cargoes in Segments } B1^c, B2^c \text{ and } B3^c} * AT\_B1^c$$

$$+ \frac{\text{total number of cargoes in Segment } B2^c}{\text{total number of cargoes in Segments } B1^c, B2^c \text{ and } B3^c} * AT\_B2^c$$

$$+ \frac{\text{total number of cargoes in Segment } B3^c}{\text{total number of cargoes in Segments } B1^c, B2^c \text{ and } B3^c} * AT\_B3^c \qquad (2.21)$$

Finally, the estimated cycle time per time interval, termed *AT*, is obtained by calculating the simple average from the three time intervals. Namely,

$$AT = (AT^a + AT^b + AT^c)/3 \qquad (2.22)$$

Likewise, an 8-hour policy or a 4-hour policy can be implemented, by dividing a 24-hour time window into three or four time zones respectively and the proposed methodology can be used to analyze these policies. However, to implement these two policies, a much larger area will have to be assigned in the acceptance area to house the needed bins.

2.5 Comparison Study by Simulation

In this section, the comparison study is complemented by performing a simulation for the 4 policies – the current policy, the 12-hour policy, the 8-hour policy and the 4-hour policy. Assumptions 1 and 2 are removed in the simulation. Instead, to reflect the realistic behavior of the problem, the cargo arrival density is assumed to follow a triangular distribution with the density starting at zero at 20 hours before the cut-off time and increasing uniformly to its peak at the cut-off time. Suppose ETD is the generated estimated time of a flight departure. Denote T_a as the time for an arrival of a loose cargo for this flight. Then it can be shown easily that T_a is generated from

$$T_a = ETD - 24 + 20\sqrt{U} \tag{2.23}$$

where U is a random number that lies between 0 and 1. Having ETD minus 24 is because cargoes start to arrive as early as 24 hour before ETD. The number of loose cargoes in a given flight, which is 55 for example, will determine the number of times that T_a have to be generated for each flight. Given the generated cargoes' arrival times of all the flights, these cargoes are assigned to the bins according to the respective policy used.

In addition, assumption 3 is also removed in the simulation where it is not necessary that the bins will be fully filled during the two-hour interval. A total of 1000 replications are run for this analysis. To avoid the transient states, each replication is run for nine full days, and only those cargoes arrive between the second to the eighth day are considered.

The results are presented in Table 2.3. For the analytical results, the same six assumptions are used except that the incremental rate is assumed to be one cargo per hour. For the simulation, to recap, the discreteness of a uniform increment is relaxed. In other words, cargoes of a given flight are assumed to arrive at a rate according to a continuous triangular distribution. Also due to the randomness of the cargo arrival times some of the bins may not be fully filled at each 4-hour retrieval time interval.

Table 2.3: Comparisons among the analytical results versus simulation results.

	Simulation				**Analytical**				**Difference in %**	
	No. of Handling/hr	**Ratio to Current Policy**	**Cycle Time**	**Ratio to Current Policy**	**No. of Handling/hr**	**Ratio to Current Policy**	**Cycle Time**	**Ratio to Current Policy**	**No. of Handling/hr**	**Cycle Time**
Current Policy	40.05	1.00	6.40	1.00	39.21	1.00	6.25	1.00	2.14%	2.40%
12-hr Policy	30.07	0.75	4.45	0.70	30.26	0.77	4.36	0.70	-0.63%	2.06%
8-hr Policy	26.65	0.67	3.82	0.60	26.67	0.68	3.85	0.62	-0.07%	-0.78%
4-hr Policy	21.00	0.52	2.00	0.31	21.00	0.54	2.00	0.32	0.00%	0.00%

It is observed that the simulation results are quite close to the analytical results especially on the estimated cycle times which have a deviation of less than 3%. The reduction of amount of handling over the current policy can be as high as 48% by implementing the new policies; while the cycle time reduction can be as high as 69%. These results show a significant improvement over the current policy.

To extend the analysis further, confidence interval is used to measure the significant difference between the analytical results and the simulation results. Two different α-values are set at 0.01 and 0.05 and the results are shown in Table 2.4 and Table 2.5 respectively.

Table 2.4: Confidence Interval analysis on number of handlings.

α=0.01						
Policy	**No. of Handling/hr (Simulation)**	**Std Dev**	**No. of Handling/hr (Analytical), μ_0**	**Lower Confidence Limit**	**Upper Confidence Limit**	**Reject /Accept**
Current Policy	40.05	11.4	39.21	39.21	40.89	Accept
12-hr policy	30.07	3.6	30.26	29.80	30.34	Accept
8-hr policy	26.65	0.25	26.67	26.63	26.67	Accept
4-hr policy	21.00	0.00	21.00	21.00	21.00	Accept
α=0.05						
Policy	**No. of Handling/hr (Simulation)**	**Std Dev**	**No. of Handling/hr (Analytical), μ_0**	**Lower Confidence Limit**	**Upper Confidence Limit**	**Reject /Accept**
Current Policy	40.05	11.4	39.21	39.34	40.76	Reject
12-hr policy	30.07	3.6	30.26	29.85	30.29	Accept
8-hr policy	26.65	0.25	26.67	26.63	26.67	Accept
4-hr policy	21.00	0.00	21.00	21.00	21.00	Accept

From the table above, it is shown that with a 99% confidence interval, all the number of handlings calculated analytically fall between the lower and upper confidence limits. However, the number of handlings of the current policy calculated analytically falls below the lower confidence limit when a 95% confidence interval is constructed. Let us take a look at the cycle time analysis.

Table 2.5: Confidence Interval analysis on cycle time.

α=0.01						
Policy	**Cycle Time in hr (Simulation)**	**Std Dev**	**Cycle Time in hr (Analytical), μ_0**	**Lower Confidence Limit**	**Upper Confidence Limit**	**Reject /Accept**
Current Policy	6.40	1.75	6.27	6.27	6.53	Accept
12-hr policy	4.45	1.2	4.36	4.36	4.54	Accept
8-hr policy	3.82	0.56	3.85	3.78	3.86	Accept
4-hr policy	2.00	0.02	2.00	2.00	2.00	Accept
α=0.05						
Policy	**Cycle Time in hr (Simulation)**	**Std Dev**	**Cycle Time in hr (Analytical), μ_0**	**Lower Confidence Limit**	**Upper Confidence Limit**	**Reject /Accept**
Current Policy	6.40	1.75	6.27	6.29	6.51	Reject
12-hr policy	4.45	1.2	4.36	4.38	4.52	Reject
8-hr policy	3.82	0.56	3.85	3.79	3.85	Accept
4-hr policy	2.00	0.02	2.00	2.00	2.00	Accept

From the table above, it is shown that with a 99% confidence interval, all the cycle times calculated analytically fall between the lower and upper confidence limits. However, the cycle times for both current and the 12-hour policies calculated analytically falls below the lower confidence limit when a 95% confidence interval is constructed.

2.5.1 Simulation Analysis on Actual Weekly Flight Schedule

The simulation is further extended to an actual weekly flight schedule of a leading international airport. In this case study, the number of cargoes lodged in depends on the aircraft type and there are eight different aircraft types. Based on a statistical analysis of a collection of airway bills from the airport terminal over several days, the minimum and maximum numbers of airway bills (AWB) lodged in before the cut-off time for each aircraft type are determined. This is shown in Appendix B. To allow for variability in the problem, an aircraft type for a given departure time is randomly generated from the eight aircraft types. Furthermore, given an aircraft type for a particular flight, the total number of cargoes lodged in over the 20 hour interval is randomly generated between the minimum and maximum numbers of AWBs. The simulation also tries to study the effect of non-uniformity on the cargo sizes. To do this, one equivalent unit as a measure of the smallest cargo size is introduced. Each bin capacity is assumed to be of 72 equivalent units.

Again a total of 1000 replications are run for this analysis. The numbers of handling per hour, the average cycle times of a bin and the ratios of both the numbers of handling per hour and the average cycle times of the different policies over the current policy are computed in every replication. The associated standard deviations of the means for these performance measures are computed. Also four different simulation scenarios in terms of the profile of cargo sizes are designed. Table 2.6 summarizes the result.

Table 2.6: Simulation results for various cargo sizes.

Cargo of same size that are equal to 6

Expected no. of handling:						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	18.158	11.679	10.097	7.475		0.643	0.556	0.412
Std Dev of the Mean	0.014	0.009	0.007	0.005		2.137E-04	1.62E-04	1.28E-04
Estimated cycle time (hour):						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	8.584	4.819	4.449	3.568		0.561	0.518	0.416
Std Dev of the Mean	0.003	0.002	0.001	0.001		2.08E-04	1.84E-04	1.43E-04

Cargo of different sizes that are distributed uniformly between size 5 to 7

Expected no. of handling:						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	20.152	14.051	12.427	9.471		0.664	0.574	0.412
Std Dev of the Mean	0.014	0.009	0.008	0.005		1.63E-04	1.48E-04	1.16E-04
Estimated cycle time (hour):						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	8.608	4.715	4.414	3.535		0.548	0.513	0.411
Std Dev of the Mean	0.003	0.002	0.001	0.001		1.97E-04	1.76E-04	1.35E-04

Cargo of different sizes that are distributed uniformly between size 4 to 8

Expected no. of handling:						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	18.152	14.079	12.451	9.471		0.665	0.576	0.412
Std Dev of the Mean	0.014	0.009	0.008	0.005		1.67E-04	1.53E-04	1.16E-04
Estimated cycle time (hour):						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	8.596	4.713	4.413	3.535		0.548	0.513	0.411
Std Dev of the Mean	0.003	0.002	0.001	0.001		2.07E-04	1.80E-04	1.39E-04

Cargo of different sizes that are distributed uniformly between size 3 to 9

Expected no. of handling:						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	20.152	14.063	12.439	9.471		0.665	0.575	0.412
Std Dev of the Mean	0.014	0.009	0.008	0.005		1.72E-04	1.58E-04	1.16E-04
Estimated cycle time (hour):						Ratio to 24-hour policy		
	24 hr	12 hr	8 hr	4 hr		12:24	8:24	4:24
Mean	8.592	4.712	4.413	3.534		0.549	0.514	0.411
Std Dev of the Mean	0.003	0.002	0.001	0.001		2.07E-04	1.78E-04	1.41E-04

From the standard deviations of the means for the numbers of handling, cycle times and the respective ratios, it is clear that the simulation results are quite consistent. Hence, by implementing the new policies, not only will there be a reduction in manpower to handle the cargoes, but also there will be an increase of the capacity of the storage system. A tradeoff for implementing these policies is that more bins would be needed in the acceptance area. Therefore if space is a constraint, a 12-hour policy could be chosen which would only require additional 3 bins and the savings as large as 35% in terms of the average number of handling and close to 40% on the average cycle time can be realized. In fact, it is noted that a change from the current policy to a 12-hour policy gives the largest incremental drop in the average number of handling and average cycle time. This improvement remains valid even when cargoes vary in sizes.

2.6 Conclusion

In summary, this chapter presents a quantitative model to evaluate the operational policies of assigning cargoes to storage bins. Two performance measurements are proposed. One is the labor required to handle the cargoes and the other one is the storage capacity required to store the cargoes. Based on the model, a comparison is made between an existing policy against a few proposed policies in which time is used to segregate storage bins. The results show that the proposed policies give rise to a great reduction in both manpower and the storage capacity requirement. These results are further confirmed by a simulation study in which simplicity assumptions on the analytical model are removed.

Chapter 3

Manpower Problem at Air Cargo Terminal

3.1 Introduction

The problem addressed in this chapter is the manpower problem of the export Checking Team operation in the air cargo terminal. This work provides a good solution to the terminal aiming to minimize the manpower requirement while not compromising on the customer service level. In this introduction, the problem and our approach will be put in the context of large-scale optimization.

The solution provided is a roster, or what is called a dummy roster in that individual workers are not yet assigned. In analogy, bidlines are such dummy rosters in the aircrew scheduling problem where trips or tasks are assigned to monthly schedule for the crew members. In that context, bidlines are monthly and are required to be equitable so that work is evenly spread out over the bidlines. The process of making bidlines is to first form pairings (a sequence of duties and rest periods that starts at a crew base), or trips, and then to make rosters from the pairings. It is not practical to make pairings and roster in one solution process (Weir and Johnson (2004)).

In our problem, shifts are made first and then a roster is made up from the shifts. This approach is used in bus crew rostering and other rostering applications.

However, our roster is required to be a big cycle of shifts so as to assure equity of work schedules for all workers. This big-cycle requirement is similar to that imposed in the airplane rotation problem where the aim is to assure even usage and maintenance on all aircraft. Here it is imposed to assure equitable work assignment.

The problem is, thus, solved in two phases: First, a shift scheduling model determines all shifts. Then, these shifts are input to the roster model to form a complete, cyclic roster for the workers.

In airline crew scheduling, the cost in terms of extra pay for poor quality pairings and the coverage of all legs is in the pairing problem. Thus, the rostering or bidline phase is basically an equity issue. The same is true in much of the rostering work. Thus, this two phase approach does not give up optimality and does gain computational tractability. In our problem, coverage and minimizing the total labor costs go into the shift optimization. Worker equity is inherent in the nature of the big-cycle solution to the rostering problem. Thus, coverage and costs are optimized in the shift phase and equity is built into any feasible solution in the rostering phases.

However, to model the shift problem, there is one difficulty: How much worker time will go into each of the tasks. This question is difficult because it will vary from week to week. So we propose a heuristic to approximate, in the long-term, the work required.

In order to provide a better understanding of the work required for each task (cargoes being loaded on to the flights) and in order to understand what the workers do in our problem, before going into the models and solutions, a description of the export Checking Team working process, the current way used to form the roster in the air cargo terminal, as well as the motivations to work on this problem are presented in the next section. We then go into more detail on the model to be developed here and give a literature review of prior work done in this type and similar rostering problems before developing our model.

3.1.1 Export Flight Checking Process

The flight checking process is a very critical process within the terminal warehouse and it is performed by the export Checking Team, which consists of one Checker and one Hand. The Checker has greater responsibilities as he has to perform the pre-planning on how to retrieve the cargo and to build-up the cargo according to the pre-manifest planned by the flight planning division. The Hand plays a supporting role to help in cargo retrieval and build-up as instructed by the Checker. To start the flight checking process, the Checking Team needs to prepare some empty pallets or containers and then retrieve all the cargoes belonging to the flight assigned to the team. The cargoes can be stored in any of the temporary storage locations mentioned in Chapter 1 earlier. The team has to consolidate the cargoes and build them into pallets or put them into the air cargo containers. This process is also referred as palletization while the pallet or container filled with cargoes is called Unit Load Device (ULD). The goal of the Checking Team is to complete all the build-up activities for a particular flight to handover to the Ramp Officer in time. The Ramp Officer is in-charge of releasing the ULDs of the flights to the air craft site. The terminal's standards are to have all the ULDs to be ready approximately u minutes before Scheduled Time of Departure (STD). The activity to complete all the build-up process of a flight is called flight closing. While the time to close the flight is referred to as the close-out time of the flight and it is depicted in Figure 3.1.

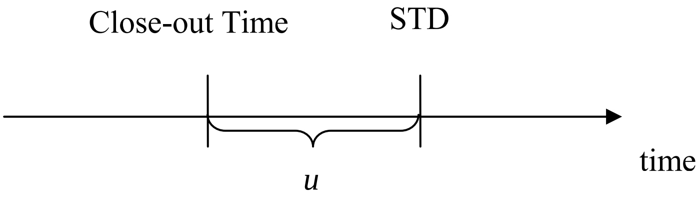


Figure 3.1: The close-out time of a flight.

Each Checking Team is responsible to build-up for around three flights per shift. Some of the flights being assigned are required to be closed during the Checking Team's shift while some others are pre-check flights which will be handed-over to the Checking Team on the next shift to close the flights. Pre-checking is a process to start building-up the cargo for the flights to be closed in the next shift. Depending on the shift the Checking Team is working on, the team will either help the next team to pre-check some flights or take over some pre-checked flights from the previous shift. The terminal allows pre-checking of flights to smooth out the workload of the checking team.

A summary of the process flow is given in Figure 3.2.

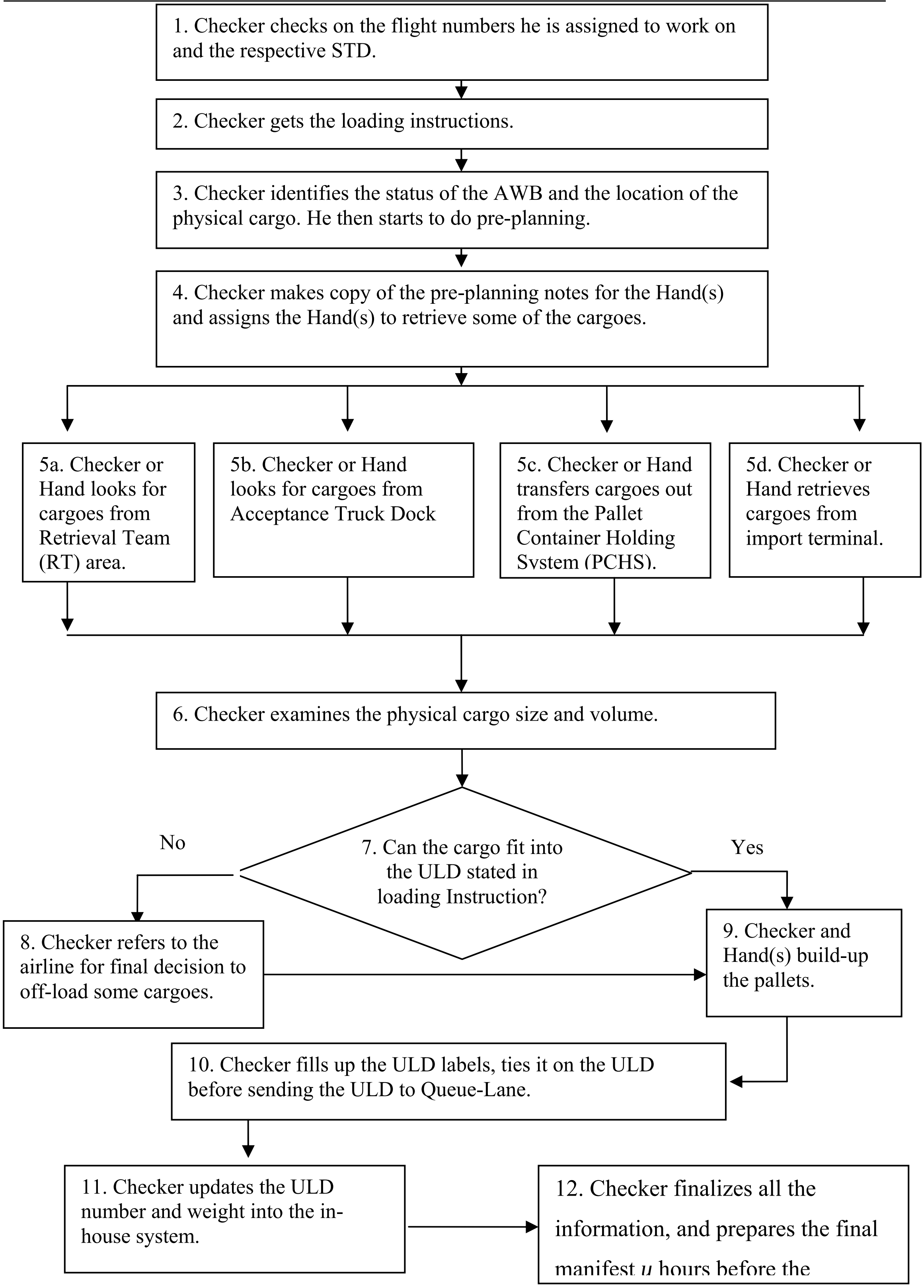


Figure 3.2: Flight checking process

3.1.2 Current Roster Formation

The roster plan is driven by the flight schedule. A major revision occurs every six months due to the change in the flight schedule, i.e. Northern Winter (October to March) and Northern Summer (April to September) schedules.

The Supervisor needs to ensure that the labor laws are complied with when developing the master roster, i.e. (i) each worker can only work t_n normal hours per week (inclusive of break time), (ii) the total working hours (including the overtime) cannot exceed t_{ot} hours per week, and (iii) each worker must have at least t_b hours break between two working shifts.

In addition to that, the Supervisor needs to take care of the company rules stated below:

i. Each worker must have at least two rest days before switching from the night shift to the morning or afternoon shift, while one rest day is required to switch from a morning or an afternoon shift to a night shift.
ii. Each worker must be given one hour of break during each shift.
iii. The night-shift work stretches should not exceed seven night shifts in a roll. However, there is no specific requirement for the morning- and afternoon-shift work stretches as long as the working hours within one calendar week do not exceed t_n hours.

3.1.2.1 Descriptions of the shift

There are three major shifts per day, namely night shift, morning shift and afternoon shift. Each of these shifts consists of shifts with different start and end times. There are three different shift durations too, i.e. 8-hour, 9-hour and 10-hour respectively. All these shifts have as many as 12 to 15 different starting times and are mainly flight schedule driven. An example of a roster with different shift durations and starting times is shown in Table 3.1.

Most of the teams in the roster are assigned with a daily flight (this is usually the pre-assigned flights shown in the roster) which must be completed within the shift. Each Checking Team from a group will report to work according to the group’s roster in a cyclic way. To illustrate this, Table 3.1 shows a sample of the roster for Group 1. It is noticed that there are altogether 18 Checking Teams, from Week 1 to Week 18, in this roster. All 18 Checking Teams start work simultaneously following the schedule on different weeks. For instance, if Checking Team 1 is working on Monday following the Week 1 schedule, this team will have to start work at 1000hours on Monday and the shift ends at 1900hours on the same day. The team will report to work at 0900hours on Tuesday and finish work at 1700hours. On Tuesday, this Checking Team is pre-assigned to work on flight TT135. This Checking Team has a rest day on Wednesday and it will follow the Week 1 schedule until Sunday and rotate to Week 2 schedule on the following Monday. It will come back to Week 1 schedule again 18 weeks later. Similarly, Checking Team 2 will start on Week 2 schedule in the first week and then rotates to Week 3 schedule in the second week. It will come back to Week 2 schedule again after 18 weeks.

There is a week in the roster called "Redeployment" without any working time indicated. Any team working in this week will be covering other team members who need help to close a flight because of team members going on training, on sick leave or on any other types of leaves. In short, the Checking Team who is on "Redeployment" shift will still have to work up to t_n hours per week. The only difference is that there is no pre-determined shift start and end times as well as rest days. The Cargo Officer will notify this Checking Team on when to report to work by phone calls.

The pre-checking flight is not shown in the roster as it will be assigned to the Checking Team on daily basis by the Cargo Officer. As mentioned earlier pre-checking is a process to start building-up the cargo for the flights to be closed in the next shift. The Checking Team will either pre-check flights for the next team or taking over pre-checked flights from the previous team.

Table 3.1: A sample of the roster

Week	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1	1000 - 1900	0900 - 1700 TT135	REST	0100 - 0900 TT608	0100 - 0900 TT680	0001 - 1000 TT100	0100 - 0900 TT680
2	0100 - 1100	0100 - 1100 TT608	0100 - 1100	REST	REST	1600 - 0100 TT982	1500 - 0100 TT816
3	1900 - 0300	1700 - 0100	1400 - 2400 TT288	1300 - 2100 TT343	0900 - 1700	0900 - 1700 TT200	REST
4	REDEPLOYMENT						
5	1700 - 0100	1300 - 2100 TT343	0900 - 1700 TT200	0900 - 1700	REST	0100 - 1000 TT680	0100 - 1000 TT608
6	0001 - 1000 TT001	0001 - 1000 TT001	0100 - 1100 TT680	0100 - 1100	0100 - 1000	REST	REST
7	REST	1600 - 2400 TT099	1400 - 2200 TT346	1400 - 2400 TT604	1400 - 2200 TT436	1300 - 2100 TT443	0900 - 1700 TT200
8	REST	1400 - 2400 TT282	1400 - 2200 TT328	1400 - 2200 TT643	1400 - 2200 TT328	1900 - 0300	1700 - 0100
9	1300 - 2100 TT240	0900 - 1700	REST	1700 - 0100	1400 - 2400 TT640	1300 - 2100 TT240	0900 - 1700
10	0800 - 1600	REST	0100 - 0900 TT680	0200 - 1000 TT680	0100 - 0900	0100 - 0900	0001 - 1000 TT101
11	0200 - 1200 TT780	0100 - 1100	REST	REST	1500 - 0100 TT168	1400 - 2400 TT604	1300 - 2200 TT343
12	1600 - 2400 TT909	1300 - 2200 TT448	1100 - 1900 TT479	1000 - 1900 TT634	0900 - 1700 TT200	REST	1700 - 0100 TT218
13	1600 - 2400 TT298	1400 - 2200 TT643	1300 - 2100 TT434	1300 - 2200	1100 - 2000 TT634	REST	1400 - 2200 TT443
14	1400 - 2200 TT436	1100 - 2000 TT463	0900 - 1700	0900 - 1700	REST	0100 - 1000 TT680	0001 - 0800
15	0100 - 1000 TT680	0100 - 1100 TT608	0001 - 1000	0001 - 1100	0001 - 1000 TT101	REST	REST
16	REST	1700 - 0100	1600 - 2400 TT909	1600 - 2400 TT289	1400 - 2200 TT321	1300 - 2200 TT463	1300 - 2200 TT284
17	1000 - 1900	REST	1700 - 0100 TT128	1600 - 2400 TT168	1300 - 2100 TT343	1100 - 1900 TT479	1000 - 1900 TT634
18	0900 – 1700 TT612	0900 - 1700	REST	1600 – 2400 TT604	1400 – 2200 TT436	1300 – 2100 TT443	0900 – 1700

3.1.3 Current Problems and Motivations

Some of the problems in the current system are presented in this section. Our work is aimed to help the air cargo terminal to solve some of these problems so as to reduce its cost and to increase its operation efficiency and productivity.

One of the challenges of the terminal is to maintain and further enhance the customer service level by reducing the mishandlings and errors, and to increase the productivity. A factor which could impact the customer service level potentially is that the current system is not proactive enough to cater for the actual dynamic system as the Cargo Officer allocates the flights to the Checking Teams based on the past experience and some crude information. For instance, if an incoming flight from which the transshipment cargo needs to be retrieved is delayed with no proactive adjustments to the workload assignment to the Checking Team, it will disrupt the Checker Team's working schedule. The Checking Team will either need to work overtime or rush to close the flight. This situation may impact the build-up activities for other flights and hence may lead to cargo being bumped-off indirectly if the Checking Team is not able to complete the task in time due to the flight delay. Consequently, the customer service level will drop. In addition, errors and mishandlings may occur in a messy environment/ process causing additional operational cost.

Having a fixed number of workers at certain hours around the 24-hour clock similar to the manufacturing environment will not work for the air cargo terminal environment as the demand or the workload has high fluctuations between hours which is highly dependent on the flight schedules; while the production line in the manufacturing environment has a relatively stable workload. For instance, the peak hours for an air cargo terminal might be the four to five hours in the evening where a lot of flights are scheduled to depart. Therefore more manpower is required during these hours to handle the cargoes. In order to maintain a stable workforce while meeting the fluctuating demand, the shift schedules of the air cargo terminal should vary according to the demand requirements. To avoid over-hiring at non-peak periods and under-hiring at peak periods, it should be noted that the shifts should be designed in such a way that more shifts are overlapped during the peak periods while fewer shifts are required during the non-peak hours. In short, the shift scheduling should have the flexibility to cover the surge and lumpy demand pattern yet maintain a constant workforce. This can be achieved by staggering the shifts which means the start times and end times for the shifts are different and the shifts may overlap. The roster can be designed in such way that there are more overlapping shifts during the peak hour when more labor is needed and less or no overlaps during the non-peak hours.

In the air cargo terminal being studied by us, there are tens of Checking Teams and more than hundreds of flights that need to be handled each week. The Cargo Supervisor is responsible to work on the shift planning and to develop the roster for all the teams. According to the Cargo Supervisor, the roster is highly driven by the flight schedule and it is a very tedious job to develop a good roster satisfying all the different rules such as the labor laws, company rules, Checking Team compatibilities, etc., while still meeting the workload requirements. The initial rosters developed were designed to segregate the flight sectors into four different groups based on geographical locations for better management. However, due to new flights added throughout all these years and the complexity to develop new master rosters, some of the groups were assigned with cross-sector flights. Certainly this problem is very difficult to solve manually when the airline continues to experience changes.

As mentioned earlier, the Cargo Officer is responsible for assigning the flights to the Checking Teams. According to the Cargo Officer interviewed by us, the workload of the flights is estimated based on his past experience as well as the information provided by the airline, such as the number of AWBs, weight and pieces of the cargoes to be loaded on the flights. However, this information may not reflect the actual workload involved. A Checking Team may be under utilized if all or most of the flights assigned to them carry more palletized cargoes than the loose cargoes. On the other hand, the team may be overloaded if all the flights have a lot of loose cargoes. This unbalance of workload will incur cost to the airport terminal directly since the Checkers and the Hands whom are underutilized will still be paid fully while the Checkers and the Hands whom are overloaded and cannot complete all the work in time will be paid overtime. Through the observation, the Checking Team spends most of the time in searching and retrieving the cargoes from the various locations. Hence, in addition to the cargoes' information mentioned above, the traveling distances to various storage locations, the cargoes' release times and the retrieval times should be considered in order to estimate the actual workload involved.

We also observe that the forklifts and workers are moving everywhere to retrieve or search for cargoes. Some of these trips are unfortunately wasted due to inaccurate information of the cargo storage locations or without a good planning and this has increased the traffic flow within the terminal and may further lead to congestion. Hence, a better retrieval plan in assisting the Checking Teams to reduce the wasted trips can be helpful.

The subsequent sections are organized as follow. The previous works done are reviewed in Section 3.2. The solution approaches are discussed in Section 3.3 where a detail description of the approaches as well as the results and analyses are included in the subsections.

3.2 Literature Review

The previous works done are reviewed in this section. A work done to solve an air freight terminal manpower scheduling problem is first discussed in Section 3.2.1 followed by the literature on shift scheduling in Section 3.2.2. Lastly, the day-off scheduling works are discussed in Section 3.2.3.

3.2.1 Air Freight Terminal Manpower Scheduling Problem

Surprisingly, there are not many works done directly on this topic and the most related paper found is the work done by Nobert and Roy (1998). They presented a work on the scheduling of freight handling employees at air cargo terminals with the objective of minimizing the total labor costs while satisfying the demand. This problem is traditionally solved in two stages. First, the manpower requirements are determined for each job category and for a typical workday in a given planning period. Then, an efficient work schedule that satisfies the manpower requirements and complies with the rules and regulations and budget constraints is designed. The major contribution of their work is to include the "demand leveling" approach by spreading some of the workloads to earlier times within certain interval in the first stage problem to determine the manpower requirement. Next, the manpower requirement obtained from the first stage was used to generate the schedule for the workers in the second stage. Their solution approach is shown in Figure 3.3.

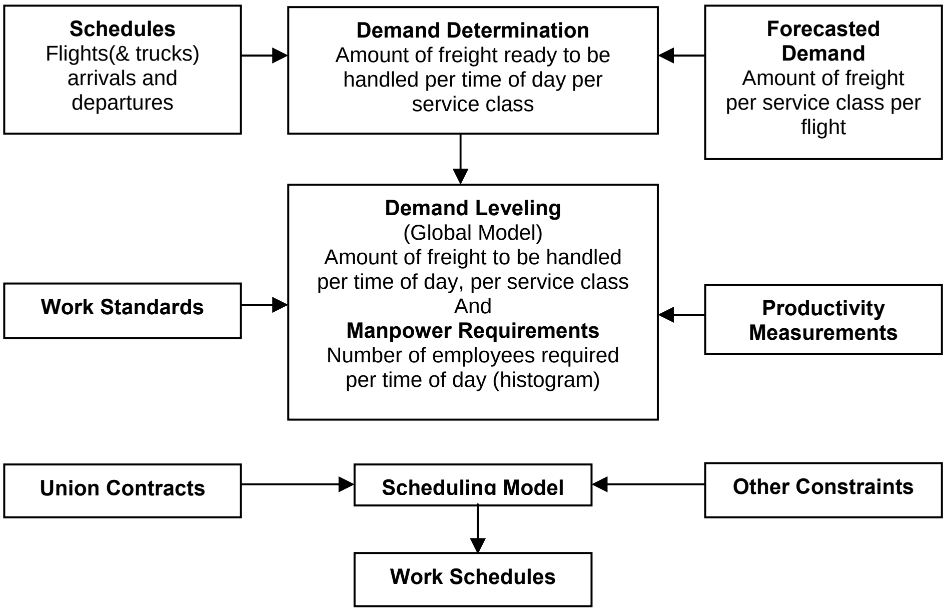


Figure 3.3: Solution approach by Nobert and Roy (1998).

The authors formulated the problem as an integer programming problem and called it Global Model (GM). The planning horizon of the model was 24-hour day. Thus, the model would be used to generate the manpower requirement on a day-to-day basis. The GM is presented below:

Global Model (GM)

$$Min\ Z = \sum_{t \in T} c_t y_t \tag{3.1}$$

$$s.t: \sum_{k \in D_{ij}} x_{ij}^k = h_{ij}, \forall i, j \tag{3.2}$$

$$\sum_{ij} x_{ij}^k = x^k, \forall k \tag{3.3}$$

$$d^k = x^k / q, \forall k \tag{3.4}$$

$$\sum_{\{t:k \in P_t\}} y_t \geq d^k, \quad t \in T \tag{3.5}$$

$$x_{ij}^k, x^k, d^k, y_t \geq 0, \forall i, j, k, t$$

$$y_t = \text{integer}, \forall t$$

The parameters of the model are presented below followed by the variables used:

Parameters:

h_{ij} = number of kilos ready to be processed at the beginning of period i and due at the beginning of period j ($j > i$).

D_{ij}= set of feasible periods when kilos of h_{ij} can be processed in order to be ready at the beginning of period j (assuming a kilo of freight can be completely processed in at most 1 hour).

q = number of kilos that can be processed by one employee in one period.

T = set of schedules under which employees can work (this is established according to the union agreement and lasts for eight consecutive hours).

P_t= periods of the day covered by a schedule $t \in T$.

Variables:

x^k_{ij} = number of kilos out of of h_{ij} kilos processed during period k. ($k \in D_{ij}$)

x^k = number of kilos processed at period k.

d^k = minimum number of employees required at period k in order to process x^k kilos.

y_t = number of employees working according to schedule $t \in T$.

The GM could have been used as a single model to provide the work schedules; however, due to the integrality of y_t, it was not easy to obtain its optimal solution. As a result, the authors proposed to use the GM to obtain the minimum manpower requirement by relaxing the integrality condition. Then a heuristic, using another model called the Scheduling Model (SM), was developed to solve the second stage problem. Let Z_0 be the optimal value of the relaxed linear program, P_0, and d^k_0 be the value of d^k in the optimal solution. The authors then solved the SM defined as follows.

Scheduling Model (SM)

$$Min\ Z = \sum_{t \in T} c_t y_t \tag{3.6}$$

$$s.t: \sum_{\{t:k \in P_t\}} y_t \geq m_k, \forall k \tag{3.7}$$

$$y_t \geq 0, \text{integer} \quad \forall t$$

$$where, m_k = \lceil d_0^k \rceil$$

Let y^*_t represent the optimal solution of SM with optimal value Z_1. Then a feasible solution was obtained by assigning $y_t = y^*_t$, and by keeping other variables of the GM to the same values as those in the optimal solution of P_0. The authors showed that if Z^* was the optimal value of GM, evidently, $Z_0 \leq Z^* \leq Z_1$.

The SM was like a minimum cost flow problem and could be solved easily. According to the authors, their approach was tested on the actual data provided by Air Canada and the solution produced by their heuristic approach was within 1% of the optimal solution. The authors also compared the result of “leveling demand” with "non-leveling demand" as well as with "linear leveling demand". They showed that employing the "leveling demand" can reduce the total labor cost.

Comparing the work done by Nobert and Roy (1998) with the air cargo terminal problem discussed in this dissertation, it is noticed that in their work, no dedicated team is assigned to handle a particular flight. In other words, the manpower was assumed to be interchangeable in their work. Moreover, there was no roster being formed and the work schedule of their work was generated on a daily basis. Lastly, they did not consider the break time. As mentioned earlier, the assumption of having dedicated teams to be responsible for the flight(s) is important for traceability as well as for ensuring the accountability of the flights handled by the Checking Team. In addition, workers need to be informed of their shift schedules well ahead of the start time. Hence, it is not practical for the air cargo terminal under study to have a work schedule generated on a day-to-day basis. Lastly, break time, observing the actual habit of the Checking Teams being studied, has to be factored in the consideration.

As other works regarding the manpower allocation in the air cargo terminal are not found, the attention is switched to looking into the works done on designing and implementation of manpower scheduling systems especially in the service-oriented industry. It appears that extensive work has been done in this area. Generally, all these works can be categorized into two main areas namely shift scheduling and day-off scheduling. A review on the works being done on these two areas is provided in more detail in the following sections.

3.2.2 Shift Scheduling

The shift scheduling problem deals with the detail level of determining the minimum number of staffs required as well as allocating the staffs to the specific shift schedule in order to meet the demand. The simplest type of the shift scheduling problem is to find the manpower required for non-overlapping shifts which means that the requirements of the staffs on each shift can be treated independently. Examples of this kind of shift can be found in the manufacturing environment where the production is run 24-hour a day without having a high fluctuation in the demand. Usually, there are only two to three shifts with the fixed shift start and end times in this type of problems and each of the shifts starts right after the previous shift ends and there is no overlapping of the shifts. Since the non-overlapping shifts are only suitable for environment with stable demand, it cannot be adopted to design shifts with high fluctuation in the demand especially in the service industry. Instead, overlapping shifts are designed for the service industry.

The challenge of the manpower allocation problem with overlapping shifts has attracted a considerable attention since it is introduced by Edie (1954) whose work introduced the problem of allocating the toll booth collectors to different shifts. He used probability distributions to estimate the demand requirement in terms of hours. Then, he found the ratio of demand hours to shift hours to estimate the number of toll booth collectors needed. Dantzig (1954) commented on Edie’s approach and proposed that the shift scheduling problem could be solved by an integer program similar to the set covering problem by first ignoring the need for relieves or breaks to have a stretched length of 7-hour per shift. Dantzig’s model is presented in the following.

$$Min\ z = \sum_{k \in K} c_k X_k \tag{3.8}$$

$$\text{s.t}: \sum_{k \in K} a_{kt} X_k \geq b_t \ , \forall t \in T \tag{3.9}$$

$$X_k \geq 0 \text{ and integer, } k \in K$$

where X_k is an integer variable defined as the number of employees assigned to shift k, T is the set of planning periods covered by the shift schedule, K is the set of all shifts, b_t is the number of employees needed in period t, c_k is the cost of assigning an employee to shift k, and a_{kt} is 1 if period t is a work period for shift k and 0 otherwise. The author pointed out that if the relieves need to be considered in this model, it could be formulated by having more shift patterns of work with time gap(s) in between.

It makes sense that having the flexibility in shift lengths, shift start times and breaks helps to reduce the total number of employees required. This is shown by Showalter and Mabert (1988). However, it is also known that the number of variables in this set covering type model will increase rapidly with the provision of different shift lengths, shift start times, and placement of breaks, causing it impractical to be solved to optimality in most applications. This has led researchers to seek for other formulations or approaches.

Aykin (1996) presented a new approach in which a set of break variables is introduced for every shift-break type combination which incorporates the break placements within a shift besides determining the shift start and end times. The objective of his model was to minimize the total labor cost. He showed that the approach leads to a significantly improved integer programming model requiring substantially smaller number of variables and less computer memory by limiting the break placements within certain time windows. Bechtold and Jacobs (1990) developed an implicit integer programming formulation inclusive of break window flexibility by recognizing the fact that not all the information concerning the placements of the break included in the set covering model was necessary to develop an optimal shift schedule. They showed that the implicit formulation introduced in their work was superior than the traditional set covering formulation with respect to execution time, computer memory requirements and the ability to generate optimal solutions to large problems. Aykin (2000) then compared his modeling approach discussed in Aykin (1996) with Bechtold and Jacobs's (1990) modeling and found that his formulation was substantially better in terms of solution time and the percentage of the problems solved optimally.

Thompson (1995) presented a doubly-implicit integer programming shift scheduling model by integrating the implicit shift modeling of Moondra (1976) with the implicit break window modeling of Bechtold and Jacobs (1990). Similarly, the model was developed to minimize the total labor cost by meeting the demand requirement. His model not only determined the shift start and end times but also the time for meal break. He showed that the doubly-implicit method was particularly effective in allowing a high degree of scheduling flexibility.

Mehrotra, Murphy and Trick (1999) presented a branch and price approach for solving the set covering type formulation efficiently. They exploited some of the advantages of the set covering model to overcome the problems in solving when the problem becomes very large. They also compared their solution approach with

Thompson's (1995) and Aykin's (1996) models. They showed that their approach was able to solve more problems to optimality and the computing time was either significantly less or at least the same as the time required by the approaches used by Thompson's (1995) and Aykin's (1996).

Besides modifying the traditional set covering problem to tackle large shift scheduling models, another commonly used method is to solve the problem by using heuristics. Segal (1974) proposed a heuristic to determine the number of workers assigned to shifts with the corresponding break and relief timings by using a network flow approach. Particularly, he considered a telephone operator scheduling problem in which each shift may consist of up to two 15-minute relieves and one 30-minute lunch break. The possible break windows were specified as 90 minutes long so that each 15-minute relief might start at six different times. The network flow based heuristics is used to solve the shift assignment and the break assignment problems separately in three stages. Heuristic approaches had been discussed in many other works. Buffa et al. (1976), Glover et al. (1984), Thompson (1990) and Brusco and Jacobs (1993) were amongst some of the works using heuristics to solve this problem.

Beaumont (1997) discussed a mixed integer program in solving the staff scheduling problem which involves employing staff to drive to and service the customers. The main objective of the paper is to minimize the total cost comprised of the manpower, vehicle and customer waiting costs. The model generated a set of shift schedules of overlapping shifts with 12 to 15 different shift start times in a day spanning 47 weeks. The paper found the optimal staff schedule which has lower cost than the company's current schedule.

Of all the papers on staff scheduling, the authors assumed that the jobs were decomposable and exchangeable. In other words, the job was non-differentiable amongst the employees working at the same time interval. However, this is not the case in our problem where each worker is responsible for the duty being assigned to. In addition in our problem, in the case when the duty exceeds the shift duration, the uncompleted job will be passed-on to the workers in the next shift. In other words, the workers working at the same time cannot exchange their duties or share flights as the company wants its workers to be accounted for their jobs. This practice is instilled by the company to help them to trace back to the workers easily if there is a need to do so.

3.2.3 Day-off Scheduling

In implementing the staff schedules, it is often necessary to provide equitable assignments by rotating the staff among day-off patterns to follow a roster. Such a rotation can be formed by numbering each day-off assignment and then in successive periods giving these assignments in sequential order to a particular staff. Each staff will be rotating on the same duty roster but starting with different day-off assignment. Baker (1974) developed a simple algorithm to assign the days-off to the workers working in a cyclical seven-day working pattern. The objective of the model was to minimize the number of workers while meeting the staffing requirement as well as permitting two consecutive days off to each employee. Basically, the model was to determine the number of workers who would be off on certain days while meeting the requirement. The algorithm was easy to implement and can be calculated by hand.

Brownell and Lowerre (1976) studied the effect of a set of seven-day operation time-off policies for a given workforce, in which N employees were required on weekdays while n employees were needed on weekends where N was at least as large as n. There were five time-off policies, namely:

Policy I	: Each employee gets two days off per week. The days off need not be two consecutive days. In other words, it is not necessary to be a two-day block time-offs.
Policy II	: Each employee gets two two-day block time-offs over a two-week period.
Policy III	: Each employee gets two two-day blocks off in two weeks but no two consecutive two-day blocks which includes weekend days.
Policy IV	: Each employee gets every other weekend off and a total of four days off in two weeks. The weekdays off need not be in two-day blocks.
Policy V	: Each employee gets every other weekend off and one other two-day block in two weeks.

Among all the five policies, the authors found that the most complicated policy was Policy V. They also showed that sometimes, the more desirable policy may not require additional manpower.

Baker and Magazine (1977) extended the work by relaxing Brownell and Lowerre's (1976) constraint that $n \leq N$, and explicitly made the maximum work stretch as a secondary criterion. They considered four different days-off policies which included Policies I, II, IV and V mentioned earlier. In each of the cases, an optimal solution of minimizing the workforce required was found. In addition to that, an algorithm for constructing a feasible schedule was suggested. Baker et al. (1979)

analyzed a day-off scheduling problem at a large hospital with the assumption that staff requirements were the same on everyday of the week. They recognized that this assumption might be less general than other works but they expected the analysis of their work would provide some building blocks for the analysis of more complicated cases. They first showed that the minimal workforce required, *W*, was

$$W = Max\{\lceil nB/(B-A)\rceil, \lceil 7n/5\rceil\} \tag{3.10}$$

Here, *B* was the number of weeks to form the cycle, *A* was the number of weekends off during the cycle, *n* was the staff requirement on each day of the week, and $\lceil x \rceil (\lfloor x \rfloor)$ was the smallest (largest) integer greater (less) than or equal to *x*. Then an algorithm was proposed to generate a feasible solution using *W* workers.

Burns and Carter (1983) generalized the model to incorporate both varying daily staff and time off requirements. The algorithm presented generated a feasible schedule for any given week but no master roster was produced that could be cycled over the workers and reused. Later, Emmons (1985) generalized the cyclical workforce scheduling to produce a feasible master roster which maintained all work stretches between two to four days, and which gave consecutive weekdays off as often as possible to any worker worked on successive weekends. The model also ensured that *A* (number of weekends off during the cycle) out of *B* (number of weeks) weekends off would be assigned. Koop (1986) presented a hypergraph model of scheduling the off weekends in the manpower scheduling problem which required a ratio of *A*/*B* off weekend constraint to be satisfied. An approach to schedule the multiple-shift manpower problem was introduced by Burns and Koop (1986). They constructed an algorithm which provided an optimal schedule with constraints that included two days-off in each week, a specified number of weekend offs in any fixed number of consecutive weekends, a maximum number of six consecutive work shifts and different staffing requirements for each shift types.

Most of the works discussed here did not consider multiple shifts, such as night shift, morning shift and afternoon shift, except Burns and Koop (1986). Generally, there are differences between the works been done and our work which will be presented in the later sections. It seems that most of the works assume that the shift start and end times need not be part of the decision variables. However, they have to be considered explicitly in forming the work stretches for our manpower problem in the air cargo terminal as there are a number of different shift start and end times and there is a requirement of having at least t_b hours of rest between these shifts. Moreover, the manpower problem in the air cargo terminal has a different rest day policy compared to these works. That is, one rest day is needed when switching from a morning or afternoon shift to a night shift while two rest days are required for the reverse. With the different rest day policies, different shift requirements as well as the maximum working hours per week, the manpower problem in the air cargo terminal has to be modeled differently.

3.3 Solution Approaches

The manpower planning problem in the air cargo terminal can be broken down into three steps. The strategic task can be solved in the first two phases similar to the airline crew scheduling problem, namely, shift planning and developing a roster for all the workers. The last step concerns with the operational problem which deals with the daily allocation of flights to the Checking Teams.

The overview on how this problem is approached is shown in Figure 3.4. To solve this problem, a heuristic to estimate the average workload of the flights is first developed using historical data. It is interesting to note the current practice is purely relied on the Cargo Officer's past experiences without any help of scientific tools. The heuristic is developed assuming that the cargo information is updated on time. It estimates the workload required for each flight by means of some of the cargo's attributes such as the weight (either volumetric weight or actual weight), storage location, and priority of the cargo etc.

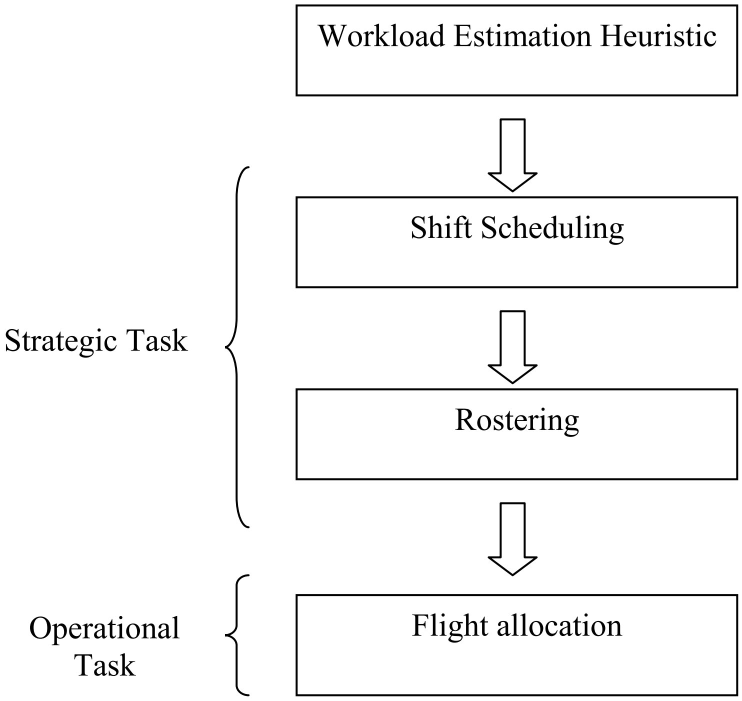


Figure 3.4: Manpower planning solution approach.

To solve the strategic problem, a shift scheduling model with the workload estimation as its input is built to determine the start and end times of all the shifts required. In addition, the scheduling model determines which flights to be assigned to the respective shifts, the specific time to have the break placements as well as the total man hours required. With the solution obtained from the shift scheduling model, the roster can be formed and subsequently the total number of Checking Teams required will be found. The roster model developed is to first form all the night-shift work stretches and the majority of the rest days required. Then the morning and afternoon shifts as well as the remaining rest days are packed in to fill-up the empty slots in between the night-shift work stretches to form a full shift rotation. Since the objective is to form a roster with the minimum number of weeks to minimize the manpower, usually the long night-shift work stretches will be chosen instead of the very short ones. This is because choosing the short night-shift work stretches will result in more rest days needed. However, as there is a preference to have not more than seven night shift working days in a roll, the longest night-shift work stretch will not exceed seven working days.

It is observed that the Cargo Officer in the air cargo terminal finalizes the flight allocations to all the Checking Teams approximately three times per day when the actual information about the loads of the flights is made available during the operation. These are done to fine-tune the workload for each Checking Team. If necessary, the Checking Team in the redeployment shift may be called back to work at certain periods and the Checking Team handling certain flight may be required to work overtime. This operational task to finalize the flight allocation is necessary, as cargo loads of a flight never stay the same throughout the time.

In fact, the workload estimation heuristic can be used to help the flight allocation job task. The heuristic can be used first to estimate the workloads for all the flights. If any flight's workload is found to be far beyond or below the shift duration, the imbalanced problem will be resolved by using the flight allocation heuristic. Besides that, the workload estimation heuristic will come in handy at this stage as it does not only estimate the workload of the flights but also generate a retrieval plan, in which it tries to maximize the utilization of each trip and to reduce the number of wasted trips within the terminal warehouse as well as to minimize the total completion time of the jobs required by the Checking Team.

The detailed discussions on each of the approaches mentioned earlier will be presented in the subsections later using a set of data collected from the air cargo terminal being studied. As mentioned earlier, the terminal has four groups of Checking Teams namely, Groups 1, 2, 3 and 4. Group 1 consists of a group of dedicated Checking Teams handling sector 1 flights while Group 2, 3 and 4 handle flights of the rest of the sectors. Here each sector represents a geographical region of the flight destination as mentioned in Chapter 1. Due to this reason, it becomes two separate problems of different scale naturally. The first problem is a smaller problem to design the shift schedule and the roster for the Checking Teams in Group 1 while the design of the shift schedules and the rosters for Groups 2, 3 and 4 is a problem of a larger scale to be solved. Analyses and results of each of the two problems are discussed in the relevant subsections.

In the following, first the workload estimation heuristic is discussed in Section 3.3.1. The models used to determine the shift schedules and to form the roster are presented in Section 3.3.2 and 3.3.3 respectively. A heuristic is developed to help the Cargo Officer to perform some adjustments to re-assign the flights to different

Checking Teams or to determine if any overtime work is needed. This will be discussed in Section 3.3.4.

3.3.1 Workload Estimation Heuristic

Researchers usually ignore the issue of getting some of the input data required for the proposed solution. For instance, it is always assumed that the workload required for the shift scheduling problem is given. Strictly speaking, the actual workload is not easy to estimate which can be stochastic and may involve the queuing theory. Similarly, it is not an easy task to estimate the workload in the airport terminal warehouse since the operation is very flexible. It is also not possible to estimate the workload of each flight purely based on the quantity, volume or weight that have to be handled.

Here we suggest a practical way to estimate the workload required based on some good and established heuristics such as the bin-packing rules and the job scheduling rules. It is undeniable that the workload needs to be estimated as close to the actual workload as possible since this critical input will determine the quality of the solution. To estimate the workload of each flight correctly, a time study was carried out earlier to measure the time taken for each task as well as to map out the workflow of the checking process. Then a heuristic, following the principle of List Scheduling in job assignment and First-Fit-Decreasing in bin packing with the consideration of urgency, is developed to estimate the workload for each flight, aiming to minimize the total completion time required by the Checking Team by cutting the wasted trips. This heuristic is developed with the assumption of having a Checker and a Hand as the default team members. If the flight cannot be completed before the flight close time, the heuristic will be re-run again by adding in one additional Helper to assist on the particular flight. In other words, an additional Helper will be continued to be added whenever the team (with or without Helper(s)) is not able to complete the workload before the flight close time.

The detail of the heuristic is presented in Appendix C while its main spirit is described below:

1. Pre-processing is done to consolidate all the available cargoes (those cargoes already in the terminal warehouse) with the same attributes and they are considered as a single job. The consolidated cargoes should weigh less than or equal to the forklift capacity.
2. Classify the jobs (the consolidated cargoes) into different categories according to the cargo available time and the prioritization. For instance, urgent jobs will have a higher priority than the jobs associated with the general cargoes.
3. Assign the jobs to either the Checker or Hand(s). Here the list scheduling heuristic is used to minimize the makespan. Once a job is assigned, both the Checker's and the Hand's times will be updated to prepare for the next job assignment.
4. Check for any newly arrived cargo and use the First Fit Decreasing rule, which is a greedy assignment approach, in bin packing to consolidate the newly arrived cargoes with the current existing available jobs.
5. Repeat step 2 to 4 until all the jobs are assigned. The total makespan will be the overall workload required.

To use this heuristic to estimate the workload of each flight to be used as an input for the shift scheduling model, this heuristic has to be run for each flight separately by assuming that all the cargoes are always ready. A way to do this is to assume that the cargoes are ready very early, i.e. at least 10 hours before the flight close time. As for the shift start time, it can be assumed that it is the same as the cargo ready time; while the shift end time is at least greater than the flight close time. By doing so, the total processing time required to close a flight can be estimated without considering the variations caused by the cargo ready times. Of course, the actual cargo ready times, the actual shift start and end times will be used when this heuristic is meant to estimate the workload at the operational stage. In other words, it is anticipated that certain cargo ready times may not be available at the beginning. Nevertheless, this has been implicitly taken care of in the design of the heuristic by performing jobs related to urgent cargoes first as it is expected that the cargo ready times will become available when time progresses.

After the workload of each flight has been estimated, the next step is to look into how the shift schedule is designed.

3.3.2 Shift Scheduling

To solve the shift scheduling problem, the workload requirement for each flight needs to be estimated first. Ideally, the workload estimation heuristic should be employed to provide the workload data for this model. However, due to the lack of actual data, an alternative is chosen to provide the workload estimation of each flight for this model. The method used to estimate the workload of each flight for the problem discussed here is presented below:

1. First the capacity allocated for each flight is found from the capacity allocation tables provided by the terminal (a sample of this is shown in Appendix D).
2. Then the allocated capacity is divided by 1200kg, which is roughly 90% of the forklift capacity. This ratio is used as an estimate of the number of trips required to retrieve all the cargoes.
3. Multiply the number of trips required by the average traveling time to obtain the total retrieval time. Here the average traveling time is estimated by taking the simple average of the traveling times of the forklift to all the temporary storage locations. In other words, it is assumed that cargoes are stored in all the temporary storage locations randomly.
4. Lastly, the total workload required to complete a flight is found by adding a fixed overhead of two hours to the total retrieval time as the Checking Team needs time to perform some pre-planning, to prepare paper works, to prepare handover documentations as well as to go for biological breaks.

Based on the above method, analysis on the current demand versus the manpower availability is done and the result for Group 1 is plotted into a chart displayed in Figure 3.5 which shows the workload demand versus the manpower available for each 1-hour interval within a week. It demonstrates that even though the manpower available matches with the demand pattern, there are instances where the demands are not covered by the manpower and these instances may lead to paying overtime for the Checking Team to complete the jobs in time. In addition, there are some gaps between the demand and the manpower available. Therefore there is room for improvement to reduce the gaps and to increase the utilization rate of the manpower. It is also calculated that the total man hour required currently is 892 which includes the 1-hour rest for each shift and the Redeployment shift is assumed to be t_n working hours per week.

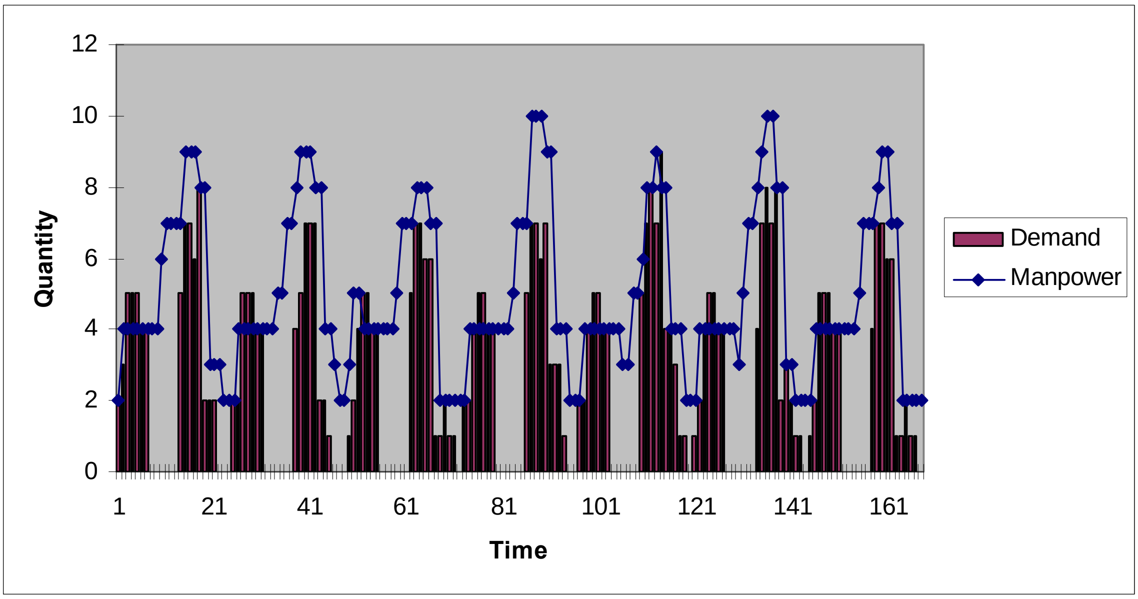


Figure 3.5: Manpower versus Demand.

The mathematical model used to solve the shift scheduling problem is discussed in the next section.

3.3.2.1 Shift Scheduling Model

Traditionally, integer programming model is used to solve the shift scheduling problem with the objective of minimizing the total number of shift hours required. Usually in the model, it assumes jobs are decomposable and exchangeable among all the servers or Checking Teams in this case. In other words, the job is non-differentiable amongst the Checking Teams working at the same time interval while in our actual study at the terminal each Checking Team working at the same time is required to be responsible for its own duties. Hence, the traditional model does not reflect the actual scenario as this requirement is relaxed by allowing different Checking Teams working at the same time interval to cover for each other.

Another practice in the air cargo terminal is that the Checking Teams will handover the incomplete workload to another Checking Team that starts work right after the earlier team. In other words, the incomplete workload will be handed over to the consecutive team. As mentioned earlier, the air cargo terminal enforces this to facilitate the traceability of the mishandled cargoes.

Hence, a new shift scheduling model is developed to cater for the non-exchangeable jobs amongst the Checking Teams. In addition, "Jumbo shifts" are added in this model to allow for pre-checking of flights when the workloads of the flights are high. A "Jumbo shift" is actually a shift that consists of two consecutive shifts. For example, a 16-hour shift is a combination of two 8-hour shifts. However, "Jumbo shift" of more than two consecutive shifts is not necessary due to the nature of the working hours where there are a few hours of break time between the peak periods. In fact, the current terminal practice does not have any "Jumbo shift" consisting of more than two consecutive shifts. The reason given was they do not feel a need to create "Jumbo shifts" of more than two consecutive shifts based on the past experience. Even if "Jumbo shifts" of more than two consecutive shifts were to be added, it is not likely that the optimum solution will select "Jumbo shifts" of more than two shifts. The results which are discussed in the next section show that only very few “Jumbo shifts” are selected in the solution in order to cover some flights which require pre-checking. As the problem itself is already a large scale problem, we do not feel it is necessary to add in “Jumbo shifts” consisting of more than two consecutive shifts.

To illustrate how the “Jumbo shift” works, Figure 3.6 shows that a 16-hour “Jumbo shift” is selected to cover Flight 1 and Flight 2. From the figure, Flight 2’s departure time is within the second half of the “Jumbo shift”. In other words, it is between *t* + 8th hour and *t* + 16th hour. Moreover, Flight 2’s workload starts from the first half of the “Jumbo shift” which is the darkly shaded region in Figure 3.6. It means the Checking Team working in the first half of the shift will pre-check part of the workload belonging to Flight 2 while the rest of the workload will be handed-over to the next Checking Team working in the second half of the shift.

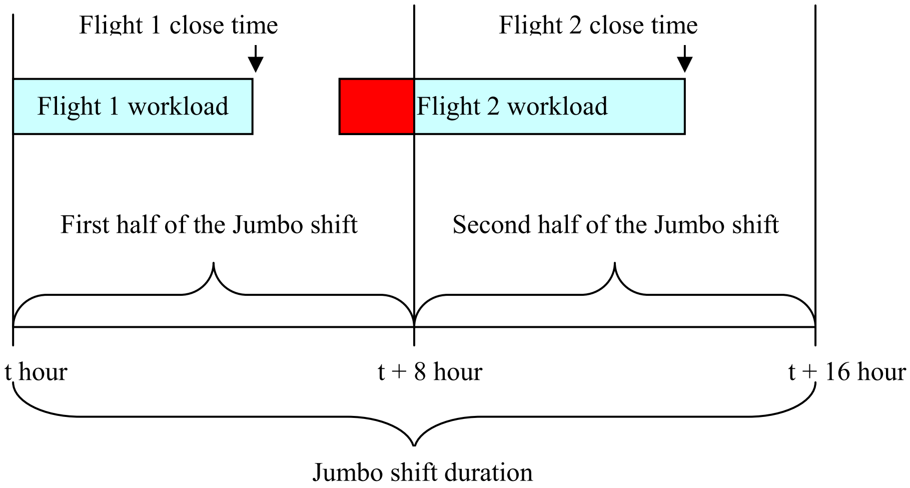


Figure 3.6: An illustration of the “Jumbo shift” and the pre-checking process.

The assumptions used for this model are presented below.

Assumptions:

1. Estimated workload information of each flight is used.
2. Flight schedule repeats weekly.
3. All the possible shift patterns with flights' workload being assigned to it, *s*, are generated based on the guidelines below:
    a. There are 8 different shifts, namely, 8-hour, 9-hour, 10-hour, 16-hour, 17-hour, 18-hour, 19-hour and 20-hour.
    b. The workload of a flight has to be covered within a shift. In other words, its start time should be later than or equal to the shift start time and its end time should be earlier than or equal to the shift end time.
    c. The workloads for two different flights can be allocated to a single shift if the workload for an assigned flight can be completed at least 60 minutes before the start time of the workload of the next assigned flight.
4. The team will go for break during the 60 minutes gap between two flights.
5. Each flight's workload does not exceed 6 hours.

New Model:

$$Min : \sum_{s} H_s x_s \tag{3.11}$$

$$s.t : \sum_{s} \beta_{fs} x_s = 1, \quad \forall f \in F \tag{3.12}$$

Where,

$$x_s = \begin{cases} 0\text{ , if shift pattern } s \text{ is not chosen} \\ 1\text{ , if shift pattern } s \text{ is chosen} \end{cases}$$

H_s = Shift duration in hours for shift s.

$$\beta_{fs} = \begin{cases} 0\text{ , if flight } f \text{ is not covered by shift } s. \\ 1\text{ , if flight } f \text{ is covered by shift s} \end{cases}$$

F = The set of flights need to be covered.

The objective function (3.11) is designed to minimize the total number of hours required. Constraint (3.12) is to ensure that every flight is covered. We wish to point out that in actual practice, the Checking Teams usually go for break after they complete the workload for one flight; hence, Assumption 3c reflects the actual operation.

3.3.2.2 Result and Analysis for the Shift Scheduling Model

A program is written to generate all the possible combinations or shift patterns, *s*, following the guidelines provided in Assumption 3. There are 13,489 possible shift patterns. The problem is solved using Cplex 8.1 running on a Pentium IV 2.4GHz computer and the total solving time is approximately 3 minutes 32 seconds. The optimal result shows that only 749 hours per week are required.

Obviously, 749 hours are the minimal hours required for Group 1. After an optimal solution is found, the next task is to form a feasible cycle for a shift rotation which abides the labor laws and company rules mentioned earlier. Table 3.2 presents all the shifts selected in the optimal solution and the model used to develop the roster is discussed in Section 3.3.3.

Table 3.2: Solution from NM

No	Shift ID	Start Time (Minutes)	End Time (Minutes)	Calendar Day	Start Time (Hour)	End Time (Hour)	Duration
1	0	0	480	1	0	8	8
2	3	0	480	1	0	8	8
3	5	60	540	1	1	9	8
4	9	120	600	1	2	10	8
5	15	660	1140	1	11	19	8
6	18	660	1140	1	11	19	8
7	20	720	1200	1	12	20	8
8	21	720	1200	1	12	20	8
9	23	720	1200	1	12	20	8
10	24	720	1200	1	12	20	8
11	354	780	1320	1	13	22	9
12	41	1020	1500	1	17	1	8
13	43	1320	1800	1	22	6	8
14	47	1440	1920	2	0	8	8
15	53	1500	1980	2	1	9	8
16	54	1560	2040	2	2	10	8
17	55	1560	2040	2	2	10	8
18	57	1980	2460	2	9	17	8
19	60	2100	2580	2	11	19	8
20	64	2100	2580	2	11	19	8
21	65	2160	2640	2	12	20	8
22	71	2160	2640	2	12	20	8
23	75	2220	2700	2	13	21	8
24	76	2220	2700	2	13	21	8
25	86	2400	2880	2	16	0	8
26	88	2820	3300	2	23	7	8
27	89	2820	3300	2	23	7	8
28	92	2880	3360	3	0	8	8
29	95	2940	3420	3	1	9	8
30	98	2940	3420	3	1	9	8
31	106	3540	4020	3	11	19	8
32	114	3600	4080	3	12	20	8
33	122	3660	4140	3	13	21	8
34	123	3660	4140	3	13	21	8
35	124	3660	4140	3	13	21	8
36	128	3720	4200	3	14	22	8
37	1372	3720	4680	3	14	6	16
38	130	3780	4260	3	15	23	8
39	141	4320	4800	4	0	8	8
40	144	4320	4800	4	0	8	8
41	149	4440	4920	4	2	10	8
42	151	4440	4920	4	2	10	8
43	155	4920	5400	4	10	18	8
44	156	4980	5460	4	11	19	8
45	162	4980	5460	4	11	19	8
46	164	5040	5520	4	12	20	8
47	165	5040	5520	4	12	20	8
48	173	5100	5580	4	13	21	8
49	356	5100	5640	4	13	22	9
50	179	5160	5640	4	14	22	8
51	1618	5340	6300	4	17	9	16
52	192	5700	6180	4	23	7	8
53	197	5760	6240	5	0	8	8
54	199	5820	6300	5	1	9	8
55	204	5880	6360	5	2	10	8
56	216	6480	6960	5	12	20	8
57	222	6480	6960	5	12	20	8
58	223	6540	7020	5	13	21	8
59	225	6540	7020	5	13	21	8
60	226	6540	7020	5	13	21	8
61	358	6540	7080	5	13	22	9
62	231	6600	7080	5	14	22	8
63	232	6600	7080	5	14	22	8
64	239	6720	7200	5	16	0	8
65	241	6720	7200	5	16	0	8
66	247	7140	7620	5	23	7	8
67	248	7140	7620	5	23	7	8
68	250	7200	7680	6	0	8	8
69	258	7320	7800	6	2	10	8
70	261	7380	7860	6	3	11	8
71	264	7860	8340	6	11	19	8
72	266	7860	8340	6	11	19	8
73	274	7920	8400	6	12	20	8
74	278	7920	8400	6	12	20	8
75	283	7980	8460	6	13	21	8
76	285	7980	8460	6	13	21	8
77	359	7980	8520	6	13	22	9
78	1374	8040	9000	6	14	6	16
79	306	8640	9120	7	0	8	8
80	308	8700	9180	7	1	9	8
81	309	8700	9180	7	1	9	8
82	314	8760	9240	7	2	10	8
83	320	9300	9780	7	11	19	8
84	323	9300	9780	7	11	19	8
85	324	9300	9780	7	11	19	8
86	325	9360	9840	7	12	20	8
87	326	9360	9840	7	12	20	8
88	360	9420	9960	7	13	22	9
89	1375	9480	10440	7	14	6	16
					Total Hours :		**749**

After solving the shift scheduling model for Checking Teams in Group 1, let us move to the shift scheduling problem for Groups 2, 3, and 4. Since Groups 2, 3 and 4 are treated as homogenous Checking Teams in the air cargo terminal, the shift scheduling problem for them is solved as a larger scale problem with more variables or shift patterns. From the shift scheduling model, there are 346,592 possible shift patterns formed and the total solving time is approximately 9 minutes 13 seconds running on the same computer. The optimal solution shows that a total of 2,313 hours is required. It is noticed that the current operation requires 892 man hours for Group 1 and 2600 man hours for Groups 2, 3 and 4. By using the model proposed, the company will only need 749 man hours and 2313 man hours respectively, which are equivalent to 16.03% and 11.03% of savings in terms of man hours required. The summary of the savings is shown in Table 3.3.

Table 3.3: Savings in man hour compared to the current operations.

	Man hour (hour)		
	Current	New	Saving
Group 1	892	749	16.03%
Group 2, 3 and 4	2600	2313	11.03%

3.3.3 Developing the Roster

Once all the shift schedules are generated from the shift scheduling model discussed in the earlier section, the next task before forming the roster is to "break" the "Jumbo shift" into two consecutive shifts, if any of the "Jumbo shift" is selected in the optimal solution generated from the shift scheduling model. To further illustrate this, from Table 3.2, the 37th shift with the shift ID 1372 is a 16-hour "Jumbo shift" which starts at 1400hours and ends at 0600hours on the next day. As it is a combination of two 8-hour shifts, this "Jumbo shift" needs to be "broken" into two consecutive shifts with the start times at 1400hours and 2200hours respectively.

After "breaking" the "Jumbo shift(s)", the next task of this manpower planning problem is to form a rotation of the shifts or roster for all the four groups of Checking Teams. Each roster contains various shifts with different starting and ending times. A few shifts, of the same category i.e. morning, or afternoon, or night shifts, are combined to form a stretch of work shifts. This is done to maintain a consistent working pattern for a minimum period and to minimize the rest days required as every switch from a night shift to a morning or an afternoon shift, or vice versa, requires rest day(s) to be added. Ideally, to have the minimum number of rest days in a roster, all the shifts of the same category should be grouped together and form a long work stretch before switching to another shift category. However, it is not preferred by the air cargo terminal and not supported by some of the studies (Salvendy (1997) and Bhattacharya (1996)). Hence, work stretches of not more than seven days for night shifts are formed. As there is no specific requirement from the air cargo terminal on the limitation of the number of morning or afternoon shifts in a work stretch, the guideline of not having more than t_n hours per calendar week is followed to form the work stretches for morning and afternoon shifts. Each stretch of work shifts inclusive of the rest days required lasts for at least 6 working days. The number of Checking Team required for each group depends on the number of weeks required to form the full rotation of the roster. Hence, each Checking Team will rotate from one stretch of work shifts to another as shown in the sample presented in Table 3.1 earlier.

3.3.3.1 Roster Model

A good roster is a roster that requires the least number of weeks to complete one cycle because it translates to the minimum number of Checking Teams required.

From the air cargo terminal’s rule, it is known that every switch from a night shift to either a morning or an afternoon shift will require two rest days. On the other hand, one rest day is required to switch from a morning or an afternoon shift to a night shift. Besides that, there is a labor law requirement that each worker cannot work more than t_w hours per 24-hour day. And lastly, the working hours within each calendar week shall not exceed t_n hours inclusive of the break hours.

To establish a good roster with the minimum number of weeks, an estimation of a tight lower bound of the weeks required is important computationally. The easiest way to estimate the lower bound of the number of weeks required is to find the maximum number of shifts required for the respective calendar days and take that as the lower bound of the number of weeks required. As shown in Table 3.4, the maximum number of shifts required for the respective calendar day is 15 on day 5. Hence at least 15 weeks are required to form a roster

Table 3.4: Number of night, morning and afternoon shifts per day for Group 1

Day	No. of Night Shifts	No. of Morning and Afternoon Shifts	Total Number of Shifts
1	5	8	13
2	5	8	13
3	5	8	13
4	5	9	14
5	5	10	15
6	5	8	13
7	5	7	12

However this approach may be over conservative. A suggestion to tighten the lower bound is given by the following steps.

Step 1. Categorize all the shifts provided in the New Model (NM) solution for each group into night, morning or afternoon shifts according to the respective days of the week.

Step 2. Find the maximum number of the night shifts for the respective days and take it as the minimum number of night-shift work stretches required as this is actually the minimum number of weeks required to cater for the night shifts. Let it be N_{night}, where N_{night} = max {Number of night shifts required in day 1, …, Number of night shifts required in day 7}.

Step 3. To find the minimum number of morning- and afternoon-shift work stretches required, the maximum number of the morning and afternoon shifts each for the respective days are found and let us call them $N_{morning/afternoon}$, where $N_{morning/afternoon}$ = max {Number of morning and afternoon shifts in day 1, …, Number of morning and afternoon shifts in day 7}. Similarly, this maximum number of morning and afternoon shifts is the minimum number of weeks needed to cater for all the morning and afternoon shift requirements.

Step 4. If any of these shift types has the same number of shifts for all the weekdays, then increase the maximum number of shifts by one. For example, if Number of night shifts in day *d* equals to five, where *d* = 1, 2, …, 7. Then, at least six night-shift work stretches are required to cover all night shifts with the necessary rest days so as not to violate the labor rules.

Step 5. The total number of weeks required:

$$w = \max\{\, N_{Night} + N_{Morning\ /\ Afternoon}\ , \lceil total\ \ number\ \ of\ \ shifts\ /\ 6 \rceil \}$$

The problem of forming a rotation with a length of w weeks or $7*w$ days in which any two night-shift work stretches need to be separated by one or two morning-afternoon-shift work stretch(es), which is the preference of the air cargo terminal mentioned earlier, can be formulated as an integer program. Let the $7*w$ days be dated as 1, 2, 3,…, $7*w$, where dates 1, 8, 15,… are Mondays, and dates 2, 9, 16, … are Tuesday, etc. Date $7*w$ is considered to be consecutive to date 1. In other words, the dates are ordered in a wrap-around way. The parameters as well as the variables of the model are presented here:

Parameters:

i = a dated night-shift work stretch pattern, starting with a rest day, followed by a few working days and followed by two rest days. The maximum number of night shifts cannot exceed seven in a roll and within a calendar week there should not be more than six night shifts, as this is required by the labor laws. I is the set of pattern i.

j= a dated day shift cum afternoon shift work stretch pattern, consisting of not more than six days of morning shift or afternoon shift work stretch(es) within a calendar week, with or without the rest day. Each work stretch formed should observe the labor laws. J is the set of pattern j.

$D = \{1,2,\ldots,7*w\}$

α_{id} = assuming a value of 1 if date d ($d \in D$) is a working day in pattern $i \in I$, 0 otherwise.

β_{jd} = assuming a value of 1 if date d ($d \in D$) is a working day in pattern $j \in J$, 0 otherwise.

η^{1}_{il} = assuming a value of 1 if pattern i has an 8-hour night shift on the l^{th} day of a calendar week, 0 otherwise.

η^{2}_{il} = assuming a value of 1 if pattern i has a 9-hour night shift on the l^{th} day of a calendar week, 0 otherwise.

η^{3}_{il} = assuming a value of 1 if pattern i has a 10-hour night shift on the l^{th} day of a calendar week, 0 otherwise.

θ^{1}_{jl} = assuming a value of 1 if pattern j has an 8-hour work morning shift on the l^{th} day of a calendar week, 0 otherwise.

θ^{2}_{jl} = assuming a value of 1 if pattern j has a 9-hour morning shift on the l^{th} day of a calendar week, 0 otherwise.

θ^{3}_{jl} = assuming a value of 1 if pattern j has a 10-hour morning shift on the l^{th} day of a calendar week, 0 otherwise.

ζ^{1}_{jl} = assuming a value of 1 if pattern j has an 8-hour afternoon shift on the l^{th} day of a calendar week, 0 otherwise.

ζ^{2}_{jl} = assuming a value of 1 if pattern j has a 9-hour afternoon shift on the l^{th} day of a calendar week, 0 otherwise.

ζ^{3}_{jl} = assuming a value of 1 if pattern j has a 10-hour afternoon shift on the l^{th} day of a calendar week, 0 otherwise.

N^{1}_{l}= total number of 8-hour night shifts required on the l^{th} day of a calendar week

N^{2}_{l}= total number of 9-hour night shifts required on the l^{th} day of a calendar week

N^{3}_{l}= total number of 10-hour night shifts required on the l^{th} day of a calendar week

D^{1}_{l}= total number of 8-hour morning shifts required on the l^{th} day of a calendar week

D^{2}_{l}= total number of 9-hour morning shifts required on the l^{th} day of a calendar week

D^{3}_{l}= total number of 10-hour morning shifts required on the l^{th} day of a calendar week

A^{1}_{l}= total number of 8-hour afternoon shifts required on the l^{th} day of a calendar week

A^2_l= total number of 9-hour afternoon shifts required on the l^{th} day of a calendar week

A^3_l= total number of 10-hour afternoon shifts required on the l^{th} day of a calendar week

Variables:

$x_i = 1$ if pattern i is selected in the rotation and 0 otherwise, where $i \in I$.

$y_j = 1$ if pattern j is selected in the rotation and 0 otherwise, where $j \in J$.

It is not difficult to see that, the rotation problem is a feasibility problem to the following constraints and its resulting feasible roster would be the optimal solution to support the workload because the underlying problem is a feasibility problem.

$$\sum_i \alpha_{id} x_i + \sum_j \beta_{jd} y_j \le 1, \ for\ all\ d \in D \tag{3.13}$$

$$\sum_i \eta^1_{il} x_i \ge N^1_l, \ for\ l = 1,2,...,7 \tag{3.14}$$

$$\sum_i \eta^2_{il} x_i \ge N^2_l, \ for\ l = 1,2,...,7 \tag{3.15}$$

$$\sum_i \eta^3_{il} x_i \ge N^3_l, \ for\ l = 1,2,...,7 \tag{3.16}$$

$$\sum_j \theta^1_{jl} y_j \ge D^1_l, \ for\ l = 1,2,...,7 \tag{3.17}$$

$$\sum_j \theta^2_{jl} y_j \ge D^2_l, \ for\ l = 1,2,...,7 \tag{3.18}$$

$$\sum_j \theta^3_{jl} y_j \ge D^3_l, \ for\ l = 1,2,...,7 \tag{3.19}$$

$$\sum_j \zeta^1_{jl} y_j \ge A^1_l, \ for\ l = 1,2,...,7 \tag{3.20}$$

$$\sum_j \zeta^2_{jl} y_j \ge A^2_l, \ for\ l = 1,2,...,7 \tag{3.21}$$

$$\sum_j \zeta^3_{jl} y_j \ge A^3_l, \ for\ l = 1,2,...,7 \tag{3.22}$$

x_i = 0, 1, for all i

y_j = 0, 1, for all j

The first set of constraint (3.13) is used to ensure that at most one shift will be chosen for a dated day *d*. Constraint (3.14) ensures that for each of the calendar day, *l*, the 8-hour night shifts selected must cover the 8-hour night shifts required. Constraints (3.15) and (3.16) serve the same purpose except that they are catered for 9-hour night shifts and 10-hour night shifts respectively. Similarly, constraint sets (3.17) to (3.19) state that for each of the calendar day, *l*, the number of 8-hour, 9-hour and 10-hour morning shifts in the solution must be greater than or equal to the total number of 8-hour, 9-hour and 10-hour morning shifts required. Constraint sets (3.20) to (3.22) are used to cater for the same purpose except that they are meant for the afternoon shifts.

This problem can be solved by the Benders decomposition (Cordeau et al (2001)). In other words, it can be viewed as a two-stage decision problem. In the first-stage, the night-shift work stretch patterns, which involve only variables x_i are selected. Given the first-stage solution, at the second stage the morning- and afternoon-shift work stretch patterns are selected which involve only variables y_j. For a given first-stage solution, if a second-stage solution can be found then the combined solution provides a complete solution to the roster problem. Failing to do this, a feasibility cut can be generated and fed back to the first stage to produce a new first-stage selection and this process can be repeated until a feasibility solution is found or the problem is found to be infeasible.

It is clear that a huge number of work stretch patterns *i* and *j* need to be generated if the solution approach described in the previous paragraph is used. This is because the number of work stretch patterns grows in an exponential magnitude of the input parameters. Conceivably, the problem will be very large and most likely it is not computationally tractable.

Examining the labor laws and the general structure of a feasible roster carefully, it is discovered that the determination of a "proper" set of night-shift work stretches plays a pivotal role in finding a feasible roster. In other words, once a "proper" set of night-shift work stretches has been identified, it is not difficult to uncover the complementary morning and afternoon shifts to form a complete roster.

To identify a "proper" set of night-shift work stretches, the dates of *D* are first collapsed into a week and the working patterns *i* can be interpreted according to this mapping. In essence, the model presented below can be viewed as a relaxed model of the first-stage decision problem for the roster problem approached by the Bender's decomposition as in this model the dates are mapped from *w* weeks into a week.

To present the model, a modified interpretation and new meaning of the notation are first given as follows:

$D = \{1,2,3,4,5,6,7\}$, sequenced in a wrap-around order

$i =$ a night-shift working pattern dated according to *D*, starting with a rest day, followed by a maximum of seven working nights and not more than six working nights in a calendar week, and followed by two rest days

A Relaxed First-Stage Roster Model

Maximize p (3.23)

s.t

$$\sum_i \eta_{il}^1 x_i \geq N_l^1,\ for\ l = 1,2,...,7 \tag{3.24}$$

$$\sum_i \eta_{il}^2 x_i \geq N_l^2,\ for\ l = 1,2,...,7 \tag{3.25}$$

$$\sum_i \eta_{il}^3 x_i \geq N_l^3,\ for\ l = 1,2,...,7 \tag{3.26}$$

$$\sum_i \gamma_{il} x_i + s_l = R_l\ ,\ for\ l = 1,2,...,7 \tag{3.27}$$

$$p \leq s_l,\ for\ l = 1,2,..,7 \tag{3.28}$$

$$s_l \geq 0;\ x_i = 0,\ 1$$

Here,

γ_{il} = 0 if pattern i has no rest day at the l^{th} day of a calendar week.

= 1 if pattern i has a rest day at the l^{th} day of a calendar week.

= 2 if pattern i has two rest day at the l^{th} day of a calendar week.

R_l = the total number of rest days allowed for the l^{th} day of a week, which is w-$N^1{}_l$-$N^2{}_l$- $N^3{}_l$- $D^1{}_l$- $D^2{}_l$- $D^3{}_l$- $A^1{}_l$- $A^2{}_l$- $A^3{}_l$

The first three constraints sets (3.24), (3.25) and (3.26) are the same as (3.14), (3.15) and (3.16) in the original problem. To capture the restriction implied by constraints (3.17) to (3.22), the fourth set of constraints (3.27) is imposed to ensure that the number of rest days on any day l of the week resulting from the chosen night shift patterns should not exceed the maximal number of rest days, R_l, allowed on that day. In other words, $s_l \geq 0$. This can be interpreted as a type of feasibility cuts to the first stage decision problem. It is perceived that given a selection of the night-shift working patterns, the complementary morning-shift and afternoon-shift working patterns can be uncovered more easily if the remaining rest days on any day of the week are as balanced as possible. To achieve this, the model is set to maximize the minimal value of the rest days $\{s_1, s_2, \ldots, s_7\}$.

It is not difficult to see that if this relaxed first-stage roster model has no solution for a given w, then the original problem will be infeasible for this same w too. Hence, if this happens, the model needs to be resolved for a bigger w. To solve the roster problem, it is proposed to run the relaxed first-stage roster model using the lower bound determined based on the steps mentioned earlier. If there is no feasible solution found then the lower bound is increased by one and the model is re-run again. A solution to the relaxed first-stage roster model can be found eventually by raising the lower bound of the weeks sufficiently large. Once a set of the night-shift work stretch patterns is identified by the first-stage roster model, the next step is to determine the allocation of these night-shift work stretches into the w-week roster. The reason for doing so is that the solution obtained from the relaxed first-stage roster model only provides the work stretch patterns, namely the start day, the number of night shifts in between and the end day of each night-shift work stretch, but not the allocation of these night-shift work stretches within the w-week roster. In short, the solution does not specify which week the particular night-shift work stretch should be allocated within the roster. An example of the output of the relaxed first-stage model can be found in the next section.

After the allocation of the night-shift work stretches into the roster, the next task is to identify the complementary morning- and afternoon-shifts between the night-shift work stretches. These shifts should be packed in a forward or clockwise direction as far as possible, moving the shifts in the order, from morning to afternoon and then to night shift, as recommended in some of the literatures (Tepas and Monk, 1987, Dekker et al., 1996, and Czeisler et al. 1982). By doing so, somehow the labor law is satisfied rather naturally. In other words, automatically there is sufficient rest time of at least t_b hours, between the two shifts. It is possible that complementary morning and afternoon shifts may not exist to allow a feasible roster to be formed. Nevertheless for the actual data being tried out in this work, this problem does not occur.

Below are the steps to allocate the night-shift work stretches in w weeks in the first phase. The main idea is to allocate all the night-shift work stretches found from the roster model solution into the w-week roster as evenly as possible. That is, the interval gap or the number of non-night-shift days between any two night-shift work stretches should not differ too much. This is to cater for the terminal's requirement of having an equally distribution of the night-shift work stretches within the roster as far as possible. Two pieces of information from the roster model solution are important to perform this task, namely the total number of weeks required to form a feasible roster, w, and the number of night-shift work stretches, denoted as N_{ws}. The steps to uncover the complementary morning and afternoon shifts between the night-shift work stretches to form a complete roster will be described in the second phase.

<u>Phase 1: Allocating the night-shift work stretches</u>

Step 0. **Initialize w, N^R, D^R and i_n**: The w is the number of weeks required to form the roster. N^R is the current number of interval gaps between the night-shift work stretches which have not been assigned. D^R stands for the number of days which have been assigned so far for the morning and afternoon shift stretches. i_n is the number of night-shift work stretches have been assigned to the roster. Initially N^R is the number of night-shift work stretches found from the roster model which is N_{ws}, D^R and i_n are 0.

Step 1. **Assign the first night-shift work stretch:** Choose any night-shift work stretch to start with and assign it to the beginning of the roster. Set $i_n = 1$ as one night-shift work stretch has been assigned to the roster.

Step 2. **Updating of N^R and D^R:** The new $N^R = N_{ws} - i_n + 1$; the new D^R = old D^R + total number of days assigned for the new interval gap determined between the night-shift work stretches. Here 1 is added in updating N^R because the assignment of days is made in the forward direction in a continuous manner and furthermore the whole stretch of days which have been assigned starts and ends respectively with a nigh-shift work stretch. Hence the number of interval gaps should be one more than the number of nigh-shift work stretches which have not been assigned.

Step 3. **Determine the upper (*UD*) and lower (*LD*) bounds:** In order to spread all the night-shifts into the w-week roster as evenly as possible, the interval gap between the night-shift work stretches needs to be determined. There are a number of ways to determine the number of days in between the night-shift work stretches. A way to determine this is obtained by calculating the *UD* and *LD* of the weeks in between any two night-shift work stretches.

$$\text{UD} = \left\lceil \frac{(w*7 - \text{Total number of night shifts} - D^R)/N^R}{7} \right\rceil \quad (3.29)$$

$$\text{LD} = \left\lfloor \frac{(w*7 - \text{Total number of night shifts} - D^R)/N^R}{7} \right\rfloor \quad (3.30)$$

Step 4. **Assign the next night-shift work stretch:** With the *UD* and *LD* found, select any night-shift work stretch which is at least *LD**7 number of days but not more than *UD**7 number of days apart from the previous night-shift work stretch, to be the next night-shift work stretch. In the case where *UD**7 = *LD**7, find the night-shift work stretch which has the smallest difference between the *UD**7 (or *LD**7) and the first day of the respective night-shift work stretch, in terms of the number of days, to be the next night-shift work stretch. Once a night-shift work stretch is assigned, advance i_n by 1.

Step 5. **Check for termination:** If $i_n = N_{\text{ws}}$ go to Phase 2. Else, go to Step 3.

Figure 3.7 summarizes the steps to allocate the night-shift work stretches into the roster. The second phase to uncover the complementary morning and afternoon shifts between the night-shift work stretches is discussed later.

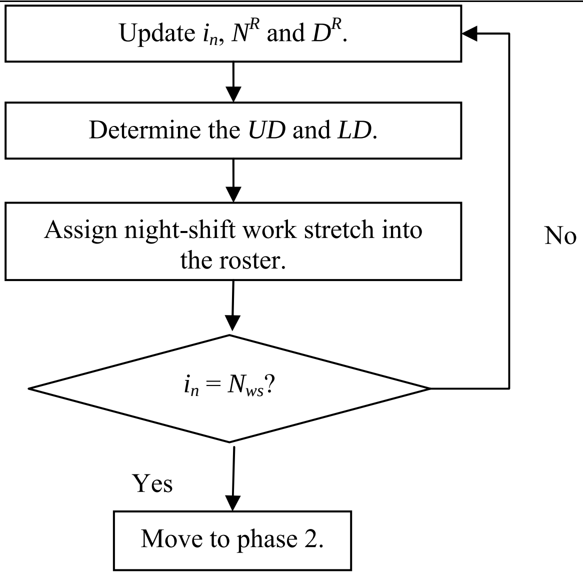


Figure 3.7: Phase 1 process flow-Steps to allocate the night-shift work stretches into the roster.

The following presents the main spirit of the heuristic used to assign the morning and afternoon shifts into the morning- and afternoon-shift work stretches. A step-by-step example is used to illustrate this in details in Section 3.3.3.2. A detail description of the heuristic is also presented in Appendix G.

The main objective in this phase is to uncover the complementary morning and afternoon shifts and assign them into the roster without violating the labor laws, i.e. the worker cannot work more than t_n hours per calendar week and each worker should have at least t_b hours of break between shifts. Before the assignment, all the morning and afternoon shifts of the respective calendar days available should be sorted according to the shift start time. The following steps are repeated for each unassigned morning- and afternoon-shift work stretches.

Phase 2: Assigning the morning and afternoon shifts into the morning- and afternoon-shift work stretches

Step 1. **Start the morning and afternoon shift assignment:** Assign the first day of the work stretch selected with the earliest shift found for that day from the list of sorted morning and afternoon shifts.

Step 2. **Selection of the shift for the next assignment:** Select the shift for the next day without violating any of the labor laws mentioned earlier. Bear in mind that these shifts should be packed in a clockwise direction as far as possible as it is recommended in some of the studies. If a shift is found, go to Step 3. Else, go to Step 4.

Step 3. **Assign the selected shift to the roster:** Assign the selected shift to the roster. If there is any other days without assignment within the same work stretch, go to Step 2. Else, go to Step 5.

Step 4. **Rest day assignment:** Assign this day as a Rest day and repeat Step 2.

Step 5. **Termination:** Stop the assignment.

In the case where some shifts are still left unassigned at Step 5, some adjustments will be required. To do the adjustments, we apply 1-swap and 2-swap. A 1-swap adjustment refers to a swap between a Rest day and the unassigned shift where both of them fall on the same calendar day and the replacement by the unassigned shift does not lead to a violation of the labor laws. A 2-swap adjustment refers to two swaps where one of the swaps performs the replacement of a Rest day by the unassigned shift while the other swap performs a swap between a Rest day with an assigned shift. An illustration of the swaps is described later in the case study example. After carrying out the adjustments by either 1-swap or 2-swap, if there are still unassigned shifts remained, then the total duration can be extended by one extra week of Rest days and the procedure can be repeated until a legal roster is formed. Figure 3.8 presents the steps involved in Phase 2 and a detail description of the implementation of this heuristic is presented in the next section.

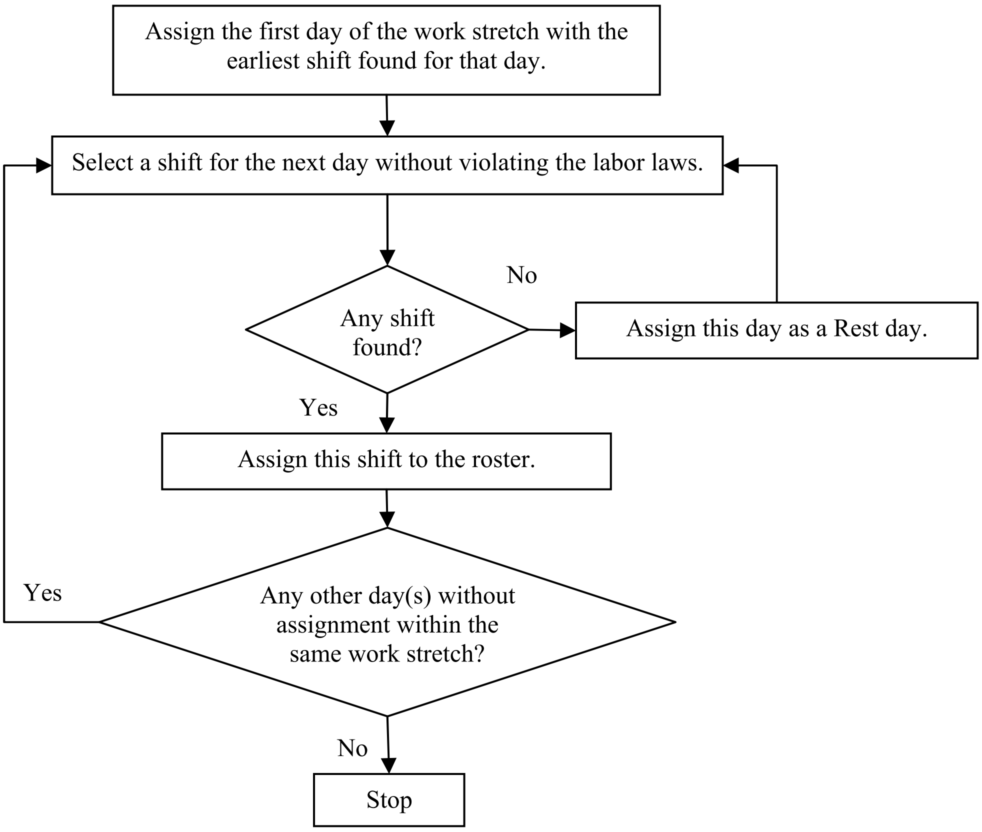


Figure 3.8: Phase 2 process flow-Steps to assign morning and afternoon shifts to each morning- and afternoon-shift work stretch.

3.3.3.2 Result and Analysis

Let us now look into developing the roster for all the four groups, namely Groups 1, 2, 3 and 4. First, the way to form Group 1 roster is shown and then followed by the other three groups. Table 3.4 presented earlier summarizes the number of night, morning and afternoon shifts per day from our Group 1 optimal solution obtained from the shift scheduling model.

The approach introduced in the previous section is used to form the roster for the Checking Teams in Group 1. Before all the shifts with specific start and end times for the respective calendar days are assigned to the roster, the lower bound number of weeks, w, needs to be determined by following the steps used to find the lower bound of the weeks required to form the roster.

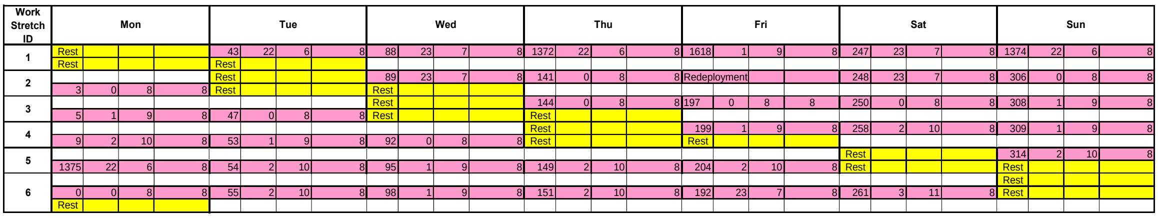
First, the maximum number of night shift weeks, N_{night}, needs to be found. As all the days have the same number of night shifts, one additional week is added. Hence, $N_{night} = 5 + 1 = 6$. Then, the maximum number of morning and afternoon shift weeks needs to be found, where, $N_{morning/afternoon} = 10$, this is shown in Table 3.4 in the earlier section. The lower bound of the weeks required to form a complete roster, $w = \max\{16, \lceil 93/6 \rceil\} = 16$, where the total number of shifts required is 93. Then the roster model is solved with the parameters shown in Table 3.5 below.

Table 3.5: Parameters used to solve the roster problem.

Total Shifts in Day 1	**Total Shifts in Day 2**	**Total Shifts in Day 3**	**Total Shifts in Day 4**	**Total Shifts in Day 5**	**Total Shifts in Day 6**	**Total Shifts in Day 7**
13	13	13	14	15	13	12
Rest day in Day 1, R_1	**Rest day in Day 2, R_2**	**Rest day in Day 3, R_3**	**Rest day in Day 4, R_4**	**Rest day in Day 5, R_5**	**Rest day in Day 6, R_6**	**Rest day in Day 7, R_7**
16–13 =3	16-13=3	16-13=3	16-14=2	16-15=1	16-13=3	16-12=4

With the lower bound number of weeks, where w is set as 16, there is no feasible solution found. One more week is added to w and the R_l's are added by 1. A solution is found with w = 17. The solution which indicates the start and end days of each night-shift work stretch as well as the Night-shift Work Stretch ID is presented in Table 3.6.

Table 3.6: Roster model solution for Group 1.

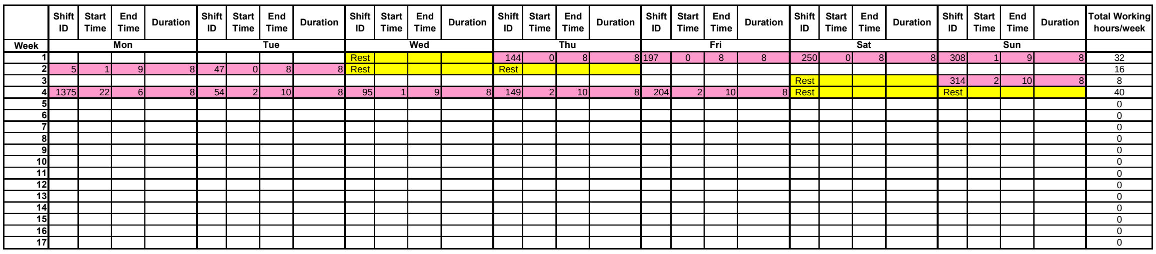


Work Stretch ID	Mon				Tue				Wed				Thu				Fri				Sat				Sun			
1	Rest				43	22	6	8	88	23	7	8	1372	22	6	8	1618	1	9	8	247	23	7	8	1374	22	6	8
	Rest				Rest																							
2					Rest				89	23	7	8	141	0	8	8	Redeployment				248	23	7	8	306	0	8	8
	3	0	8	8	Rest				Rest																			
3									Rest				144	0	8	8	197	0	8	8	250	0	8	8	308	1	9	8
	5	1	9	8	47	0	8	8	Rest				Rest															
4													Rest				199	1	9	8	258	2	10	8	309	1	9	8
	9	2	10	8	53	1	9	8	92	0	8	8	Rest				Rest											
5																					Rest				314	2	10	8
	1375	22	6	8	54	2	10	8	95	1	9	8	149	2	10	8	204	2	10	8	Rest				Rest			
6																									Rest			
	0	0	8	8	55	2	10	8	98	1	9	8	151	2	10	8	192	23	7	8	261	3	11	8	Rest			
	Rest																											

With the roster model solution, it is now ready to form the complete roster by first allocating all the night-shift work stretches into the roster and then by packing the morning and afternoon shifts to the non-night shift days between any two night-shift work stretches. Steps mentioned in the previous section to form a complete roster are used. First, the w, N^R, D^R and i_n are initialized, where $w = 17$, $N^R = N_{ws} = 6$, $D^R = 0$, $i_n = 0$ and the total number of night shifts (inclusive of the rest days) = 54. After the initialization of these parameters, the first night-shift work stretch is selected at random. For this case, Night-shift Work Stretch 3 is chosen and assigned to the roster. As one night-shift work stretch has been assigned, $i_n = 1$. Followings are the iterations to assign the rest of the night-shift work stretches into the roster.

Iteration 1: As Night-shift Work Stretch 3 is assigned to the roster, $i_n = 1$, $N^R = 6 - 1 + 1 = 6$, and $D^R = 0$. Hence, $UD = \left\lceil \frac{(17*7-54-0)/6}{7} \right\rceil = 2$ and $LD = \left\lfloor \frac{(17*7-54-0)/6}{7} \right\rfloor = 1$. The number of non-night shift days between the first and the second night-shift work stretches should be at least $LD*7 = 1*7 = 7$ days but not greater than $UD*7 = 2*7 = 14$ days. Night-shift Work Stretch 5 is selected to be the second night-shift work stretch which starts eight days later. This is shown in Table 3.7.

Table 3.7: The allocation of the first two night-shift work stretches.



	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	Mon				Tue				Wed				Thu				Fri				Sat				Sun				
1									Rest				144	0	8	8	197	0	8	8	250	0	8	8	308	1	9	8	32
2	5	1	9	8	47	0	8	8	Rest				Rest																16
3																					Rest				314	2	10	8	8
4	1375	22	6	8	54	2	10	8	95	1	9	8	149	2	10	8	204	2	10	8	Rest				Rest				40
5																													0
6																													0
7																													0
8																													0
9																													0
10																													0
11																													0
12																													0
13																													0
14																													0
15																													0
16																													0
17																													0

Iteration 2: As Night-shift Work Stretch 5 is assigned to the roster, $i_n = 2$, $N^R = 6 - 2 + 1 = 5$, and $D^R = 8$. Hence, $UD = \left\lceil (\frac{17*7-54-8)/5}{7} \right\rceil = 2$ and $LD = \left\lfloor \frac{(17*7-54-8)/5}{7} \right\rfloor = 1$.

Similarly, the number of non-night shift days between Night-shift Work Stretch 5 and the next night-shift work stretch should be at least $LD*7 = 1*7 = 7$ days but not greater than $UD*7 = 2*7 = 14$ days. Night-shift Work Stretch 6 is selected to be the third night-shift work stretch which starts 13 days later.

Iteration 3: As Night-shift Work Stretch 6 is assigned to the roster, $i_n = 3$, $N^R = 6 - 3 + 1 = 4$, and $D^R = 8 + 13 = 21$. Hence, $UD = \left\lceil (\frac{17*7-54-21)/4}{7} \right\rceil = 2$ and $LD = \left\lfloor \frac{(17*7-54-21)/4}{7} \right\rfloor = 1$.

Similarly, the number of non-night shift days between Night-shift Work Stretch 6 and the next night-shift work stretch should be at least $LD*7 = 1*7 = 7$ days but not greater than $UD*7 = 2*7 = 14$

days. Night-shift Work Stretch 1 is selected to be the next night-shift work stretch which starts 13 days later.

Iteration 4: As Night-shift Work Stretch 6 is assigned to the roster, $i_n = 4$, $N^R = 6 - 4 + 1 = 3$, and $D^R = 8 + 13 + 13 = 34$. Hence, $UD = \left\lceil \frac{(17*7-54-34)/3}{7} \right\rceil = 2$ and $LD = \left\lfloor \frac{(17*7-54-34)/3}{7} \right\rfloor = 1$.

Once again, the number of non-night shift days between Night-shift Work Stretch 1 and the next night-shift work stretch should be at least $LD*7 = 1*7 = 7$ days but not greater than $UD*7 = 2*7 = 14$ days. Night-shift Work Stretch 4 is selected to be the next night-shift work stretch which starts eight days later.

Iteration 5: As Night-shift Work Stretch 6 is assigned to the roster, $i_n = 5$, $N^R = 6 - 5 + 1 = 2$, and $D^R = 8 + 13 + 13 + 8 = 42$. Hence, $UD = \left\lceil (\frac{17*7-54-42)/2}{7} \right\rceil = 2$ and $LD = \left\lfloor \frac{(17*7-54-42)/2}{7} \right\rfloor = 1$.

Once again, the number of non-night shift days between Night-shift Work Stretch 4 and the next night-shift work stretch should be at least $LD*7 = 1*7 = 7$ days but not greater than $UD*7 = 2*7 = 14$ days. In this case, since there is only one night-shift work stretch left, Night-shift Work Stretch 2 is chosen and allocated to the roster.

Iteration 6: As $i_n = N_{ws} = 6$, all the night-shift work stretches are assigned and the iteration stops here.

The completed night-shift work stretch allocation is shown in Table 3.8.

Table 3.8: The night-shift work stretches allocation.

	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	Mon				Tue				Wed				Thu				Fri				Sat				Sun				
1									Rest				144	0	8	8	197	0	8	8	250	0	8	8	308	1	9	8	32
2	5	1	9	8	47	0	8	8	Rest				Rest																16
3																					Rest				314	2	10	8	8
4	1375	22	6	8	54	2	10	8	95	1	9	8	149	2	10	8	204	2	10	8	Rest				Rest				40
5																													0
6																									Rest				0
7	0	0	8	8	55	2	10	8	98	1	9	8	151	2	10	8	192	23	7	8	261	3	11	8	Rest				48
8	Rest																												0
9																													0
10	Rest				43	22	6	8	88	23	7	8	1372	22	6	8	1618	1	9	8	247	23	7	8	1374	22	6	8	48
11	Rest				Rest																								0
12													Rest				199	1	9	8	258	2	10	8	309	1	9	8	24
13	9	2	10	8	53	1	9	8	92	0	8	8	Rest				Rest												24
14																													0
15					Rest				89	23	7	8	141	0	8	8	Redeployment				248	23	7	8	306	0	8	8	32
16	3	0	8	8	Rest				Rest																				8
17																													0

After all the night shifts have been assigned, it is ready to pack in the morning and afternoon shifts into the roster by assigning the morning and afternoon shifts of the respective calendar day to the unassigned days according to the calendar day in the roster following the clockwise direction as far as possible. In addition, the t_b-hour rule will be followed where any two shifts have to be at least t_b hours apart. The first task to assign all the morning and afternoon shifts to the roster is to sort all the morning and afternoon shifts according to the shift start time with respect to the calendar day. Table 3.9 presents the sorted morning and afternoon shifts of the respective days for the Group 1 Checking Teams.

From Table 3.8, select any morning- and afternoon-shift work stretch to start with. In this case, the first morning- and afternoon-shift work stretch right after the first night-shift work stretch is selected. The first day of this morning- and afternoon-shift work stretch is a Friday or day 5. The earliest shift found on Friday is Shift 216 as indicated in Table 3.9. Shift 216 is assigned to the roster. The total working hours per week and the remaining hours per week are checked and since it has not violated the labor laws, let us move to the next day, which is Saturday. Again, a Saturday-shift is selected from Table 3.9 with respect to the labor laws mentioned in the previous section. A shift with a start time not earlier than the previous shift's start time and a shift duration not more than the remaining hours per week is found. Choosing a start

Table 3.9: Sorted morning and afternoon shifts for Group 1.

Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration
Mon				Tue				Wed				Thu				Fri				Sat				Sun			
15	11	19	8	57	9	17	8	106	11	19	8	155	10	18	8	216	12	20	8	264	11	19	8	320	11	19	8
18	11	19	8	60	11	19	8	114	12	20	8	156	11	19	8	222	12	20	8	266	11	19	8	323	11	19	8
20	12	20	8	64	11	19	8	122	13	21	8	162	11	19	8	223	13	21	8	274	12	20	8	324	11	19	8
21	12	20	8	65	12	20	8	123	13	21	8	164	12	20	8	225	13	21	8	278	12	20	8	325	12	20	8
23	12	20	8	71	12	20	8	124	13	21	8	165	12	20	8	226	13	21	8	283	13	21	8	326	12	20	8
24	12	20	8	75	13	21	8	128	14	22	8	173	13	21	8	358	13	22	9	285	13	21	8	360	13	22	9
354	13	22	9	76	13	21	8	1372	14	22	8	356	13	22	9	231	14	22	8	359	13	22	9	1375	14	22	8
41	17	1	8	86	16	0	8	130	15	23	8	179	14	22	8	232	14	22	8	1374	14	22	8				
												1618	17	1	8	239	16	0	8								
																241	16	0	8								

time of not earlier than the previous shift's start time is to follow the recommendations of some of the studies where the shifts should be assigned in a clockwise direction. As the previously assigned shift has a start time of 1200hours, the first two Saturday shifts with the start time of 1100hours in Table 3.9 are not selected. However, the third shift with shift ID 274 is a potential candidate for the assignment as its start time is 1200hours, which is the same as Shift 216. Once again, the total working hours and the remaining hours per week are updated. Since the shift duration of Shift 274 is eight hours which is less than the remaining hours of (t_n – 8)hours, it is obvious that the labor laws will not be violated. As a result, Shift 274 is selected and assigned to the roster.

As there are still shifts yet to be assigned to the roster and the current morning- and afternoon-shift work stretch is not fully filled-up, this process is continued until all the shifts have been assigned to the roster or all the work stretches have been assigned with shifts. In the case when all the shifts can be assigned to the roster, a complete roster is formed and changes of some of the identified Rest days to Redeployment days can be made. However, if some shifts are still left unassigned after all the work stretches have been assigned with either shifts or Rest days, then some adjustments will be needed as this indicates that too many Rest days have been assigned to the roster. For this example in the initial trial, one shift of day 7 with shift ID 360 is left unassigned after all the work stretches have been assigned with shifts and Rest days. Adjustment is needed to pack this shift into the roster.

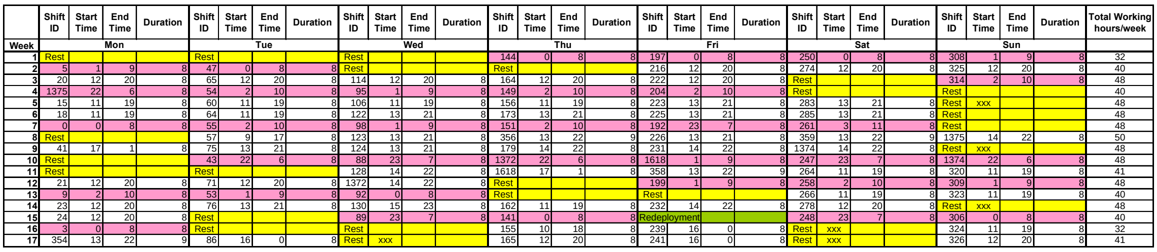
To perform this adjustment, let us set $D^u = 7$, which is the calendar day of Shift 360. Let us also name Shift 360 as Shift S^u. Now, let us first go through all the

Rest days with the same calendar day $D^u = 7$. If a Rest day with the same calendar is found to be a feasible candidate to be replaced by Shift S^u, then the adjustment is done. For this example, a Rest day of Week 4 with the calendar day D^u is identified. However this Rest day of Week 4 is part of the night-shift work stretch. Hence it can not be selected for the adjustment and another Rest day has to be identified. The next Rest day found is a Rest day in Week 5 with calendar day D^u. In this instance, the total working hours for this week are 48 hours and replacing this Rest day by Shift S^u will violate the labor law which does not allow more than t_n working hours per calendar week. As a result, this Rest day is not selected. Similarly, the Rest day on Weeks 6 and 7 with calendar day D^u belong to a night-shift work stretch; thus, they cannot be used either. The search goes further and it is found that both Weeks 9 and 14 have potential candidates of Rest day with calendar day D^u. However, the total working hours for both of these weeks are again 48 hours and replacing any of the two Rest days by Shift S^u will violate the labor law of not having more than t_n working hours per calendar week. As a result, none of the Rest days with calendar day D^u is found to be suitable for the adjustment.

Hence, the 1-swap adjustment fails and the 2-swap adjustment is needed where we have to go one step further by looking for other calendar days for a swap of the Rest day and the working day in order to make room for the unassigned shift, Shift S^u. The steps involved to search for a candidate for the swap is described below.

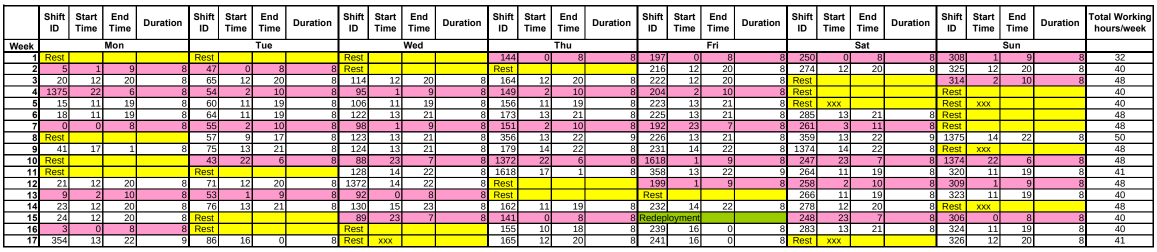
To search for such a candidate systematically, it is recommended to start with the first Rest day found in the last work stretch. The reason to get a Rest day from the last work stretch is because generally there are more Rest days being assigned in the last work stretch. As shown in Table 3.10, the first Rest day found in the last work stretch is a Saturday or day 6 in Week 16. To find a working day of day 6 in the roster which is eligible for a swap, let us start from Week $w^c = 1$ and then move forward to the subsequent weeks until an eligible candidate is found. An eligible candidate here should be a working day with an assigned shift while the day D^u of the same week should be a Rest day. By searching through the column of day 6, the day 6 of Week 5 has been identified as the suitable candidate for a swap as there is a Rest day of D^u within the same calendar week and day 6 of this week is a working day with an assigned shift 283. Hence, Shift 283 originally in Week 5 is swapped with the Rest day with calendar day 6 in Week 16 as shown in Table 3.11. Then, Shift 360 is moved to the day 7 of Week 5 to replace the day D^u Rest day in Week 5 and this is shown in Table 3.12. Lastly, some of the Rest days are changed to Redeployment day without violating the labor laws. Now, the Group 1 roster is completed finally and it is shown in Table 3.13.

Table 3.10: All the shifts are packed in except Shift 360.



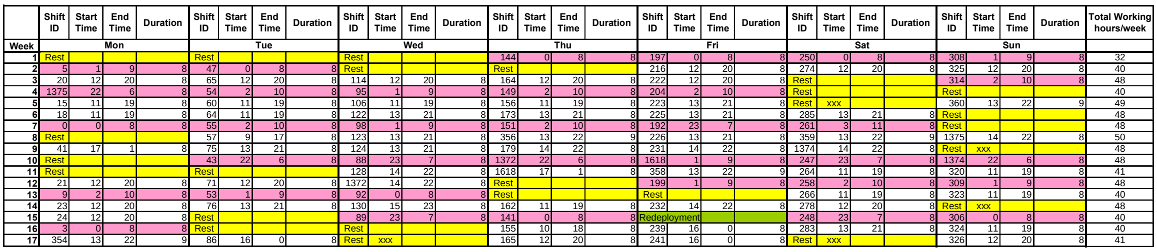
	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	Mon				Tue				Wed				Thu				Fri				Sat				Sun				
1	Rest				Rest				Rest				144	0	8	8	197	0	8	8	250	0	8	8	308	1	9	8	32
2	5	1	9	8	47	0	8	8	Rest				Rest				216	12	20	8	274	12	20	8	325	12	20	8	40
3	20	12	20	8	65	12	20	8	114	12	20	8	164	12	20	8	222	12	20	8	Rest				314	2	10	8	48
4	1375	22	6	8	54	2	10	8	95	1	9	8	149	2	10	8	204	2	10	8	Rest				Rest				40
5	15	11	19	8	60	11	19	8	106	11	19	8	156	11	19	8	223	13	21	8	283	13	21	8	Rest	xxx			48
6	18	11	19	8	64	11	19	8	122	13	21	8	173	13	21	8	225	13	21	8	285	13	21	8	Rest				48
7	0	0	8	8	55	2	10	8	98	1	9	8	151	2	10	8	192	23	7	8	261	3	11	8	Rest				48
8	Rest				57	9	17	8	123	13	21	8	356	13	22	9	226	13	21	8	359	13	22	9	1375	14	22	8	50
9	41	17	1	8	75	13	21	8	124	13	21	8	179	14	22	8	231	14	22	8	1374	14	22	8	Rest	xxx			48
10	Rest				43	22	6	8	88	23	7	8	1372	22	6	8	1618	1	9	8	247	23	7	8	1374	22	6	8	48
11	Rest				Rest				128	14	22	8	1618	17	1	8	358	13	22	9	264	11	19	8	320	11	19	8	41
12	21	12	20	8	71	12	20	8	1372	14	22	8	Rest				199	1	9	8	258	2	10	8	309	1	9	8	48
13	9	2	10	8	53	1	9	8	92	0	8	8	Rest				Rest				266	11	19	8	323	11	19	8	40
14	23	12	20	8	76	13	21	8	130	15	23	8	162	11	19	8	232	14	22	8	278	12	20	8	Rest	xxx			48
15	24	12	20	8	Rest				89	23	7	8	141	0	8	8	Redeployment				248	23	7	8	306	0	8	8	40
16	3	0	8	8	Rest				Rest				155	10	18	8	239	16	0	8	Rest	xxx			324	11	19	8	32
17	354	13	22	9	86	16	0	8	Rest	xxx			165	12	20	8	241	16	0	8	Rest	xxx			326	12	20	8	41

Table 3.11: Saturday of Week 16 is identified and swapped with Shift 283.



	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	Mon				Tue				Wed				Thu				Fri				Sat				Sun				
1	Rest				Rest				Rest				144	0	8	8	197	0	8	8	250	0	8	8	308	1	9	8	32
2	5	1	9	8	47	0	8	8	Rest				Rest				216	12	20	8	274	12	20	8	325	12	20	8	40
3	20	12	20	8	65	12	20	8	114	12	20	8	164	12	20	8	222	12	20	8	Rest				314	2	10	8	48
4	1375	22	6	8	54	2	10	8	95	1	9	8	149	2	10	8	204	2	10	8	Rest				Rest				40
5	15	11	19	8	60	11	19	8	106	11	19	8	156	11	19	8	223	13	21	8	Rest	xxx			Rest	xxx			40
6	18	11	19	8	64	11	19	8	122	13	21	8	173	13	21	8	225	13	21	8	285	13	21	8	Rest				48
7	0	0	8	8	55	2	10	8	98	1	9	8	151	2	10	8	192	23	7	8	261	3	11	8	Rest				48
8	Rest				57	9	17	8	123	13	21	8	356	13	22	9	226	13	21	8	359	13	22	9	1375	14	22	8	50
9	41	17	1	8	75	13	21	8	124	13	21	8	179	14	22	8	231	14	22	8	1374	14	22	8	Rest	xxx			48
10	Rest				43	22	6	8	88	23	7	8	1372	22	6	8	1618	1	9	8	247	23	7	8	1374	22	6	8	48
11	Rest				Rest				128	14	22	8	1618	17	1	8	358	13	22	9	264	11	19	8	320	11	19	8	41
12	21	12	20	8	71	12	20	8	1372	14	22	8	Rest				199	1	9	8	258	2	10	8	309	1	9	8	48
13	9	2	10	8	53	1	9	8	92	0	8	8	Rest				Rest				266	11	19	8	323	11	19	8	40
14	23	12	20	8	76	13	21	8	130	15	23	8	162	11	19	8	232	14	22	8	278	12	20	8	Rest	xxx			48
15	24	12	20	8	Rest				89	23	7	8	141	0	8	8	Redeployment				248	23	7	8	306	0	8	8	40
16	3	0	8	8	Rest				Rest				155	10	18	8	239	16	0	8	283	13	21	8	324	11	19	8	40
17	354	13	22	9	86	16	0	8	Rest	xxx			165	12	20	8	241	16	0	8	Rest	xxx			326	12	20	8	41

Table 3.12: Rest day of day 7 in Week 5 is replaced by Shift 360.



	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	Mon				Tue				Wed				Thu				Fri				Sat				Sun				
1	Rest				Rest				Rest				144	0	8	8	197	0	8	8	250	0	8	8	308	1	9	8	32
2	5	1	9	8	47	0	8	8	Rest				Rest				216	12	20	8	274	12	20	8	325	12	20	8	40
3	20	12	20	8	65	12	20	8	114	12	20	8	164	12	20	8	222	12	20	8	Rest				314	2	10	8	48
4	1375	22	6	8	54	2	10	8	95	1	9	8	149	2	10	8	204	2	10	8	Rest				Rest				40
5	15	11	19	8	60	11	19	8	106	11	19	8	156	11	19	8	223	13	21	8	Rest	xxx			360	13	22	9	49
6	18	11	19	8	64	11	19	8	122	13	21	8	173	13	21	8	225	13	21	8	285	13	21	8	Rest				48
7	0	0	8	8	55	2	10	8	98	1	9	8	151	2	10	8	192	23	7	8	261	3	11	8	Rest				48
8	Rest				57	9	17	8	123	13	21	8	356	13	22	9	226	13	21	8	359	13	22	9	1375	14	22	8	50
9	41	17	1	8	75	13	21	8	124	13	21	8	179	14	22	8	231	14	22	8	1374	14	22	8	Rest	xxx			48
10	Rest				43	22	6	8	88	23	7	8	1372	22	6	8	1618	1	9	8	247	23	7	8	1374	22	6	8	48
11	Rest				Rest				128	14	22	8	1618	17	1	8	358	13	22	9	264	11	19	8	320	11	19	8	41
12	21	12	20	8	71	12	20	8	1372	14	22	8	Rest				199	1	9	8	258	2	10	8	309	1	9	8	48
13	9	2	10	8	53	1	9	8	92	0	8	8	Rest				Rest				266	11	19	8	323	11	19	8	40
14	23	12	20	8	76	13	21	8	130	15	23	8	162	11	19	8	232	14	22	8	278	12	20	8	Rest	xxx			48
15	24	12	20	8	Rest				89	23	7	8	141	0	8	8	Redeployment				248	23	7	8	306	0	8	8	40
16	3	0	8	8	Rest				Rest				155	10	18	8	239	16	0	8	283	13	21	8	324	11	19	8	40
17	354	13	22	9	86	16	0	8	Rest	xxx			165	12	20	8	241	16	0	8	Rest	xxx			326	12	20	8	41

Table 3.13: Group 1 Checking Team’s full shift rotation

	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	Mon				Tue				Wed				Thu				Fri				Sat				Sun				
1	Redeployment				Redeployment				Rest				144	0	8	8	197	0	8	8	250	0	8	8	308	1	9	8	32
2	5	1	9	8	47	0	8	8	Rest				Rest				216	12	20	8	274	12	20	8	325	12	20	8	40
3	20	12	20	8	65	12	20	8	114	12	20	8	164	12	20	8	222	12	20	8	Rest				314	2	10	8	48
4	1375	22	6	8	54	2	10	8	95	1	9	8	149	2	10	8	204	2	10	8	Rest				Rest				40
5	15	11	19	8	60	11	19	8	106	11	19	8	156	11	19	8	223	13	21	8	Rest	xxx			360	13	22	9	49
6	18	11	19	8	64	11	19	8	122	13	21	8	173	13	21	8	225	13	21	8	285	13	21	8	Rest				48
7	0	0	8	8	55	2	10	8	98	1	9	8	151	2	10	8	192	23	7	8	261	3	11	8	Rest				48
8	Rest				57	9	17	8	123	13	21	8	356	13	22	9	226	13	21	8	359	13	22	9	1375	14	22	8	50
9	41	17	1	8	75	13	21	8	124	13	21	8	179	14	22	8	231	14	22	8	1374	14	22	8	Rest	xxx			48
10	Rest				43	22	6	8	88	23	7	8	1372	22	6	8	1618	1	9	8	247	23	7	8	1374	22	6	8	48
11	Rest				Rest				128	14	22	8	1618	17	1	8	358	13	22	9	264	11	19	8	320	11	19	8	41
12	21	12	20	8	71	12	20	8	1372	14	22	8	Rest				199	1	9	8	258	2	10	8	309	1	9	8	48
13	9	2	10	8	53	1	9	8	92	0	8	8	Rest				Rest				266	11	19	8	323	11	19	8	40
14	23	12	20	8	76	13	21	8	130	15	23	8	162	11	19	8	232	14	22	8	278	12	20	8	Rest	xxx			48
15	24	12	20	8	Rest				89	23	7	8	141	0	8	8	Redeployment				248	23	7	8	306	0	8	8	40
16	3	0	8	8	Rest				Rest				155	10	18	8	239	16	0	8	283	13	21	8	324	11	19	8	40
17	354	13	22	9	86	16	0	8	Redeployment				165	12	20	8	241	16	0	8	Rest	xxx			326	12	20	8	41

Let us now look into the rosters for Groups 2, 3 and 4. As mentioned earlier, Groups 2, 3 and 4 are homogenous and they can be treated as one big group to be solved in both the scheduling and the roster models. Nevertheless, the resulting roster will take a long time for the Checking Teams to complete the full rotation for such a big group which may create difficulty in transiting to a new plan when the flight schedule changes. It is therefore preferable to break the roster into smaller groups. We were also told that smaller groups are preferred by the terminal because of easier management. Hence we form three roughly equal-size rosters instead of one big roster for Groups 2, 3, and 4.

The optimal result obtained from the shift scheduling model is presented in Table 3.14, which shows the number of shifts per shift type per day as well as the total number of shifts required for each day. The same approach is used to look for the lower bound of the weeks to start with. From Table 3.14, it is obvious that the lower bound of the weeks to start with is the maximum of 41 and 46. For this case, it is necessary to keep increasing the lower bound of the weeks required until it reaches 51 in order to reach the optimal solution. To form three equal-size rosters, we divide 51 weeks by 3, resulting in 17 weeks. Hence each group will comprise of 17 Checker Teams.

Table 3.14: Number of night, morning and afternoon shifts per day For Group 2, 3 and 4

Day	No. of Night Shifts	No. of Morning and Afternoon Shifts	Total Number of Shifts
1	15	22	37
2	16	24	40
3	15	23	38
4	16	22	38
5	17	24	41
6	15	24	39
7	16	22	38

As in the solution there is a total of 19 night-shift work stretches, dividing the 19 night-shift work stretches by three results in two groups having six night-shift work stretches and one group having seven night shift work stretches. Once again, the night-shift work stretches are assigned to the *w*-week (*w*=17) roster with certain number of days apart by following the steps discussed in the previous section. Lastly, the morning and the afternoon shifts are packed in to the interval gaps between the night-shift work stretches. These shifts are rotated in the clockwise direction as far as possible. This rule synchronizes one of the labor laws. That is, there must be a break of at least t_b hours between the shifts. Tables 3.15, 3.16 and 3.17 show the complete roster generated.

Table 3.15: Group 2 Checking Team’s full shift rotation

	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	Mon				Tue				Wed				Thu				Fri				Sat				Sun				
1	11309	12	22	10	12793	12	22	10	1480	14	22	8	Rest				2177	3	11	8	Redeployment				19242	4	14	10	46
2	131	4	12	8	4890	3	12	9	13337	4	14	10	Rest				Rest				2828	5	13	8	Redeployment				35
3	4512	12	21	9	971	12	20	8	Rest				7062	12	21	9	71636b	13	21	8	3176	14	22	8	3719	15	23	8	50
4	Rest				30187b	21	5	8	130687b	22	7	9	52601b	23	7	8	63700b	22	6	8	76907b	0	8	8	3256	21	5	8	49
5	8	0	8	8	Rest				Rest				1773	6	14	8	2440	10	18	8	18535	11	21	10	20017	12	22	10	44
6	464	13	21	8	1012	14	22	8	6167	12	21	9	63700a	14	22	8	Rest				2677	1	9	8	90171b	22	6	8	49
7	Redeployment				30560b	23	7	8	41965b	22	6	8	627001b	20	6	10	Rest				Rest				19362	5	15	10	36
8	210	6	14	8	5318	9	18	9	1368	10	18	8	7065	12	21	9	2547	14	22	8	90171a	14	22	8	Rest				50
9	Redeployment				595	0	8	8	1135	2	10	8	1573	0	8	8	2102	0	8	8	478823b	21	7	10	Rest				42
10	Rest				723	5	13	8	5820	5	14	9	60248a	6	14	8	2443	10	18	8	9069	12	21	9	3679	13	21	8	50
11	4557	13	22	9	1017	14	22	8	52601a	15	23	8	Rest				2117	0	8	8	2675	1	9	8	90416b	23	7	8	49
12	Redeployment				607	1	9	8	1136	2	10	8	1580	0	8	8	Rest				Rest				9529	5	14	9	33
13	375	10	18	8	944	11	19	8	1455	13	21	8	7072	12	21	9	8073	13	22	9	3180	14	22	8	Rest				50
14	4611	14	23	9	41965a	14	22	8	6253	13	22	9	7209	15	0	9	Rest				Redeployment				19231	4	14	10	45
15	10	0	8	8	Rest				Rest				15359	11	21	10	17056	13	23	10	18655	12	22	10	532706b	14	24	10	48
16	492	14	22	8	5497	14	23	9	1527	17	1	8	Rest				2093	23	7	8	2743	3	11	8	9468	4	13	9	50
17	Rest				Rest				52381a	14	22	8	7179	14	23	9	8073	13	22	9	3150	13	21	8	9948	12	21	9	43

Table 3.16: Group 3 Checking Team’s full shift rotation

	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	**Mon**				**Tue**				**Wed**				**Thu**				**Fri**				**Sat**				**Sun**				
1	30560a	15	23	8	13009	18	4	10	Rest				1602	1	9	8	2126	1	9	8	2673	1	9	8	3315	2	10	8	50
2	41	1	9	8	629	2	10	8	Rest				Rest				2240	5	13	8	189927a	6	14	8	3628	11	19	8	40
3	4528	12	21	9	Rest				1441	13	21	8	7118	13	22	9	76116a	14	22	8	90416a	15	23	8	3763	17	1	8	50
4	Rest				Redeployment				5688	2	11	9	1610	1	9	8	2128	1	9	8	2707	2	10	8	3314	2	10	8	41
5	3867	2	11	9	Rest				Rest				60462a	6	14	8	68378b	10	18	8	18546	11	21	10	9923	12	21	9	44
6	Rest				5418	12	21	9	6181	12	21	9	7168	14	23	9	2582	15	23	8	Rest				9363	2	11	9	44
7	3871	2	11	9	654	3	11	8	5686	2	11	9	1628	2	10	8	68378a	2	10	8	2726	3	11	8	Rest				50
8	Rest				12860	13	23	10	5830	5	14	9	7184	14	23	9	8013	12	21	9	9116	13	22	9	Rest				46
9	4561	13	22	9	38159b	13	21	8	1532	17	1	8	Rest				7382	2	11	9	2730	3	11	8	3335	3	11	8	50
10	3883	2	11	9	4816	2	11	9	13249	3	13	10	1648	3	11	8	Rest				Rest				532706a	5	14	9	45
11	168	5	13	8	923	10	18	8	1385	10	18	8	2048	16	0	8	Rest				9079	12	21	9	9971	13	22	9	50
12	4610	14	23	9	130687a	14	22	8	1518	16	0	8	Rest				2170	3	11	8	8332	2	11	9	3337	3	11	8	50
13	113	4	12	8	657	3	11	8	13252	3	13	10	1651	3	11	8	Rest				Rest				9977	13	22	9	43
14	470	13	21	8	732	5	13	8	6243	13	22	9	1920	10	18	8	2479	11	19	8	189927b	14	23	9	Redeployment				50
15	Rest				661	3	11	8	5733	3	12	9	1658	3	11	8	2175	3	11	8	2738	3	11	8	9428	3	12	9	50
16	127	4	12	8	Rest				Rest				Redeployment				Redeployment				2849	5	13	8	9980	13	22	9	25
17	Rest				12887	13	23	10	6237	13	22	9	7077	12	21	9	8034	12	21	9	18667	12	22	10	Redeployment				47

Table 3.17: Group 4 Checking Team's full shift rotation

	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Shift ID	Start Time	End Time	Duration	Total Working hours/week
Week	**Mon**				**Tue**				**Wed**				**Thu**				**Fri**				**Sat**				**Sun**				
1	Rest				114746b	21	6	9	Redeployment				52381b	22	6	8	63687b	22	6	8	17692	4	14	10	194843b	21	6	9	44
2	1	0	8	8	Rest				Rest				1721	5	13	8	2279	6	14	8	3060	10	18	8	19900	11	21	10	42
3	10580	5	15	10	38159a	5	13	8	Redeployment				60462b	14	22	8	8120	14	23	9	194843a	13	21	8	Rest				43
4	3972	4	13	9	668	3	11	8	1166	3	11	8	6628	4	13	9	2184	3	11	8	2789	4	12	8	Rest				50
5	Rest				4998	5	14	9	13424	5	15	10	15453	12	22	10	8014	12	21	9	Redeployment				9973	13	22	9	47
6	507	15	23	8	Rest				41856b	21	5	8	1687	4	12	8	2188	3	11	8	76116b	22	6	8	9475	4	13	9	49
7	108019a	4	12	8	36401a	3	11	8	Rest				Rest				2256	5	13	8	3066	10	18	8	9930	12	21	9	41
8	114746a	13	21	8	41856a	13	21	8	Rest				15453	12	22	10	8016	12	21	9	Redeployment				10039	14	23	9	44
9	11580	18	4	10	Rest				1161	3	11	8	1686	4	12	8	2213	4	12	8	2676	1	9	8	3348	3	11	8	50
10	20	0	8	8	696	4	12	8	Rest				Rest				71636a	5	13	8	2817	5	13	8	3722	15	23	8	40
11	378	10	18	8	5427	12	21	9	6186	12	21	9	63687a	14	22	8	76907a	16	0	8	Rest				3379	4	12	8	50
12	30	1	9	8	4805	2	11	9	5722	3	12	9	1661	3	11	8	7511	4	13	9	Rest				Rest				43
13	4457	10	19	9	5415	12	21	9	627001a	10	20	10	Redeployment				Rest				9164	14	23	9	10029	14	23	9	46
14	Redeployment				36401b	11	19	8	6226	13	22	9	60248b	14	22	8	8097	14	23	9	3210	15	23	8	Rest				42
15	33	1	9	8	608	1	9	8	5679	2	11	9	1597	1	9	8	7322	0	9	9	Redeployment				Rest				42
16	Rest				12783	12	22	10	6173	12	21	9	Redeployment				478823a	12	21	9	18563	11	21	10	3744	16	0	8	46
17	30187a	13	21	8	Rest				6272	14	23	9	1983	13	21	8	2575	15	23	8	3196	15	23	8	10046	14	23	9	50

Note:
Darkly shaded : Night Shift
Lightly shaded : Rest Day

Compared with the current allocation for Group 1, the new result requires 1 team less than the current operation. In other words, it is a 5.6% of savings in terms of the number of Checking Teams required as shown in Table 3.18. As for Groups 2, 3 and 4, one Checking Team is saved, which is close to 2%, when compared to the current operation.

Table 3.18: Savings in Checking Teams required compared to the current operations.

	Checking Teams (number of teams)		
	Current	New	Saving
Group 1	18	17	5.6%
Group 2, 3 and 4	52	51	1.9%

3.3.4 Flight Allocation Heuristic

This section is to tackle the operational tasks being performed by the Cargo Officer approximately three times per day to assign the flights to each Checking Team. Based on the solution found in Section 3.3.2, all the flights are actually assigned to each Checking Team following the Shift ID given. This is shown in Table 3.19. However, the cargo load of a flight changes from week to week and adjustment has to be made as the workload is better estimated when it is closer to the actual flight departure time. The heuristic proposed here is to help the Cargo Officer to perform this task. Bearing in mind that the workloads of the flights should be found by using the workload estimation heuristic introduced earlier before the flight allocation heuristic is executed. The main spirit of the heuristics is to find out the gaps between the actual workload and the shift duration of each shift. If there is no gaps exist, the Checking Team will follow the flights being assigned in the roster. However, if there are gaps, either the workload exceeds the shift duration or shift duration is much more than the actual workload, adjustments will be made by re-allocating some of the flights to different Checking Teams. This is to ensure that workload is distributed as evenly as possible while not compromising to the customer service level. The detail heuristics is presented in Appendix H.

3.4 Conclusion

The problem presented here is a large-scale optimization problem where all the shifts start and end times are first determined based on the flights' workload. Then a cyclic roster is formed with these shifts being assigned in to the roster. With this newly proposed method, the terminal will be able to reduce two Checking Teams in total without compromising to the current service level while having a more evenly distributed workload among all the Checking Teams.

Table 3.19: Workload of the shifts.

No	Shift ID	Shift Start Time (Minutes)	Shift End Time (Minutes)	Flight Number 1	Workload 1	Flight Number 2	Workload 2	Flight Number 3	Workload 3	Total Workload (Minutes)	Shift Duration (Minutes)	Free Time (Shift Duration - Total Workload - Rest Hour) (Minutes)
1	0	0	480	1	420	0	0	0	0	420	480	0
2	3	0	480	4	300	0	0	0	0	300	480	120
3	5	60	540	3	315	0	0	0	0	315	480	105
4	9	120	600	5	300	0	0	0	0	300	480	120
5	15	660	1140	9	285	0	0	0	0	285	480	135
6	18	660	1140	12	195	0	0	0	0	195	480	225
7	20	720	1200	7	300	0	0	0	0	300	480	120
8	21	720	1200	8	285	0	0	0	0	285	480	135
9	23	720	1200	10	300	0	0	0	0	300	480	120
10	24	720	1200	11	255	0	0	0	0	255	480	165
11	41	1020	1500	13	270	0	0	0	0	270	480	150
12	43	1320	1800	15	285	0	0	0	0	285	480	135
13	47	1440	1920	16	390	0	0	0	0	390	480	30
14	53	1500	1980	19	285	0	0	0	0	285	480	135
15	54	1560	2040	17	300	0	0	0	0	300	480	120
16	55	1560	2040	18	285	0	0	0	0	285	480	135
17	57	1980	2460	22	150	0	0	0	0	150	480	270
18	60	2100	2580	21	300	0	0	0	0	300	480	120
19	64	2100	2580	25	210	0	0	0	0	210	480	210
20	65	2160	2640	20	300	0	0	0	0	300	480	120
21	71	2160	2640	26	300	0	0	0	0	300	480	120
22	75	2220	2700	23	255	0	0	0	0	255	480	165
23	76	2220	2700	24	195	0	0	0	0	195	480	225
24	86	2400	2880	27	285	0	0	0	0	285	480	135
25	88	2820	3300	28	285	0	0	0	0	285	480	135
26	89	2820	3300	31	255	0	0	0	0	255	480	165
27	92	2880	3360	30	285	0	0	0	0	285	480	135
28	95	2940	3420	29	345	0	0	0	0	345	480	75
29	98	2940	3420	32	240	0	0	0	0	240	480	180
30	106	3540	4020	33	180	0	0	0	0	180	480	240
31	114	3600	4080	34	300	0	0	0	0	300	480	120
32	122	3660	4140	35	285	0	0	0	0	285	480	135
33	123	3660	4140	36	285	0	0	0	0	285	480	135
34	124	3660	4140	37	300	0	0	0	0	300	480	120
35	128	3720	4200	39	225	0	0	0	0	225	480	195
36	130	3780	4260	40	270	0	0	0	0	270	480	150
37	141	4320	4800	42	420	0	0	0	0	420	480	0
38	144	4320	4800	45	270	0	0	0	0	270	480	150
39	149	4440	4920	44	300	0	0	0	0	300	480	120
40	151	4440	4920	46	240	0	0	0	0	240	480	180
41	155	4920	5400	52	210	0	0	0	0	210	480	210
42	156	4980	5460	47	315	0	0	0	0	315	480	105
43	162	4980	5460	53	210	0	0	0	0	210	480	210
44	164	5040	5520	48	300	0	0	0	0	300	480	120
45	165	5040	5520	49	300	0	0	0	0	300	480	120
46	173	5100	5580	50	300	0	0	0	0	300	480	120
47	179	5160	5640	54	210	0	0	0	0	210	480	210
48	192	5700	6180	57	315	0	0	0	0	315	480	105
49	197	5760	6240	60	270	0	0	0	0	270	480	150
50	199	5820	6300	59	315	0	0	0	0	315	480	105
51	204	5880	6360	61	240	0	0	0	0	240	480	180
52	216	6480	6960	63	285	0	0	0	0	285	480	135
53	222	6480	6960	69	300	0	0	0	0	300	480	120
54	223	6540	7020	62	300	0	0	0	0	300	480	120
55	225	6540	7020	64	315	0	0	0	0	315	480	105
56	226	6540	7020	65	285	0	0	0	0	285	480	135
57	231	6600	7080	67	225	0	0	0	0	225	480	195
58	232	6600	7080	68	240	0	0	0	0	240	480	180
59	239	6720	7200	70	225	0	0	0	0	225	480	195
60	241	6720	7200	72	270	0	0	0	0	270	480	150
61	247	7140	7620	73	300	0	0	0	0	300	480	120
62	248	7140	7620	76	270	0	0	0	0	270	480	150
63	250	7200	7680	74	375	0	0	0	0	375	480	45
64	258	7320	7800	75	315	0	0	0	0	315	480	105
65	261	7380	7860	77	240	0	0	0	0	240	480	180
66	264	7860	8340	78	315	0	0	0	0	315	480	105
67	266	7860	8340	80	285	0	0	0	0	285	480	135
68	274	7920	8400	81	285	0	0	0	0	285	480	135
69	278	7920	8400	85	285	0	0	0	0	285	480	135
70	283	7980	8460	82	270	0	0	0	0	270	480	150
71	285	7980	8460	84	225	0	0	0	0	225	480	195
72	306	8640	9120	91	285	0	0	0	0	285	480	135
73	308	8700	9180	89	360	0	0	0	0	360	480	60
74	309	8700	9180	90	315	0	0	0	0	315	480	105
75	314	8760	9240	92	270	0	0	0	0	270	480	150
76	320	9300	9780	95	300	0	0	0	0	300	480	120
77	323	9300	9780	98	195	0	0	0	0	195	480	225
78	324	9300	9780	99	195	0	0	0	0	195	480	225
79	325	9360	9840	93	300	0	0	0	0	300	480	120
80	326	9360	9840	94	285	0	0	0	0	285	480	135
81	354	780	1320	6	195	14	210	0	0	405	540	75
82	356	5100	5640	51	150	55	225	0	0	375	540	105
83	358	6540	7080	66	150	71	225	0	0	375	540	105
84	359	7980	8520	79	180	86	255	0	0	435	540	45
85	360	9420	9960	96	150	100	255	0	0	405	540	75
86	1372	3720	4680	38	210	41	150	43	285	645	960	195
87	1374	8040	9000	83	195	87	225	88	285	705	960	135
88	1375	9480	10440	97	285	101	165	2	285	735	960	105
89	1618	5340	6300	56	255	58	390	0	0	645	960	195

Chapter 4

Conclusions and Future Research

4.1 Conclusions

Recognizing that the air cargo industry is growing rapidly, more and more air cargo terminals will be expanded to cater for the increasing air cargo volume, and to operate in a cost effective manner while maintaining the high competencies, improving the productivity of the air cargo terminal is an obvious choice. As the air cargo terminal operation is manpower intensive, productivity improvement of this precious resource has become the main focus of this study. Two works are done aiming to help the terminal to increase the productivity of the workers in the air cargo terminal. The first project is done to improve the operations of the ASRS retrieval policy; while the manpower planning model for the Checking Team is discussed in the second project.

As ASRS will most likely be installed at airports facing tight space constraint, it is vital to have efficient operational strategies to increase the productivity. Chapter 2 of this dissertation presents a quantitative model to evaluate the operational policies of assigning cargoes to storage bins. Two performance measurements are proposed. One is the labor required to handle the cargoes and the other one is the storage capacity required to store the cargoes. Based on the model, a comparison is made between an existing policy against a few proposed policies in which the flight departure time is used to segregate storage bins. The results show that the proposed policies give rise to great reduction in both manpower and storage capacity requirement. These results are further confirmed by a simulation study in which simplicity assumptions on the analytical model are removed.

Even though the manpower planning problem has been discussed in many works done previously, none of the research found has the assumption of non-exchangeable duties. The problem is formulated with this assumption as required by the air cargo terminal and solved by Cplex to obtain the optimal shift schedules. Then, the optimal shift schedule is used as an input to the roster problem to determine the night-shift work stretches to form a good roster for the Checking Team. Next, a heuristic approach is used to assign all the night-shift work stretches and then the morning- and afternoon-shift work stretches into the roster. Savings of 16% and 11% were shown compared to the current operation in terms of man hours for Group 1 and Groups 2, 3, 4 respectively. When compared in terms of the number of Checking Teams required, the approach presented in this work gives rise to a saving of two teams in total.

4.2 Future Research

It is believed that since the suggested ASRS policies are able to help the export terminal to improve the productivity of the air cargo terminal operations, similar approaches can be applied to the import terminal. However, some changes to the assumptions as well as the guidelines to group the cargoes are needed. For example, the cargoes being stored in the ASRS waiting to be retrieved by the truck dock officer to be presented to the freight forwarders can be grouped by some of the major freight forwarders instead of being stored randomly. It is also interesting to evaluate other storage policies as the current work is only confined to the storage policy of the export cargoes using the ASRS aiming to reduce the number of handlings required.

As an extension to the manpower problem discussed in Chapter 3, the manpower planning on other groups instead of Checking Teams can be studied. Based on the observations, the air cargo terminal may require some help to schedule the manpower at the truck dock area. Besides that, a quantitative but easy to solve model may be developed to form the master roster for other manpower scheduling problems. In addition, the different worker's capabilities can also be factored into the problem as the current study assumes all the workers are homogenous. Other than the manpower, it is observed that forklift is another resource which is heavily used in the air cargo terminal. Research can be done to help the terminal determine the optimum number of forklifts required. Lastly, material flow is always a critical issue in any warehouse, it is believed that more works can be done to further improve the material flow within the air cargo terminal warehouse; hence, reducing the traffic flow which is causing congestion in the warehouse during peak period.

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Appendix A

A Sample of the ASRS Bin

Figure A. 1: An ASRS bin carried by forklift

Appendix B

Number of AWB Carried by Each Aircraft Type

Table B.1: Aircraft type with maximum and minimum number of AWB.

Aircraft Type	Max no. of AWB	Min no. of AWB
A313	48	1
A343	57	1
B744M	53	1
B744R	54	2
B772	59	1
B772A	46	1
B773	62	1
MD11	38	1

Appendix C
Workload Estimation Heuristics

The heuristic is designed with the following assumptions.

Assumptions:

1. Checker should have checked with the dedicated Retrieval Team on what are the AWBs/bins which have been retrieved before the pre-planning. Hence, for the bins that have yet to be retrieved, the Checker will key in the bin numbers into the ASRS before the Checking Team start to retrieve all the cargoes. This will help to reduce the idle time of the Checking Team by performing other retrieval jobs while waiting for the ASRS machine to retrieve the bins. This should be part of the pre-planning process.
2. Checker also should notify the ETV (Elevated Transfer Vehicle) EO on all the cargoes stored in the PCHS as part of the pre-planning process. Similarly, this will help to reduce the idle time as other tasks can be done while waiting for the PCHS to retrieve the cargoes.
3. There is no misallocation of the cargoes, no wasted trips on searching for the cargoes blindly without knowing the exact locations. Cargo ready time is also known. The ideal case is when the RFID is installed; otherwise, it is assumed that the in-house centralized IT system is updated with the necessary information as soon as possible.
4. Each team consists of one Checker and one Hand by default without any Helper.
5. Each of the Checking Team members (with or without Helper) can retrieve the cargoes independently and a trip can be assigned to any one of them at any one time except the valuable cargo (VAL), which can only be retrieved by the Checker.
6. The Hand (and Helper(s) if applicable) will have a higher priority to be assigned a retrieval job compared to the Checker, as the Checker is responsible to

perform other tasks such as flight closing documentations, retrieval of VAL cargoes, etc., besides retrieving the general cargoes.

7. Forklift is not a constraint. That is, each team member has a forklift.
8. Forklift lifting capacity is 1200kg.
9. All teams have the homogenous capability.
10. For cargoes in bins, a forklift can carry at most 2 bins per trip.
11. The flight close time is between the shift start and end times. When this heuristic is used to estimate the flight workload for the shift scheduling problem, it is assumed that all the cargoes are ready at time = flight close time – 10 hours (or any time which is definitely larger than the flight workload), shift start time = current time = cargo ready time, and the shift end time ≥ flight close time. By doing so, the total processing time required to close a flight can be estimated without considering the variations caused by the cargo ready times. However, the actual cargo ready times, the actual shift start and end times will be used when this heuristic is meant to estimate the workload at the operational stage.
12. The idle time(s) of the Checker, Hand or Helper(s) in between any two retrievals are not considered as Free Time. In other words, these idle times cannot be used to help other Checking Teams.
13. All the cargoes or jobs with the release time + the processing time of the respective jobs must be less than or equals to the flight close time. This is to ensure that all the jobs being assigned to the Checking Team can be closed before or at the flight close time. Otherwise, it is not a feasible job to be uploaded to the particular flight.
14. Current_time_1 and Current_time_2 are assumed to be equals to the shift starts time at the initial stage.

The inputs of this heuristics are shift starts and ends time, flight schedule, cargoes attributes, number of Helper(s) and forklift capacity. While the outputs of the heuristics are the workload, namely the duration, start and end work time. Figure C.1 presents the overview of the workload estimation heuristic while the detail descriptions of the heuristic are presented below.

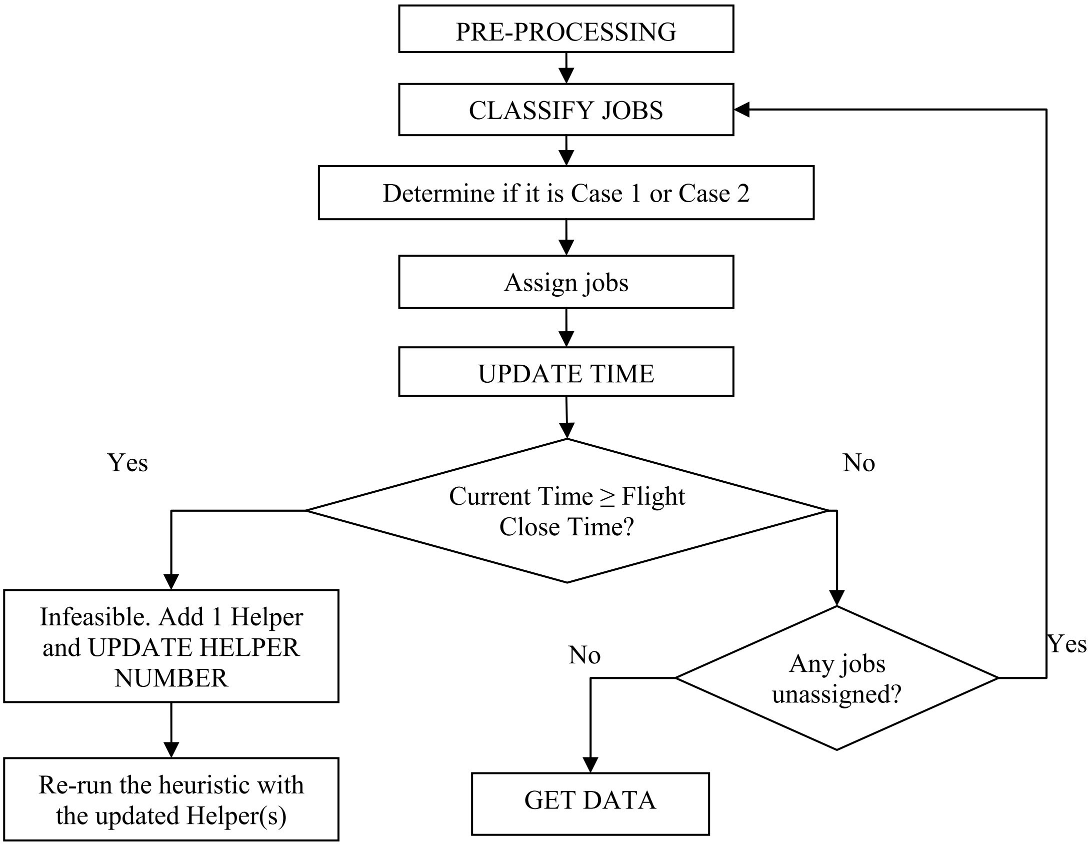


Figure C.1: Workload estimation heuristic.

Heuristic:

1. Perform the PRE-PROCESSING procedure where all the jobs with the same attributes are grouped as one unique job and create a list of jobs called Job List A.

Initialize the current time = *t*, where *t* is the time Checking Team is ready to retrieve the jobs.

2. Perform the CLASSIFY JOBS procedure. This is to classify each job into different classifications namely, the Urgent full load job, the Urgent less than full load job, the Urgent VAL job, the Full Load job, the Less than full load job and the VAL job, according to the flight closing time, storage locations as well as the weight of the jobs.
3. To determine whether Case 1 or 2 shall be the next step. This is to set the priority of the jobs to be selected and assigned to each Checking Team member, where Case 1 means the urgent jobs are identified while Case 2 means there is no urgent jobs being identified. Following describes how the priority is set when these two cases occur.
    a. Case 1: If there are urgent jobs identified, prioritize these jobs according to the smallest value of close time. Among the jobs with the same urgency, always carry out the Urgent full load job first, then followed by the Urgent less than full load job and lastly to the Urgent VAL;
    b. Case 2: If there is no urgent job identified, priority will be given to the Full Load job, then followed by the Less than full load job and lastly by the VAL job;
4. Next, assign the job selected following the respective procedure,
    a. Urgent full load will follow the URGENT FULL LOAD JOB ASSIGNMENT procedure;
    b. Urgent less than full load will follow the URGENT LESS THAN FULL LOAD JOB ASSIGNMENT procedure;

    c. Urgent VAL will follow the URGENT VAL JOB ASSIGNMENT procedure;
    d. Full load will follow the FULL LOAD JOB ASSIGNMENT procedure;
    e. Less than full load will follow the LESS THAN FULL LOAD JOB ASSIGNMENT procedure;
    f. VAL will follow the VAL JOB ASSIGNMENT procedure;
5. After each job assignment, the total processing times and current times of each team member should be updated and the UPDATE TIME procedure should be performed.
6. If the current time ≥ flight close time, it is infeasible. This means more manpower is needed to complete the flight's workload. One Helper is added, the UPDATE HELPER NUMBER procedure should be performed and the heuristic is re-run again with the new information. Else, go to Step 7.
7. If there are jobs unassigned, perform CLASSIFY JOBS procedure again to update all the status of the jobs. Then go to Step 3. Else, go to Step 8.
8. Lastly, the GET DATA procedure is performed to retrieve all the data required.

The detail descriptions of each of the procedures mentioned in the heuristic earlier is presented in the following.

PRE-PROCESSING procedure:

To form unique jobs before these jobs are assigned to the Checker, the Hand and the Helper(s) (if applicable).

i. For all the FG (Floor Goods), VC (Vulnerable Cargo) and transshipment cargoes from the import terminal: find the cargoes from the same location, same release time and same close time. Sum up the weight for these cargoes. Then, split it into n_{job} numbers of jobs with a new ID. Where,

$$n_{job} = \left\lceil \frac{\text{cargo weight}}{1200} \right\rceil$$

(The reason is that since retrieving these cargoes in a single trip is a more sensible way, it is treated as a single job).

ii. Combine two bins with the same attributes (location, release time and close time) and give this job a new ID. The last bin which cannot be combined with the other bins will be considered as a job by itself and hence carries an ID by itself.

Create a job list with a list of all these unique jobs. Let us call this Job List A.

CLASSIFY JOBS:

Classify the jobs with release time (or ready time, which will be used interchangeably here) ≤ current time into six categories in descending priority, namely: Urgent full load, Urgent less than full load, Urgent VAL, Full load, Less than full load, and VAL.

i. Find the jobs with release time ≤ current time. If there is no job found (in other words, current time < all the release times of all jobs), go to Step ii. Else, go to Step iv.

ii. Let current time = min {all the release times}.

iii. Update the Checker's current time, current_time_1 = max {current time, current_time_1}. Update the Hand's current time, current_time_2 = max {current time, current_time_2}. Update the Helper *h*'s current time (if applicable), current_time_h = max {current time, current_time_h}, where, h = 3, …, Helper Number + 2.

iv. Classify the jobs as below:

   a. If the earliest flight close time of these job(s) ≤ current time + x hours (or any stipulated hours), and the job's weight = 1200kg, set the status = Urgent full load. The stipulated hour is used to serve as a cut-off time to distinguish the urgent job from non-urgent job.

   b. If the earliest flight close time of these job(s) ≤ current time + x hours (or any stipulated hours), and the job(s) weight < 1200kg, set the status = Urgent less than full load.

   c. If the earliest flight close time of these job(s) ≤ current time + x hours (or any stipulated hours), and the location of the job(s) = VAL, set the status = Urgent VAL.

   d. If the earliest flight close time of these job(s) > current time + x hours (or any stipulated hours), and the job(s) weight = 1200kg, set the status = Full load.

   e. If the earliest flight close time of these job(s) > current time + x hours (or any stipulated hours), and the job(s) weight < 1200kg, set the status = Less than full load.

   f. If the earliest flight close time of these job(s) > current time + x hours (or any stipulated hours), and the location of the job(s) = VAL, set the status = VAL.

UPDATE TIME procedure:

This is to update the Checking Team's Start Work time, the Helper's Start Work time, as well as the current time. These times are updated as mentioned below.

1.Checker's Time :

Update the Checker's Start Work time = the time the Checker starts working on that job if it is the first job being assigned to the Checker.

Update the Checker's current time, current_time_1 = previous current_time_1 + processing time of the job assigned (if applicable).

2. Hand's Time:

Update the Hand's Start Work time = the time the Hand starts working on that job if it is the first job being assigned to the Hand.

Update the Hand's current time, current time 2 = previous current_time_2 + processing time of the job assigned (if applicable).

3. Helper's Time:

Update the Helper h's Start Work time = the time the Helper h starts working on that job if it is the first job being assigned to the Helper h.

Update Helper h's current time, current time h = previous current_time_h + processing time of the job assigned (if applicable).

Where, h = 3, …, Helper Number + 2.

4. Current time:

Update current time = min {current_time_1, current_time_2,..., current_time_h}.

URGENT FULL LOAD JOB ASSIGNMENT procedure:

Find the job with the earliest flight close time and assign it to either the Checker or the Hand (or the Helper(s) if applicable), whichever with the least amount of processing time already assigned.

FULL LOAD JOB ASSIGNMENT procedure:

Find the job with the longest processing time and assign the job to the Checker or the Hand (or the Helper(s) if applicable) with the least amount of processing time already assigned.

URGENT LESS THAN FULL LOAD JOB ASSIGNMENT procedure:

Combine these jobs based on First Fit Decreasing rule. Then find the job with the earliest flight close time and assign to either the Checker or the Hand (or the Helper(s) if applicable), whichever with the least amount of processing time already assigned. The details are described as follow:

i. Sort all the jobs with status = Urgent less than full load in decreasing order based on the weight. Then, combine these job(s) based on First Fit Decreasing rule (according to the cargo weight) with the load of ≤ full load (1200kg), form new ID for the new combination of job(s) and update the attributes of these newly formed jobs, i.e. the release time = max {release times of the jobs combined}, the close time = min {close times of the jobs combined} and the processing time = total processing time of the jobs combined. Identify the newly combined job with the earliest flight close time to be the job for this assignment and call it New Job. Ignore all the other newly formed jobs with flight close time later than it. Delete the Urgent less than full load jobs which have been combined to form this New Job from Job List A and update Job List A with this New Job.

ii. If the New Job is still less than full load, try to combine more jobs with status = Less than full load to maximize the load (make it as close to full load as possible). If there are jobs with status = Less than full load to be combined, go to Step iii. Else, go to Step iv.

iii. Sort all the Less than full load jobs in decreasing order based on the weight. Then combine these jobs based on First Fit Decreasing rule (according to the cargo weight) with the New Job which is less than full load until it is as close to full load as possible. Update the New Job's attributes, i.e. the release time = max {release times of the jobs combined}, close time = min {close times of the jobs combined}, processing time = total processing time of the jobs combined. Delete these Less than full load jobs which have been combined with this New Job from Job List A.

iv. Assign this job to the Checker or the Hand (or the Helper(s) if applicable) with the least amount of processing time already been assigned.

LESS THAN FULL LOAD JOB ASSIGNMENT procedure:

Combine the job(s) based on First Fit Decreasing rule. Then, assign the jobs to the Checker or the Hand (or Helper(s) if applicable) based on the longest processing time found.

i. Find all the jobs with status = Less than full load and sort these jobs in decreasing order based on the weight. Combine these job(s) based on First

Fit Decreasing rule (according to the cargo weight) with the load of ≤ full load (1200kg).

ii. Form new ID for the new combination of job(s). Update the release time = max {release times of the jobs combined}, close time = min {close times of the jobs combined}, processing time = total processing time of the jobs combined. Identify the newly formed job with the longest processing time to be the job for this assignment and call it New Job. Ignore other newly formed jobs. Delete these Less than full load jobs which have been combined to form this New Job from Job List A and update Job List A with this New Job.

iii. Assign this job to the Checker or the Hand (of the Helper(s) if applicable) with the least amount of processing time already assigned.

URGENT/VAL JOB ASSIGNMENT procedure:

Assign the job to the Checker.

GET DATA procedure:

To get the data required such as the flight completion time, the Free Time 1 (the idle time before the Checking Team starts all the retrieval jobs), the Free Time 2 (the idle time after the Checking Team closes a flight), the number of Helpers needed as well as the Start Work and End Work times for the Helper.

i. Checking Team's Start Work time = min {the Checker's Start Work time, the Hand's Start Work time}.

ii. Flight completion time = max {Current time 1, Current time 2,…, Current time h (if applicable)}.

iii. Free Time 1 = Checking Team’s Start Work time – Checking Team’s Shift start time.

iv. Free Time 2 = Checking Team’s Shift end time – Flight completion time.

v. Number of Helper(s) = Helper Number (from UPDATE HELPER NUMBER).

vi. Helper(s)’ Start Work time = min {all the Helpers’ Start Work time}. This is because it is always preferred to have all the Helpers to start work at the same time for an easier management.

vii. Helper(s)’ End Work time = max {all the Helpers’ Current time h}. This is done for the same reason as in vi.

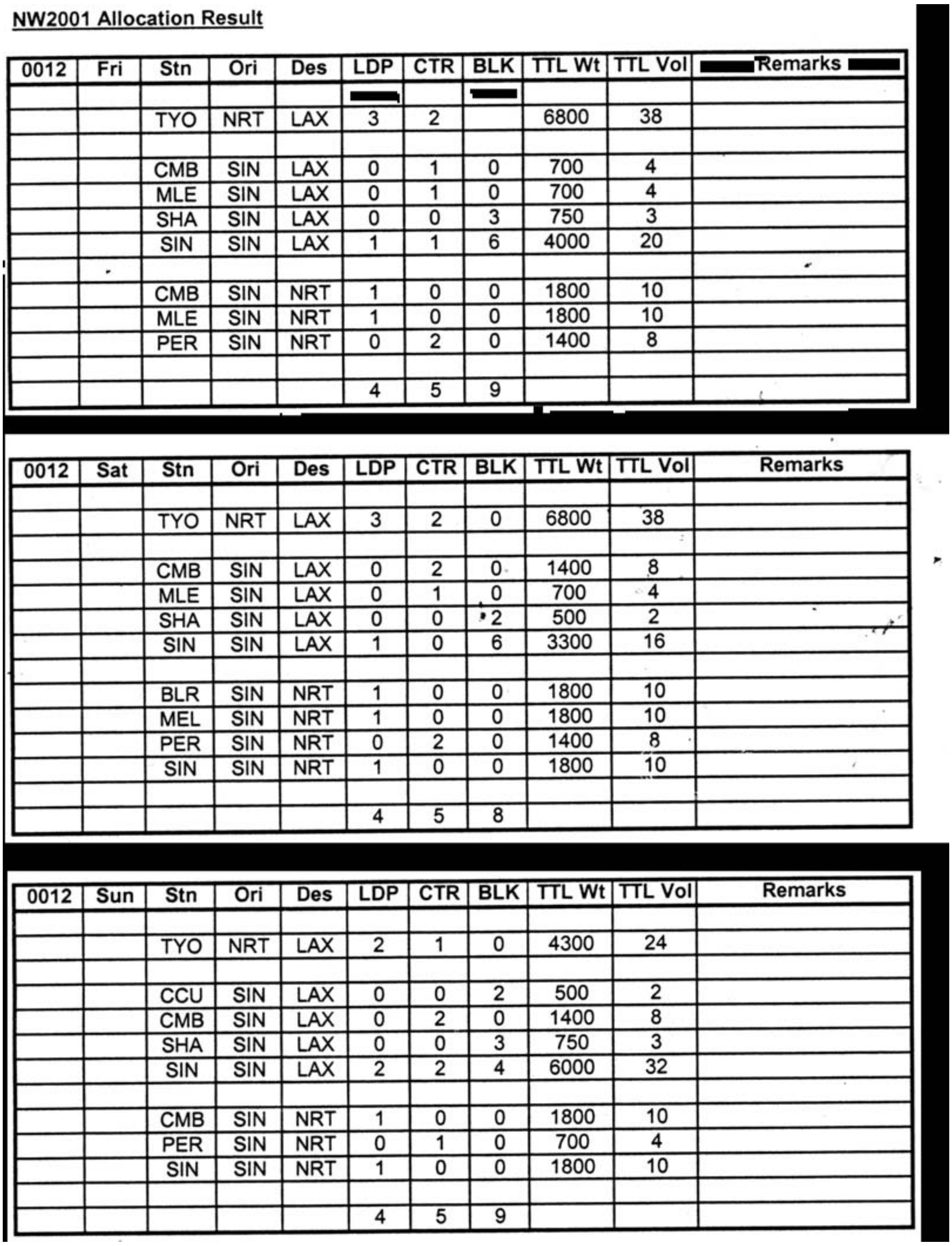
UPDATE HELPER NUMBER procedure:

Helper Number = Helper Number + 1.

Appendix D

Capacity Allocation Table – A Sample

Table D.1: Capacity Allocation Table



NW2001 Allocation Result

0012	Fri	Stn	Ori	Des	LDP	CTR	BLK	TTL Wt	TTL Vol	[redacted] Remarks [redacted]
					[redacted]		[redacted]			
		TYO	NRT	LAX	3	2		6800	38	
		CMB	SIN	LAX	0	1	0	700	4	
		MLE	SIN	LAX	0	1	0	700	4	
		SHA	SIN	LAX	0	0	3	750	3	
		SIN	SIN	LAX	1	1	6	4000	20	
		CMB	SIN	NRT	1	0	0	1800	10	
		MLE	SIN	NRT	1	0	0	1800	10	
		PER	SIN	NRT	0	2	0	1400	8	
					4	5	9			

0012	Sat	Stn	Ori	Des	LDP	CTR	BLK	TTL Wt	TTL Vol	Remarks
		TYO	NRT	LAX	3	2	0	6800	38	
		CMB	SIN	LAX	0	2	0	1400	8	
		MLE	SIN	LAX	0	1	0	700	4	
		SHA	SIN	LAX	0	0	2	500	2	
		SIN	SIN	LAX	1	0	6	3300	16	
		BLR	SIN	NRT	1	0	0	1800	10	
		MEL	SIN	NRT	1	0	0	1800	10	
		PER	SIN	NRT	0	2	0	1400	8	
		SIN	SIN	NRT	1	0	0	1800	10	
					4	5	8			

0012	Sun	Stn	Ori	Des	LDP	CTR	BLK	TTL Wt	TTL Vol	Remarks
		TYO	NRT	LAX	2	1	0	4300	24	
		CCU	SIN	LAX	0	0	2	500	2	
		CMB	SIN	LAX	0	2	0	1400	8	
		SHA	SIN	LAX	0	0	3	750	3	
		SIN	SIN	LAX	2	2	4	6000	32	
		CMB	SIN	NRT	1	0	0	1800	10	
		PER	SIN	NRT	0	1	0	700	4	
		SIN	SIN	NRT	1	0	0	1800	10	
					4	5	9			

Appendix E

ILog Cplex Solutions for Shift Scheduling Problem
-- Group 2, 3 and 4

Shift ID	Start Time (Min)	End Time (Min)	Start Time (Hr)	End Time (Hr)	Duration	Day (follow start time)	Shift Type	Flt No 1	Flt No 2	Flt No 3	Flt No 4	Flt No 5
1	0	480	0	8	8	1	N	1	17	0	0	0
8	0	480	0	8	8	1	N	2	23	0	0	0
10	0	480	0	8	8	1	N	4	0	0	0	0
20	0	480	0	8	8	1	N	12	22	0	0	0
30	60	540	1	9	8	1	N	3	24	0	0	0
33	60	540	1	9	8	1	N	5	20	0	0	0
41	60	540	1	9	8	1	N	8	21	0	0	0
3867	120	660	2	11	9	1	N	6	28	0	0	0
3871	120	660	2	11	9	1	N	7	27	0	0	0
3883	120	660	2	11	9	1	N	9	25	0	0	0
113	240	720	4	12	8	1	N	10	32	0	0	0
127	240	720	4	12	8	1	N	14	29	0	0	0
131	240	720	4	12	8	1	N	16	30	0	0	0
3972	240	780	4	13	9	1	N	11	31	0	0	0
108019a	240	720	4	12	8	1	N	13	26	39	63	0
168	300	780	5	13	8	1	M	19	33	0	0	0
10580	300	900	5	15	10	1	M	15	38	0	0	0
210	360	840	6	14	8	1	M	18	37	0	0	0
375	600	1080	10	18	8	1	M	34	57	0	0	0
378	600	1080	10	18	8	1	M	35	47	0	0	0
4457	600	1140	10	19	9	1	M	36	52	0	0	0
4512	720	1260	12	21	9	1	E	41	60	0	0	0
4528	720	1260	12	21	9	1	E	45	58	0	0	0
11309	720	1320	12	22	10	1	E	44	53	0	0	0
108019b	720	1260	12	21	9	1	E	13	26	39	63	0
464	780	1260	13	21	8	1	E	46	68	0	0	0
470	780	1260	13	21	8	1	E	49	64	0	0	0
4557	780	1320	13	22	9	1	E	40	66	0	0	0
4561	780	1320	13	22	9	1	E	43	61	0	0	0
114746a	780	1260	13	21	8	1	E	48	59	74	0	0
30187a	780	1260	13	21	8	1	E	50	65	75	0	0
492	840	1320	14	22	8	1	E	54	69	0	0	0
4610	840	1380	14	23	9	1	E	42	72	0	0	0
4611	840	1380	14	23	9	1	E	51	62	0	0	0
507	900	1380	15	23	8	1	E	56	70	0	0	0
30560a	900	1380	15	23	8	1	E	55	71	80	0	0
11580	1080	1680	18	4	10	1	E	67	73	0	0	0
114746b	1260	1800	21	6	9	1	N	48	59	74	0	0
30187b	1260	1740	21	5	8	2	N	50	65	75	0	0
30560b	1380	1860	23	7	8	2	N	55	71	80	0	0
595	1440	1920	0	8	8	2	N	82	0	0	0	0
607	1500	1980	1	9	8	2	N	76	0	0	0	0
608	1500	1980	1	9	8	2	N	77	96	0	0	0
629	1560	2040	2	10	8	2	N	81	92	0	0	0
4805	1560	2100	2	11	9	2	N	78	95	0	0	0
4816	1560	2100	2	11	9	2	N	79	100	0	0	0
654	1620	2100	3	11	8	2	N	84	102	0	0	0
657	1620	2100	3	11	8	2	N	85	99	0	0	0
661	1620	2100	3	11	8	2	N	87	97	0	0	0
668	1620	2100	3	11	8	2	N	89	101	0	0	0
4890	1620	2160	3	12	9	2	N	83	103	0	0	0
36401a	1620	2100	3	11	8	2	N	86	104	114	0	0
696	1680	2160	4	12	8	2	N	90	108	0	0	0
723	1740	2220	5	13	8	2	M	91	106	0	0	0
732	1740	2220	5	13	8	2	M	93	109	0	0	0
4998	1740	2280	5	14	9	2	M	88	105	0	0	0
38159a	1740	2220	5	13	8	2	M	94	98	111	132	0
5318	1980	2520	9	18	9	2	M	107	124	0	0	0
923	2040	2520	10	18	8	2	M	110	128	0	0	0
944	2100	2580	11	19	8	2	M	112	133	0	0	0
36401b	2100	2580	11	19	8	2	M	86	104	114	0	0
971	2160	2640	12	20	8	2	E	119	131	0	0	0
5415	2160	2700	12	21	9	2	E	113	138	0	0	0
5418	2160	2700	12	21	9	2	E	115	140	0	0	0
5427	2160	2700	12	21	9	2	E	118	134	0	0	0
12783	2160	2760	12	22	10	2	E	116	129	0	0	0
12793	2160	2760	12	22	10	2	E	117	139	0	0	0
12860	2220	2820	13	23	10	2	E	120	135	0	0	0
12887	2220	2820	13	23	10	2	E	125	136	0	0	0
38159b	2220	2700	13	21	8	2	E	94	98	111	132	0
41856a	2220	2700	13	21	8	2	E	123	141	147	0	0
1012	2280	2760	14	22	8	2	E	127	144	0	0	0
1017	2280	2760	14	22	8	2	E	130	143	0	0	0
5497	2280	2820	14	23	9	2	E	122	137	0	0	0
130687a	2280	2760	14	22	8	2	E	126	146	154	0	0
41965a	2280	2760	14	22	8	2	E	121	145	149	0	0
13009	2520	3120	18	4	10	2	E	142	148	0	0	0
41856b	2700	3180	21	5	8	2	N	123	141	147	0	0
130687b	2760	3300	22	7	9	2	N	126	146	154	0	0
41965b	2760	3240	22	6	8	2	N	121	145	149	0	0
1135	3000	3480	2	10	8	3	N	151	168	0	0	0
1136	3000	3480	2	10	8	3	N	152	163	0	0	0
5679	3000	3540	2	11	9	3	N	153	169	0	0	0
5686	3000	3540	2	11	9	3	N	155	170	0	0	0
5688	3000	3540	2	11	9	3	N	156	167	0	0	0
1161	3060	3540	3	11	8	3	N	159	171	0	0	0
1166	3060	3540	3	11	8	3	N	161	172	0	0	0
5722	3060	3600	3	12	9	3	N	158	173	0	0	0
5733	3060	3600	3	12	9	3	N	160	178	0	0	0
13249	3060	3660	3	13	10	3	N	150	176	0	0	0
13252	3060	3660	3	13	10	3	N	157	175	0	0	0
13337	3120	3720	4	14	10	3	N	162	181	0	0	0
5820	3180	3720	5	14	9	3	M	165	174	0	0	0
5830	3180	3720	5	14	9	3	M	166	177	0	0	0
13424	3180	3780	5	15	10	3	M	164	179	0	0	0
1368	3480	3960	10	18	8	3	M	180	185	0	0	0
1385	3480	3960	10	18	8	3	M	183	199	0	0	0
627001a	3480	4080	10	20	10	3	M	182	191	215	224	0
6167	3600	4140	12	21	9	3	E	184	204	0	0	0

Shift ID	Start Time (Min)	End Time (Min)	Start Time (Hr)	End Time (Hr)	Duration	Day (follow start time)	Shift Type	Flt No 1	Flt No 2	Flt No 3	Flt No 4	Flt No 5
6173	3600	4140	12	21	9	3	E	187	202	0	0	0
6181	3600	4140	12	21	9	3	E	189	203	0	0	0
6186	3600	4140	12	21	9	3	E	190	207	0	0	0
1441	3660	4140	13	21	8	3	E	186	212	0	0	0
1455	3660	4140	13	21	8	3	E	196	208	0	0	0
6226	3660	4200	13	22	9	3	E	192	200	0	0	0
6237	3660	4200	13	22	9	3	E	193	209	0	0	0
6243	3660	4200	13	22	9	3	E	195	213	0	0	0
6253	3660	4200	13	22	9	3	E	197	214	0	0	0
1480	3720	4200	14	22	8	3	E	201	216	0	0	0
6272	3720	4260	14	23	9	3	E	188	206	0	0	0
52381a	3720	4200	14	22	8	3	E	198	217	219	0	0
52601a	3780	4260	15	23	8	3	E	194	218	227	0	0
1518	3840	4320	16	0	8	3	E	210	0	0	0	0
1527	3900	4380	17	1	8	3	E	205	0	0	0	0
1532	3900	4380	17	1	8	3	E	211	0	0	0	0
627001b	4080	4680	20	6	10	3	N	182	191	215	224	0
52381b	4200	4680	22	6	8	3	N	198	217	219	0	0
52601b	4260	4740	23	7	8	3	N	194	218	227	0	0
1573	4320	4800	0	8	8	4	N	220	236	0	0	0
1580	4320	4800	0	8	8	4	N	223	239	0	0	0
1597	4380	4860	1	9	8	4	N	221	234	0	0	0
1602	4380	4860	1	9	8	4	N	222	0	0	0	0
1610	4380	4860	1	9	8	4	N	226	0	0	0	0
1628	4440	4920	2	10	8	4	N	225	240	0	0	0
1648	4500	4980	3	11	8	4	N	228	245	0	0	0
1651	4500	4980	3	11	8	4	N	229	241	0	0	0
1658	4500	4980	3	11	8	4	N	230	247	0	0	0
1661	4500	4980	3	11	8	4	N	231	246	0	0	0
1686	4560	5040	4	12	8	4	N	232	252	0	0	0
1687	4560	5040	4	12	8	4	N	233	248	0	0	0
6628	4560	5100	4	13	9	4	N	235	251	0	0	0
1721	4620	5100	5	13	8	4	M	237	254	0	0	0
1773	4680	5160	6	14	8	4	M	243	253	0	0	0
60248a	4680	5160	6	14	8	4	M	238	249	259	283	0
60462a	4680	5160	6	14	8	4	M	242	244	255	285	0
1920	4920	5400	10	18	8	4	M	256	270	0	0	0
15359	4980	5580	11	21	10	4	M	257	273	0	0	0
7062	5040	5580	12	21	9	4	E	250	278	0	0	0
7065	5040	5580	12	21	9	4	E	258	281	0	0	0
7072	5040	5580	12	21	9	4	E	261	277	0	0	0
7077	5040	5580	12	21	9	4	E	262	274	0	0	0
15453	5040	5640	12	22	10	4	E	263	271	0	0	0
1983	5100	5580	13	21	8	4	E	268	282	0	0	0
7118	5100	5640	13	22	9	4	E	264	275	0	0	0
7168	5160	5700	14	23	9	4	E	267	276	0	0	0
7179	5160	5700	14	23	9	4	E	269	287	0	0	0
7184	5160	5700	14	23	9	4	E	272	280	0	0	0
60248b	5160	5640	14	22	8	4	E	238	249	259	283	0
60462b	5160	5640	14	22	8	4	E	242	244	255	285	0
63687a	5160	5640	14	22	8	4	E	260	286	293	0	0
63700a	5160	5640	14	22	8	4	E	265	279	289	0	0
7209	5220	5760	15	0	9	4	E	266	288	0	0	0
2048	5280	5760	16	0	8	4	E	284	0	0	0	0
63687b	5640	6120	22	6	8	4	N	260	286	293	0	0
63700b	5640	6120	22	6	8	4	N	265	279	289	0	0
2093	5700	6180	23	7	8	4	N	296	0	0	0	0
2102	5760	6240	0	8	8	5	N	290	310	0	0	0
2117	5760	6240	0	8	8	5	N	303	0	0	0	0
7322	5760	6300	0	9	9	5	N	291	305	0	0	0
2126	5820	6300	1	9	8	5	N	294	308	0	0	0
2128	5820	6300	1	9	8	5	N	295	314	0	0	0
7382	5880	6420	2	11	9	5	N	297	316	0	0	0
68378a	5880	6360	2	10	8	5	N	292	321	336	0	0
2170	5940	6420	3	11	8	5	N	298	319	0	0	0
2175	5940	6420	3	11	8	5	N	299	318	0	0	0
2177	5940	6420	3	11	8	5	N	300	313	0	0	0
2184	5940	6420	3	11	8	5	N	301	315	0	0	0
2188	5940	6420	3	11	8	5	N	302	317	0	0	0
2213	6000	6480	4	12	8	5	N	304	325	0	0	0
7511	6000	6540	4	13	9	5	N	309	323	0	0	0
2240	6060	6540	5	13	8	5	M	307	324	0	0	0
2256	6060	6540	5	13	8	5	M	312	326	0	0	0
71636a	6060	6540	5	13	8	5	M	311	320	328	352	0
2279	6120	6600	6	14	8	5	M	306	329	0	0	0
2440	6360	6840	10	18	8	5	M	322	345	0	0	0
2443	6360	6840	10	18	8	5	M	327	343	0	0	0
68378b	6360	6840	10	18	8	5	M	292	321	336	0	0
2479	6420	6900	11	19	8	5	M	330	350	0	0	0
8013	6480	7020	12	21	9	5	E	332	359	0	0	0
8014	6480	7020	12	21	9	5	E	333	356	0	0	0
8016	6480	7020	12	21	9	5	E	334	349	0	0	0
8034	6480	7020	12	21	9	5	E	337	353	0	0	0
16949	6480	7080	12	22	10	5	E	331	346	0	0	0
478823a	6480	7020	12	21	9	5	E	335	344	362	366	384
8073	6540	7080	13	22	9	5	E	342	361	0	0	0
17056	6540	7140	13	23	10	5	E	341	351	0	0	0
71636b	6540	7020	13	21	8	5	E	311	320	328	352	0
2547	6600	7080	14	22	8	5	E	340	354	0	0	0
8097	6600	7140	14	23	9	5	E	339	358	0	0	0
8120	6600	7140	14	23	9	5	E	347	357	0	0	0
76116a	6600	7080	14	22	8	5	E	338	363	375	0	0
2575	6660	7140	15	23	8	5	E	348	364	0	0	0
2582	6660	7140	15	23	8	5	E	355	0	0	0	0
76907a	6720	7200	16	0	8	5	E	360	365	386	0	0
478823b	7020	7620	21	7	10	5	N	335	344	362	366	384
76116b	7080	7560	22	6	8	5	N	338	363	375	0	0
76907b	7200	7680	0	8	8	6	N	360	365	386	0	0
2673	7260	7740	1	9	8	6	N	367	385	0	0	0

Shift ID	Start Time (Min)	End Time (Min)	Start Time (Hr)	End Time (Hr)	Duration	Day (follow start time)	Shift Type	Flt No 1	Flt No 2	Flt No 3	Flt No 4	Flt No 5
2675	7260	7740	1	9	8	6	N	368	389	0	0	0
2676	7260	7740	1	9	8	6	N	369	0	0	0	0
2677	7260	7740	1	9	8	6	N	370	380	0	0	0
2707	7320	7800	2	10	8	6	N	372	0	0	0	0
8332	7320	7860	2	11	9	6	N	371	392	0	0	0
2726	7380	7860	3	11	8	6	N	373	391	0	0	0
2730	7380	7860	3	11	8	6	N	374	388	0	0	0
2738	7380	7860	3	11	8	6	N	376	394	0	0	0
2743	7380	7860	3	11	8	6	N	377	393	0	0	0
2789	7440	7920	4	12	8	6	N	382	398	0	0	0
17692	7440	8040	4	14	10	6	N	379	390	404	0	0
2817	7500	7980	5	13	8	6	M	378	396	0	0	0
2828	7500	7980	5	13	8	6	M	381	403	0	0	0
2849	7500	7980	5	13	8	6	M	387	397	0	0	0
189927a	7560	8040	6	14	8	6	M	383	395	406	429	0
3060	7800	8280	10	18	8	6	M	400	407	0	0	0
3066	7800	8280	10	18	8	6	M	401	417	0	0	0
18535	7860	8460	11	21	10	6	M	399	422	0	0	0
18546	7860	8460	11	21	10	6	M	402	428	0	0	0
18563	7860	8460	11	21	10	6	M	405	425	0	0	0
9069	7920	8460	12	21	9	6	E	409	424	0	0	0
9079	7920	8460	12	21	9	6	E	410	430	0	0	0
18655	7920	8520	12	22	10	6	E	411	421	0	0	0
18667	7920	8520	12	22	10	6	E	412	427	0	0	0
3150	7980	8460	13	21	8	6	E	414	431	0	0	0
9116	7980	8520	13	22	9	6	E	408	432	0	0	0
194843a	7980	8460	13	21	8	6	E	415	426	442	0	0
3176	8040	8520	14	22	8	6	E	418	436	0	0	0
3180	8040	8520	14	22	8	6	E	419	435	0	0	0
9164	8040	8580	14	23	9	6	E	413	433	0	0	0
189927b	8040	8580	14	23	9	6	E	383	395	406	429	0
90171a	8040	8520	14	22	8	6	E	416	437	443	0	0
3196	8100	8580	15	23	8	6	E	420	438	0	0	0
3210	8100	8580	15	23	8	6	E	434	0	0	0	0
90416a	8100	8580	15	23	8	6	E	423	439	441	454	0
3256	8460	8940	21	5	8	6	N	440	0	0	0	0
194843b	8460	9000	21	6	9	6	N	415	426	442	0	0
90171b	8520	9000	22	6	8	6	N	416	437	443	0	0
90416b	8580	9060	23	7	8	6	N	423	439	441	454	0
3314	8760	9240	2	10	8	7	N	444	0	0	0	0
3315	8760	9240	2	10	8	7	N	445	460	0	0	0
9363	8760	9300	2	11	9	7	N	446	461	0	0	0
3335	8820	9300	3	11	8	7	N	448	465	0	0	0
3337	8820	9300	3	11	8	7	N	449	462	0	0	0
3348	8820	9300	3	11	8	7	N	452	464	0	0	0
9428	8820	9360	3	12	9	7	N	453	467	0	0	0
3379	8880	9360	4	12	8	7	N	456	471	0	0	0
9468	8880	9420	4	13	9	7	N	451	474	0	0	0
9475	8880	9420	4	13	9	7	N	455	466	0	0	0
19231	8880	9480	4	14	10	7	N	447	476	0	0	0
19242	8880	9480	4	14	10	7	N	450	473	0	0	0
9529	8940	9480	5	14	9	7	M	459	463	470	0	0
19362	8940	9540	5	15	10	7	M	458	475	0	0	0
532706a	8940	9480	5	14	9	7	M	457	468	479	509	0
3628	9300	9780	11	19	8	7	M	472	494	0	0	0
19900	9300	9900	11	21	10	7	M	469	486	505	0	0
9923	9360	9900	12	21	9	7	E	477	495	0	0	0
9930	9360	9900	12	21	9	7	E	478	496	0	0	0
9948	9360	9900	12	21	9	7	E	484	497	0	0	0
20017	9360	9960	12	22	10	7	E	483	491	0	0	0
3679	9420	9900	13	21	8	7	E	489	499	0	0	0
9971	9420	9960	13	22	9	7	E	480	507	0	0	0
9973	9420	9960	13	22	9	7	E	481	504	0	0	0
9977	9420	9960	13	22	9	7	E	482	506	0	0	0
9980	9420	9960	13	22	9	7	E	485	502	0	0	0
10029	9480	10020	14	23	9	7	E	487	501	0	0	0
10039	9480	10020	14	23	9	7	E	488	508	0	0	0
10046	9480	10020	14	23	9	7	E	492	500	0	0	0
532706b	9480	10080	14	24	10	7	E	457	468	479	509	0
3719	9540	10020	15	23	8	7	E	490	511	0	0	0
3722	9540	10020	15	23	8	7	E	493	510	0	0	0
3744	9600	10080	16	0	8	7	E	498	0	0	0	0
3763	9660	10140	17	1	8	7	E	503	0	0	0	0

Appendix F

ILog Cplex Solutions for Roster Problem
-- Group 2, 3 and 4

Work Stretch ID	Mon				Tue				Wed				Thu				Fri				Sat				Sun			
1													Rest				2177	3	11	8	Redeployment				19242	4	14	10
	131	4	12	8	4890	3	12	9	13337	4	14	10	Rest				Rest											
2	Rest				30187b	21	5	8	130687b	22	7	9	52601b	23	7	8	63700b	22	6	8	76907b	0	8	8	3256	21	5	8
	8	0	8	8	Rest				Rest																			
3																	Rest				2677	1	9	8	90171b	22	6	8
	Redeployment				30560b	23	7	8	41965b	22	6	8	627001b	20	6	10	Rest				Rest							
4													Rest				2117	0	8	8	2675	1	9	8	90416b	23	7	8
	Redeployment				607	1	9	8	1136	2	10	8	1580	0	8	8	Rest				Rest							
5																	Rest				Redeployment				19231	4	14	10
	10	0	8	8	Rest				Rest																			
6																									Rest			
	Redeployment				595	0	8	8	1135	2	10	8	1573	0	8	8	2102	0	8	8	478823b	21	7	10	Rest			
	Rest																											
7													Rest				2093	23	7	8	2743	3	11	8	9468	4	13	9
	Rest				Rest																							
8									Rest				1602	1	9	8	2126	1	9	8	2673	1	9	8	3315	2	10	8
	41	1	9	8	629	2	10	8	Rest				Rest															
9	Rest				Redeployment				5688	2	11	9	1610	1	9	8	2128	1	9	8	2707	2	10	8	3314	2	10	8
	3867	2	11	9	Rest				Rest																			
10													Rest				7382	2	11	9	2730	3	11	8	3335	3	11	8
	3883	2	11	9	4816	2	11	9	13249	3	13	10	1648	3	11	8	Rest				Rest							
11													Rest				2170	3	11	8	8332	2	11	9	3337	3	11	8
	113	4	12	8	657	3	11	8	13252	3	13	10	1651	3	11	8	Rest				Rest							
12	Rest				661	3	11	8	5733	3	12	9	1658	3	11	8	2175	3	11	8	2738	3	11	8	9428	3	12	9
	127	4	12	8	Rest				Rest																			
13	Rest				114746b	21	6	9	Redeployment				52381b	22	6	8	63687b	22	6	8	17692	4	14	10	194843b	21	6	9
	1	0	8	8	Rest				Rest																			
14																									Rest			
	3972	4	13	9	668	3	11	8	1166	3	11	8	6628	4	13	9	2184	3	11	8	2789	4	12	8	Rest			
	Rest																											
15					Rest				41856b	21	5	8	1687	4	12	8	2188	3	11	8	76116b	22	6	8	9475	4	13	9
	108019a	4	12	8	36401a	3	11	8	Rest				Rest															
16					Rest				1161	3	11	8	1686	4	12	8	2213	4	12	8	2676	1	9	8	3348	3	11	8
	20	0	8	8	696	4	12	8	Rest				Rest															
17																					Rest				3379	4	12	8
	30	1	9	8	4805	2	11	9	5722	3	12	9	1661	3	11	8	7511	4	13	9	Rest				Rest			
18																									Rest			
	33	1	9	8	608	1	9	8	5679	2	11	9	1597	1	9	8	7322	0	9	9	Redeployment				Rest			
	Rest																											
19																					Rest				9363	2	11	9
	3871	2	11	9	654	3	11	8	5686	2	11	9	1628	2	10	8	68378a	2	10	8	2726	3	11	8	Rest			
	Rest																											

Appendix G

Detail Descriptions of Assigning the Morning and Afternoon Shifts into the Roster.

Before implementing the steps below, all the morning and afternoon shifts of the respective days are sorted according to the shift start times. The procedures below are repeated for each unassigned morning- and afternoon-shift work stretch.

Phase 2: Assigning the morning and afternoon shifts into the morning- and afternoon-shift work stretches

Step 6. Start with any randomly selected unassigned morning- and afternoon-shit work stretch. Set $i = 0$, where i is the number of days already assigned with a shift or a Rest day within the selected work stretch. G = number of days in the selected morning- and afternoon-shift work stretch.

Step 7. The first assignment: Assign the first day of the work stretch selected with the earliest shift found for that day from the list of sorted morning and afternoon shifts. Set $i = 1$ as one shift has been assigned to the morning- and afternoon-shift work stretch.

Step 8. Update hours: Update the total working hours per calendar week as well as the remaining hours available per calendar week for the shift assignment.

i. Total working hours = the duration of the shift selected.

ii. Remaining hours = t_n – total working hours.

Step 9. The subsequent assignment: Let D = calendar day of the day for the next assignment. Select the shift of day D with the shift duration not greater than the remaining hours according to the following rules:

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i. Pick a shift of day D with the shift start time ≥ the previous shift start time. If a shift is found, set $i = i + 1$, go to Step 4. Else, go to Step 3 ii.

ii. Pick a shift of day D which is at least t_b hours apart from the previous shift end time. If a shift is found, set $i = i + 1$, go to Step 4. Else, go to Step 5.

Step 10. Update hours: Update the total working hours per calendar week as well as the remaining hours available for shift assignment.

i. New total working hours = the old working hour + the duration of the shift selected.

ii. New remaining hours = t_n – total working hours.

Step 11. Rest day assignment: Since there is no suitable shift found for this day, this day is assigned as Rest day tentatively, let $i = i + 1$ and the total working hours and the remaining hours unchanged.

Step 12. Check for termination: If $i = G$, the assignment is completed for the current morning- and afternoon-shift work stretch. Else, repeat Step 3.

In any case where there are still shifts unassigned after all the morning- and afternoon-shift work stretches have been filled up with either shifts or Rest days, some adjustments will be needed. The Adjustment procedure is introduced below to make room for the unassigned shift in the roster. The procedure below should be repeated for each of the unassigned shifts found.

Adjustment steps:

Step a. Let S^u be the unassigned shift and let D^u be the calendar day of shift S^u.

Step b. Find a Rest day with the calendar day = D^u from the roster. Bear in mind that the Rest day should not be one of the Rest days belonging to the night-shift work stretches.

Step c. If the Rest day found can be replaced by a working day with shift S^u, go to Step l. Else, this Rest day found will not be selected and go to Step d.

Step d. Anymore Rest day with the calendar day = D^u and does not belong to the night-shift work stretches? If yes, go to Step c. Else, go to Step e.

Step e. Since a Rest day with the calendar day D^u is not found, let us start to look for other calendar day for the adjustment. Usually a Rest day is selected from the last morning- and afternoon-shift work stretch as there are more Rest days in the last morning- and afternoon-shift work stretch.

Step f. Find the first Rest day within the last morning- and afternoon-shift work stretch and let D^o = the calendar day of this Rest day.

Step g. Search for a working day that permits a swap with the D^o Rest day found from the last work stretch through all the weeks in the roster starting from the first week. Let us set $w^c = 1$, where w^c represents the week number. For example, $w^c = 1$ means Week 1 of the roster.

Step h. Is the day D^o of week w^c a working day and day D^u of week w^c a Rest day? If yes, go to Step i. Else, move to the next week and let $w^c = w^c +1$, go to Step k.

Step i. Can the D^o Rest day from the last morning- and afternoon-shift work stretch swap with the D^o working day identified in week w^c without violating the labor laws? If yes, go to Step j. Else, since no working day can be identified in week w^c, let us move to the next week by setting $w^c = w^c + 1$ and go to Step k.

Step j. Swap the Rest day and the working day of day D^o identified. Go to Step l.

Step k. Check if the search has reached the last week in the roster. If $w^c = w$, find the next Rest day within the last work stretch and let D^o = the calendar day of the new Rest day found, go to Step g. Else, go to Step h.

Step l. Replace the Rest day of day D^u by shift S^u.

After assigning all the shifts into the roster, some of the rest days can be changed to Redeployment day without violating the t_n hour rule if necessary, and this completes the development of a roster.

Figure G.1 depicted the flow of assigning the morning and afternoon shifts into the roster, while Figure G.1 shows the Adjustment procedure.

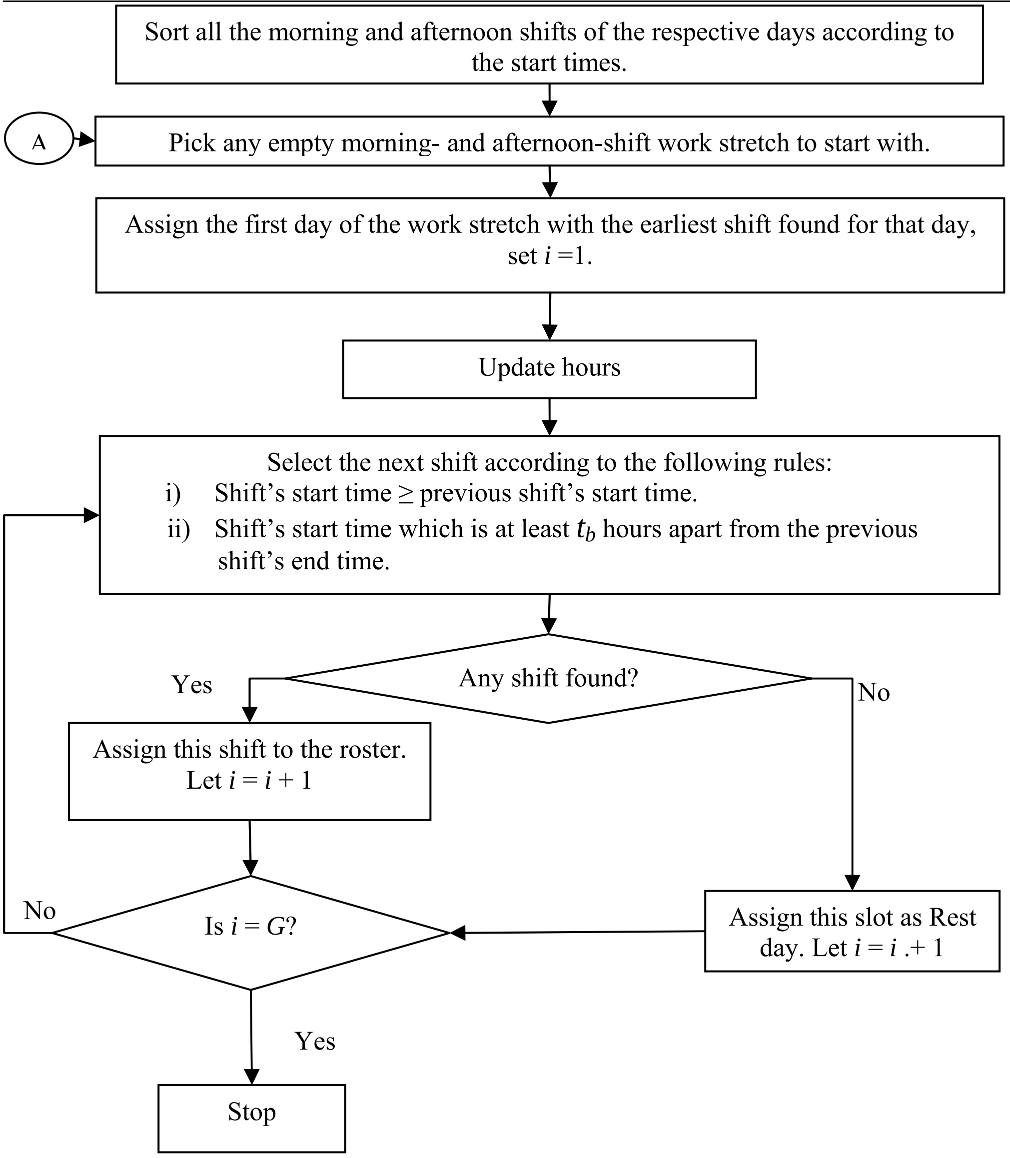

Figure G.1: Phase 2 process flow-Steps to assign morning and afternoon shifts

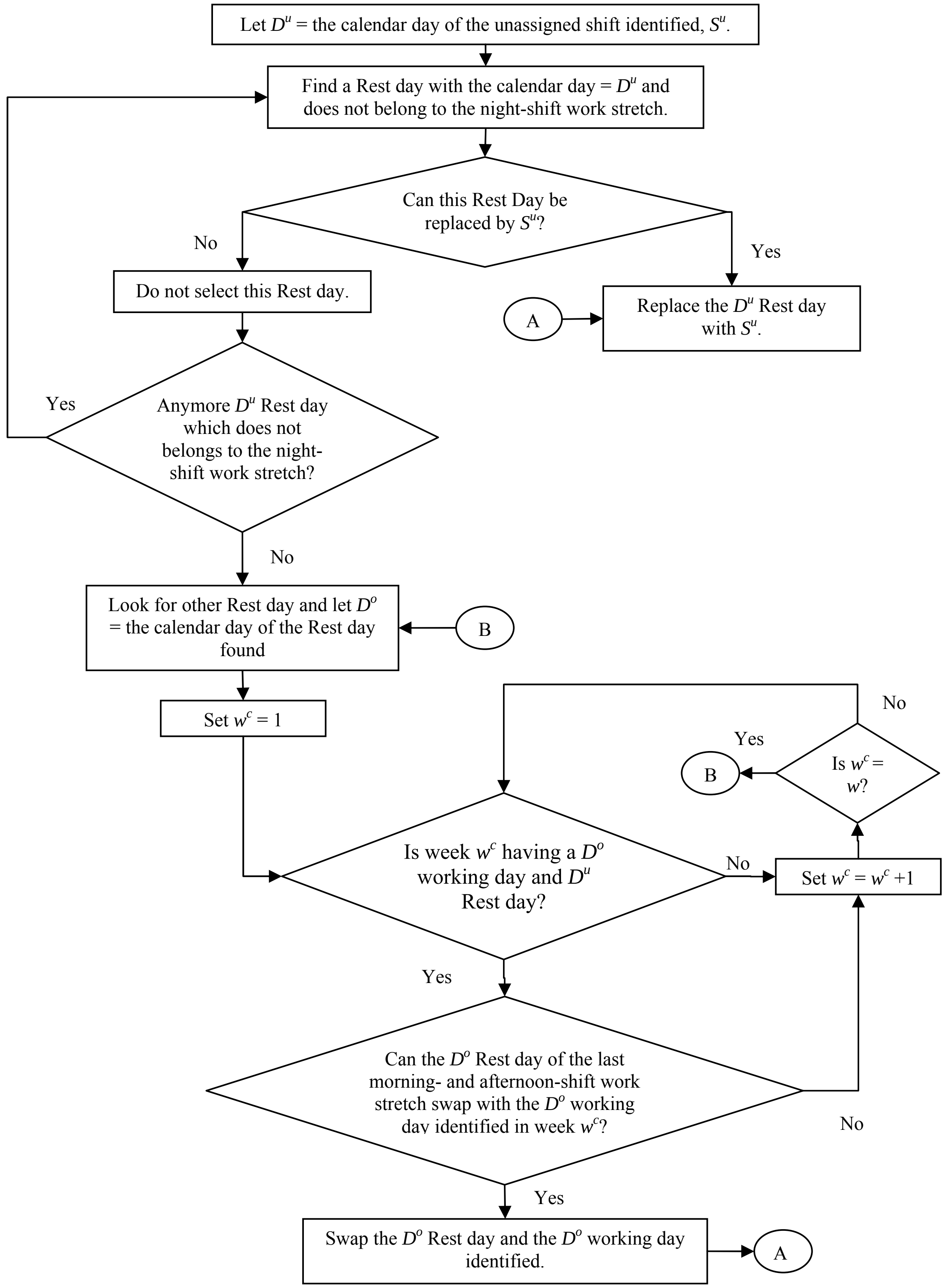

Figure G.2: Stage 2 process flow-Adjustment steps.

Appendix H

Flight Allocation Heuristic

Surplus workload : the workload of each flight being covered by the Helper(s). This is obtained from the workload heuristic.

Free Time 1 and 2 : the idle times obtained from the workload estimation heuristic.

Shift with Surplus: Group A

Shift with Free Time: Group B

Heuristic:

1. Check if there is any shift with Surplus workload which needs the Helper(s) to complete the flight. If yes, go to Step 2. Else, stop here and just follow the flights being assigned in the roster.
2. For each shift with Surplus workload, group it under Group A. Find the start times and end times for the Helper(s) from the workload estimation heuristic.
3. Is calling the Redeployment shift a preferred option? If yes, go to Step 9. Otherwise, proceed to Step 4.
4. For each shift without Surplus workload, find the Free Time 1 and 2 for these shifts and group them under Group B.
5. For the shift in Group A, find matching shift(s) from Group B which has the Free Time 1 or 2 duration ≥ the Surplus workload of the respective shift in Group A. If no matching shift(s) from Group B is found, go to Step 9. Otherwise, go to Step 6.
6. For the shift in Group A with matching shift(s) found from Group B, select the matching shifts satisfying the following criteria:
    a. Free Time 1 or 2 start time ≤ the Helper(s) start time.

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   b. Free Time 1 or 2 end time ≥ the Helper(s) end time.
   c. If there are more than one shifts from Group B match these criteria, choose the one with greater Free Time duration available. If no matching shift(s) from Group B is found, go to Step 9.

7. Group B shift(s) will be assigned with additional workload once a matching Surplus is found.
8. If all the Surpluses are assigned, stop here. Otherwise, go to Step 9.
9. Call the Redeployment shift to report to work as the Helper(s) for those Checking Team(s) which needs help.